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A multi-exposure, high resolution camera for the production of a resolving power test target, with extended range

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A MULTI-EXPOSURE, HIGH RESOLUTION CAMERA FOR THE PRODUCTION OF A RESOLVING POWER TEST TARGET, WITH EXTENDED RANGE

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SENIOR RESEARCH PROJECT

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ABSTRACT

Since 1888, a series of mutually perpendicular lines have been used as a test object for evaluation of optics, systems, products, etc.(1) The availability of such test objects has traditionally been in the frequency range of about one cycle per millimeter to a couple hundred cycles per millimeter. These have been available from a few manufacturers, none of which offers the extended range of .25 cycles per millimeter to greater than one thousand cycles per millimeter proposed in this project. The usefulness of such an extended range serves to make it an all-purpose test target for measurement of enlarging, contact and reduction systems. Since the test object is on film, it can be used with ease in each of these systems. The actual test object range obtained was from .25 cycles per millimeter to greater than one thousand cycles per millimeter. The camera attained this by a simple but effective three station, multi-exposure method. The advantage of such an exposure method is that optimum independent line width control can be used at each exposure step. Breaking the total frequency range into three groups eases exposure and optical restrictions but does produce mechanical registration problems.

It is obvious that with a reasonable budget a sturdier, higher precision and more reproducible instrument could be built such that this extended range resolving power test target could be produced on a production basis.

HYPOTHESIS

Is it possible to make a high resolution camera which employs a three station, multi-exposure method that will be capable of producing a high resolution resolving power test object of extended range?

OBJECTIVES

1. To construct a high resolution camera incorporating a three stage multi-exposing method and having the necessary associated mechanical and optical systems.
2. To produce the glass plates and film intermediates required by the camera.
3. To make from the camera a high resolution resolving power test object on film with a frequency range from .25 cycles per millimeter to greater than one thousand cycles per millimeter.
4. To evaluate the test object, intermediates and camera.

PROCEDURES AND RESULTS

There have been many schemes for making various test objects.[2,3,4] High resolution camera have also been built.[5] This offers another possible method of making resolving power test targets -- but with an extended range, using a high resolution camera.

Construction Considerations

A wooden frame with the properly drilled and routed holes was constructed. It was three-legged for best support. Each leg sits on a piece of isomode rubber for elimination of high frequency vibrations. The size of the isomode has been calculated such that each leg distributes fifteen pounds (total weight of camera is 45 pounds). It uses conventional 110 volt A.C. A vacuum pump capable of twenty P.S. I.G. was used. Two steel plates were fabricated, and a microscope with the proper optics was obtained and assembled to the main frame, as were the lamps and wiring. This being a three station camera and each station requiring its own illumination and vacuum system required electrical switches and vacuum valving. When these were in position, the transport arm was assembled and the intermediates were placed in the camera. The transport arm and associated reference system were required to precisely locate and register the 4" x 5" film sheet at each station. Adhesive on the underside of the transport arm assisted in holding and transporting the film. Figures 2 through 5 show the camera fully assembled and ready to use.

Operation

Immediately after focusing, a sheet of film is centered on station number three and the vacuum is switched on and draws the emulsion to immediate contact with the cover glass. The transport arm is positioned against the referencing screw and the exposure is made. Next, vacuum of the transport arm is switched on, and when it "takes hold" of the films' base side, the emulsion side vacuum is cut off. The film is now held to the transport arm by vacuum and adhesive. It then is rotated to station number two. The vacuum is applied to the emulsion so that the film is contacted to the glass plate intermediate. When the emulsion side vacuum "holds" the transport arm vacuum is released. The film then is exposed. The base vacuum is now applied and the emulsion vacuum released. The transport arm with the film held to it is positioned to the referencing screw of station number one. The emulsion vacuum is applied and the base side vacuum released. The proper exposure is made and the test object is now fully exposed. The image is allowed to stabilize for 20 minutes and then is processed.

Optical Considerations

The objective of greater than one thousand cycles per millimeter requires a microscope objective to be the optic used. The one selected is a Bausch and Lomb achromat, 8 mm (21X) with a numerical aperture of 0.50. This was used in conjunction with a 10X Huygenian eyepiece to produce a total reduction of 210 diameters. These were placed in a microscope that had a coarse and fine focus knob, which was necessary for obtaining optimum focus. The numerical aperture is required to obtain the high resolution.

Using the formulas[6]:

$$\text{Resolution limit (in cycles per millimeter)} = \frac{10^6}{(\text{f number})(\lambda)}$$

$$\text{and} \quad f \text{ number} = \frac{1}{2N.A.}$$

where λ is the wavelength in millimicrons of the light used and N.A. is the numerical aperture of the objective, we obtain

$$\text{Resolution limit} = \frac{10^6}{(2)(.5)(550)} \cong 1860 \text{ cycles per millimeter.}$$

Using this in conjunction with a statement by Altman[5] that the resolution limit is usually greater than the calculated limit and that the limit should be approximately 2000 divided by the f number a limit of 2000 cycles per millimeter was assumed. Then assuming this to be a diffraction limited objective the Modulation Transfer Factor of the lens was calculated[7] and is shown in Chart I. This shows approximately a 39% modulation at 1000 cycles per millimeter. This coupled with a high gamma process and high resolution film indicates 1000 cycles per millimeter should be well resolved. On the final test object these calculations were proven valid for the high frequencies were well resolved.

Since these are achromatic optics chromatic aberations were eliminated by the use of a narrow band pass filter. A Wratten #99 (green) peaking at 550 $m\mu$[8] fell within the spectral sensitivity of the 649 GH[9] spectroscopic film being used. The filter was then sandwiched in glass with the station number three intermediate and made the illumination sufficiently monochromatic such that no color fringing was noted on inspection of the aerial image and high resolution was obtained.

A cover glass was used in front of the objective with the upper surface of the glass being the image plane. A vacuum channel around the glass allowed the emulsion of the film to be brought into contact with the cover glass. This is illustrated by Figure 6. Variation in film base thickness is not a problem when using this type of system. For some reason the optical system did not produce a 210 diameter reduction but more like a 202 diameter reduction. The source of this variation has not been located.

INTERMEDIATES

These were the glass plates and film in the camera that were used to print the final test object.

Station No. one intermediate is a high resolution glass plate with a frequency range from .25 cycles per millimeter to .90 cycles per millimeter and a polarity of clear bars on a dark surround. It was glued in its proper position on the camera. This is a contact print station.

Station No. two intermediate is a high resolution glass plate with a frequency range from 1.00 cycles per millimeter to 57.28 cycles per millimeter, with clear bars on a dark surround. This glass was cut and cemented into a steel block that was fastened to the camera. This is a contact print station.

Station No. one and two intermediates were obtained from contact printing the necessary frequencies of a Buckbee-Mears resolving power test target. These intermediates are therefore second generation and optimum line width was not expected to be printed from them.

Station No. three intermediate is on high resolution film (649GH) and is a ten diameter reduction of master art work. The master art work had serifs on the bars to assure square corners on the final print.[10] This was the all important step to bring out the high resolution. Frequency range of this custom made intermediate was from .3048 cycles per millimeter to .6152 cycles per millimeter with clear lines on a dark surrounding. When used in conjunction with the microscope optics the frequency range of the image is 64 cycles per millimeter to 1292 cycles per millimeter.

Evaluation of this intermediate was on an Ansco Model Four microdensitometer. A random sample of frequencies was traced and the results chronicled in Table II. The frequencies were within 1% of aim which was considered quite acceptable. Density levels and bar: space ratio were also favorable. The intermediate was then sandwiched in glass with a Wratten 99 (green) filter and placed in the camera. Exposing indicated that attenuation of frequencies was necessary. Thus the six, seven and eight groups ended up with a .40 neutral density and the nine group had a .20 neutral density and the ten group had no attenuation.

For all intermediates the squares, normally found on this type format test target, has been omitted or opaqued out. This is to reduce development effects caused by the squares. There was an exception: one large square was left on for macro densitometry purposes.

The entire frequency range expected from all three intermediates is listed in Table 1. The final result when measured appeared to have a 4.4% variation from the aim frequencies. Figure 7a, 7b, 7c presents the format of the intermediates and Figures 8a, 8b, 8c illustrates what the prints from each of the intermediates look like individually. Figure 9 presents the composite print using the three station multi-exposure method.

Test Object Considerations

Because of the high resolution expected the product best suited to record the information was 649 GH spectroscopic film. Its sensitivity also makes it convenient to use in a darkroom with safelight illumination.

The final test object configuration follows that given in Military Standard - 150A[11] of a bar being 2.5 times as long as it is wide. The progression of the bars was to decrease by the sixth root of two.

On the final test object the information capacity was calculated.[12]

Where $C = M^2_r$, C = information capacity

M_r = the resolving power in cycles per millimeter on the film

assuming M_r = 1235 cy/mm

$$C = 1.5 \times 10^6 \text{ bits/mm}^2$$

This reflects the information capacity that the camera and film is capable of. It is approximately half the value given by McCamy as the capacity of high resolution emulsion.

Evaluation

Camera:

Focus and reference of a frequency set within another frequency set was quite consistant. The camera did need focus daily but remained in focus once best focus was obtained. Occasionally it would drift. The transport arm has adhesive on it as insurance that film curl would not suddenly pop the film free of the arm. Aside from this trivial point all vacuum and illumination systems and intermediates performed their functions well. The instrument is capable of transporting and precisely registering a 4 by 5 inch film sheet at each of the exposing stations. Evaluation of Figure 9 test object bears this out as do the photomicrographs of Figs. 10,11, and 12.

Evaluation of station number three intermediate shows a high Dmax and only the ten group shows any sign of a noticeable Dmin. Frequencies obtained are within one percent of aim and the clear bars are slightly narrower than the dark spaces between them. This is a favorable condition.

Test Object:

The evaluation of the test object produced by stations one and two is not very quantitative. It was done by viewing the target through a microscope, and observation of photomicrograph Fig. 12. These stations aren't to be evaluated critically because the intermediates are second generation and improving edge sharpness, bar shape and bar:space ratio etc., in the low frequency range is trivial. With master plates for these stations the parameters could easily be met.

Generally, the target for the low frequency range has good edge sharpness, bar shape and bar:space ratio. The exception is the five group which displays the cigar effect due to the loss of high frequency information (corners contain high frequencies) when going through the three generations that produced the print. This is noticed in Fig. 11.

Evaluation of the test target produced by station number three was done on an Ansco Model 4 microdensitometer. The same frequencies traced on the intermediate were traced on the test target, where possible. The limiting factor is the effective aperature used for tracing of .94 microns. This will allow tracing to frequencies to ca. five hundred cycles per millimeter. However practical limitations restricts tracing to a couple hundred cycles per millimeter. Beyond this tracing is impractical for if the bar:space ratio isn't unity the aperture would be integrating a bar and a space simultaneously. There is also diffraction by the bars that could remove light from the zero order main beam. This could result in higher density values for clear areas or lower density values for dense areas.

The tracing results are listed in Table 111. This shows that the test object was on an average 4.4% below the aim frequencies. This error is unexplainable. Why not call it experimental error ?

The Dmax is not consistant throughout all frequencies and indicates that further manipulation of neutral densities is in order and perhaps more exposure and process could be used. The bar:space ratio shows narrow dark bars and also indicates additionable exposure would be tolerable. The decrease in the density difference in the high frequencies is thought not to be as real as it appears. For this is the region of instrumentation readout problems and also the Dmin when viewed in a microscope appears very low throughout the test object range.

Photomicrographs were made of the test target (see Figures 10, 11 and 12). Figure 10 shows the maximum resolution obtained to be 1235 cycles per millimeter. Perhaps if additional steps were on the ten group, they could be resolved. It should be noted that a loss of resolution, edge sharpness, etc., occur when making the photomicrographs. One must also be sure that the optics for viewing the test object are of sufficient quality so that the bars can be resolved. Figures 11 and 12 do not resolve the high frequency bars because of the optics quality.

In general, the bar shape and test object appearance is quite acceptable for a high resolution resolving power test target of extended range.

CONCLUSIONS

The hypothesis has been validated, and all aims set forth in the objectives of this project were attained. The camera was built and the proper intermediates produced. When used in conjunction with the three station multi-exposing method, a resolving power test object of extended range was produced. The technique presented has many attractive features, including making test objects of other frequency ranges. Breaking exposure down into contact and optical stations allows obtaining a frequency range that can not be easily accomplished by any other means.

Evaluation of the camera, intermediates and test target indicates this to be an acceptable system to produce resolving power test targets with extended range.

RECOMMENDATIONS

1. The camera should be made sturdier and of a higher precision to increase repeatability so that extended range test objects could be produced on a production basis.

2. Obtaining a master test target for the lower frequencies could produce an improved test object.

3. Consolidation of station number one and two may be possible. Line width control could be obtained by using neutral density filters on the necessary frequencies (base side of course). The use of the filters worked well to control the exposure level of the higher frequencies.

4. Test objects of other frequency ranges could also be obtained from the camera. One cycle per millimeter to greater than a thousand, or .25 cycles to 64 cycles per millimeter are useful for many systems.

5. The camera should be used directly to test resolution of films, papers, etc.

ACKNOWLEDGEMENT

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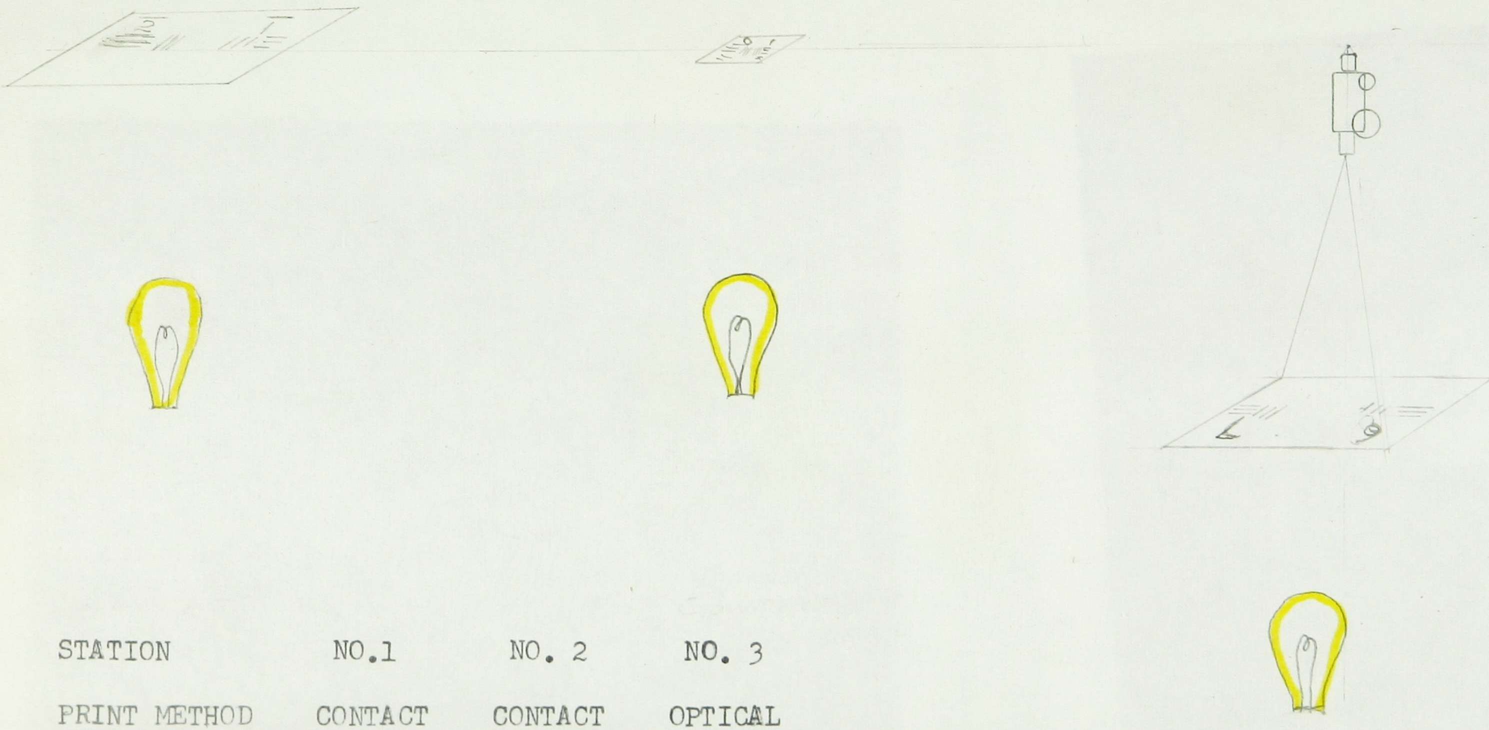
APPENDIX

STATION NO. 1 STATION NO. 2 STATION NO. 3



STATION	NO.1	NO. 2	NO. 3
PRINT METHOD	CONTACT	CONTACT	OPTICAL
REDUCTION	1:1	1:1	200X

FIGURE 1

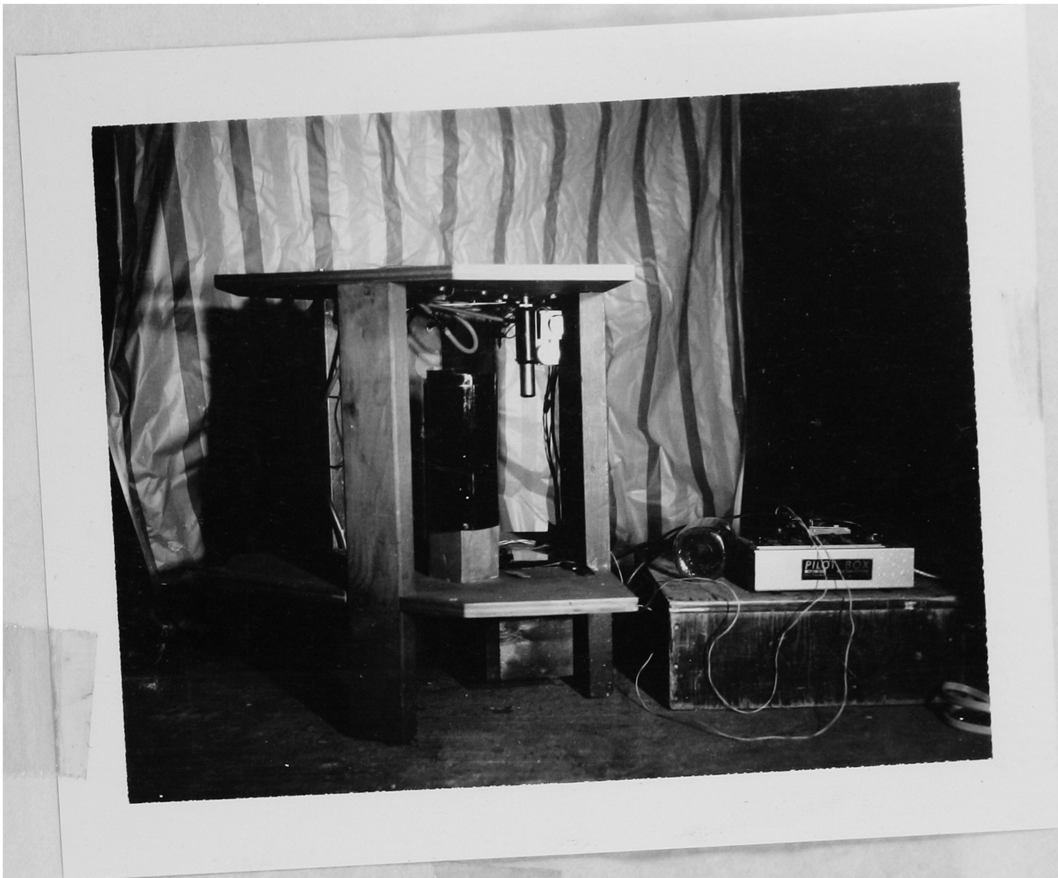


FIGURE 2

FIGURE 3

FIGURE

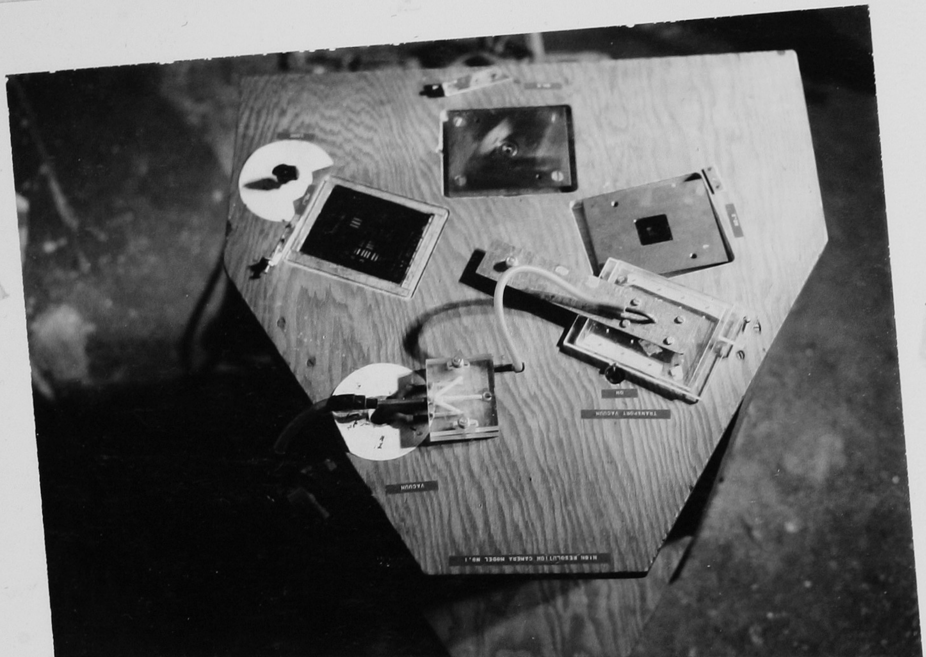
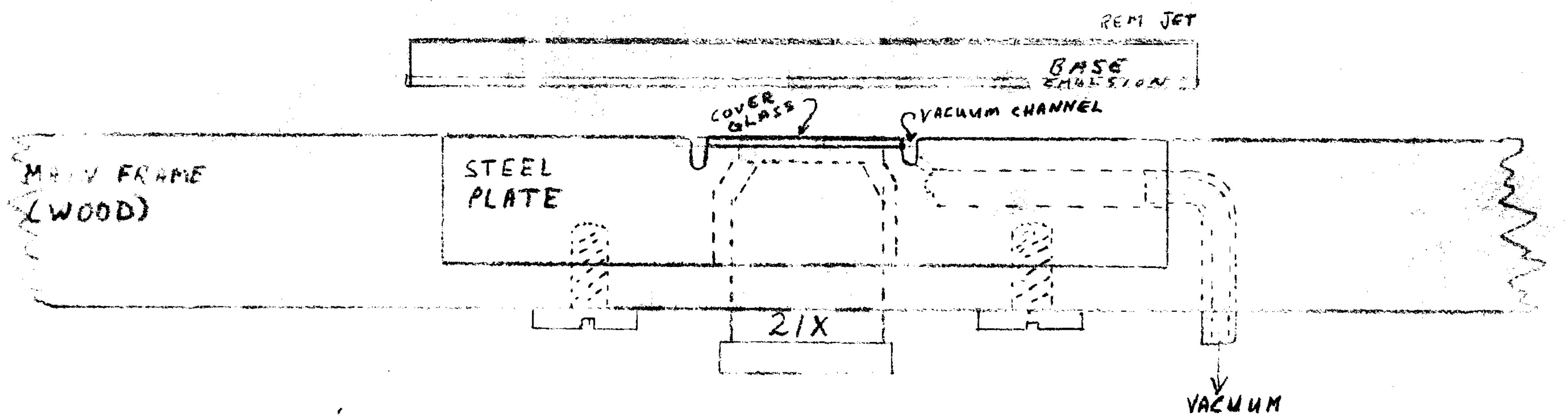


FIGURE 5

STATION NO. 3 TRANSPORT ARM AGAINST REFERENCE SCREW

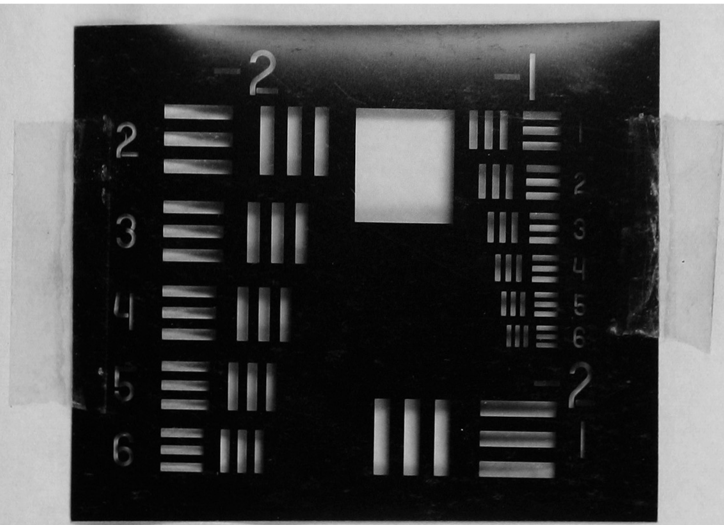

REM JET
BASE
EMULSION
COVER GLASS
VACUUM CHANNEL
STEEL PLATE
(WOOD)
21X
VACUUM

FIRURE 6

INTERMEDIATES

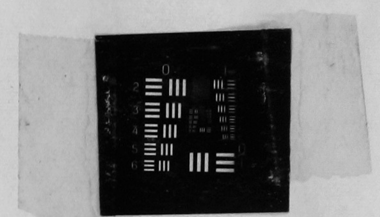
REPRESENTATIVE OF THOSE USED AT EACH STATION

fi
FIGURE 7a



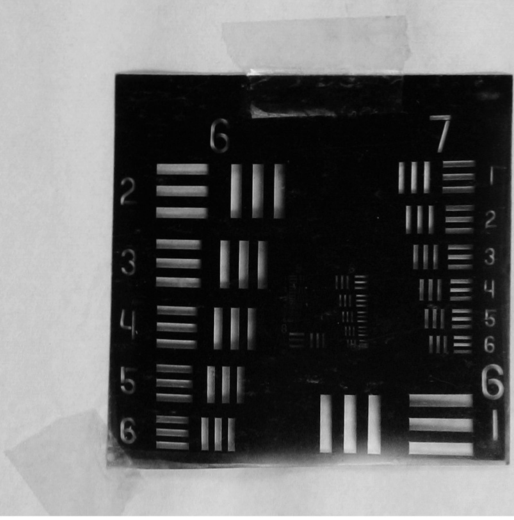
STATION NO.1

FIGURE 7b



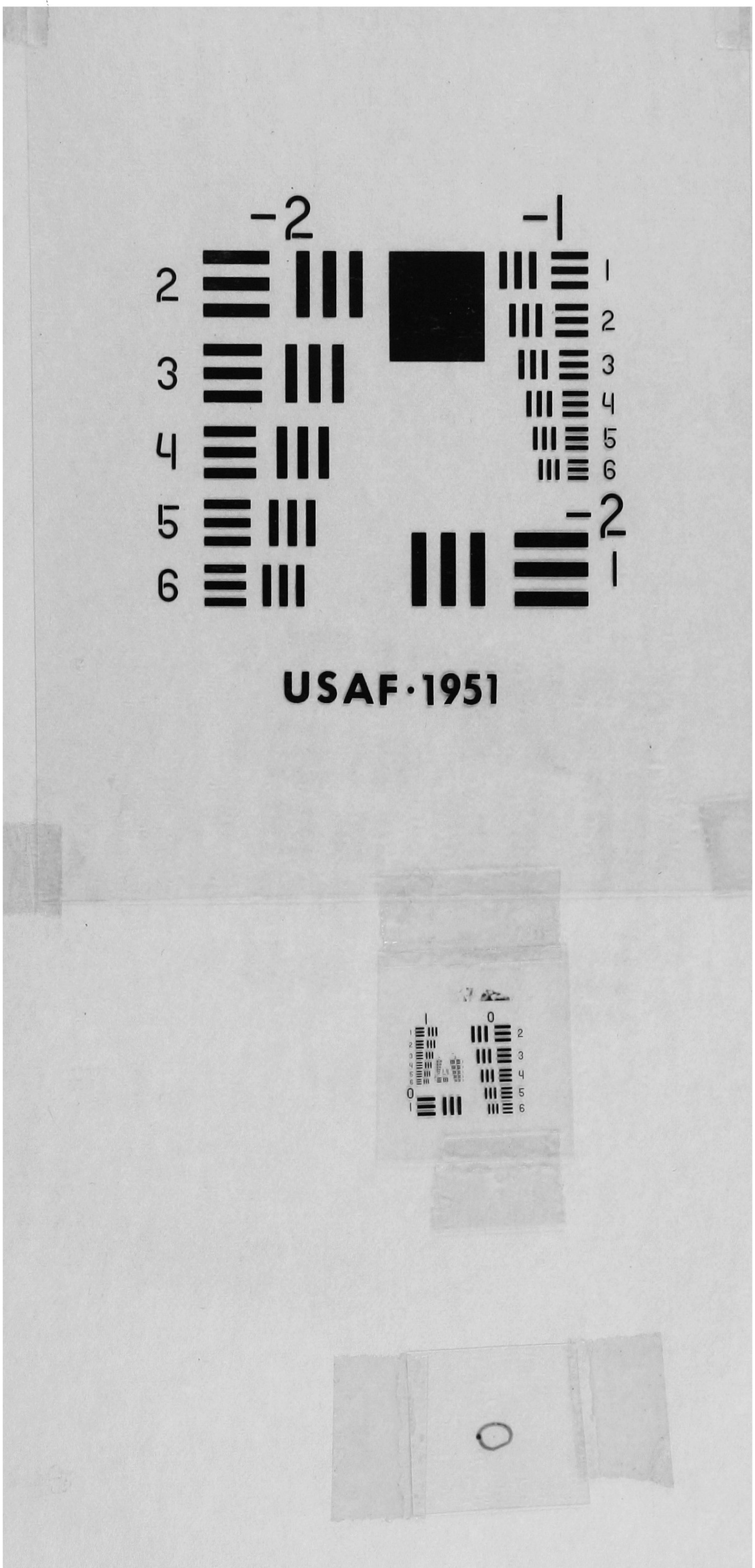
STATION NO.2

FIGURE 7c



STATION NO.3

PRINTS FROM EACH STATION INDEPENDENTLY



STATION NO. 1

FIGURE 8a

STATION NO. 2

FIGURE 8b

STATION NO. 3

FIGURE 8c

HIGH RESOLUTION RESOLVING POWER TEST TARGET

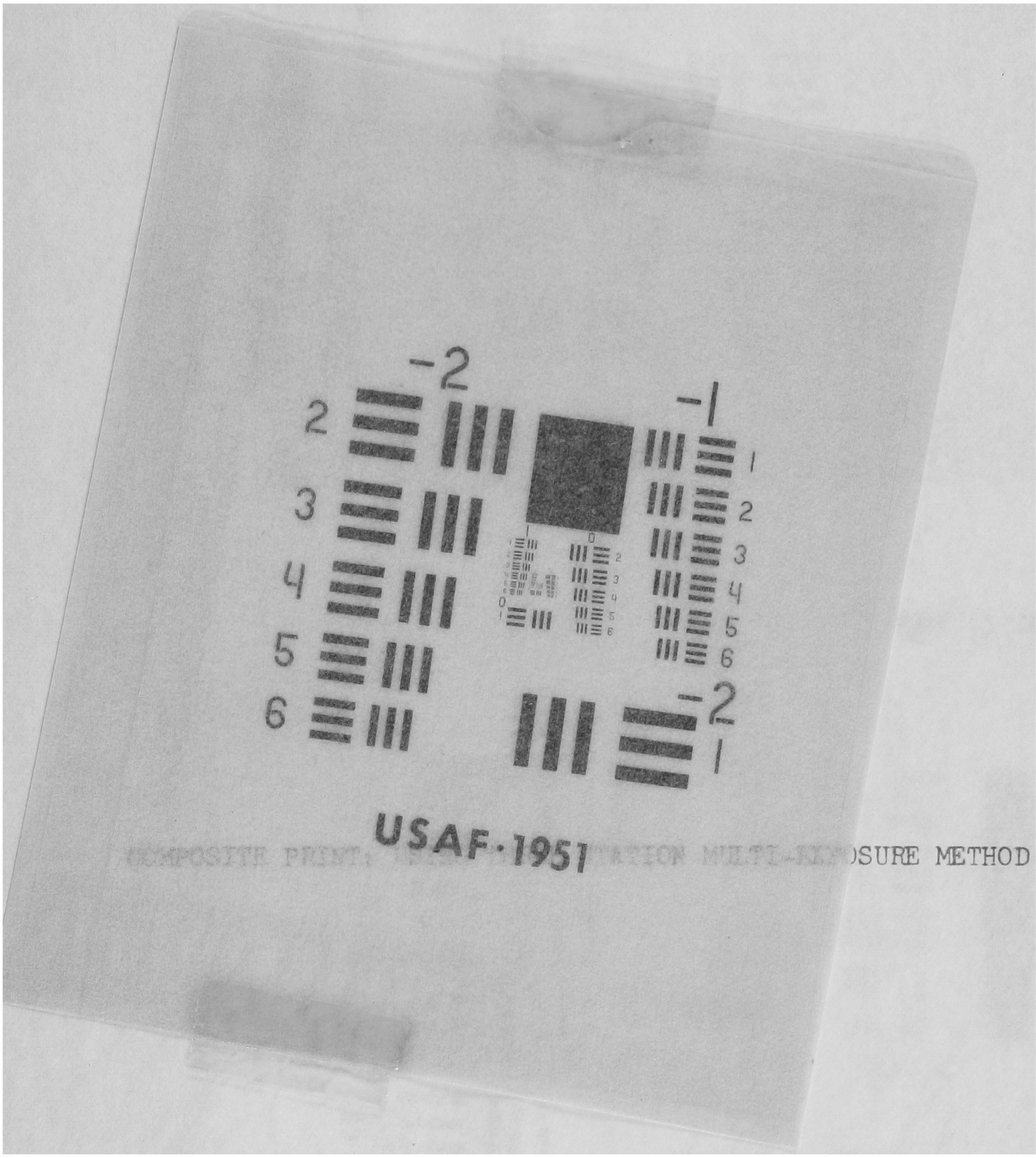


FIGURE 9

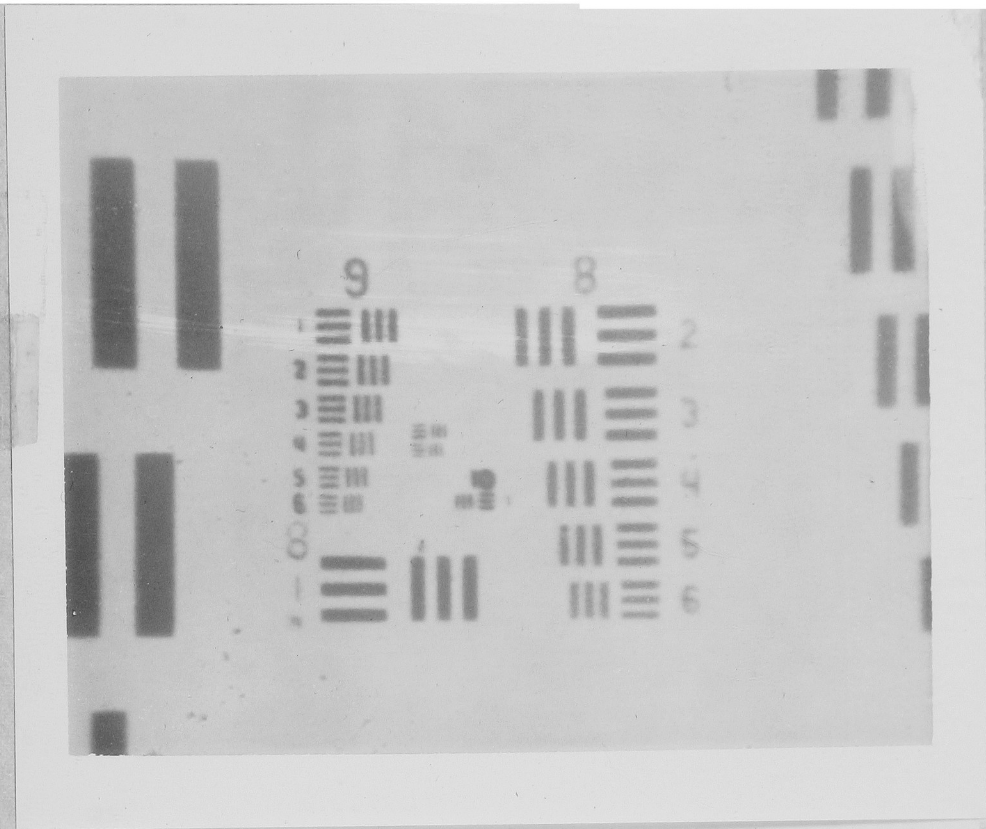


FIGURE 10

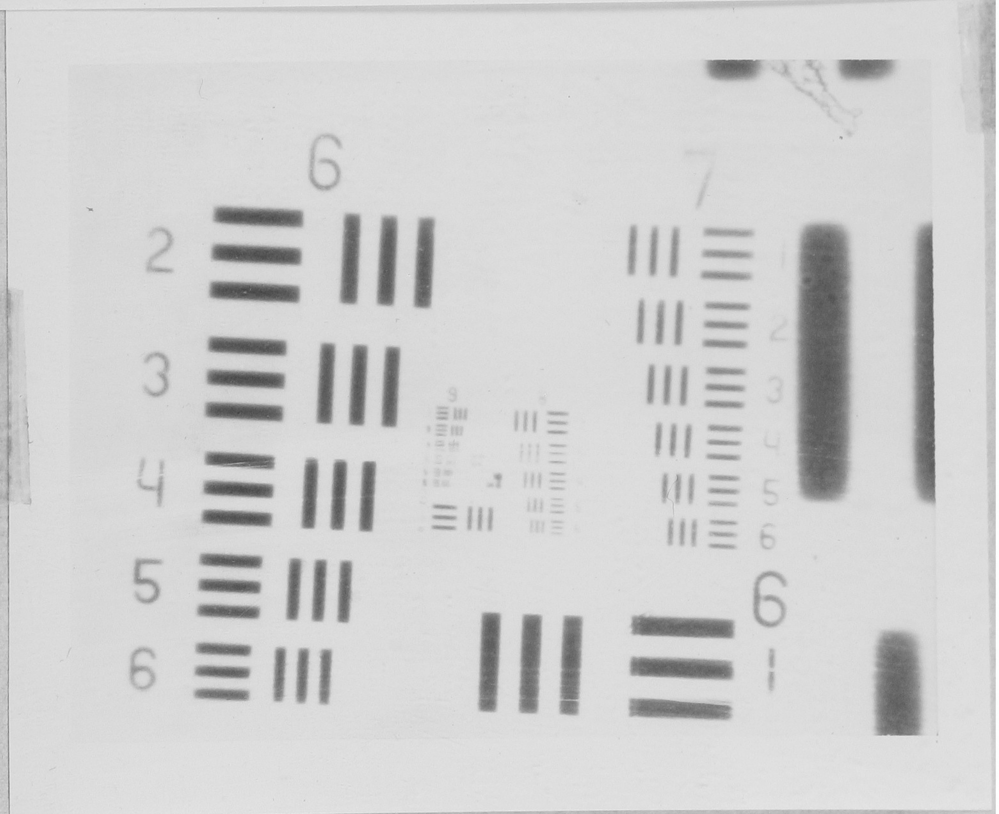
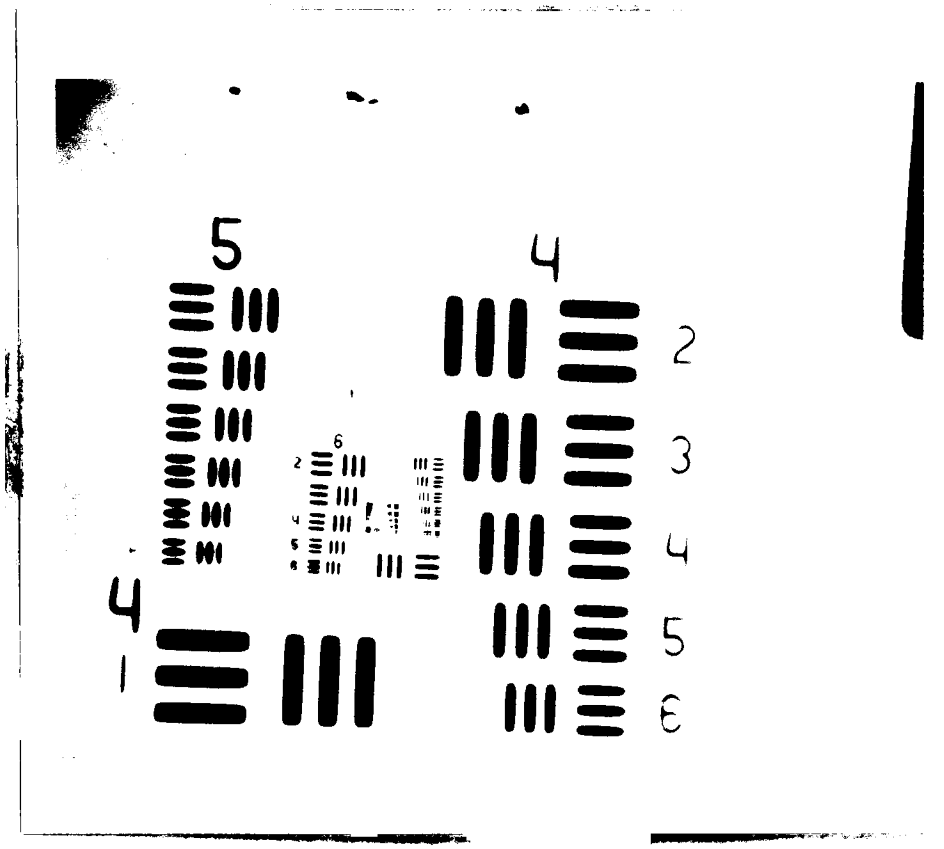


FIGURE 11

200X ENLARGED

PHOTOMICROGRAPHS (CON'T)



50X ENLARGED

FIGURE 12

TABLE I

RESOLVING POWER TEST OBJECT

REPRODUCED 1:1 LINES PER MM.

Group	-2/1	-1/1	0	1	2	3	4	5	6	7	8	9	10
Step													
1	0.25	0.50	1.00	2.00	4.00	8.00	16.00	32.00	64	128	256	512	1024
2	0.28	0.56	1.12	2.24	4.48	8.96	17.92	35.84	72	143	287	574	1148
3	0.31	0.63	1.26	2.52	5.04	10.08	20.16	40.32	81	161	323	646	1292
4	0.35	0.71	1.42	2.84	5.68	11.36	22.72	45.44	91	182	363	726	
5	0.40	0.79	1.59	3.18	6.36	12.72	25.44	50.88	102	204	407	814	
6	0.45	0.90	1.79	3.58	7.16	14.32	28.64	57.28	115	229	458	916	

TABLE II

GROUP/STEP	AIM FREQUENCY*	ACTUAL FREQUENCY*	% of AIM	DMAX	DMIN	BAR:SPACE RATIO
6/1	.3048	.3062	100.10	3.70	.01	1:1.14
6/4	.4328	.4417	97.98	4.00	.01	1:1.04
6/5	.4846	.4792	101.10	4.00	.01	1:1.08
7/2	.6827	.6684	97.91	3.60	.01	1:1.30
7/6	1.091	1.0367	95.02	3.30	.01	1:1.36
8/1	1.219	1.159	95.10	4.00	.01	1:1.33
8/5	1.938	1.954	100.80	3.90	.01	1:1.08
9/4	3.457	3.479	100.60	3.60	.03	1:0.88
9/5	3.876	3.834	98.92	3.50	.01	1:1.00
9/6	4.362	4.379	100.40	3.60	.03	1:0.92
10/1	4.876	4.932	101.10	4.00	.06	1:1.05

Average =99.01% of aim

Polarity of intermediate is clear bars on a black surround

Measured on an ANSCO MODEL 4 microdensitometer

*in cycles per millimeter

TABLE III

Evaluation of Test Target from Station Number Three.

Group/Step	Aim Frequency*	Actual Frequency*	% of Aim	DMAX	DMIN	Bar:Space Ratio
6/1	64	61	95.3	2.45	.07	1:1.12
6/4	91	88	97.1	2.25	.07	1:1.16
6/5	102	102	100%	2.15	.07	1:1.20
7/2	143	129	90.2	1.45	.07	1:1.21
7/6	229	214	93.9	1.44	.10	1:1.20
8/1	256	243	94.9	.70	.10	1:1.12
8/5	407	406	99.8	.60	.12	1:1.18
9/4	726	678	93.2	.61	.42	1:1.03
9/5	814	774	95.1	.60	.44	1:1.19
9/6	916	Can't be measured on μD		.62	.48	1:1.18
10/1	1024	Can't be measured on μD				

Average = 95.6% of aim; therefore, 4.4% error.

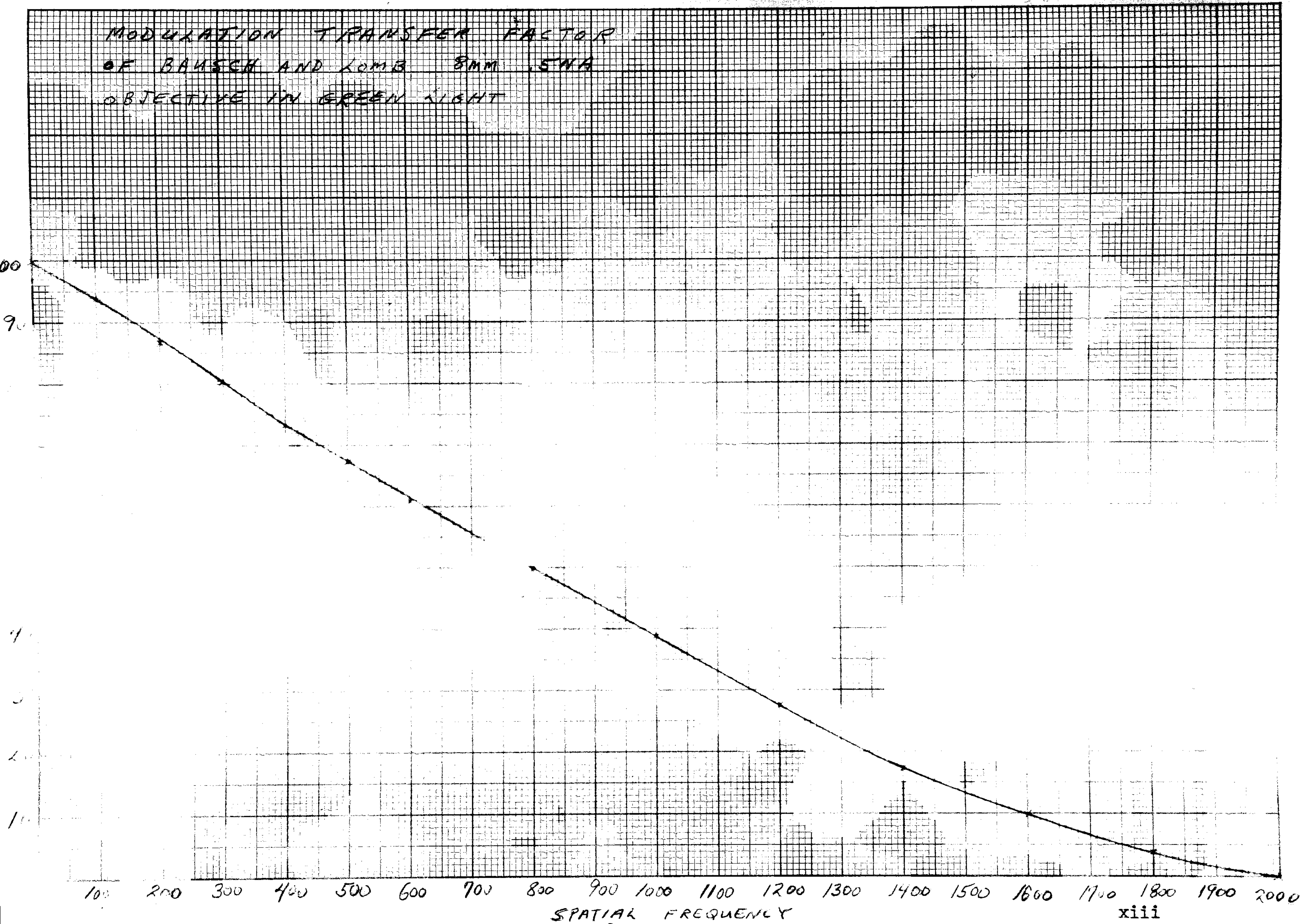
Bars are dense (printed from clear bar of intermediate)

All tracing was done on an Ansco Model 4 Microdensitometer.

An effective aperture of .94 microns was used to evaluate the target.

*in cycles per millimeter.

CHART I



MODULATION TRANSFER FACTOR
OF BAUSCH AND LOMB 8MM .5NA
OBJECTIVE IN GREEN LIGHT
100
90
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
SPATIAL FREQUENCY