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John Tuller

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SPECTRAL ABSORPTION AND RELATED SPREAD FUNCTION OF A PHOTOGRAPHIC LAYER

by
JOHN GLADDEN TULLER

CANDIDATE FOR THE MASTER OF SCIENCE DEGREE
IN PHOTOGRAPHIC SCIENCE

COLLEGE OF GRAPHIC ARTS AND PHOTOGRAPHY
ROCHESTER INSTITUTE OF TECHNOLOGY

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Name Illegible
Burt H. Carroll
Al Rickmers

ADVISOR: DR. BURT H. CARROLL

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Introduction

The spread of the imaging light in a photographic emulsion (i.e. the width of the Spread Function) not only depends on the optical turbidity, but also on the absorptance of the photographic layer. Although the optical turbidity is high, the image spread may be slight if the scattered light is strongly absorbed.

Most Silver Bromide-Iodide emulsions exhibit a marked increase in spectral absorption in the wavelength region from 500 nm (weakly absorbed) through 350 nm (strongly absorbed). Therefore, isolating different portions of this wavelength region to expose a photographic layer offers a means of studying change in image spread (resulting from a shift in absorption) without change in the other emulsion properties. The purpose of this paper is to discuss and report the results of an experimental study of the spectral absorption and related image spread of a non spectrally sensitized Silver Bromide-Iodide photographic layer.

Theory and Experimental Method

The theory behind the methods used in this study to measure image spread is well established.[1,2] In the phtographic reproduction of relatively small detail, the effective exposure may not be the same as the incident exposure due to the spreading of the imaging light in the photographic layer. This modification of the incident exposure is characterized by the Spread Function of the photographic emulsion. A result of this image spread is image quality which usually decreases with the size of the detail being reproduced. The image quality of a photographic emulsion is characterized by the Modulation Transfer Function of the emulsion. A Fourier transformation relates the Spread Function (SF) to the Modulation Transfer Function (MTF).

Spread Function

An equation with a single parameter has been suggested by Frieser to describe the light diffusing properties of a photographic layer:[3,4]

$$dI = \frac{2.3}{K} I_o \, 10^{-2|x|/K} \, dx \qquad (1)$$

Where dI is the effective intensity which is produced at a distance x from a very narrow slit illuminated with intensity I_o. The only parameter in the equation, K, represents the sidewise distance at which flux is attenuated to 1/10 its original value. K has the following relation for the specific case of an opaque line of width b:

$$\log \frac{I_o}{I_{center}} = b/K \qquad (2)$$

Therefore in the case where K is equal to the line width

$$\log \frac{I_o}{I_{center}} = 1 \text{ or } I_{center} = 1/10 \, I_o$$

On the assumption that equation (1) represents the emulsion Spread Function, the explicit form of this function would be:

$$A(x) = \frac{2.3}{K} 10^{-2|x|/K} \qquad (3)$$

A number of experimental determinations of emulsion Spread Functions show that this equation represents the SF of many photographic emulsions.[2,5]

Modulation Transfer Function (MTF)

Taking equation (3) as the SF, the MTF (normalized Fourier Transform of the SF) is:[2]

$$A(f) = \left[1 + (\pi Kf/2.3)^2\right]^{-1} \qquad (4)$$

where f = frequency in mm^{-1}. This equation was established by Frieser in 1935, and although many equations to represent the MTF of photographic layers have been proposed, a survey by Paris indicates this equation is usually as good as any and better than most.[5]

An experimental determination of the MTF of a photographic layer may be obtained directly without first determining the SF. The methods are generally well known and have been described in detail elsewhere.[6] Therefore only a brief review of the concepts of the particular method used in this study will be given. In order to determine the transfer function of a photographic layer, it is necessary to know both the modulation which the film receives and the modulation in the developed image. This can be determined by imaging a series of sinusoidal test patterns. The modulations of the patterns falling onto the film can be measured by scanning each with a slit and a photoelectric cell. The sinusoidal patterns are then exposed onto the test film (at the same exposure time) along with a step tablet or gray scale.

The developed image is then scanned with a micro-densitometer. The scan across the image of the gray scale will yield density which can be plotted against the exposure originally impressed upon the film. This curve can then be used as a transfer curve to relate the maximum and minimum values from the trace of the sinusoidal pattern back to a value of Δlog E. This

$\Delta \log E$ corresponds to the modulation of the original test object modified by the transfer factor of the lens used to expose the film and further modified by the transfer factor of the film. The transfer factor of the lens-film combination may then be divided by that of the lens (already determined by a similar method) leaving the transfer factor for the film alone. The film transfer factor for each spatial frequency in the test object plotted against the spatial frequency gives the MTF curve.

Instrumentation and Experimental Procedure

The photographic emulsion chosen for this study is a medium-fine grained blue sensitive duplicating film. The spectral absorption was determined with the use of an automatic spectrophotometer by measuring the light transmitted and reflected at all angles to the surface. This was accomplished with the aid of an integrating sphere. Figure I gives the data for the test emulsion. The absorptance at any wavelength is the sum of the percent reflectance and transmittance subtracted from 100 percent. ($A = 1 - R - T$)

The optical characteristics of the interference filters (narrow pass band) used to isolate portions of the wavelength region from 400 to 550 nm are listed in the following table:

wavelength at peak of pass band	transmittance at peak	half width
415 nm	40%	11 nm
440 nm	44%	11 nm
480 nm	42%	10 nm
510 nm	48%	18 nm

The narrow band filter transmission data and the corresponding film absorption data are shown together in figure II.

FIGURE I

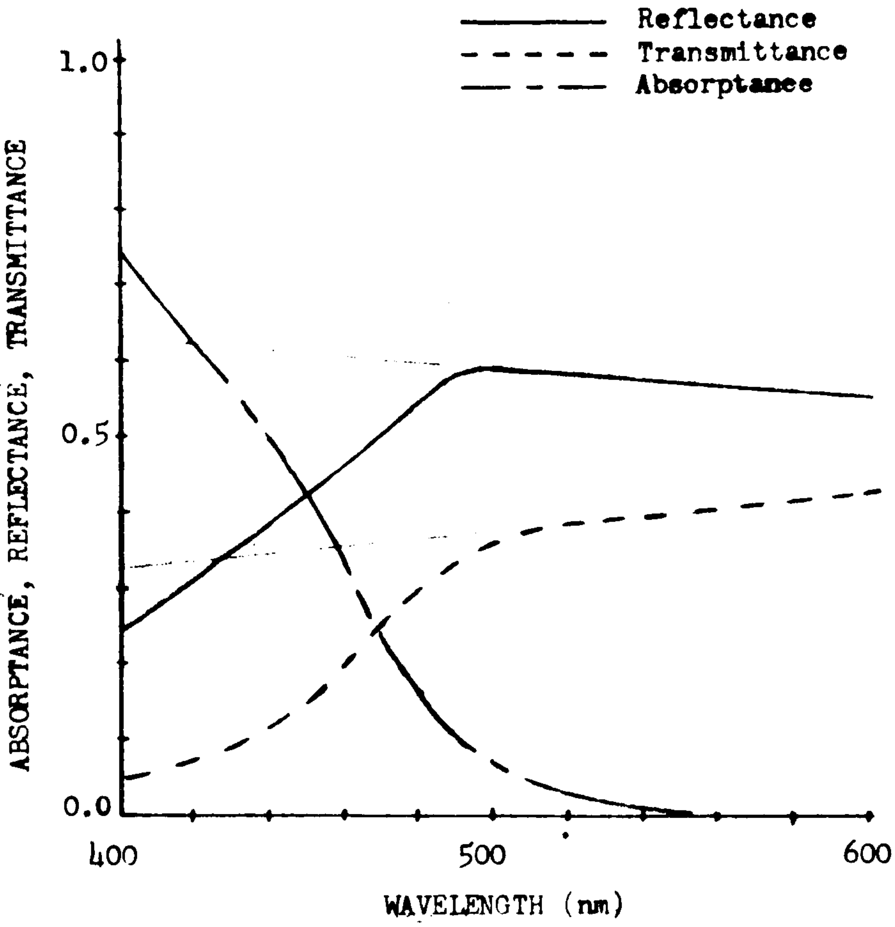
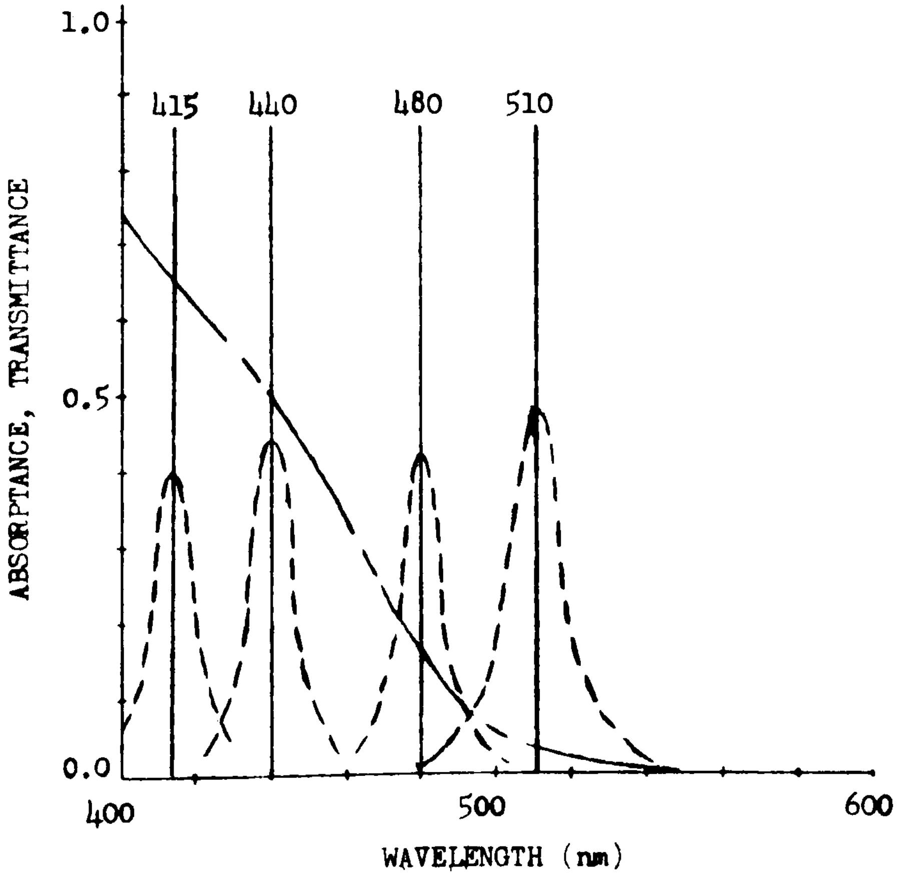


FIGURE II



A test object was designed for use in determining the image spread in the photographic layer as characterized by the SF and the MTF of the emulsion. This test object which is illustrated in figure III, includes a series of sinusoidal patterns[7] and a gray scale for obtaining sine wave response data. It also contains a set of line objects for determining the K values used by Frieser to describe the intensity distribution within an emulsion layer. A three-bar resolution chart is included for evaluating each focus series. When mounted on a uniformly illuminated light box and imaged with a microcamera at 30X reduction, this test object produces a series of sinusoidal patterns from 11 to 90 cycles /mm as well as a group of opaque lines each 15 micrometers in the film plane.

The microcamera used for this study is pictured in figure IV. A vacuum tube attached firmly to the objective and mounted with the opening close to the image plane proved to be a very sensitive method for running a focus series. Once the tube is adjusted properly, the readings from the vacuum pressure gauge can be used to indicate focus changes of less than one micrometer.

The procedure for exposing, processing and scanning the test film in this study is simple and straightforward. Using the microcamera, a fine focus series was run when each test was exposed, after which the film was processed in a sensitometric processing machine in D-76 with continuous aggitation to minimize adjacency effects. Finally an Ansco Model IV microdensitometer was used to scan the images.

The procedure for determining the values of K for the test emulsion is illustrated in figure V.[4] A microdensitometer

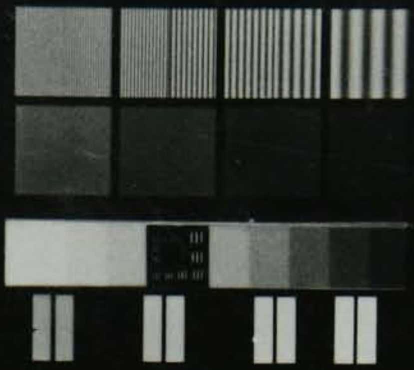


FIGURE III

EXPERIMENTAL TEST OBJECT

FIGURE IV

MICROCAMERA

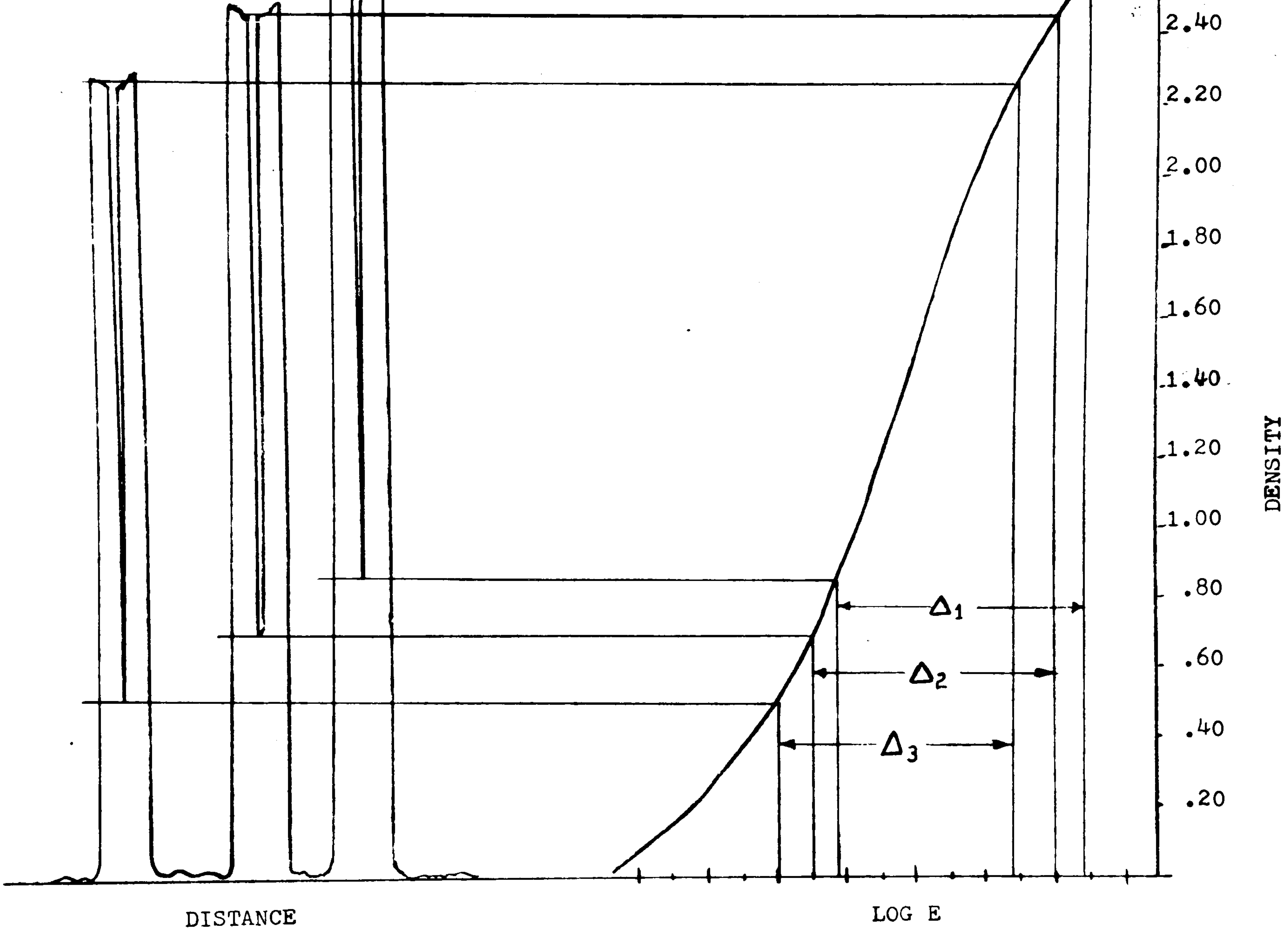

2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
.80
.60
.40
.20
DENSITY
Δ_1
Δ_2
Δ_3
DISTANCE
LOG E

FIGURE V

trace of the opaque line objects determines the distribution of densities. In this study a microdensitometer with an effective slit aperture of 30 μm width and 60 μm length was used to scan the line images on the left. The differences between the densities of the line and its surround were worked back through the characteristic curve on the right to find the corresponding Log I differences for each of the three exposure levels. Within the limits of experimental error, these Log I differences are equal if no distortion from development has occurred. From these differences the value of b/K is obtained based on the relationship in equation (2), where b = line width. Since b is known, the value of K is determined using the following equation:

$$K = \frac{b}{\log \frac{I_o}{I_{center}}} \quad [\mu m] \qquad (5)$$

A 15 μm line with 80 μm wide slits on each side is used here as described by Frieser. Limiting the surround to double slits 80 μm wide offers the advantage of protection against reflected halation from the film base and still permits K values as high as 80 μm to be measured. Since b in this case equals 15 μm, K is then:

$$K = \frac{15}{\Delta \log I} \quad [\mu m] \qquad (6)$$

Use of the series of sinusoidal patterns in the test object is illustrated in figure VI. The average maximum and minimum values from each spatial frequency group are extracted and worked back through the characteristic curve on the right to obtain the related Δlog E values. The corresponding E values

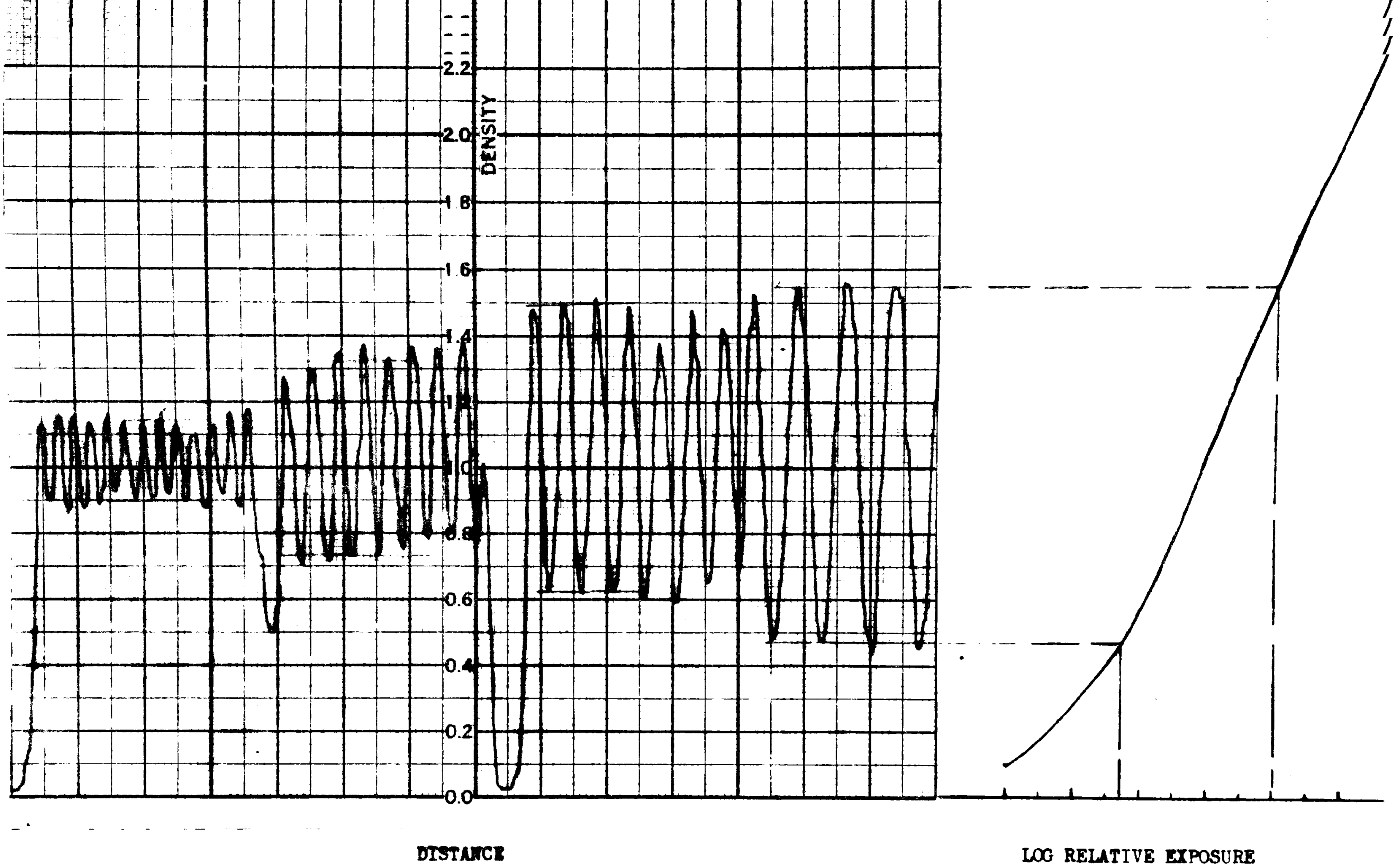

2.2
2.0
DENSITY
1.8
1.6
1.4
1.0
0.8
0.6
0.4
0.2
0.0
DISTANCE
LOG RELATIVE EXPOSURE

FIGURE VI

represent the modulation of the original test object as modified by the imaging lens and the film. The modulation factor for each spatial frequency is determined by first using the following equation to obtain the modulation of the output (the image).

$$M_{image} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \qquad (7)$$

This output (M_{image}) is then divided by the input modulation of the target. In this study the modulation of the target at all spatial frequencies is 65% ($M_{object} = .65$).[7] Therefore the lens-film modulation factor for each frequency is $\frac{M_{image}}{.65}$.

Since the modulation of the image as modified by the film alone is of interest in this study, the modulation factor of the imaging lens must be divided out. The exact modulation transfer function for the optics used to image the target has not been determined. However, test with high resolution plates show that the maximum resolution obtainable is near the theoretical limit. Therefore, from lack of a better estimate of the transfer function for the imaging lens, it is assumed that the optics used are diffraction limited.

Experimental Results

A summary table of experimental results from this study (Table A) lists different emulsion characteristics associated with each average wavelength of exposing light. K' represents an average value obtained from three replications of the outlined procedure for determining Frieser's parameter, K, which describes the 1/10th width of the spread function.

Three replications of the procedure set forth for obtaining

TABLE A

wave-length	%A	%R	%T	D(log $\frac{1}{T}$)	K'	$t = \frac{K'D}{2}$	t*	K_p**
415	67.25%	28.25%	4.50%	1.35	19.6µm	13.02µm	10.65µm	15.8µm
440	50.75%	37.25%	12.00%	..92	25.7µm	11.81µm	10.65µm	23.2µm
480	16.50%	54.75%	28.75%	..54	27.8µm	7.50µm	10.65µm	39.4µm
510	3.75%	60.00%	36.25%	.44	22.6µm	4.97µm	10.65µm	48.4µm

* thickness of emulsion layer

** predicted k' value using the relation $k = \frac{2t}{D}$

(see appendix for mean K value statistical data)

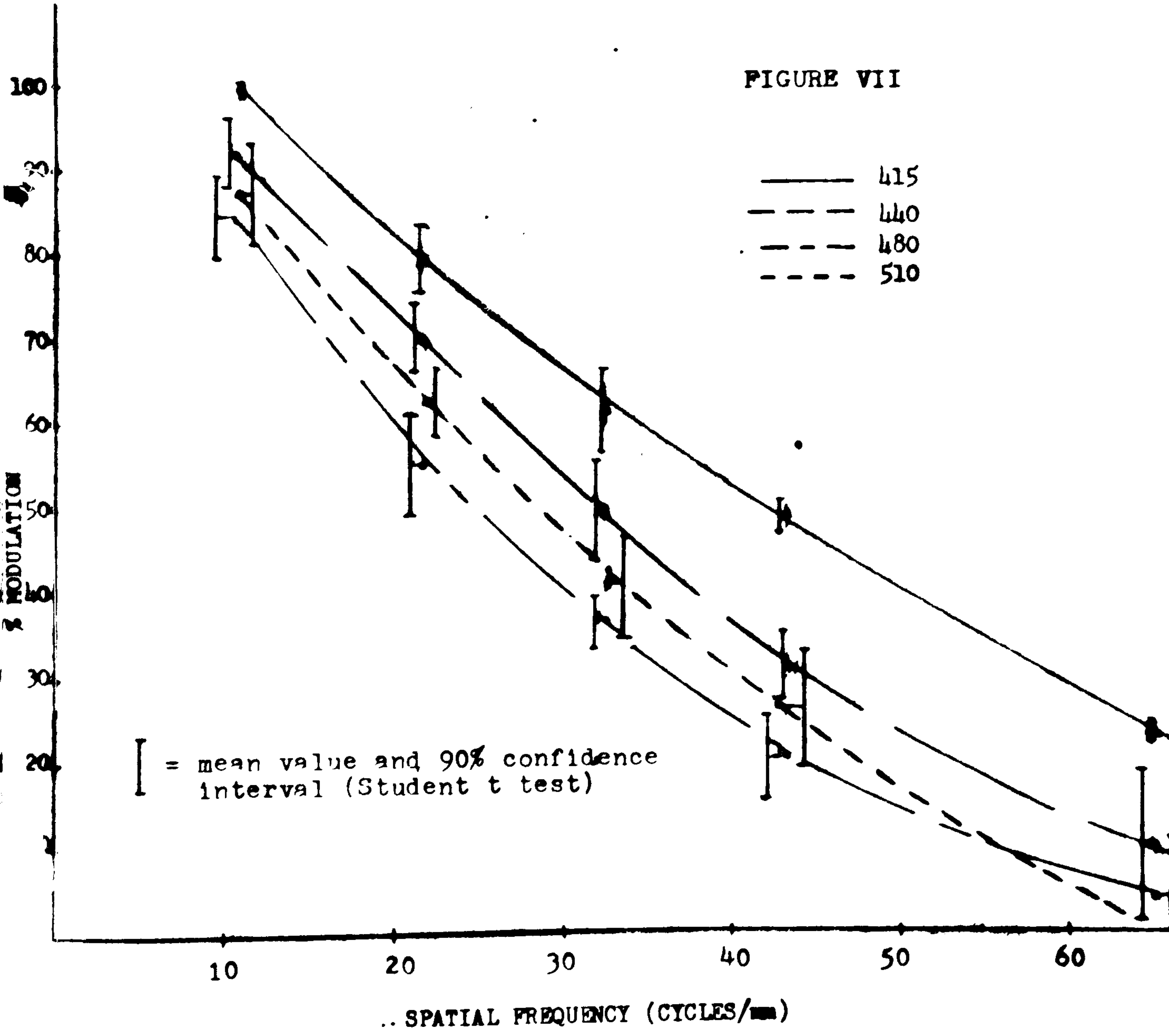


FIGURE VII

sine wave response data produced the average modulation factors plotted in figure VII. These curves represent the modulation transfer functions of the test material for the different wavelengths of exposure.*

(Image Spread and Absorption)

An indication of the spread of imaging light in the emulsion layer as a function of different wavelengths of exposing light is provided by the average K values. The relationship between the image spread and absorption associated with the increase in wavelength is not a consistent one. The results in Table A show that as the absorption decreased for the region 415nm to 440nm (65%-50%), the image spread increased (larger K value). A decrease in absorption would permit the scattered light in the emulsion layer to travel further before being absorbed, thus resulting in more image spread. However, this relationship does not hold for the region of weak absorption. In the 510 nm region where the absorption is very low the image spread has fallen off, resulting in a lower K value. Possible reasons for this deviation from expected results are discussed later.

Discussion

(Relating horizontal attenuation of scattered light to vertical attenuation of incident light)

When the imaging light is scattered in the turbid medium of a photographic layer, the image spread is limited by the gradual intensity loss of the scattered light. Therefore one can attempt to relate the horizontal attenuation of scattered light intensity (as represented by K values) to the vertical attenuation of incident light (as represented by diffuse density

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*The effects attributed to the MTF of the microdensitometer have been removed from these data (see appendix).

of the unexposed emulsion).[2] The K value as described by Frieser represents the 1/10 width of the distribution of scattered light around a narrow slit. Therefore at K/2 distance from the point of exposure in a horizontal direction scattered light will be attenuated to 1/10 its original intensity. In the vertical direction through the emulsion layer of thickness t, the degree of attenuation of scattered light is described by D, the diffuse density of the unexposed emulsion. If attenuation of scattered light in both directions can be related, K/2 will equal t/D. Such a relation has been found to exist in the wavelength region of strong absorption. Table A shows that the predicted thickness of the emulsion layer, using experimental results from the shorter wavelength region is within a few micrometers of the actual layer thickness. The relation does not hold true for the longer wavelength region.

(Interference Filters)

The deviation from expected results lead to consideration of two areas requiring further investigation. The transmission characteristics of the interference filters is one factor which could have possibly affected the experimental results. Each of the filters used in this study have an additional window in the near U.V. (350nm) region of the spectrum. It was assumed that this would not present a problem since the optics of the microcamera were believed to have strong absorption in this same region. However, if there were any transmission at this region of the spectrum, it would affect the test results from the longer wavelength exposures more than those at the shorter wavelengths-- the sensitivity of the test film being much higher in the near U.V. than at the longer wavelengths.

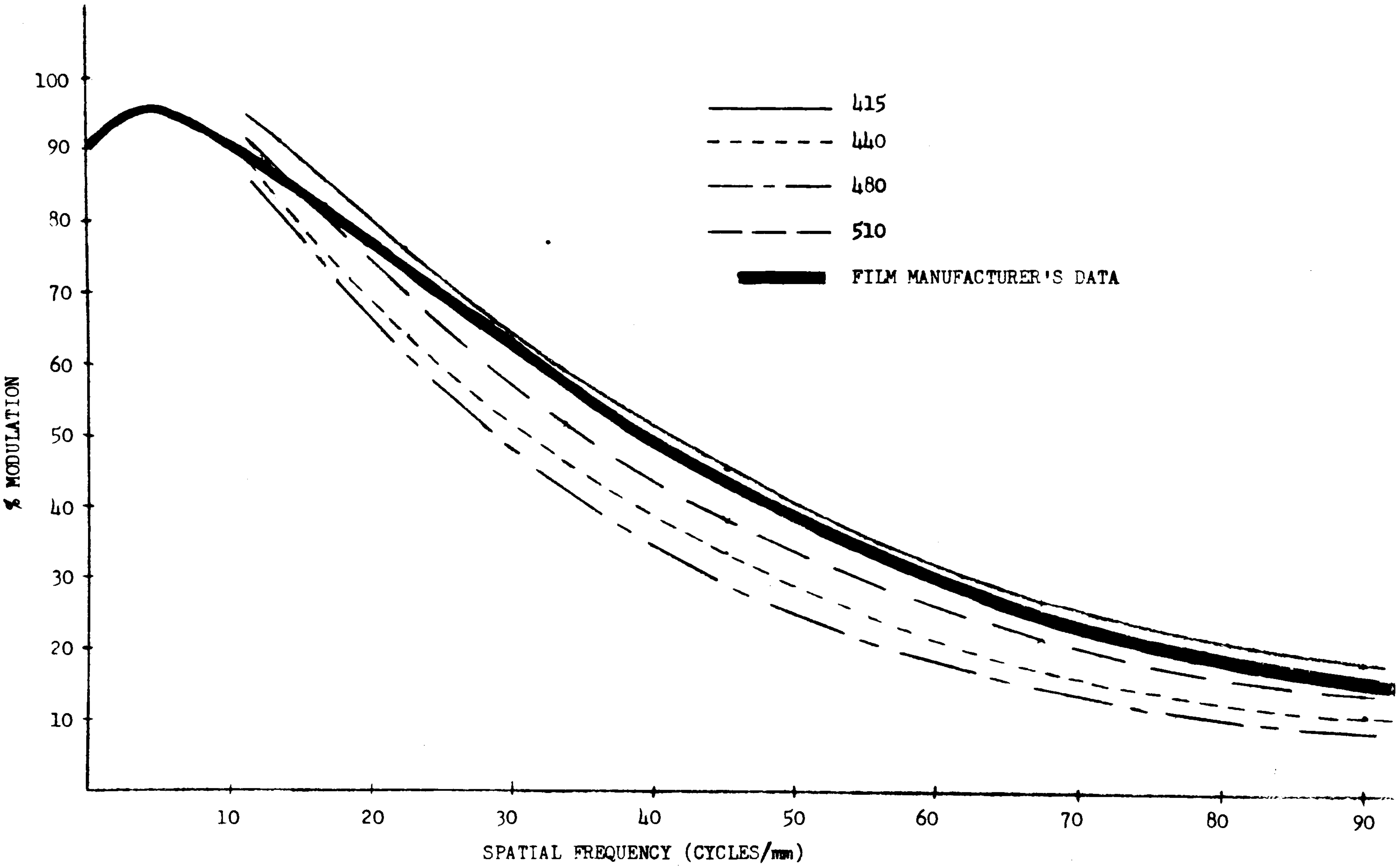
Additional exposures were made imaging a step tablet. This was done with each of the interference filters used alternately with and without an additional Wratten 2B filter (sharp transmission cutoff at 400nm). The log E shift after correcting for the 2B filter factor was used to calculate the percent of the effective exposure attributed to the peak wavelength of interest (415, 440, 480, 510). It was determined that in each test case at least 85% of the effective exposure was attributed to energy from the designated regions of the spectrum. Thus eliminating the possibility of an appreciable window in the U.V.

(Emulsion light scattering properties)

Another factor which could have affected the experimental results is the light scattering properties of the test emulsion. Although the scattering characteristics as a function of exposing wavelength for the test emulsion are not available, further insight into the changes resulting from the increase in wavelength of exposing light might be gained by considering the MTF curves obtained from the K values and the sine wave response data. When the MTF curves plotted from the sine wave response data are compared with the MTF curves obtained using equation 4 (Fourier Transform of the SF described by the parameter K) the following observations can be made:

1) MTF values calculated with K are slightly greater than the sine wave values at the higher spatial frequences, especially for longer wavelength exposures. Nevertheless, the sine wave and K value results are both in the neighborhood of the MTF (white light) values published by the film manufacturer (figure VIII).

2) The MTF curves calculated using the parameter K all



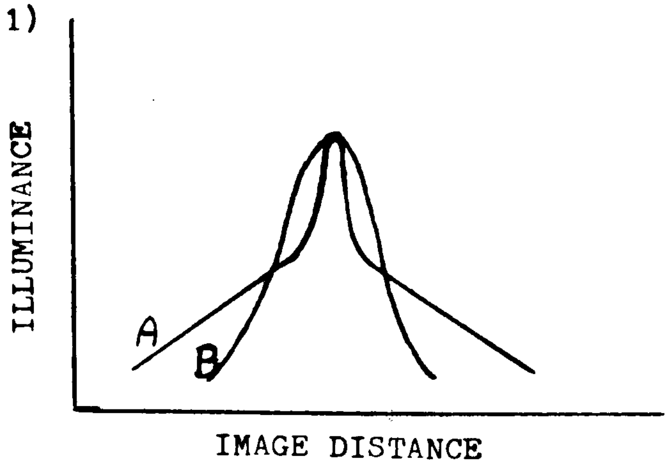
100
90
80
70
60
50
40
30
20
10
% MODULATION
10
20
30
40
50
60
70
80
90
SPATIAL FREQUENCY (CYCLES/mm)
415
440
480
510
FILM MANUFACTURER'S DATA

FIGURE VIII

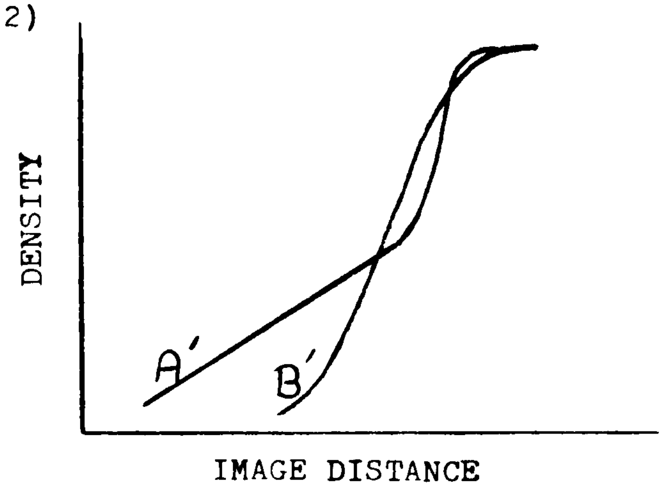
have the same general shape. Those obtained using the sine wave response data do not have the same basic shape.

3) In spite of the slight difference in the magnitude of the transfer factors, both methods of assessing image quality show agreement as to the general trend toward improvement between 480nm and 510nm. They also show agreement as to the basic shape of the MTF curves for the shorter wavelength exposures, but the two method do not agree as to the general shape of the MTF curves for the longer wavelength exposures.

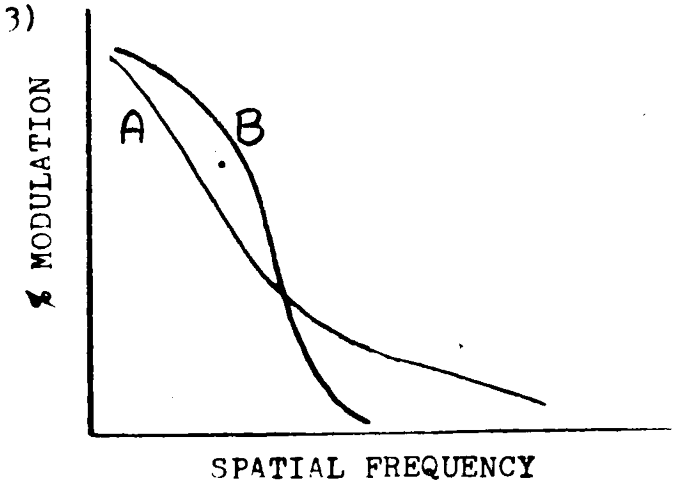
Therefore, although the K values offer the advantage of a single value to represent image spread, a more complete picture can be obtained by examining the general shape of the MTF curves generated from the sine wave response data. It has already been stated that the shape of the image transfer curves as obtained from these data vary with the wavelength of exposure. Some reasons for this variation might be explained by examining the two hypothetical line spread functions having forms A and B shown in block 1 of figure IX. Spread function B can result when a medium is only slightly turbid and has very little absorption, while spread function A will result with a turbid medium of high absorption.[8] The corresponding edge traces which are likely to result from imaging a knife edge are shown in the 2nd block. The edge A' corresponding to the line spread function shaped like A with the narrow neck and flaring skirt, will tend to produce a lower acutance value than the edge B' which corresponds to the line spread function shaped like B. Block 3 illustrates the results obtained by extending the comparison to show the relative differences in image quality transfer which are likely to occur.



LINE SPREAD FUNCTIONS



EDGE TRACES



MTF CURVES

FIGURE IX

System B is superior for reproducing details that correspond to the lower spatial frequencies, but system A will produce resolution where system B fails. This is an oversimplified comparison of the possible differences which can result depending upon the absorption and scattering properties of a photographic emulsion. Nevertheless, it is helpful in gaining insight into the changes which could be taking place with each increase in wavelength of exposing light. Comparison of the MTF curves obtained from the sine wave response data indicates a trend in curve shape associated with the increased wavelength of exposure. The MTF curves corresponding to the shorter wavelengths have a slope similar to that of curve B but, as the wavelength of exposing light is increasedthe MTF curves take on a shape more like curve A. This trend indicates a decrease in turbidity, as well as absorption in the lower wavelength region.

Reasons for the variation in shape of the MTF curves have only been discussed qualitatively. Also, as has already been stated, the emulsion scattering properties are not available. However, figure I shows something characteristic of undyed emulsions which may reveal more information about the trends associated with a change in wavelength. Beyond the region where absorption is no longer noticeable (past 520 nm) reflectance decreases and the transmittance increases. This is evidence that scatter is decreasing with increasing wavelength. It is obviously not Rayleigh scattering since the magnitude of the change is too small. It has been noted however, that the lines showing transmittance and reflectance as a function of wavelength are almost perfectly straight after 520 nm (where absorption ceases to control the density of the raw emulsion). There may be no real signigicance to the linearity, but it seems that these lines can be safely extrapolated to show a trend toward decreased optical turbidity in the wavelength region of interest.

Frieser has suggested that in certain cases the simple relation of equation (1) with the single parameter K does not hold; especially when a large part of the exposing light is transmitted without scattering. In some thinner and more modern emulsions the proportion of light diffused sidewise is appreciably less than unity. Frieser therefore proposed a two-term equation to describe the Spread Function of such emulsions; where the second term represents the nondiffused or slightly diffused light (in this 2nd term, K is very small). No attempt has been made in this study to use the two-term equation. Nevertheless, the possibility that undeviated light in the lower absorption region could form images which, of course, would be sharper and decrease the overall value of K, was considered. The possibility of an appreciable amount of non-scattered exposing light, however, was eliminated by the data resulting from forward scatter spectrophotometric measurements performed with the test emulsion. Transmission data similar to that shown in figure I was obtained using a modified integrating sphere. A spot, masking only that portion of the light which passes undeviated through the emulsion layer, allows all but the non-scattered transmitted light to be measured. A plot of the emulsion transmission data obtained in this manner proved to be essentially the same as that in figure I, which clearly shows that the proportion of non-scattered light for the wavelength region of interest is negligable.

In spite of the foward scatter data which proves the absence of non diffused, imaging light, there is sufficient evidence to denote a trend toward decreased scatter with increasing wavelength. The effect of this trend (which is evidenced by the extrapolated transmittance and reflectance data; figure I) can be seen in the results from both the sine wave response data as well as the K values (two relatively independent methods of assessing image quality). High absorption is the controlling factor in the 415 - 440nm region as indicated by the low K values which represent image quality of the same magnitude as that published by the film manfacturer. The effect of scatter, however, becomes evident in the lower absorption region at 480nm, since there is only a small increase in K in spite of the large change in absorptance (from 50% to 16%). It is questionable though, that the decrease in scatter alone, can account for a decrease in K between 480 - 510nm. Adjacency effects may be a contributing factor. K will obviously be affected by adjacency effects, and an accurate result can be obtained only when these effects are absent. The sine wave data for 415nm gives a modulation almost greater than 1.00 which may mean the use of effective exposure was in error. If this is not due to adjacency effects it is caused by some other effect which produces a change in the relation between macro and micro contrast. But regardless of the other factors involved, it is clear that in the wavelength region where the absorptance of the photographic layer is very slight, any decrease in the amount of scatter can be an influencing factor in the resulting image quality.

Conclusion

Two opposing effects are evident as the wavelength of exposure increases - decreasing absorption and decreasing scatter. In the shorter wavelength region (410-440 nm), absorption is high and will control the image quality even if the turbidity is also high. However, in the longer wavelength region (480-510 nm), where the absorption decreases rapidly, the effect of decreased scatter is evident, since the Spread Function does not increase proportionally. The exact importance of these effects have not been determined, but the general trends and pertinent data have been carefully documented to assist in any further tests conducted as a follow up to this study.

Acknowledgements

The assistance from the people at Bausch & Lomb who made the interference filters available for this study, and the help from those at the Kodak Research Laboratories who provided the spectrophotometric data for the test emulsion is gratefully acknowledged. Also the guidance from the Rochester Institute of Technology photographic science faculty and especially the many helpful suggestions from Dr. B. H. Carroll are appreciated.

REFERENCES

1. F. H. Perrin, "Methods of Appraising Photographic Systems", Part I and Part II, Jour. of SMPTE, 69: March and April (1960).
2. H. Frieser, "Spread Function and Contrast Transfer Function of Photographic Layers," Phot. Sci. Eng., 4: 324 (1960).
3. H. Frieser, Kino-Technik, 17: 167 (1935).
4. H. Frieser, Phot. Korr. 92: 51: 183 (1956).
5. D. Paris, J. Opt. Soc. Am., 51, 988 (1961).
6. R. L. Lamberts, "Application of Sine-Wave Techniques to Image-Forming Systems", Jour. of SMPTE, 71: 9: September (1962).
7. R.L. Lamberts, "The Production and Use of Variable-Transmittance Sinusoidal Test Objects", 2: 273: March (1963).
8. G. C. Higgins, "Information Capacity of Photographic Materials", <u>Photographic Systems for Engineers</u>,Farnsworth Press, Boston, Mass. 1966 p. 177.

APPENDIX

Statistical confidence limits on the mean K values were determined using the Student t test. The mean K values with 90% confidence for each wavelength are:

wavelength	K value
415	19.6 ± .3
440	25.7 ± .8
480	27.8 ± 1.2
510	22.6 ± 1.2

MTF of the microdensitometer

The values used in determining the transfer factor of the test emulsion were influenced, of course, by the effective slit aperture (3.0 um) and optics of the microdensitometer which scanned the sine wave images. In order to determine the MTF of the microdensitometer, a near perfect edge or step function (low contrast "knife" edge) was scanned with the same optics and slit used to trace the test images. Three separate edge traces were made. A single set of data points, obtained from a statistical "least squares" best fit of the three traces, were compiled as input to a computer program. The program was run on an IBM 360 computer to calculate the MTF of the microdensitometer.** The computer output was then used to divide out the effect of the microdensitometer, leaving the MTF of the film alone as shown in figure VII. Table B lists the MTF values calculated for each of the three edge traces as well as the "least squares" best fit. The data from the latter are plotted(fig.X

** The computer program is the property of Eastman Kodack Co.

Table B

Microdensitometer MTF Values

(calculated from edge trace analysis)

Spatial Frequency	Trace #1 Response	Trace #2 Response	Trace #3 Response	"Least Squares" Best Fit Response
0.0	1.00	1.00	1.00	1.00
12.5	.99	.99	.99	.99
25.0	.98	.96	.97	.98
37.5	.96	.92	.95	.95
50.0	.94	.88	.91	.91
62.5	.90	.83	.86	.87
75.0	.86	.79	.80	.82
87.5	.80	.75	.75	.76
100.0	.74	.71	.68	.70
112.5	.67	.67	.62	.65
125.0	.60	.62	.55	.59
137.5	.53	.56	.49	.53
150.0	.47	.50	.43	.48
162.5	.42	.44	.37	.42
175.0	.38	.38	.33	.37
187.5	.34	.33	.28	.32
200.0	.30	.29	.24	.27
212.5	.26	.25	.20	.23
225.0	.21	.21	.16	.19
237.5	.17	.17	.12	.15
250.0	.13	.14	.09	.12
262.5	.10	.10	.07	.09
275.0	.07	.06	.07	.07
287.5	.04	.03	.07	.05
300.0	.01	.01	.07	.04

These data represent the calculated MTF of the RIT GAF Model IV microdensitometer under the following conditions: 20X objective, 12.5X eyepiece and 3.0 µm slit. The 20X objective has a .4 numerical aperture.

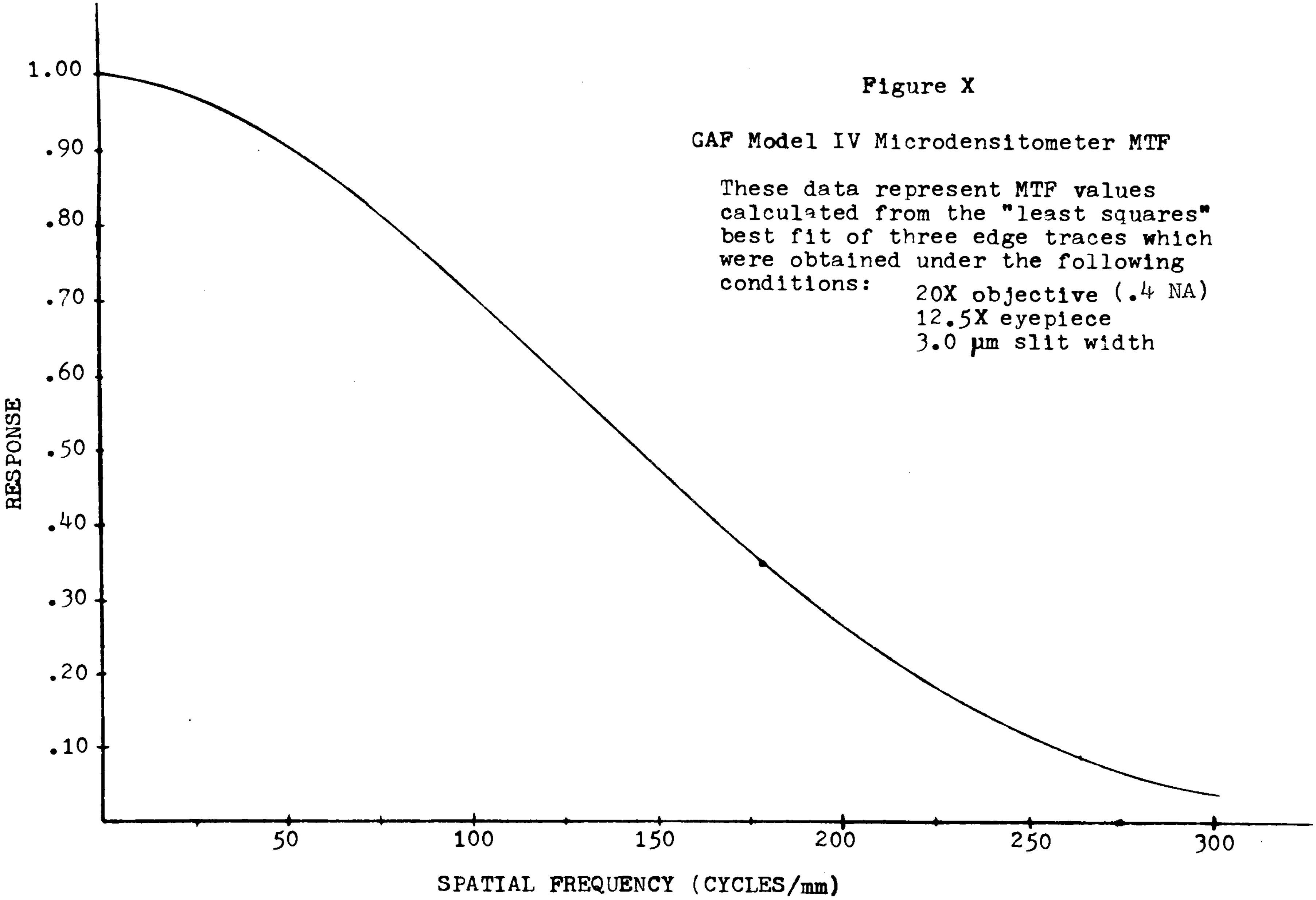


Figure X

GAF Model IV Microdensitometer MTF

These data represent MTF values calculated from the "least squares" best fit of three edge traces which were obtained under the following conditions:
20X objective (.4 NA)
12.5X eyepiece
3.0 µm slit width