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An investigation of film and contact screen effects in the halftone dot system

Michelle Bushnell

AN INVESTIGATION OF FILM AND CONTACT SCREEN EFFECTS IN THE HALFTONE DOT SYSTEM

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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.

Signature of the Author Michelle Bushnell
Photographic Science and Instrumentation

Certified By E. Granger
Thesis Advisor

Accepted by Ronald Francis
Supervisor, Undergraduate Research

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ABSTRACT

A model was tested which, given a certain film and contact screen, can predict halftone modulation transfer functions. A relationship was derived which, given the halftone MTF, can predict the halftone dot gradient for the system.

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LIST OF SYMBOLS

MTF	Modulation Transfer Function
e(x)	Edge Function
l(x)	Line Spread Function
OTF	Optical Transfer Function
NA_c	Condenser Numerical Aperture for Microdensitometer
NA_o	Objective Numerical Aperture for Microdensitometer
w_{max}	Max. Frequency of Microdensitometer System
w_o	Frequency of Interest
n	Interger
a	Halftone Dot Width
l	Halftone Screen Frequency

INTRODUCTION

Halftone photography is a system used primarily in the printing industry. Through the halftone procedure, the printer is able to reproduce a continuous tone image using ink of a single density.

Because most printing equipment (ie; lithographic presses and letterpresses) cannot distribute ink with variable density, continuous tone is obtained by controlling the halftone dot area. If the dot size is small, the eye is not able to resolve the individual dot but perceives the ratio of dense ink spots to unprinted white paper as a gray tone.[1] By varying the size of the dots on the paper, a range of continuous gray tones may be reproduced.

A halftone negative is made by exposing a piece of high contrast lithographic film through a contact screen. It is the contact screen that transforms the intermediate tones of the original into solid dots of equal density but varying size.

The highlight area of the original reflects the most light to the screen/film combination thereby creating broad ninety-five percent highlight dots covering most of the area exposed on the developed negative. Likewise, the original's shadow areas reflect little light to the screen creating the five percent dot area of the film.[2] Dot percentages always refer to the size of the black dots.[3]

One of the variables controlling the characteristics of the halftone dot is the halftone screen. There are two distinct catagories of screen; crossline and contact.

Each of the screens has its own disadvantages and advantages, but the end result from either one is the same; the production of images made up of equally-spaced dots of varying size.

The crossline screen is made up of two flat pieces of glass. Each of these glass plates are ruled with black parallel lines at an angle of forty-five degrees to the edge. The two plates are then cemented together in such a way that the rulings are ninety degrees to each other. This halftone screen is then placed in the halftone system at a predetermined distance from the lens and film plane. Because crossline screens are costly to produce as well as require the operator to calculate screen position relative to the lens, the contact screen has gained popularity in the printing industry.[4]

A contact screen may be positive or negative working, magenta or gray, square or elliptical in elemental structure.[5]

The primary difference between an elliptical and square dot screen is the pattern imaged on the halftone negative. An elliptical dot screen produces football shaped middletone dots that join only two corners as the dot sizes approach fifty percent. The square screens produce a sometimes objectionable "jump" in density in the middletone of the reproduction where the four corners join.[6]

A magenta contact screen is made up of dyed film material. These screens are used when tone reproduction characteristics can be altered by using a magenta or yellow filter in the light path. The gray screens are used when no filtration tone control is necessary.

The classification of a screen as either positive or negative working refers to the screen's ability to reproduce a scene range and the eventual number of exposures necessary for optimium tonal reproduction.

A positive working screen requires three exposures; the main exposure, the flash, and the bump; whereas the negative only requires a main and bump exposure.[7]

The main exposure will reveal the Basic Density Range, BDR, of a screen. This BDR is the range of exposures that the screen is capable of reproducing. To extend the range of tones a screen can reproduce, a flash exposure is used in addition to the main exposure. The flash is made with only the screen over the film thereby producing five percent dots in all the highlight areas on the negative. The bump exposure is nonimage forming and is made after the screen is removed. The result of the bump is an increase of the contrast of the negative in the area of greatest density.[8]

There are several high contrast films that are used for the halftone dot system. Two such films are Eastman Kodak's Kodalith Ortho film 2556 Type 3 and Kodalith Pan film. These films are able to reproduce sharp halftone dots suitable for printing.[9]

Although there has been extensive literature published pertaining to halftone photography, few attempt to correlate the variables in the process (ie; film, screen and chemistry interrelationships) to the final tone reproduction. Of these investigations published, most are purely subjective in nature and offer little or no scientific analysis.

Recently, some scientific progress has been made in examining the halftone process in a mathematical fashion.[10,11,12]

P. Engeldrum developed a mathematical model of a contact screening system.[10] M. Tayima and Y. Komatsiu have analyzed and correlated methods of measuring dot quality.[11] The research of P. Oittinen and H. Saarelma indicated that linear image transfer theory can be applied to the halftone system.[12]

The basic model for linear systems states that system output is related to the initial input by the convolution of the input with the system's line spread function. In terms of Fourier analysis, the output can be predicted by back transforming the product of the input transform and the system transfer function.[13]

The system's modulation transfer function is a quantitative measure of image quality. From the MTF curve the information content of an image can be deduced. MTF describes the ability of a system, as a function of spatial frequency, to reproduce input contrast to the image. By knowing the MTF of the individual subsystems of a process, the entire MTF can be calculated.[14]

Mathematically, MTF can be calculated providing certain characteristics of the system are known.

How a system degrades the image of a perfect line, when imaged through the system, is called the line spread function. The edge function can be determined by the following relationship;

$$e(x) = \int_{-\infty}^{\infty} l(x)\, dx.$$

The system's optical transfer function is defined as the Fourier transform of the line spread funtion. MTF can be determined by the following relationship;

$$\left| OTF\ (f) \right| = MTF(f)$$

In order to calculate film MTF curves, B. Tatian determined a method for obtaining the transfer function from an edge exposure.[17] Tatian's method of MTF determination expresses the transfer function as a trigonometric series whose coefficents are proportional to the sampled values of the edge response function. Using the method, computer programs can easily be written that determine MTF given the edge, in terms of exposure, as input.

A microdensitometer, according to P. Oittinen, may be used to accurately determine the edge needed to calculate the MTF.[18] Because a microdensitometer can be set up to approximate incoherency, and a linear system, the equipment's MTF can be easily measured, given the numerical apertures of the lenses involved as well as the slit dimensions. According to work done by J. Dainty and R. Shaw, illumination in any practical microdensitometer is neither coherent or incoherent but partially incoherent.[19] But, for a system with known numerical apertures, it is possible to produce effectively incoherent conditions by selecting the proper choice of the size of the field stop and the numerical aperture of the substage condenser. Work done by Swing showed that the following conditions would approximate the effective incoherence required by Dainty and Shaw;[20]

$$\frac{NA_c}{NA_o} = 1 + \frac{w_{max}}{w_o}$$

Because a system can be constructed which will allow linear transfer theory to be applied, the microdensitometer can be used to accurately measure both the MTF of the film as well as the MTF of the halftone produced on the film.

P. Oittinen and H. Saarelma used the linear transfer theory to develop a relationship between halftone and continuous tone MTF;[21]

$$MTF_{halftone} = MTF_{cont.\ tone} \left(\frac{a}{l} \right) \cdot \mathrm{Sinc} \left(\frac{na}{l} \right) \delta (f-nl)$$

Obviously, from this relationship, screening construction and film MTF has a drastic effect on the frequency transfer. It is the purpose of this research to establish experimental data in order to test the theoretical halftone quality prediction given by linear theory and esbalish to what degree screening and film MTF effect halftone tone reproduction ability.

EXPERIMENTAL

I. Equipment Calibration and Characterization

Initially, the equipment to be used in this experiment had to be calibrated and characterized. The MacBeth model 504 digital macrodensitometer was used in all macro-density measurements. This equipment was checked, using its standard wedge and control chart prior to each use. The Ansco microdensitometer by G.A.F was used for al micro-density measurements. The Ansco was calibrated prior to its use. Calibration was done, after a half hour warm up period, using a characterized set of glass filters placed directly in front of the phototube with no sample in the light path. Both the edges and the halftone dots were scanned while the densitometer was within .02 of calibration. Conditions required for incoherency were established in the densitometer. This was done by using a 10X condenser with a numerical aperture of .20 in the light path along with an 10X objective with a numerical aperture of .10. The stop between the lamp housing and the condenser was closed down until it almost caused a deflection in the chart drive pen. This reduced system flare. The eyepiece in the light path, located behind the objective, had magnification 12.5 . The slit in front of the phototube was .25mm by 20mm. The small aperture assured that the sample image filled the phototube aperture. The chart drive was set at a speed of two inches of paper per minute. All edges were scanned at a rate of .10mm per minute and all dots were scanned at a rate of .25mm per minute. The point source sensitometer used in this experiment consisted of a lamp housing located in a darkroom ceiling approximately nine feet from the floor. Approximately three inches directly below the lamp housing, a remote controlled wheel supported six different neutral density filters. These filters, the shutter time, as well as the lamp intensity, could be controlled by the operator. On the floor, below the lamp, was a vaccuum exposing frame and a vaccuum control unit. Using a Luna-Pro light meter, exposure units were recorded in lux for each intensity and filter combination. These values would be used when absolute exposure was necessary in order to generate the film characteristics curves.

II. Material Characterization

The films and screens used in this experiment were as follows;

1. Kodalith Ortho Type III 2557
2. Kodalith MP II
3. ES Scanner Film

1. 100 lines/inch line screen
2. 60 lines/inch line screen

A graphic arts exposure calibration target, supplied by Kodak and commonly used in industry, was used to determine correct exposure. The target incorporates most of the commonly used screen frequencies, ranging from sixty to one hundred and thirty three lines per inch. For each frequency, a series of patches containing five through ninety percent dots were arranged on the target. Proper exposure for a particualr film was defined as being that exposure which produced fifty percent dots for that density on the target which corresponds to the screen frequency of interest, and read .3 on the macrodensitometer.

An exposure time series was run on each film combination used. The test samples were then tray processed in Kodalith A and B developers. As recommended by Kodak, the developer was kept at a temperature of 68°F and the development time was two and one half minutes with constant agitation. After development, the negatives were placed in stop bath for thirty seconds and then in Kodak Rapid Fixer for five minutes. The negatives were then washed in a print bath washer for ten minutes and dried.

Once the correct exposure time was determined for a particular film and screen combination, it was used for the remainder of the experiment.

III. Data Generation

Each of the screens was imaged on to each of the films. Along with the screens, a .05 increment step wedge was imaged on the film. In an effort to produce films which significantly differ in MTF, several exposures were made using a diffusing material placed between the film and the screen. The diffusing material used was 3M Thermafax overhead projector film. The uniform density of this material was about .02.

All final sample exposures were taken to Eastman Kodak's Photo Technology Division in Rochester, New York for processing. The film was processed in an automatic processor maintained in control by Kodak using MPII lithographic chemistry. The processing time was approximately one and one half minutes (development) and the chemistry temperture was maintained at 80^{o}F.

One step of the wedge exposure was used in the calculation of MTF. This edge exposure was scanned on the microdensitometer. The resulting edge in density space was then converted, using the film's characteristic curve to exposure space. The exposure values for the edge were then used in Tatian's method of MTF calculation. All calculations were performed by a program, stored on floppy disk, in an Apple II Plus computer. The computer program both calculates and plots the MTF values for an edge. This program was written by R. Guttosch of Rochester Institute of Technology, Rochester, New York. All the MTF's of the screens were calculated using the formula approximation as mentioned in the introduction. These values were multiplied, point by point, by the film MTF and plotted. The MTF's were also calculated for each corresponding halftone and the experimental results were plotted versus the theoretical data.

IV. Analysis

The halftone negative generated by the printer will, eventually, be used to produce an image on a press plate. This press plate will be used to transfer the single density ink to paper. The fringe on the halftone dot of the negative will have an effect on the dot imaged on the plate. An investigation was made reguarding the effects of film MTF and screen frequency on dot gradient.

RESULTS

Low contrast edges were scanned on the microdensitometer and Tatian's method was used to calculate the MTF of each film. Several examples of the MTF curves derived may be found in the appendix.

Figure one shows the approximate MTF of the 60 and 100 lines per inch screens. These curves were generated using the approximation derived by Oittinen. This formula states that; $MTF_{screen} \simeq \mathrm{Sinc}\left(\frac{na}{l}\right)$.

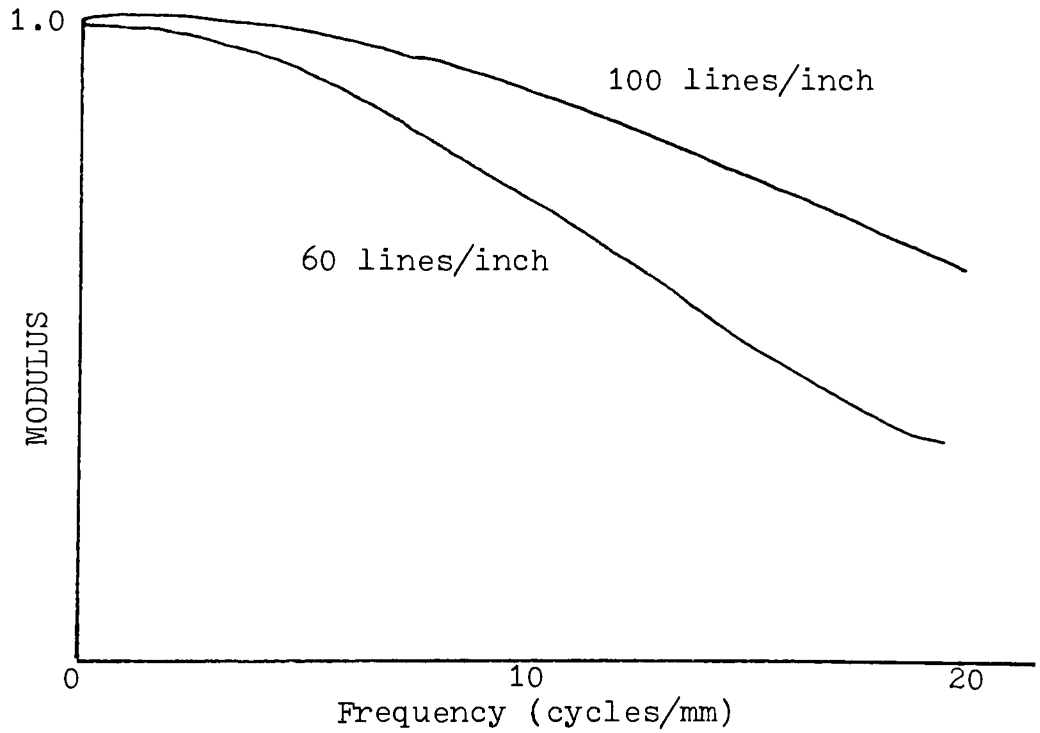

Figure 1. Approximate MTF for 60 and 100 lines per inch screen.

Because of the principles of linear theory, the MTF curve of the halftone may be approximated by the product of the film and screen MTF. In other words;

$$MTF_{cont.\ tone} \cdot MTF_{screen} = MTF_{halftone}$$

This model was tested by multipling calculated film and screen MTF's and comparing the results to the halftone MTF's derived experimentally. Figure 2 shows an example of this comparison and figure 3 illustrates the theoretical's deviation from the experimental (residual) averaged over all films tested.

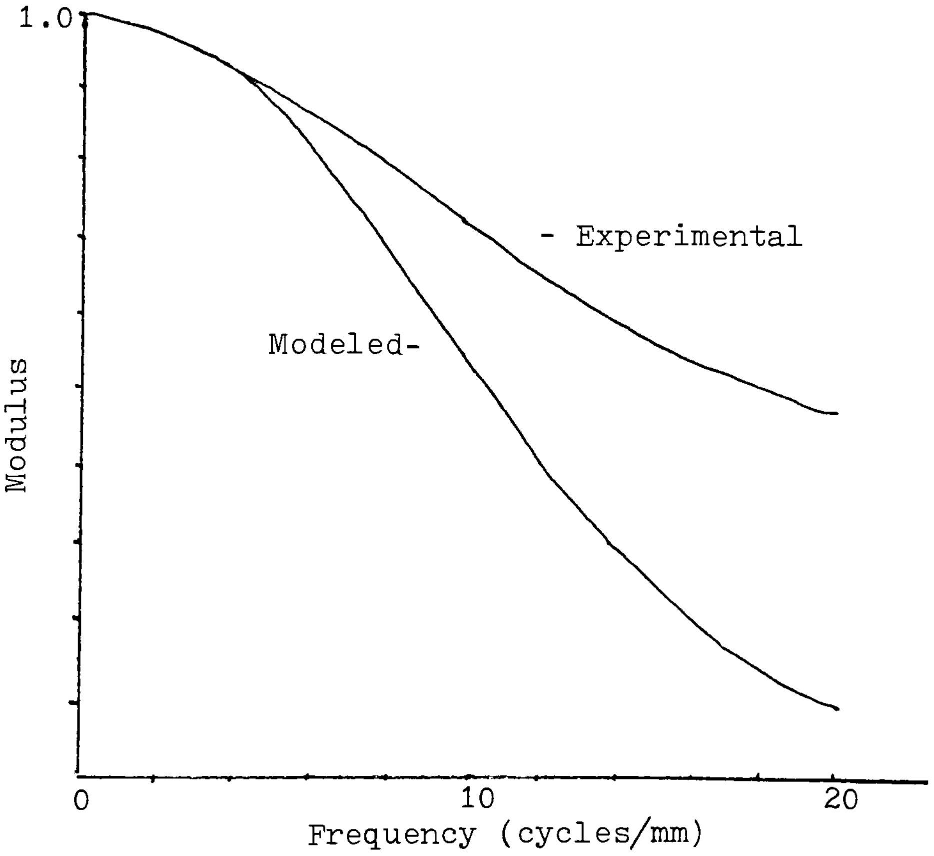

Figure 2. ES Scanner Film MTF Curves

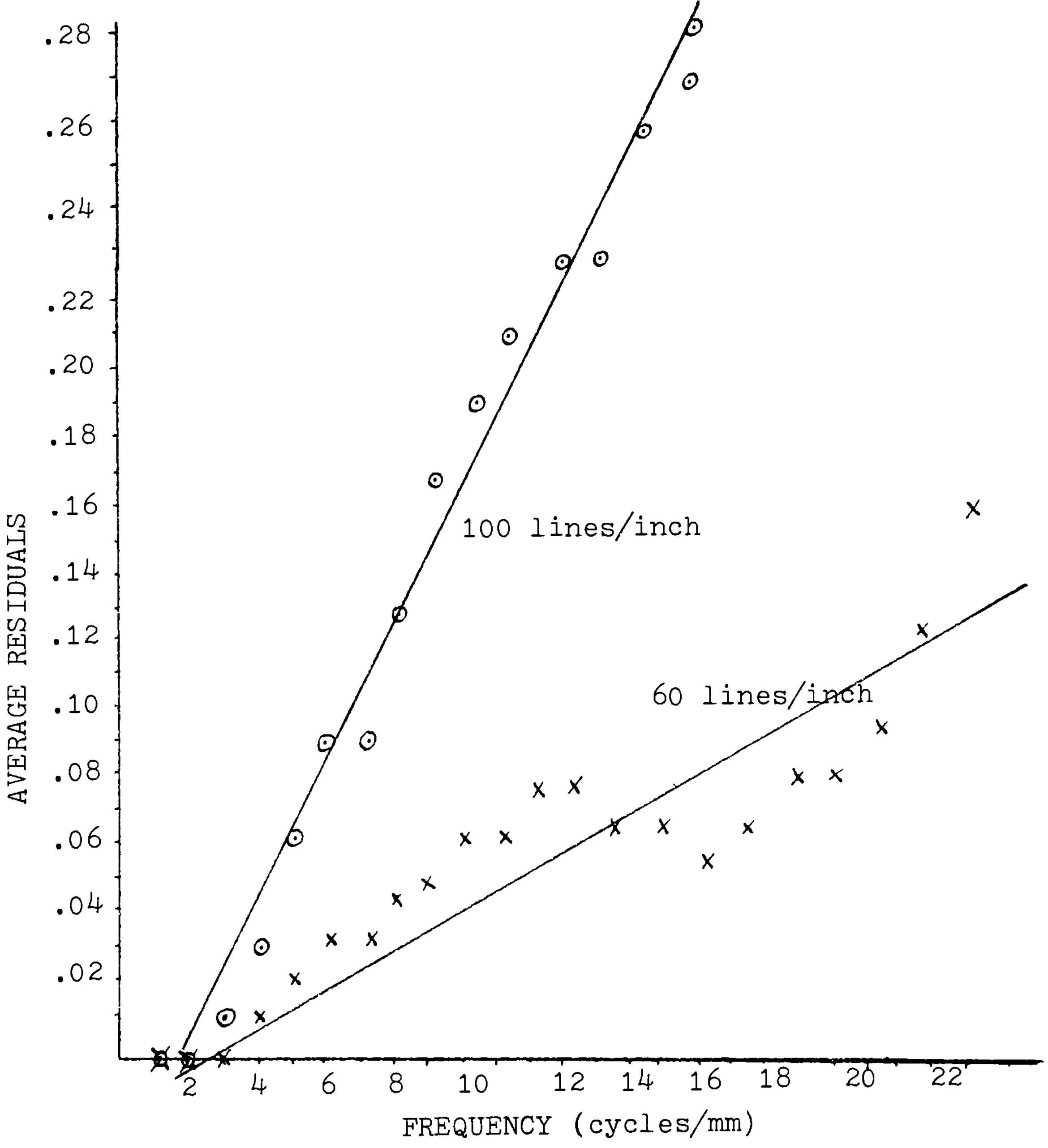

Figure 3. Average residuals.
This plot is the average residual per frequency of each film.

In order to investigate the relationship between film MTF and halftone MTF the following plot was drawn.

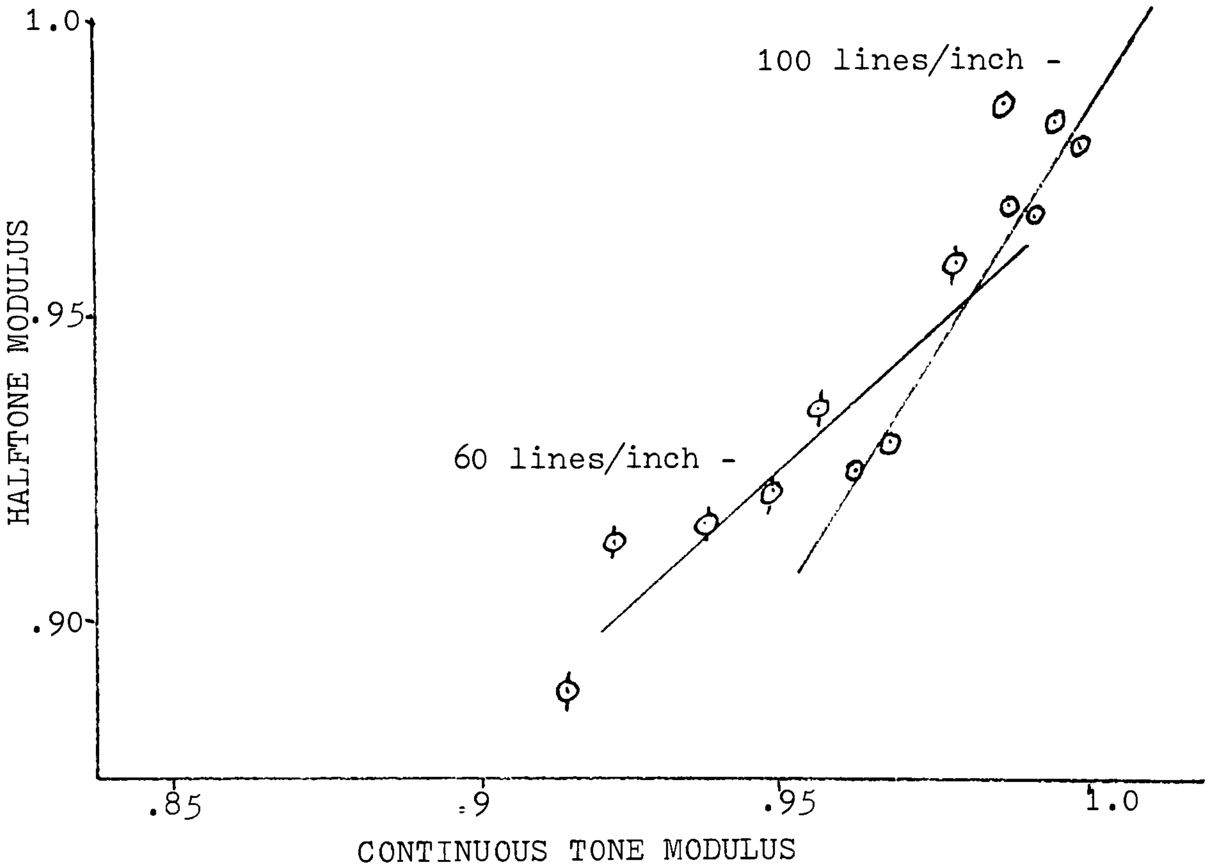

Figure 4. Continuous vs. halftone modulus for 60 and 100 lines/inch screen

From the data generated experimentally, the average halftone MTF value and dot gradient were taken at each screen frequency. Linear regression was used to derive a model to relate the two values:

dot gradient = 58.22 - 52.39$\cdot$ (halftone modulus)

R^2 = .83

Confidence Limits on R^2 for 95% : ($.79 < R^2 < .87$)

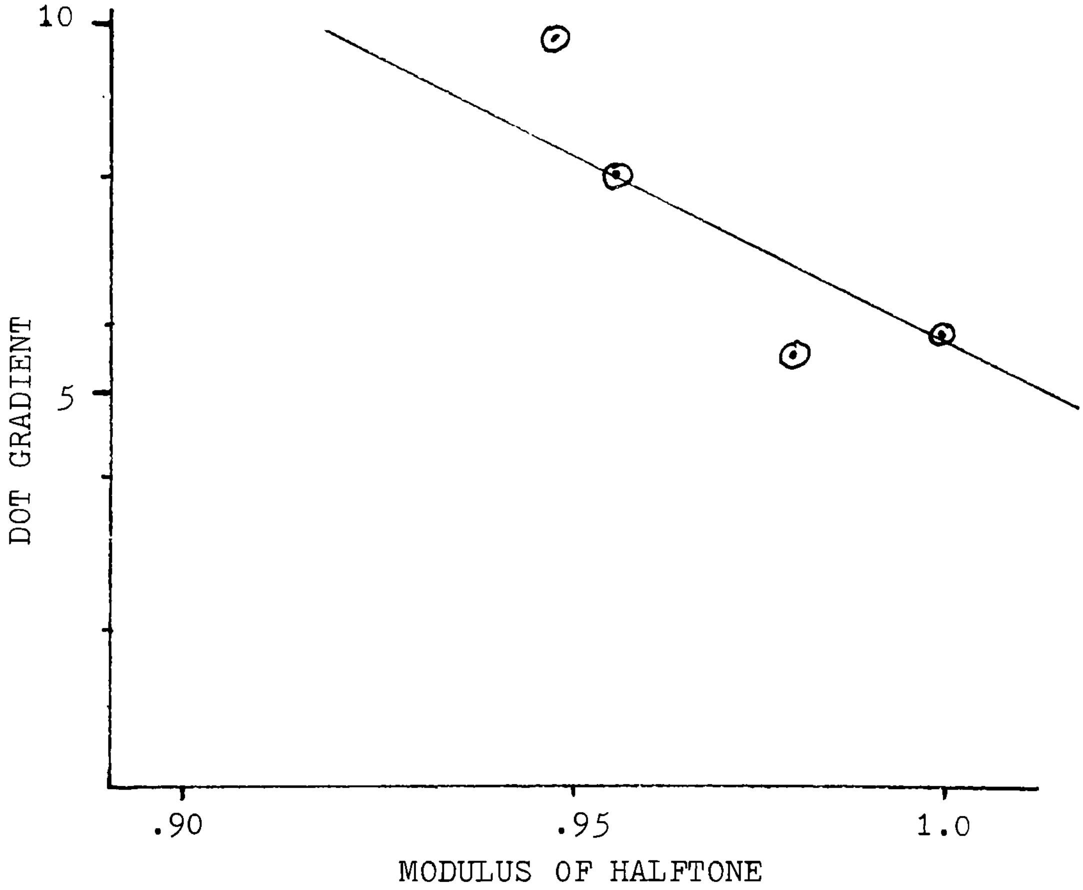

Figure 5. Halftone Modulus vs. Dot Gradient

The goal of this modeling is to enable dot gradient to be determined providing certain film and screen characteristics are known. The model is meant to be used in this way:

1. If a 60 or 100 lines per inch screen is being used, the halftone MTF value at those frequencies can be determined providing film MTF is known.
2. Once halftone MTF is determined, the regression relationship can be used in order to determine dot gradient.
3. If the screen to be used is neither 60 nor 100 lines per inch, the screen MTF approximation may be used in order to use linear theory to determine halftone MTF.

The characteristics of several untested films were measured in the same manner as the films used in the derivation. These films were used in the model as outlined above. The following represents the results.

Unknown film modulus (60 l/inch)	Gradient (Modeled)	Gradient (Actual)
.977	7.03	5.27
.968	7.5	8.1
(100 l/inch)		
.955	8.2	8.4
.980	6.7	6.0

DISCUSSION

According to the results of the error between actual halftone MTF and the formula approximation, the formula seems acceptable for only low frequency screen. Fortunately, screens most commonly used in industry fall between the 60 to 100 lines per inch frequency range. It is over this range that the model performed the best. As can be seen from the residual plot (see figure 3), the model seems to lose accuracy drastically for values greater then 100 lines per inch. Because of the linearity of the error, it may be that a more accurate model could be derived. Perhaps with the addition of another term, the model's residual error could be reduced.

If either the 60 or 100 lines per inch screen are used, the graph derived (see figure 4) may be used as a model for halftone MTF. If,on the other hand, another screen frequency is used, linear transfer theory would allow halftone MTF to be determined by the multiplication of screen MTF and film MTF. Because only two screens were used, this theory could not be investigated.

When unknown films were used in this model the variation of known versus unknown gradient values did not indicate that one screen or film worked better, but rather that the model incorporates enough variability to lead one to question its accuracy.

The variability for the four films tested was;

	Modulus	% error
60 l/inch	.977	30
	.968	7.0
100 l/inch	.955	2 .1
	.980	12.0

This variation in gradient may become more meaningful should some work be done as to how much variation can occur before image degradation occurs on the press plate.

CONCLUSION

The results of this work indicate that, for screens of frequencies below 100 lines per inch, linear transfer theory can be used to predict the image dot gradient.

Using the graphical model (in cases using the same screens) and the relationship; $\text{gradient}=58.22-52.39\left(\frac{\text{halftone}}{\text{modulus}}\right)$, it is possible to approximate the gradient of the imaged dot. Because of limitations introduced in this experiment (ie; only 2 screens were investigated), it is suggested that work be continued along these lines in order to test this relationship using other screen frequencies.

Because the screens used were all line screens, it is unknown as to how a different screen construction would work in this model.

This method of modeling dot gradient may be useful in those circumstances were extreme accuracy is not necessary. If in no other aspect it is useful in that it supports the theoretical work of P. Oittinen and indicates that an accurate relationship could exist and be found with further investigation.

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APPENDIX

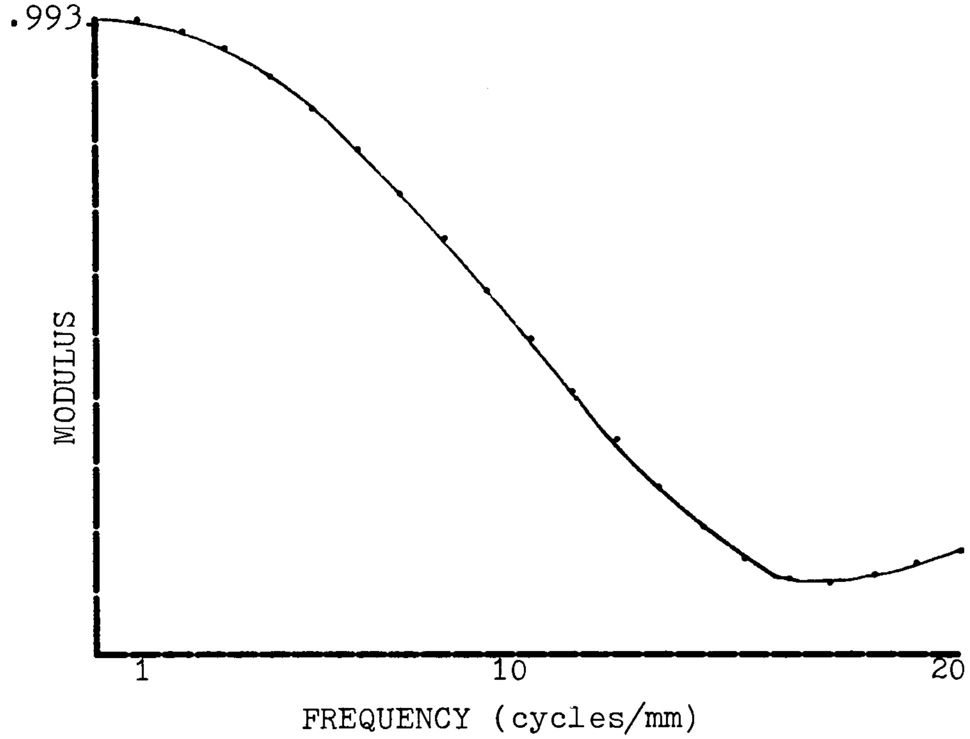

Figure 6. MTF for Kodalith MPII with 1' diffusers

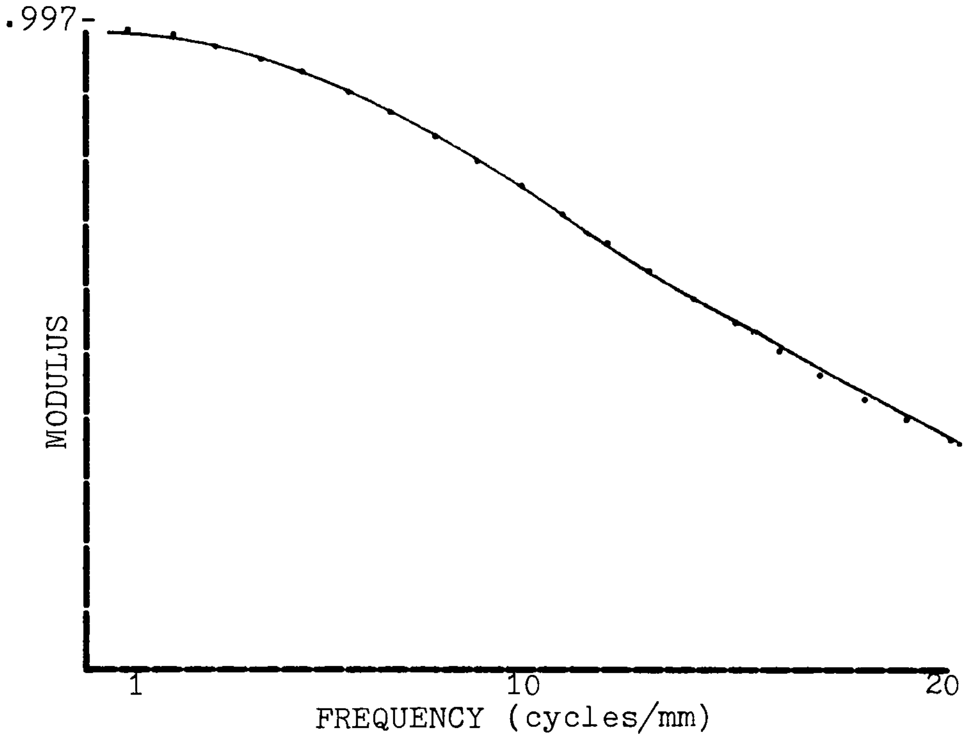

Figure 7. MTF for Kodalith MP II with no diffusers