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PAR 251

FINAL REPORT

Image Enhancement Studies Using Ring Smear Techniques

15 May 1970

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date: 11 June 1970

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SUMMARY

Ring smear is a photographic enhancement technique that has been applied for image enhancement of aerial photographs. The technique permits selection of the spatial frequency for maximizing enhancement, plus an adjustment of the amount of enhancement included in each photograph.

Photographic image enhancement by ring smear has been developed as a semi-production enhancement technique using the BPE* breadboard enlarger.

Equipment to perform ring smear enhancement was designed and tested on the BPE breadboard. Appropriate films to be used in the ring smear enhancement process were selected, and tolerances were established for image density ranges and processing gammas.

The enhancement technique was evaluated by both subjective and sine wave MTF (Modulation Transfer Function) analyses to determine the most suitable and practical ring smear techniques. An experiment was included to determine if any real gain in information was afforded by ring smear enhancement. It was found that no additional information could be extracted from ring smear enhanced photographs. However, subjective evaluations indicated the probability that information is extracted easier and faster with such enhancement -- especially in the case of photography from poorer quality systems, and smeared or de-focused photography from high quality systems.

25X1 Selected material from the [redacted] system was enhanced and submitted to demonstrate the capabilities on actual mission photography.

25X1 [redacted] Precision Enlarger.

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SUBJECT: Image Enhancement Studies Using Ring Smear Techniques

TASK/PROBLEM

1. Design, fabricate, and mount a ring smear device on the BPE breadboard enlarger, and using this equipment:

a. Develop equipment necessary to hold enlarged product and ring smear mask in registration during subsequent printing.

b. Perform image enhancement on selected mission originals.

c. Train selected contractor and customer exploitation personnel in ring smear enhancement techniques.

d. Study operating parameters of ring smear technique with the goal of improving the method.

INTRODUCTION

2. A technique known as unsharp masking has been used successfully to increase the contrast of fine photographic detail relative to detail at lower spatial frequencies. This has been accomplished by generating a "fuzzy," negative copy of the original and superimposing it with the original to form a composite. Because the overall contrast of this composite is reduced, compared to the original, high-contrast printing is used in recording the composite image. The resulting image will have a lower contrast at lower frequencies than at high frequencies. The schematic in Figure 1a illustrates this form of unsharp masking.

3. Armitage, Lohmann and Herrick[1] proposed a variation of this unsharp masking technique that produces a greater relative increase in the contrast of fine detail. In this technique, known as ring smear, the MTF (Modulation Transfer Function) used in making the mask is such that a phase inversion in the fine detail of the image spectrum takes place. Figure 1b illustrates the ring smear enhancement process.

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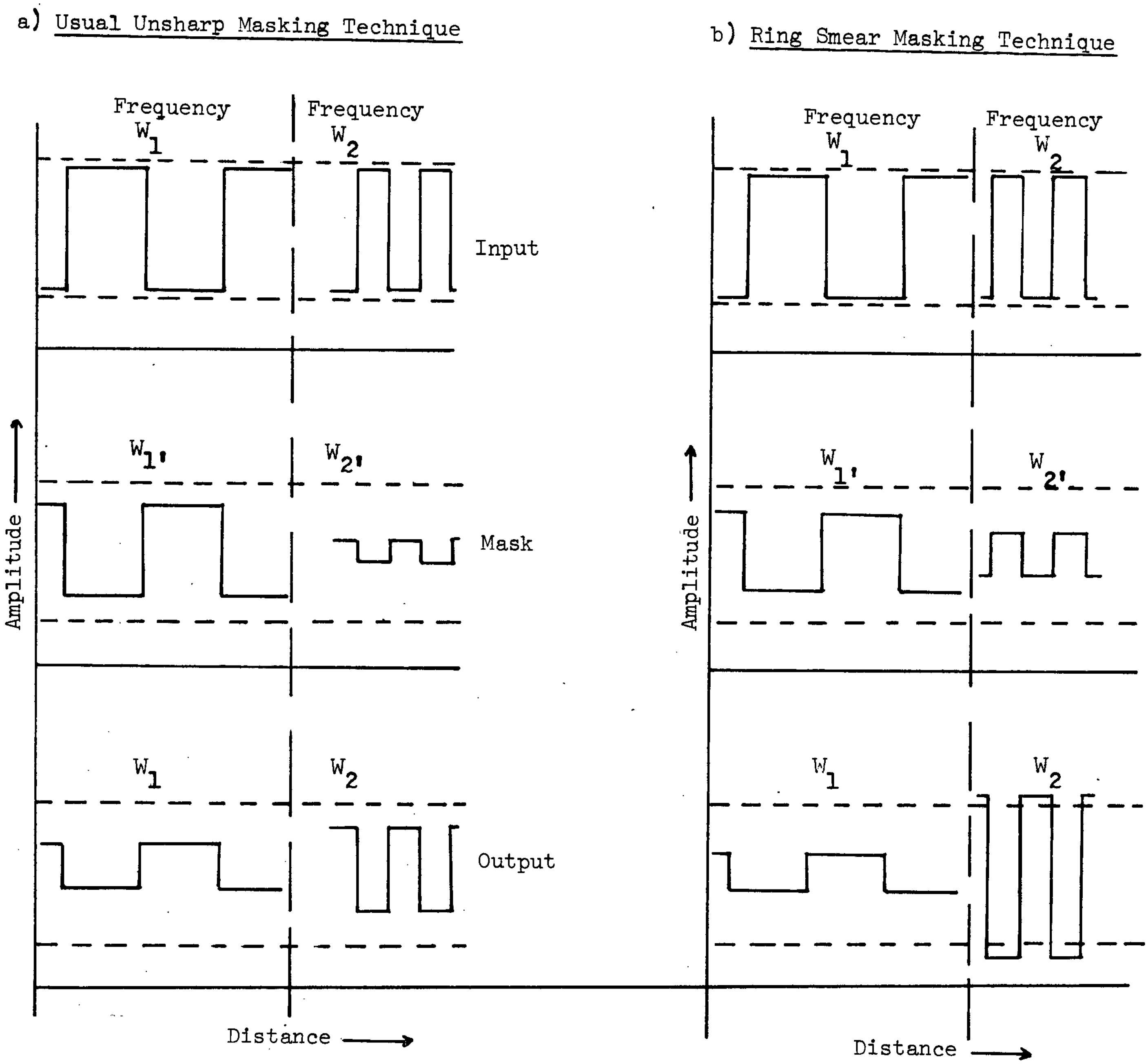
Figure 1

The Effect of Conventional and Ring Smear Masking
on the Amplitude of Two Spatial Frequencies
(for simplicity, demodulated square waves were drawn as square waves)



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4. The results of the analysis performed by Armitage, Lohmann and Herrick show that, under certain conditions, the transfer function of the unsharp masking process is given by the following relation:

$$\tau = 1 - \gamma_M \cdot \tau_M \tag{1}$$

where τ = the transfer function of the unsharp masking procedure

γ_M = the gamma of the photographic material upon which the unsharp mask is recorded

τ_M = the transfer function of the unsharp mask generation procedure

The conditions required for this relationship to hold are that the modulation of the unsharp mask be less than that of the original, and that the modulation of both be less than some maximum value, approximately 0.3. Both of these conditions can be reasonably well satisfied. The quantity τ, given in the above equation, is the transfer function corresponding to the processing spread function of the unsharp masking process. Any desired form of τ may be obtained, provided the appropriate mask transfer function, τ_M, can be generated. To obtain enhancement over some band of frequencies, the value of τ must be greater than 1.0. It can be seen that this condition will occur for the appropriate value of γ_M, whenever τ_M becomes negative. Such transfer functions are known; e.g., a defocused lens. However, Armitage, Lohmann and Herrick proposed another method of generating a strongly negative transfer function. This method is called "ring smear".

5. To generate an unsharp mask by the ring smear method, every point in the original photograph is smeared into a ring in the mask. The transfer function of this process is given by:

$$\tau_M = J_o\,(2\pi\rho\upsilon) \tag{2}$$

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where: J_o = a Bessel function of the first kind, of zero order

ρ = the radius of ring smear

υ = the spatial frequency

This transfer function, plotted in Figure 2, goes very strongly negative to a maximum of about -0.4. The resulting enhancement function, τ, given by Equation (1), is plotted in Figure 3 for $\gamma_M = 1.0$. Note that τ goes above 1.0 to a maximum value of 1.4.

6. The unsharp mask is generated by rotating, during the exposure, a tilted glass plate approximately 4.0mm thick placed in the optical path of the enlarger system. Figure 4 outlines a typical procedure for making and using the mask in ring smear enhancement.

DISCUSSION

7. Equipment

a. The ring smeared mask is generated by smearing each point of the aerial image into a ring. The image is smeared by rotating a piece of tilted glass in the converging, image-forming rays. The angle at which this glass is tilted with respect to the optical axis determines the ring size which in turn determines the frequency of maximum enhancement. Consequently, the glass must be essentially free of wedging so that the ring size is formed as calculated.

b. A minimum number of rotations of the glass during exposure is required so that the entire ring receives an acceptably uniform exposure. Any density variations in the ring would make the degree of enhancement a function of direction.

c. Area of the glass must be great enough to prevent any vignetting of the image forming beam at the largest tilt angle anticipated.

d. The vacuum register board, which holds the raw stock, must be capable of precisely repositioning the straight print and ring smear mask after processing so that near perfect registration will be maintained. Rigorous requirements are therefore placed on processing and drying conditions to prevent changes in film dimensions.

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Figure 2

Mask Transfer Function τ_M Ring Smear

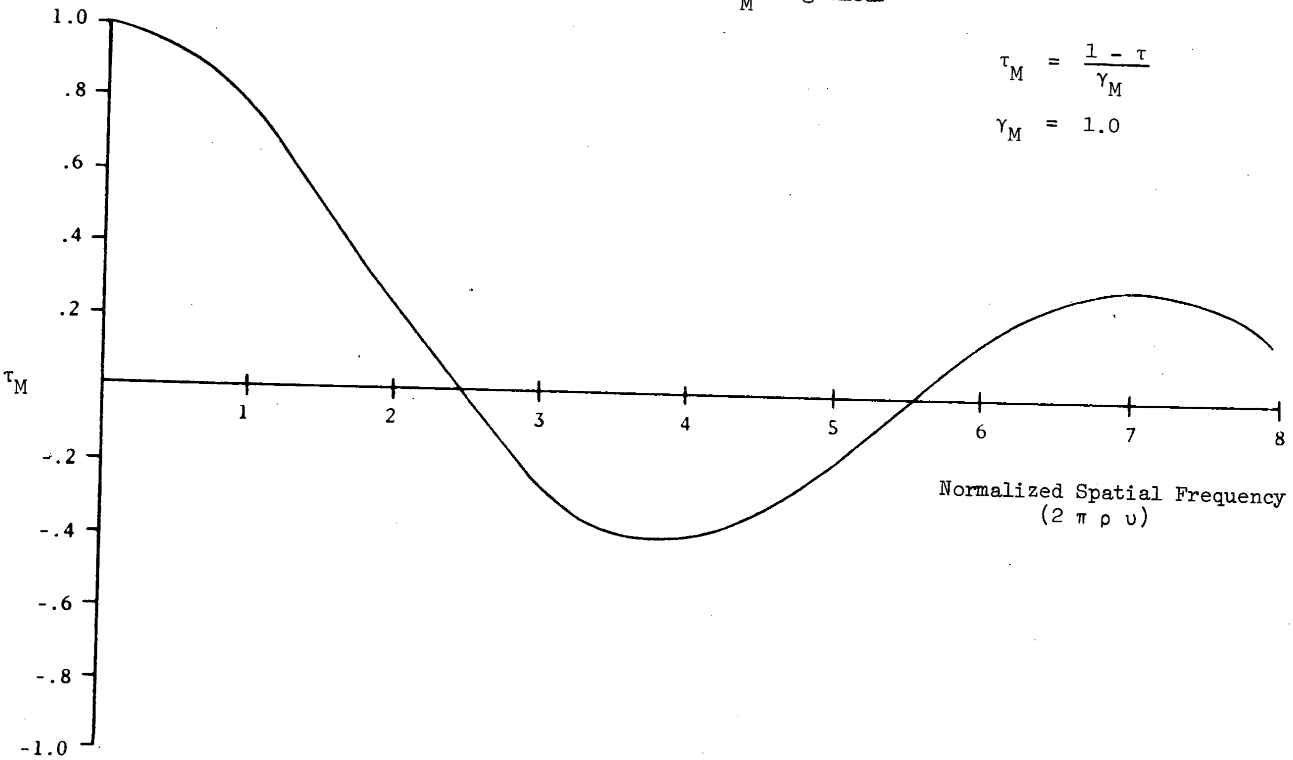

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Figure 3

System Transfer Function τ for Ring Smear

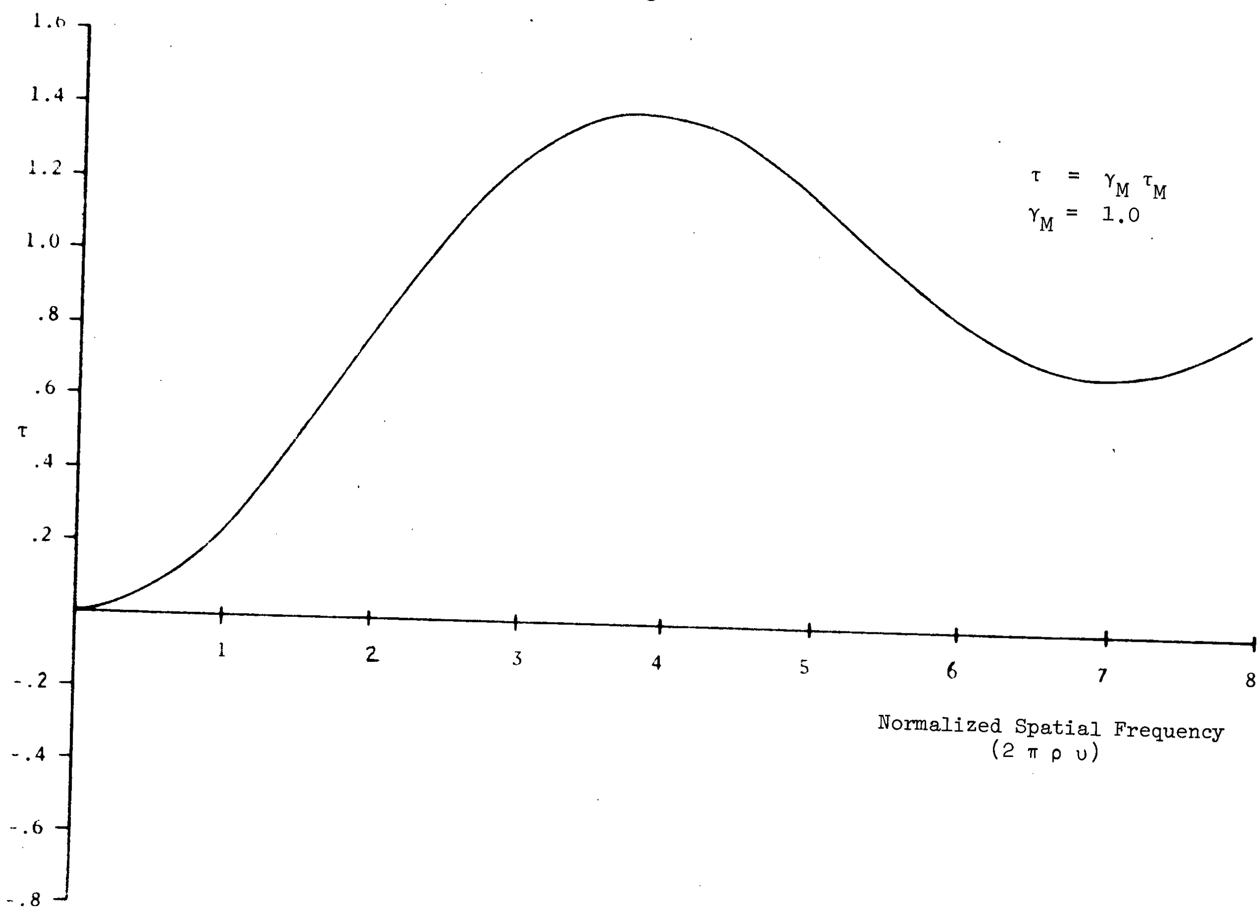

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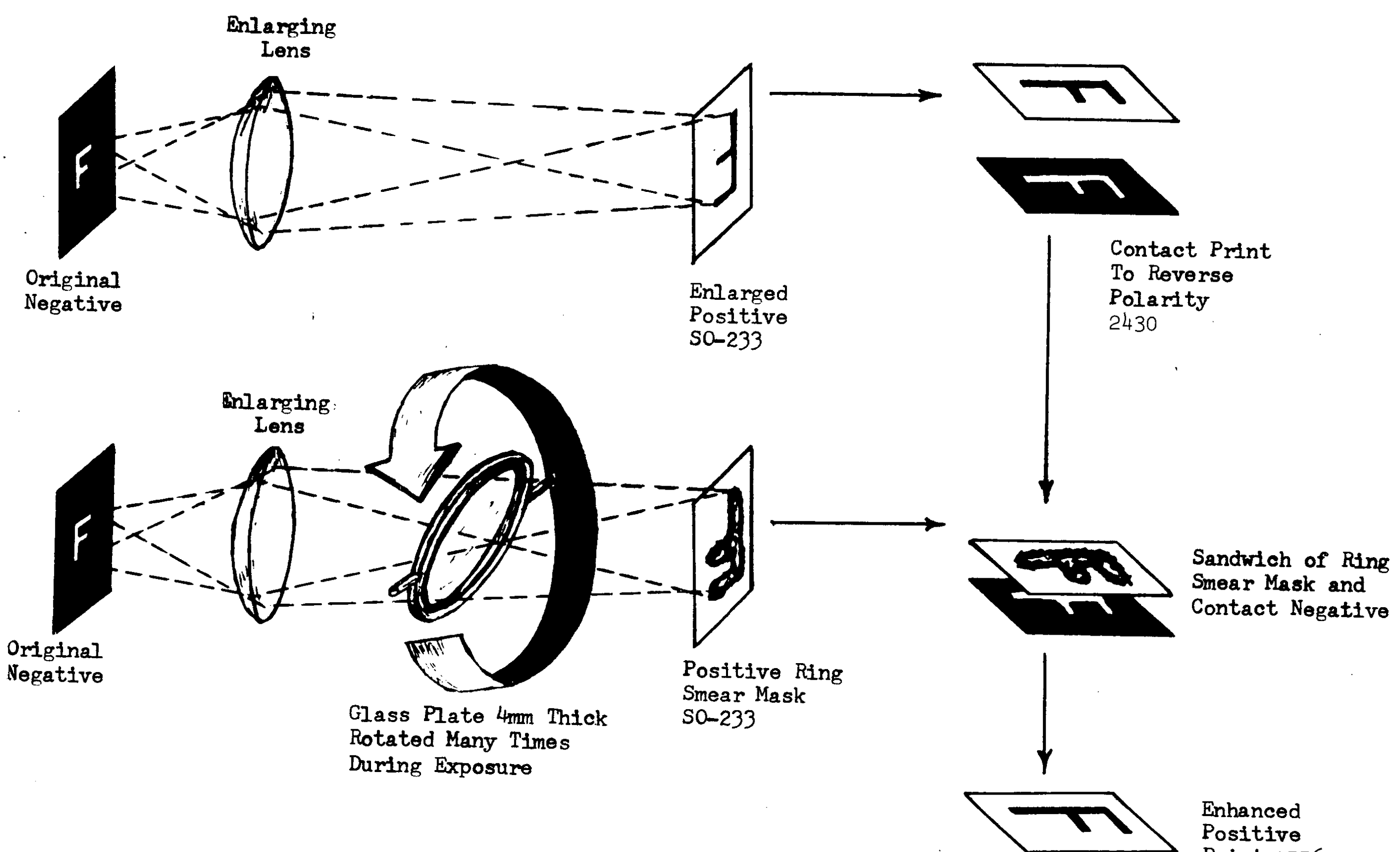
Figure 4

Schematic Diagram of the Procedure for Ring Smear Enhancement



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e. The final enhanced transparency is made by contact printing the low-contrast, straight-print/mask sandwich onto a high-contrast film, using the vacuum register board and the BPE light source. A more detailed discussion of equipment is given in Appendix A.

8. Procedure

a. The conventional ring smear enhancement technique requires the production of a negative straight-print enlargement and a low-contrast, ring-smeared positive enlargement. These are registered and contact printed onto a high contrast film* to yield the enhanced transparency.

b. To meet this goal with normal photographic films, four steps are necessary to obtain the polarities required in each step. By the use of a direct reversal film, the number of photographic steps can be reduced to three.

c. The major drawback to this technique is the loss in enhancement from the mask not being in contact with the raw stock during contact printing. Intimate contact between the mask and raw stock cannot be obtained since the mask is in registration with the straight-print which, in turn, is in contact with the raw stock.

d. Two unconventional ring smear enhancement techniques were examined to circumvent this "lack of contact" problem. This is discussed in Appendix B. However, the most consistent results, with the least amount of effort and highest enhancement potential, are obtained with the conventional technique of making a separate straight-print negative and ring-smeared mask which are placed in register and contact printed.

* e.g., Kodalith Ortho Film 3556, Type 3 (Estar Thin Base)

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e. The first step in ring smear enhancement is to enlarge the original negative onto a direct reversal duplicating film to obtain an enlarged negative. This enlarged negative is considered the straight print, since it is simply a normal enlargement of the original. This negative straight print is processed to a gamma of about 1.3. The second step is to make an enlarged, low-contrast, ring-smeared mask. The gamma of this step is maintained at 1.0 or less. Both the straight print and mask are exposed through the base of the raw stock so that the proper orientation of the original is preserved. The straight-print can then be printed emulsion-to-emulsion with a high contrast duplicating film. Enlargements of 20X to 50X are used so that limiting resolution is comfortably presented to the eye at about 5 cycles/mm.

f. The final enhanced transparency is made by reregistering the straight-print negative and positive ring-smeared mask on the vacuum, pin-register board, and contact printing this sandwich onto a high-contrast duplicating film. The BPE breadboard light source is used.

9. Analytical and Subjective Analyses

a. Sine Wave MTF Analysis. The ring smear enhancement technique was evaluated quantitatively by sine wave modulation transfer function analysis.

(1) Images of sine waves photographed onto 3404 film* were enlarged and enhanced by ring smear. Three ring smear enhancement techniques were evaluated in the study. These techniques included two versions of conventional ring smear enhancement (multiplicative and additive exposures) and the new aerial image masking process. In addition, a straight-print enlargement of the sine wave image was evaluated. These techniques are discussed in Appendix C.

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* Kodak High Definition Aerial Film 3404 (Estar Thin Base)

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(2) The sine waves were evaluated for modulation, expressed in terms of exposure, and ratioed with the input modulation. The input modulation is the actual modulation of the 3404 film image. Effects of the enlarging lens were not removed since the MTF of this lens is constant for all enhancement cases.

(3) The measured MTF values are subject to considerable variability because of tone reproduction discrepancies, and inaccuracy in registering the masks and straight prints.

(4) Although the ring smear enhancement technique is not strictly linear in terms of exposure, MTF analysis was useful in pointing out the relative degrees of enhancement between the different ring smear techniques. It was partly on this basis that the original, ring smear enhancement process was selected as the best technique. The results of this MTF analysis are discussed in more depth in Appendix C.

b. Subjective Analysis

(1) Although MTF curves show a marked increase in modulation, they do not indicate whether any real increase in information extraction is afforded. To determine information content, sets of 2:1 contrast geometric figures photographed onto 3404 film were enlarged and enhanced. These geometric objects were enhanced under four separate conditions with enhancement maximized at different frequencies for each condition.

(2) Each of five observers attempted to identify the objects in each array. The number of correctly identified objects gives an indication of the information extractable with each enhancement process.

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(3) The results of this analysis are listed in Table 1. There is no significant difference in the number of identifiable objects for each condition. Obviously, the enhanced pictures did not yield any more real information. However, the observers commented that the enhanced images were easier to look at, and they thought they were identifying more objects.

(4) This ease in evaluation in itself may justify enhancement even though no increase in extracted information was obtained.

(5) Further discussion of the subjective analysis results is given in Appendix C.

10. Training. Customer personnel were given a three-day training course (May 11-May 13 at the contractor's facility) on the theory and operation of the BPE breadboard/ring smear enhancement equipment. This course included the enhancement of several samples of operational material and an examination of ring smear enhancement potential on original material with gross amounts of linear image smear. The course included instructions for selecting the proper ring smear glass tilt angle, and suggestions on film processing gammas and exposure conditions. All aspects of the ring smear enhancement technique were demonstrated under darkroom conditions.

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Table 1

Geometric Figure Identification Analysis

Array	Straight Print (A)		Frequency of Maximum Enhancement Relative to Limiting Resolution: 150% (B)		100% (C)		80% (D)		40% (E)	
	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s
1	40.6	3.435	39.8	3.421	40.4	3.362	40.4	3.782	40.4	5.225
2	35.6	3.578	34.0	3.317	34.0	4.743	34.4	4.159	34.4	7.765
3	34.0	4.690	33.2	3.768	31.6	4.561	33.2	2.683	31.2	5.541
4	24.4	4.669	25.0	2.345	24.4	2.074	24.8	3.962	23.4	4.099

Parameters of Comparison between Straight Print and Enhanced Prints

	A and B		A and C		A and D		A and E	
	v	t	v	t	v	t	v	t
1	10.0	0.369	9.99	0.093	9.89	0.088	8.37	0.072
2	9.93	0.733	9.16	0.602	9.74	0.488	6.44	0.314
3	9.45	0.297	9.99	0.820	7.55	0.331	9.68	0.862
4	6.85	0.257	6.28	0.0	9.69	0.146	9.80	0.360

At a 99% confidence level, t must be greater than approximately 2.7 for $\overline{X}_i \neq \overline{X}_j$

$\overline{X}$ = average correct identifications over five observers

s = estimate of standard deviation of correct identifications

v = degrees of freedom

t = percentage point of student's t distribution

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CONCLUSIONS

11. Ring smear enhancement makes aerial photographs more pleasing to look at and easier to evaluate, but does not appear to increase the amount of information available from any given photograph. Because ring smear affects both the signal portion of the photograph and the noise (i.e., granularity) portion, there does not appear to be a significant change in the signal-to-noise ratio with treatment. Benefits of the ring smear technique are related to the size of the smallest details resolved in the original negative. Consequently, with photo optical systems limited primarily by film granularity, there is little benefit from ring smear enhancement to the extracting of information, with the exception of possibly increasing the ease and speed of photointerpretation. If the frequency spectrum of film granularity shows equal power at all frequencies (which is highly probable) the enhancement technique will yield equal results -- whether the cause of the limiting resolution in the original negative is film grain or low signal modulation.

12. There is a more than adequate tolerance in the frequency selected for maximum enhancement relative to the cutoff frequency. This makes plate tilt angle less critical. Also, the processing contrasts for both masks and straight prints are not critical as long as they comply within reasonable limits.

RECOMMENDATIONS

13. That the customer use the ring smear device at his facility to determine further values of this enhancement technique on operational imagery.

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REFERENCES

1. Armitage, Lohmann and Herrick, Applied Optics, Vol. 4, No. 4, April 1965.

2. James and Southall, Mirrors, Prisms and Lenses, 3rd Edition, MacMillan Company, 1954, pp. 101, 102.

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APPENDIX A

Equipment

1. Tilted Glass Plate

a. The glass plate should be between 4mm and 5mm in thickness. This thickness permits meeting the glass flatness requirements with reasonable effort. In addition, the necessary ring radii can be obtained only within a range of 0-15° tilt angle. The ring radius is linearly related to tilt angle as shown by the equation given below[2]. With a 4mm thick glass plate, ring radii of 0 - 0.35mm can be obtained over the 15° tilt range. This range corresponds to a frequency enhancement range from infinity to 1.75 cycles/mm.

$$r = \frac{t \sin \alpha \left(-n \cos \alpha \pm \sqrt{n_1^2 - n_2^2 \sin^2 \alpha}\right)}{\sqrt{n_1^2 - n_2^2 \sin^2 \alpha}}$$

b. Using a glass 4mm thick, the smallest practical angle used is 2°. This angle produces maximum enhancement at a frequency of about 12 c/mm. Enhancement maximized at higher frequencies is not anticipated and not practical. Enlargements which contain information at more than 10 c/mm are not practical since some magnification must then be used to see detail at limiting resolution. Limiting resolving power is best presented to the eye at no more than 5 c/mm. Furthermore, registering the straight print and mask becomes increasingly difficult at higher frequencies.

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[2] See References on previous page.

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c. If the glass plate has wedging of more than 2 seconds of arc, the smeared ring will be larger than anticipated. This problem is worsened by the fact that the ring size then becomes a factor of magnification with wedged glass. Figure A-1 demonstrates the cause of this problem. Minimum wedging of 2 seconds of arc was chosen since this would cause a ring radius of 0.01mm at 0° tilt using an 80-inch working distance (if the plate were rotated). A ring radius this small is virtually non-existent. More seriously, in the presence of wedging, the straight print would appear mis-registered from the ring-smeared mask. Along this line of thought, the glass plate must be positioned at 0° tilt during exposure of the straight print. If the glass were not at 0° tilt position during exposure of the straight print, the straight-print image would not be centered on the ring-smeared mask image. This misregistration would result in white borders on one side of all high contrast edges in the enhanced print. Figure A-2 illustrates the desired orientation of the ring-smeared mask and the straight print.

d. Assuming a processing gamma of 1.0 for the straight print, the ring smear glass plate must make at least 16 revolutions to produce virtually uniform rings. These 16 revolutions provide a maximum log exposure variation of 0.03 which is barely measurable as a change in density with a film gamma of 1.0. Ordinarily the smeared mask has a processing gamma less than 1.0 which leaves a generous safety factor. With a four-second exposure time, the motorized rotating glass plate assures a uniform ring.

e. The ring-smearing rate should be as uniform as possible. The glass should be turning immediately before and after the exposure so that there is no start-up or slow-down period.

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Figure A-1

Effect of Glass Wedging on Ring Radii

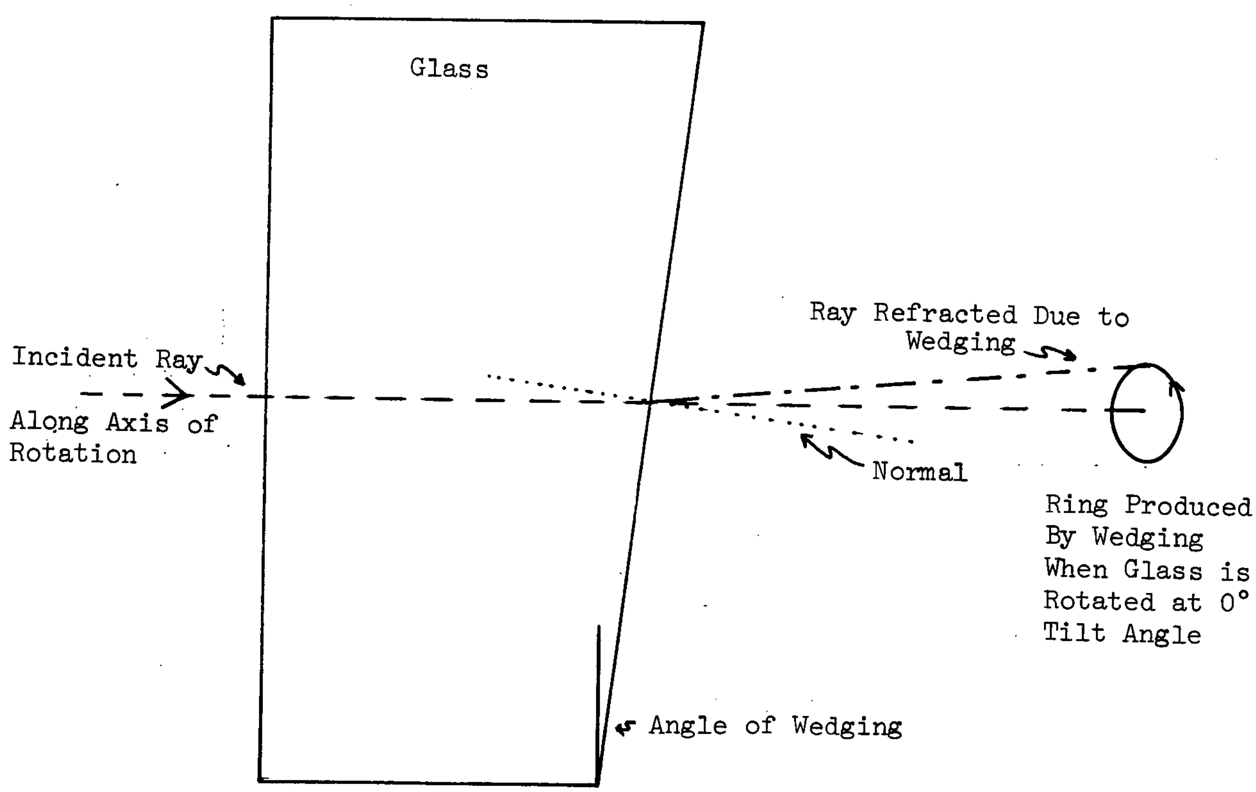

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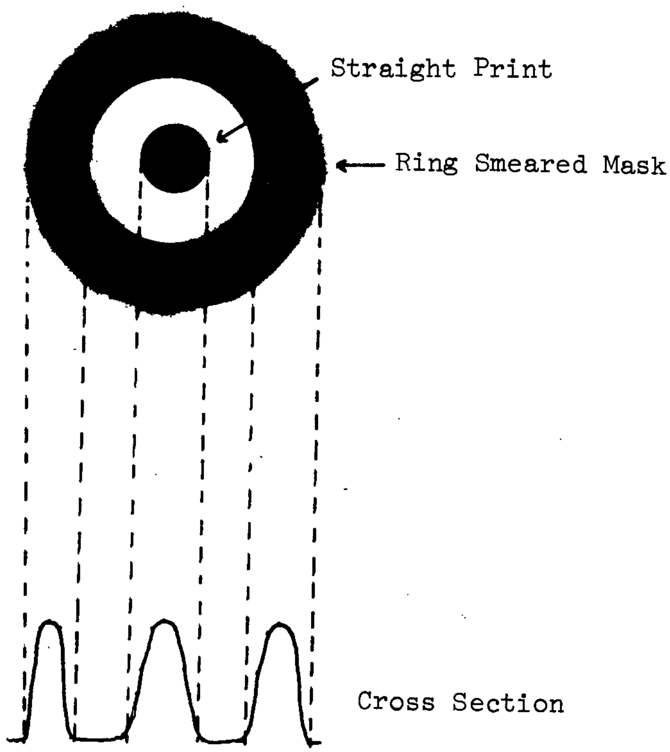
Figure A-2

Orientation of Straight Print and Ring Smeared Mask Point Spread Functions



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f. Since the glass plate is in a converging beam, there will be some astigmatism, spherical aberration and coma. However, these deficiencies have been demonstrated and calculated to be undetectable as they are present only at the long conjugate end. For a glass plate of 10mm thickness (over twice as thick as that to be used) and at a 20° tilt, the astigmatism (defined as the difference between optimum horizontal and vertical focal planes), will be 0.01173 inches for a 50mm lens at f/2.0. This amount is about 20 times less than the detectable change in focus in the image plane at a 40X enlargement. The effects of coma and spherical aberration are considerably less.

g. The largest field angle considered was 5° off-axis. Any larger angles result in images which are larger than the 9.5-inch film available, so that they were not considered. With a 15° tilt angle, and at 5° off-axis, the rings are circular. Any eccentricity in the rings across the field could not be detected.

2. Vacuum Board

a. The raw stock onto which the original negative is enlarged is held stationary and flat by a conventional Kodak dye transfer vacuum register board. This board has a set of pins which permit accurate registration of the mask and straight prints.

b. Once the ring-smeared-mask/straight-print sandwich is registered, an enhanced, high-contrast positive transparency is made by contact printing. This contact printing stage is accomplished through use of the vacuum register board. The sole purpose of this device is to maintain perfect registration between the mask and straight print, and make certain that intimate contact is maintained over the whole area of the photograph. No problems with Newton Rings appeared in this contact printing stage, primarily because of the matte finish on the Kodalith Ortho film.

c. The ring-smearing device and vacuum register board are shown mounted on the prototype BPE enlarger in Figures A-3 and A-4.

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Figure A-3

Vacuum Register Board Mounted on the BPE Breadboard Enlarger

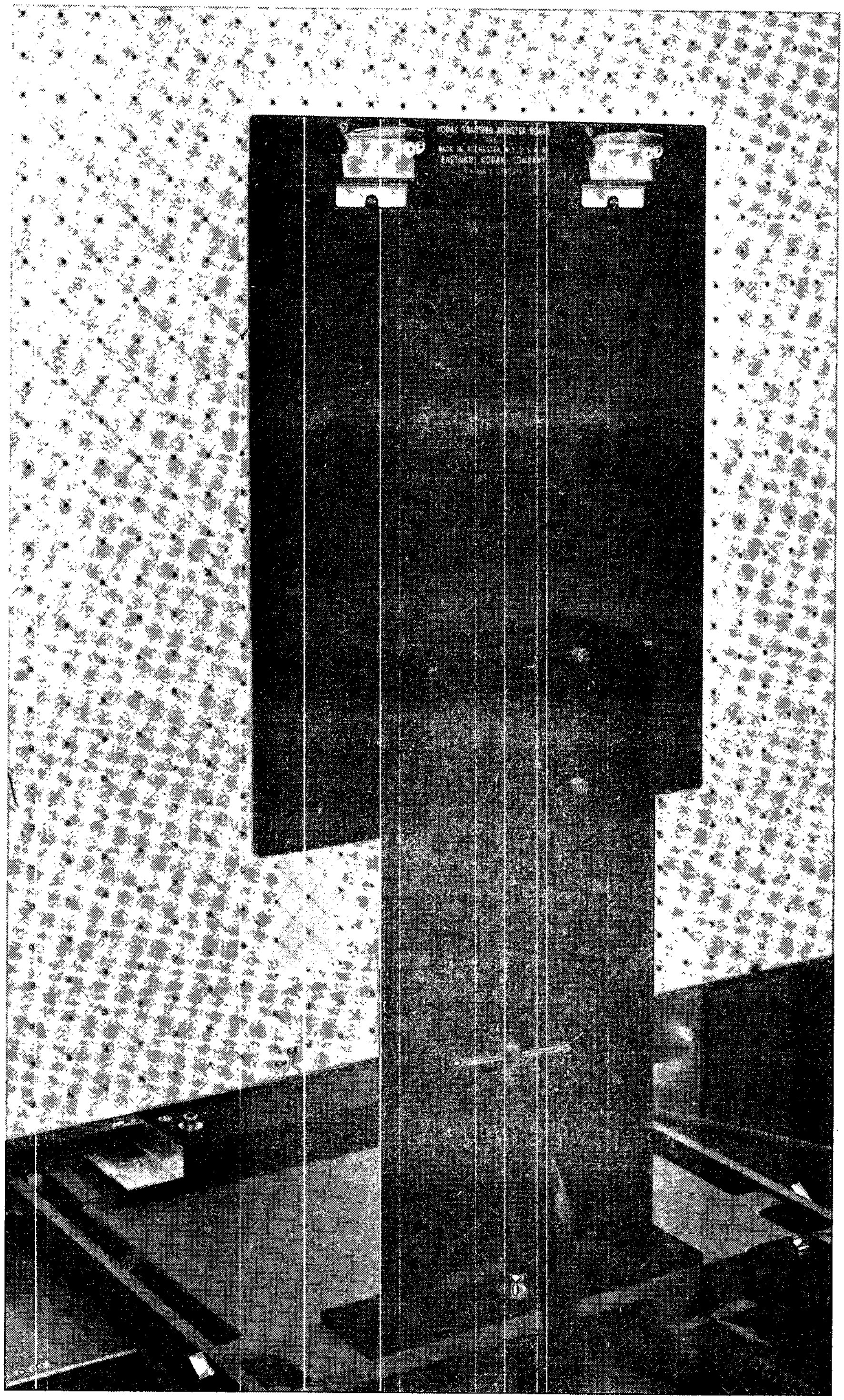

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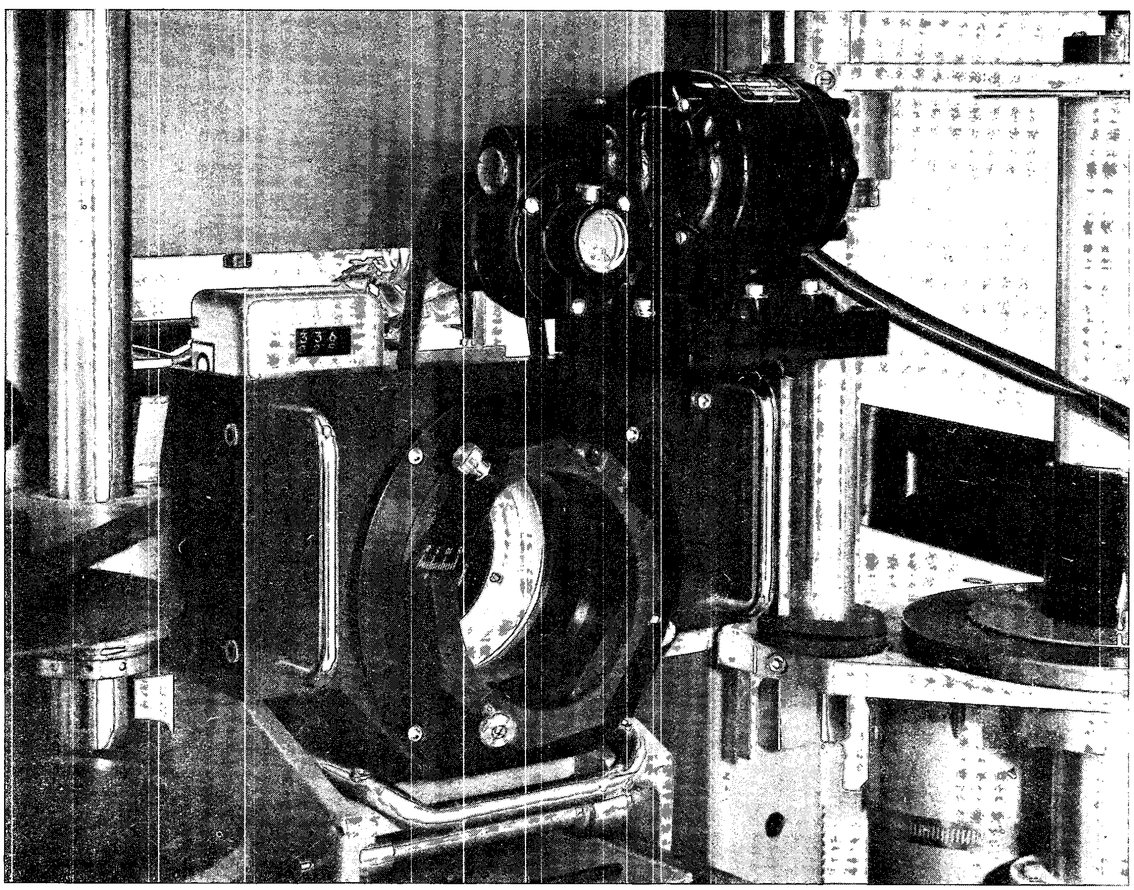
Figure A-4

Ring Smear Device Mounted on the BPE Breadboard Enlarger



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APPENDIX B

Procedure Development

1. One difficulty with the ring smear enhancement technique is the demodulation of the ring-smeared mask exposure caused by the lack of contact between this mask and the emulsion of the high-contrast copy film. Figure B-1 gives an MTF which shows the modulation losses in the mask caused by the spacer between it and the raw stock. The spacer represents the straight print. No estimates were obtained of modulation losses caused by light diffusion in the straight-print emulsion.

2. Two techniques were tried to permit intimate contact between both the raw stock and the straight print and mask. With the first technique, the mask and straight print were separately exposed onto the raw stock so that no sandwich was involved. Registration was assured by hand registering the mask and straight print before exposing onto the copy film, and punching registration holes with a standard Kodak pin register punch. The raw stock was similarly punched and placed on pins.

3. This technique eliminates any decreases in enhancement from lack of contact between the ring-smeared mask and the copy film. However, the overall enhancement potential is not as great, since the combination of straight print and mask exposures are now additive rather than multiplicative. The effect of using an additive technique instead of multiplicative is shown in Table B-1. Note how the modulation is only slightly increased when using additive exposures.

4. No enhanced prints of scenes were made using the additive technique because of the low enhancement potential. The enhancement of sine waves was accomplished and compared to the multiplicative exposure technique.

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Figure B-1

Modulation Transfer Function of Contact Printing the Ring Smeared Mask Through the Straight Print Using a Specular Light Source

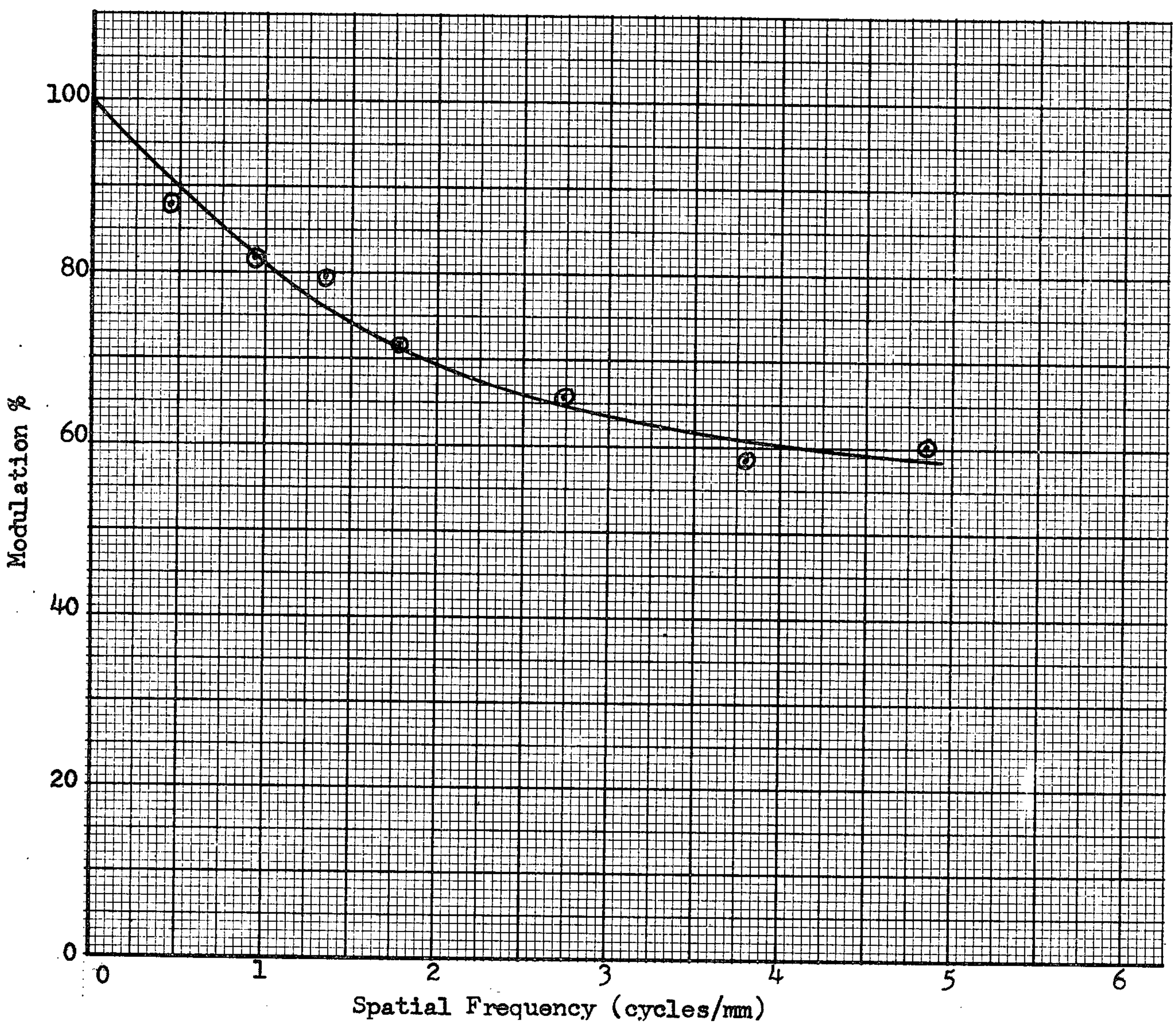

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Table B-1

Comparison of Ring Smear Enhancement Potential Using Additive or Multiplicative Mask and Straight Print Composite Exposures

	Low Frequency			High Frequency		
	Effective Transmittance	Density	Modulation	Effective Transmittance	Density	Modulation
Negative Straight Print	50% 20%	0.30 0.70	.43	50% 20%	0.30 0.70	.43
Positive Ring Smear Mask	10% 16%	1.00 0.80	.22	20% 16%	0.70 0.80	.12
Multiplicative Composite Exposure (Mask X Straight Print)	5% 3%	1.3 1.5	.22	10% 3%	1.0 1.5	.52 *
Additive Composite Exposures (Mask + Straight Print)	60% 36%	0.22 0.44	.25	70% 36%	0.16 0.44	.31 *

* Note the difference between Multiplicative and Additive High Frequency Modulation where maximum enhancement occurs.

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5. With the second technique, known as aerial image masking, the step of actually making a negative ring-smeared mask is eliminated. Instead, the original negative is projected through the positive straight-print onto a low-contrast duplicating film. During this exposure, the projected aerial image of the negative is ring-smeared -- hence the term "aerial image mask." The photographic result is a predominantly negative image superimposed with a ring-smeared positive image. The process gamma of the straight print is adjusted accordingly so that the straight-print positive polarity is dominant over the projected ring-smear negative. Since a ring-smeared mask is never actually made, no problems with contact printing are encountered.

6. Figure B-2 is a flow diagram for this procedure as discussed below.

7. The original negative is enlarged onto 2430 duplicating film* and processed to a gamma of from about 1.3 to 1.5. A gamma greater than 1.0 is necessary so that the positive straight print will have more contrast than the negative aerial image to be projected through it. If the positive straight-print contrast were not greater than 1.0, its positive polarity image would be canceled by the negative aerial image.

8. The 2430 film is exposed through the base so that when it is replaced onto the enlarger easel after processing, it can be placed emulsion to emulsion with the low contrast duplicating film SO-233.** No losses were experienced by exposing the 2430 film through the base since the film has no backing or antihalation undercoat.

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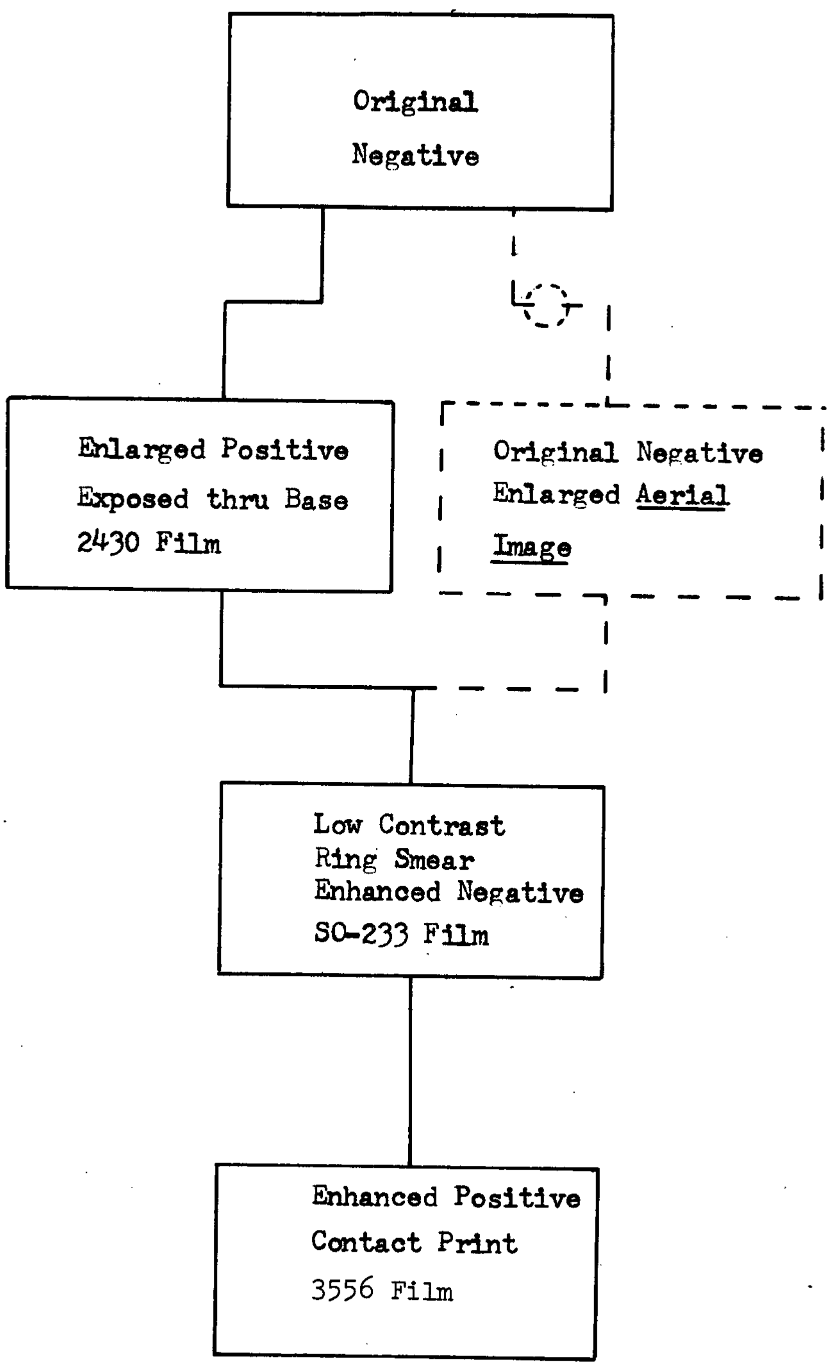
* Kodak Fine Grain Aerial Duplicating Film 2430 (Estar Base)

** Kodak Special Low Contrast Fine Grain Duplicating Film SO-233

Figure B-2

Aerial Image Masking Ring Smear Enhancement



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9. During processing of the 2430 straight print, the original negative is not removed from the enlarger film gate. This insures perfect registration between the processed positive straight print and the projected aerial image of the original negative when the straight print is replaced on the easel using the registration pins.

10. The SO-233 raw stock is located between the positive straight print and the easel board. While the original negative is exposed through the straight print onto the SO-233 film, the aerial image is ring-smeared. The developed film image is a combination straight-print negative superimposed with the ring-smeared positive. Since the positive straight-print contrast is higher than the negative aerial image ring-smeared mask, the processed image is predominantly negative.

11. The final enhanced positive is obtained by contact printing this low contrast, ring-smear enhanced negative onto a high contrast film such as Kodalith Ortho Film, Type 3.

12. Enhanced photographs were made with limited success using this technique. The technique was not developed any further; however, since it tied up the BPE breadboard for an excessive time period while the straight print was being processed. Furthermore, there was little apparent increase in image quality attributable to the elimination of contact printing difficulties.

APPENDIX C

Analytical and Subjective Analyses

1. Sine Wave MTF Analysis

a. The ring smear enhancement technique was evaluated quantitatively by sine wave MTF analysis.

b. Images of sine waves photographed onto 3404 film were enlarged and enhanced by ring smear. Three ring smear enhancement techniques were evaluated during the study. Two of these techniques were the two versions of ring smear enhancement (multiplicative and additive exposures), and the third was the new aerial image masking process. In addition, a straight-print enlargement of the sine wave image was evaluated.

c. The sine waves were evaluated for modulation by tracing the enlarged, enhanced images with a microdensitometer equipped with a 5- x 160-micron slit. The measured film image modulation was expressed in terms of exposure and ratioed with the input modulation. The input modulation is the actual modulation of the 3404 film image. Effects of the enlarging lens were not removed since the MTF of this lens is constant for all enhancement cases.

d. The measured MTF values are given in Figure C-1. These curves are subject to considerable modulation variability because of tone reproduction discrepancies and inaccuracy in registering the masks and straight prints. Since the low frequency, or large area contrast of the enhanced transparencies is lower than the contrast of the enhanced higher frequencies, some extrapolation of the large area characteristic curves was required for analysis. Figure C-2 shows a typical large area tone reproduction characteristic curve including a polarity reversal in the highlights. The extrapolation necessary to evaluate the higher frequencies which have a considerably higher density difference is shown. This extrapolation is justified by the

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Figure C-1

Modulation Transfer Functions of Four Ring Smear Enhancement Techniques and One Straight Print Enlargement Original Sine Wave on 3404 Film

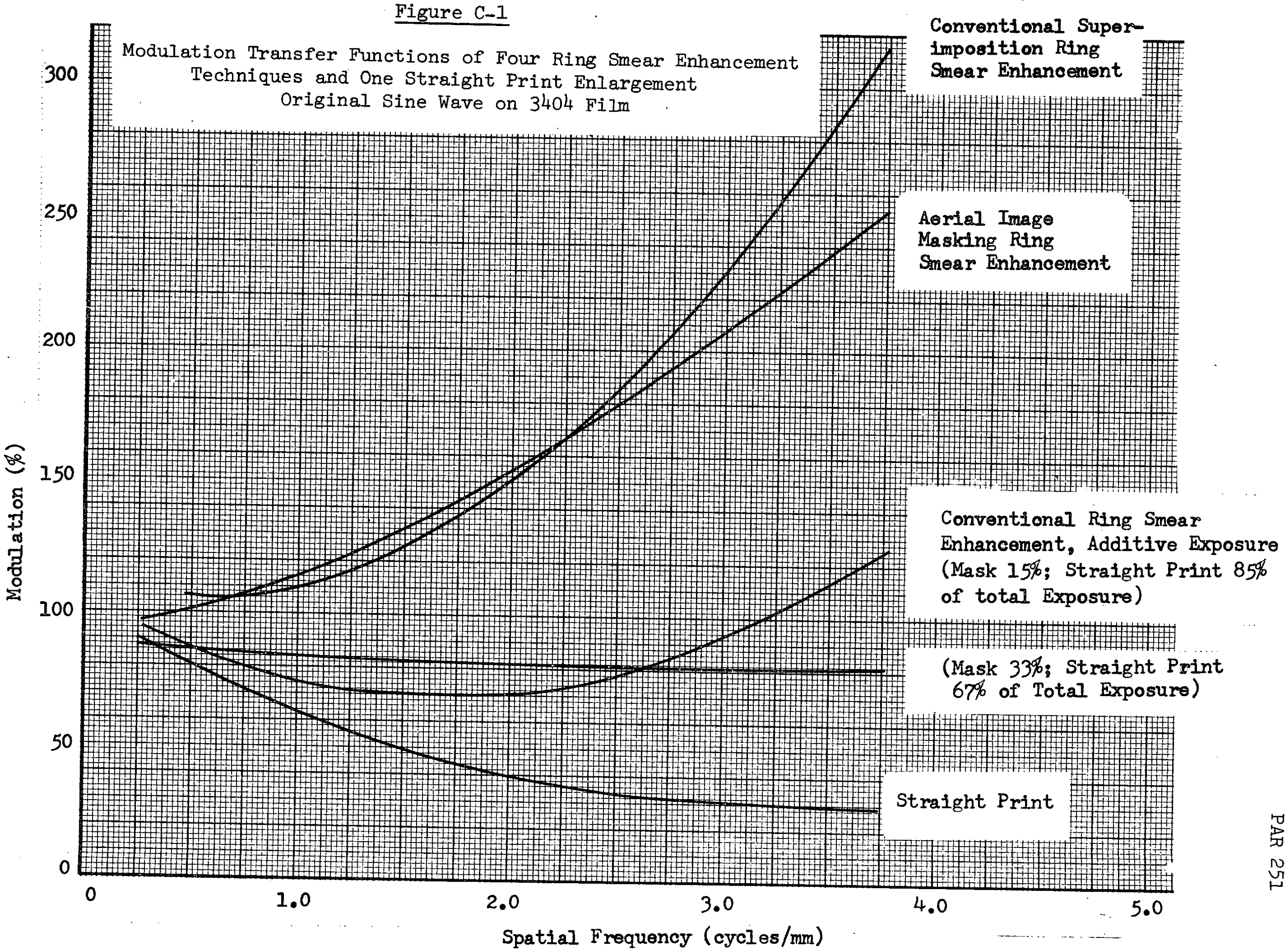

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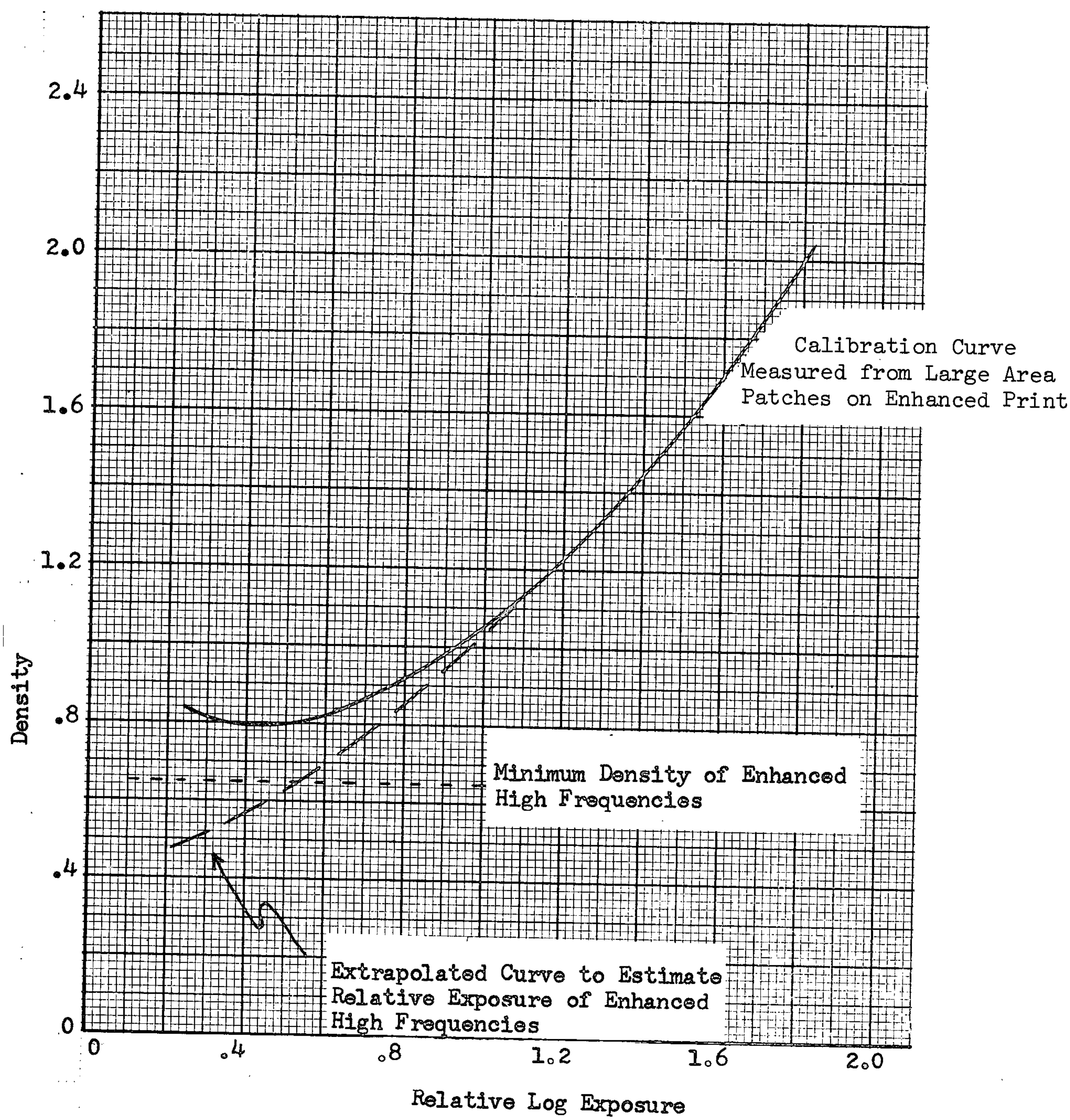
Figure C-2

Tone Reproduction Calibration Curve for Sine Wave MTF Analysis of Ring Smear Enhanced Prints



assumption that the polarity reversal, and hence the high minimum density, of the large area patches is caused by the contrast of the ring-smeared mask being nearly as high as the straight print contrast in the highlights. Since the ring-smeared image is demodulated, or may experience a phase reversal at higher frequencies, the straight print maintains a higher contrast over the mask at these higher frequencies. The result is that the extrapolation should provide reasonable or at least conservative (in the event of phase reversals) MTF values.

e. These large increases in modulation at high frequencies are somewhat at the expense of the normal tone reproduction indicated by the aforementioned partial reversals. Objects which are actually the darkest objects would appear lighter than surrounding areas in the enhanced print. Again, this problem would be minimized with dual-gamma processed original negatives. If the dual-gamma processed original negative had a density range which was still too high, this problem could be circumvented by the introduction of another photographic step. This step would either be used to increase the contrast of the straight print, or decrease the contrast of the ring-smeared mask.

2. Subjective Analysis

a. Although the MTF curves show a marked increase in modulation they do not indicate whether any real increase in information is afforded. To determine information content, sets of 2:1 contrast geometric figures photographed onto 3404 film were enlarged and enhanced. These geometric objects were enhanced under four conditions, with enhancement maximized at different frequencies for each condition. Each condition contained four arrays of geometric figures. This gave a total of sixteen enhanced arrays, plus one straight print of each of the four arrays giving a grand total of twenty arrays.

b. Each of the five observers attempted to identify the objects in each array. The number of correctly identified objects gives an indication of the information extractable with each enhancement process.

c. The results of this study were listed in Table 1 of the text. There is no significant difference in the number of identifiable objects for each condition. Obviously, the enhanced pictures did not yield any more information. However, the observers commented that the enhanced images were easier to look at and thought that they were identifying more objects.

d. It is not too surprising that no more information was obtained from the enhanced transparencies. The increase in signal modulation shown by the MTF curves is also accompanied by an equally substantial increase in noise (grain) modulation. This noise is not shown by the MTF curves. The subjective analysis of the geometric figures gives an excellent indication of the noise interference since the eye readily sees this grain. Consequently it is seen that the signal-to-noise ratio remains fairly constant, permitting no real increase in available information.

e. The enhancement had the distinct advantage of making the images easier to look at. If the original negative had been modulation limited, rather than noise limited, the enhancement may have been more useful. Consequently, photographs obtained with high quality (high film resolving power) systems do not lend themselves very well to ring smear enhancement. However, if such a system were to be out of focus, or the photographs contained linear smear, the ring smear enhancement technique might have been far more beneficial to the interpretation of these photographs. Also, the photographs from poorer quality systems, at lower resolution values, should be considered for profitable application.

f. Enhancement of high film resolving power photographs, however, did make them appear better and hence more easily evaluated. This ease in evaluation in itself may justify enhancement, although no provable increase in information was obtained.