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Optical Line Width Measurement Using Spatial Filtering

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OPTICAL LINE WIDTH MEASUREMENT
USING SPATIAL FILTERING

by

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Submitted to the Photographic Science and Instrumentation Division in partial fulfillment of the requirements for the Master of Science degree at the Rochester Institute of Technology

ABSTRACT

The measurement of line widths optically allows fast, easy non-contact measurements and finds application in both research and development areas, as well as the production environment. There exists presently a need to increase the measurement accuracy of the width of small lines in the under 10 to 20 micrometer region. As accuracy may be achieved by calibration, there is interest in reducing the measurement variability. One technique of reducing variability, that of using a coherent microscope system that allows spatial filtering of the image of the line being measured, was breadboarded using high contrast etched chromium on glass lines, and degraded line images on film base. A comparison of the estimates of variability for spatially filtered, and unfiltered images, indicated a significant improvement was found for each of the lines measured, with

improvements by as much as a factor of four found by the system used. Thus, the investigation of the technique of spatially filtering the images of small lines to reduce the variability of line width measurement, suggest interest is warranted in using the technique if the appropriate microscope objectives allowing access to the Fourier transform plane to facilitate spatial filtering become commercially available.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank those people who have helped make this project possible. My advisor, Professor John F. Carson, who offered his assistance in breadboarding the project, was of great encouragement in seeing it through to completion. To Richard Swing, who initiated interest in the subject and whose computer programs were of great help. And to John Wiley of Ultratech Corporation, whose fabrication of test lines that were measured, and whose experience in the manufacture of photo masks for integrated circuit fabrication, gave some insight into commercial line width measurement requirements.

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CHAPTER I

INTRODUCTION

INTRODUCTION

The optical measurement of the width of small lines is a practice in widespread use in certain industrial situations. As with any measurement technique, the obtainable accuracy that may be achieved is limited by the precision, or amount of variability intrinsic with the measurement process that is used. And, in the case of optical measurement of small lines, there presently is a need to look for ways to improve the measurement process in a cost effective manner.

In selecting the means of reducing measurement variability, it is important to make note of the typical application of such measurement techniques. Optical measurement allows making fast, reasonably accurate, noncontact measurements, and is often of use in industrial environments in research and development efforts, and in monitoring production processes. Particularly in the production situation, the achievement of high absolute accuracy is often not as important as simply having good measurement repeatability. Often a process may be monitored with respect to calibration samples of sizes that are known to produce acceptable product. Indeed, if the number of parties desiring to interchange sample measurement data is small, calibration

may be achieved by interchange or distibution of samples with absolute measurements that may be inaccurate or even unknown. And if necessary, once measurement repeatability is consistently high, even high degrees of absolute accuracy are possible by performing calibration to appropriate samples. The necessity of reducing variability remains however, and requires some change in measurement technique to be achieved.

Several approaches to the problem of reducing variability in the measurement of the width of small lines exist, and all are likely to have applications where they are most cost effective, or offer other desirable qualities. An exotic approach might be to digitize the image of the line to be measured, and utilize a computer to manipulate the image data via computation, to produce a modified image. The image data would be manipulated in a manner such that when converted back to an image and shown to an operator, the operator would be able to make measurements on the modified image with greater repeatability than when measuring the unmodified image directly.

An even more sophisticated approach would involve having the computer itself help in the decision making process. Such a system could combine aspects of the above system, or even eliminate the reconstructed image, and have the computer itself determine the location of the edges of the line, and hence the line width.

A third approach, however, would involve the use of optical processing to modify the image in a manner such that the operator would see a reconstructed image that would allow determination of line width with less ambiguity. At present, the operator must arbitrarily select some intensity level that is thought to be the edge. It is then up to the operator to be consistent in using their criteria, and to be consistent between making measurements of a calibration standard, and any line that requires measuring. In optical processing of the image, then, the goal would be to produce a modified image of the line that would help eliminate some of the ambiguity in determining where the edge of the line is located. Such an optical processing system could be implemented by using a microscope objective that allowed introduction of a spatial filter in the Fourier plane to allow modification of the image spectrum of the line, and a simple change of light source.

The simplicity of the spatial filtering approach suggests it would be the most cost effective of the above approaches providing a suitable microscope objective can be obtained. In addition, the spatial filtering approach would result in measurement procedures most similar to those presently in use allowing the easiest and most meaningful parallel testing of the new technique against the old one, as well as allowing easy and quick

conversion from one measurement technique to the other, so that either technique could be used for a given situation.

The purpose of this investigation is to determine if the application of spatial filtering techniques to the measurement of lines in the under ten to twenty micrometer region can result in an improvement in the repeatability with which such measurements are made. This involves selecting criteria and techniques for determining the spatial filter used, and testing the selections on a breadboarded coherent microscope system with spatial filtering capability, for the purpose of comparing the measurement variability of the normal line image, with that of the spatially filtered image.

CHAPTER II

CONSIDERATIONS OF SPATIAL FILTER DESIGN AND OPTIMIZATION

PHYSICAL CONSIDERATIONS OF SPATIAL FILTER SELECTION

The frequency spectrum of an image in a coherent optical system may be quite easily manipulated by introduction of some variable transmission object or obscuration into the Fourier plane of the imaging lens. Results of varying quality may be obtained however, depending upon the quality of the spatial filter used. A low quality spatial filter for instance, might add a considerable amount of noise. Such noise in an environment where it is desired to make precision measurements might well affect an operator's ability to make measurements repeatably. It is quite easy to fabricate both variable transmission as well as binary level spatial filters on photographic film for instance, but factors such as drying evenness and chemical effects of development upon gelatin hardness result in spatial filters that have very low quality due to a large amount of phase noise as a result of variations in dried gelatin thickness. While such effects are bound to be more prevalent in situations where a spatial filter of varying transmittance is generated, the amount of phase noise present in the clear area of a binary type of filter is still unacceptably high.

The higest quality of spatial filter that may be easily constructed consists of some type of binary level filter, where one level of transmittance is zero and the other level is one. In practice, such a filter may be

constructed for simple filter shapes by using a self supporting opaque obscuration to achieve the zero transmittance portion of the filter. As the remaining area in the Fourier plane may be devoid of a phase noise inducing component such as glass, filmbase, or gelatin, such a filter can approach the performance of ideal filter much more closely. The requirements that the obscuration be self-supporting, place certain restrictions on the type of filter that may be constructed using this method. The size of the obscuration must be sufficient to facilitate adequate mounting. The fabrication of the filter is also greatly complicated if it is attempted to construct a filter having multiple obscurations, as alignment of the obscurations with respect to each other becomes quite critical. Finally, these are some types of filters that would be impossible to construct without requiring that the obscuration be floated in free space. The spectrum of a line however, is one-dimensional, and there is no need to construct spatial filters for two-dimensional filtering. A self supporting one-dimensional filter may be used, as the frequency spectrum of a vertical line image will be oriented horizontally. Thus a simple piece of flat tape or blackened wire may function as the obscuration, and be suspended from above and below the optical axis in the Fourier plane.

PSYCHOPHYSICAL CONSIDERATIONS OF SPATIAL FILTER SELECTION

The ultimate goal of spatial filtering the image of a line is to help increase the repeatability with which an operator may make line width determinations. In general, the capability to manipulate images by altering the frequency spectrum is quite powerful. Many changes, ranging from subtle ones, to those that affect the fundamental nature of the image itself are possible. As operator variability in line width determinations usually comes as a result of inability to easily locate the edges of the line, one approach might be to improve the image of the line to the point where it more closely resembles an ideal line. The measurement of an ideal line would be simpler as such a line would have clearly pronounced edges. This approach has its drawbacks however. As a spatial filter removes power from the optical system, there would be the possibility that extensive spatial filtering of the image might make it darker or lower in contrast, and hence more difficult to see. There is also the possibility that determining the spatial filter that would produce such an image would be an extremely difficult task in itself. In taking the image of a given line, and enhancing it to more closely resemble an ideal line, certain assumptions might have to be made reguarding the final image desired (i.e. its width), so that the overall goal of measuring an unknown line width might not be achieved. Even if such a filter could

be designed unambiguously, construction of such a filter, particularly if it necessitated use of the variable transmission type of filter, could well be an even bigger task. Thus, the conceptually simple (from the operator's viewpoint) idea of providing the operator with a similar, but improved quality image, is not so simple in practice.

An alternative approach to producing an image of the same basic appearance but of better quality, is to produce an image that still allows determination of the width of the line being measured, but may differ markedly in outward appearance. As there is interest in using a spatial filter that is easy to construct and of high quality, a simple single obstruction opaque filter would be the first choice. Even more advantageous from the psychophysics standpoint however, is the type of image possible with this simple spatial filtering technique. The image consists of two dark lines, each replacing the respective edges of the image of the line to be measured, when the low frequency components of the image are removed by a central obscuration in the Fourier plane of the imaging lens. The type of measurement the operator makes on the modified image is the distance between two similar lines, or a line scale measurement, as opposed to the line width measurement that must be made on the unmodified image. This is advantageous, as measuring errors in the line scale type of measurement tend to cancel themselves out. The operator need only be consistant in

picking the same reference point on each of the two lines observed. The operator is in effect asked to find the center of each line, rather than to make a decision on where the edges of a larger, less distinct line are located. If the operator picks the wrong place for the location of the edges of the unmodified line image, the error will be multiplied by a factor of two, when a width determination is made. The simple spatially filtered image therefore, allows the use of the psychophysically preferable line scale measurement technique, rather than the more difficult direct line width measurement.

SELECTION OF CRITERIA FOR SPATIAL FILTER OPTIMIZATION

Many factors may be involved in selecting the criteria for spatial filter optimization. Factors such as ease of system calibration, operator variability, and ease of filter determination may all be important in a given situation. As direct determination of an optimum filter may be desired, simplified techniques such as system modeling with binary line images may allow filter optimization via computational algorithms. Implemented on a computer, such techniques allow quick determination of filter requirements.

A more general approach may be used to get accurate filter specifications for a given situation independent of the profile of the particular line image. In situations where adequate computer resources are available, the most

straightforward technique would select filter specifications based upon information in the spatial domain arrived at by computation on line image profile data for a typical line being measured.

Regardless of the technique selected for filter optimization, it would be generally helpful to test the recommended filters experimentally and observe the effect of the spatial filter on actual line width determinations.

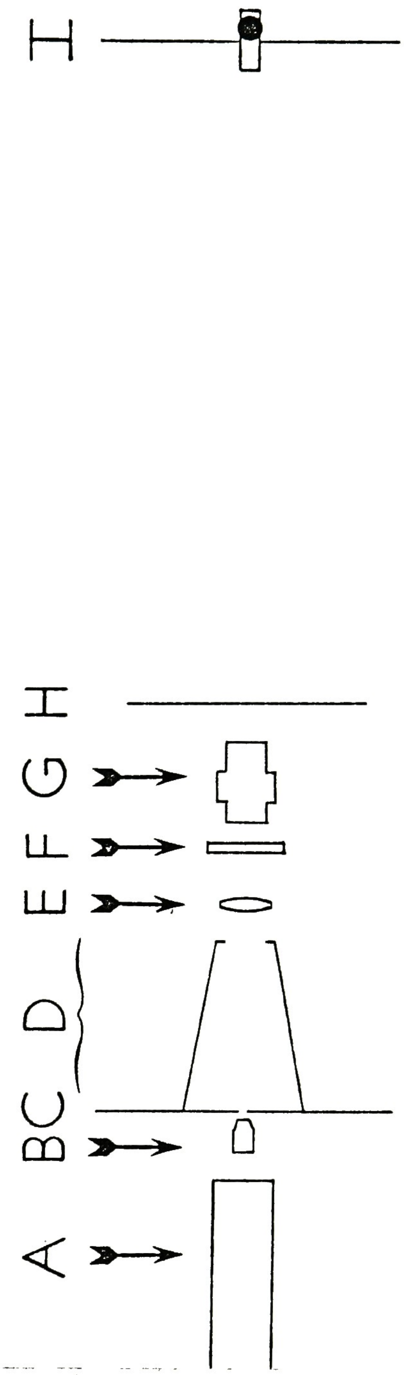
CHAPTER III

EXPERIMENTAL PROCEDURES

BREADBOARDED SYSTEM

A coherent microscope system that allowed spatial filtering of the image of a line[1] was constructed as depicted in figure 1. The light source A was a three milliwatt helium-neon laser with a 632.8nm wavelength. It was found that this provided an adequate illumination level as well as coherence necessary for spatial filtering. In order to provide an evenly illuminated field, the laser beam was focused by lens B onto pinhole C, and is collimated by lens E. Stray light is reduced by baffle and iris diaphram D.

The lines to be measured, placed at F, consisted of etched chromium on glass samples generously supplied by J. Wiley of Ultratech Corporation. The background density of the deposited chromium was approximately 4.0, with an additional sequence of lines measured with background densities ranging from 1.5 to 3.0. These lines ranged in size from 9.9 to 31.0 microns. In order to investigate the possibility of reducing measurement variability for non-binary types of lines, images of degraded lines were produced by contact printing the etched chromium on glass lines within moderately close proximity yielding line images ranging from 30.1 to 54.0 microns on Kodak High Contrast Copy film. The film was processed in DK-50 developer to minimize the effects of higher pH developers on the gelatin emulsion.



A) HeNe 632.8nm laser; B) 40x objective; C) 24μm pinhole; D) baffle; E) collimating lens; F) line object; G) objective lens; H) spatial filter in Fourier transform plane of objective lens; I) measuring eyepiece

FIGURE 1 Optical Breadboard

An important requirement of the objective lens G, was access to the Fourier transform plane, facilitating spatial filtering. This was possible with 50mm Kodak Ektar #OT138 with a numerical aperture of 0.263. The spatial filter H, was selected in different ways, depending upon the type of line image being measured. Initial selections were made using binary level line modeling and the LINFILC program, (program listings and descriptions are found in appendices G, H, and I). LINFIL was written by R. Swing, and minor modifications were necessary to run the program on the RIT Sigma 9 computer, resulting in LINFILC. Using data about the approximate line width and the upper frequency cutoff, limited by a spatial filter to 380cy/mm, this program was used to calculate the lower cutoff frequency as found with equation 19 in appendix A. When lines with a background level were used, the solution as found in appendix B, results in the same calculations as for the line without the background level, and are also performed by LINFILC. Computations used to select the spatial filters used for the degraded lines were more complicated. First the degraded line was scanned with the Ansco Model 4 microdensitometer. The data was first scaled to density by the LININ program, and then converted to transmittance and normalized by the LINTR program. To remove the effect of the microdesitometer, a trace was made on an NBS edge supplied by R. Swing. The data was

scaled to density by the LININ program, and converted to transmittance and differientiated to produce the line spread function by the ETDIFF program. The line spread function was then smoothed by MOVAVE1, and the effect of the microdensitometer removed by MDC. The data was then symmetrized by SYMAV and prepared for proper input format for FFT calculations by FRPUT. The transform of the data was taken by FFT program REV, and the filter selected iteratively by REV1. The REV1 program performs the spatial filtering of the data, then converts the result to the spatial domain by inverse transforming, and selects the filter that produces minimuma separated by the distance between the fifty percent power points of the unfiltered line image.

The measuring eyepiece I, that was available was of the Filar type. This consists of a hairline reticle that may be moved back and forth via a leadscrew controlled by a knob turned by the operator. In order to facilitate ease of data gathering and analysis, the position of the knob was resolved by a 10 turn instrumentation potentiometer with 0.1 percent linearity, and the resistance digitized and punched onto paper tape.

DATA GATHERING PROCEDURES

Line width measurements were made of the modified line images with the spatial filter inplace, and of the unmodified images without the spatial filter. Data was

gathered for high contrast chromium on glass lines of 9.9, 15.2, 18.5, 24.0 and 31.0 microns. A series of lines between 20.5 and 22.6 microns in width with deposited chromium background densities of 1.5, 2.0, 2.5 and 3.0 were also measured, as were degraded line images of 30.1, 38.2 and 54.0 microns.

The measurements were made using the technique[2] incorporated by the Institute for Basic Standards for accurate line width measurements at the National Bureau of Standards. The resulting data pairs representing measurements of the location of the edges of the lines were processed by the computer program LOGO. The program separates the data about a threshold, tests for valid data pairs, calculates the line width measurement from the valid data pairs, and shows the data in histogram form, as well as computing information on the mean and standard deviation. This program was run twice for each line measured, once with the filtered image data, and once with the unfiltered image data.

CHAPTER IV

RESULTS AND CONCLUSIONS

DISCUSSIONS OF RESULTS

After calculation of an optimized filter, it was not always possible to select a spatial filter of exactly the same dimensions. In order to attempt to visualize this effect in terms of the spatially filtered image, digitization of the expected results were carried out, and plots were made of the intensity distribution comparing the filter selected by the particular optimization technique, with the actual filter that was used experimentally. The results for the high contrast chromium on glass lines were calculated via IMCALC, a program written by R. Swing and modified for use on the RIT computer, with plotting routines added to display the data found in appendix D. The same program was also used for the chromium on glass lines with a background level, and the results normalized and shown in appendix E. The plotted data for the degraded line images is found in appendix F. For each degraded line image, there is a plot of the line profile performed by the LIPLOT program, a plot of the unfiltered frequency spectrum of the line images performed by the FPLOT program plotting the REV program data, and plots of the reconstructed image for both the selected spatial filter, and the spatial filter used, by using LIPLOT to plot the data obtained from REVO. Of importance in these plots is that the plots obtained with the actual filter used are very similar to almost identical to those obtained with the filters

that were used experimentally. Thus, it may be concluded that the filters used experimentally produced images that were very close in appearance to those that would have been obtained with the optimized filter.

For each line measured, both with and without spatial filtering, a comparison was made by comparing the standard deviation of the line width determination of the unfiltered image with the filtered image. As it is a comparison of unfiltered versus filtered that is desired, the ratio of sigma(unfiltered) / sigma(filtered) was calculated. This data is summarized in table 1 for the high contrast lines, table 2 for the lines with varied background level, and table three for the degraded line images. The frequency histograms for the measurement data gathered is found in appendix J for the high contrast lines, appendix K for the lines with varied background levels and appendix L for the degraded line images.

The data in tables 1, 2 and 3 clearly show that a significant reduction in the measurement variability was obtained in each situation, as the F test ratio for significance of 1.43 with a 0.05 alpha risk was exceeded by a moderate amount by the smallest ratio observed of 1.63, and a significantly large amount in other cases. This definitely suggests that improvements in the repeatability of the measurement of the width of small lines can be readily obtained using appropriate spatial filtering techniques.

line width (µm)	σ filtered	σ unfiltered	σ_u/σ_f
9.9	1.00099	4.10385	4.10
15.2	1.65767	3.31656	2.00
18.5	2.11860	3.45334	1.63
24.0	1.11910	3.32526	2.97
31.0	1.36074	3.05047	2.24

TABLE 1 Measurement Results with High Contrast Lines

line width & background D	σ filtered	σ unfiltered	σ_u/σ_f
21.3 @ 1.5	0.555326	1.92239	3.46
22.6 @ 2.0	0.544705	1.62419	2.98
20.8 @ 2.5	0.692432	2.13435	3.08
20.5 @ 3.0	0.776462	1.87539	2.42

TABLE 2 Measurement Results with Varying Background Lines

line width (µm)	σ filtered	σ unfiltered	σ_u/σ_f
30.1	1.79703	6.05673	3.37
38.2	1.36055	3.31558	2.44
54.0	1.06374	3.00546	2.83

TABLE 3 Measurement Results with Degraded Line Images

SUGGESTIONS FOR FURTHER RESEARCH

As there is no guarantee that the criteria used are in fact the ultimate in producing the absolutely lowest possible variability in line width measurements, there exists room for further research. Investigations in areas that pertain to the psychophysics of the measurement process would generally be helpful in determining new ways to select criteria for spatial filter optimization. Further and more exhaustive digitizations of spatial filtering systems would also be helpful in testing filter optimization algorithms, and ultimately become essential in obtaining the highest possible accuracy when dealing with actual measured data that cannot be modeled accurately enough to allow an analytic approach. In pursuing areas involving much computation however, the project muct be carefully planned in order to make maximum use of the computer resource available. The digitizations necessary for this project for instance, consumed an amount of CPU time estimated to be in excess of 100 hours, even with careful optimization, and would represent an investment conservatively priced at $20,000 in a commercial environment.

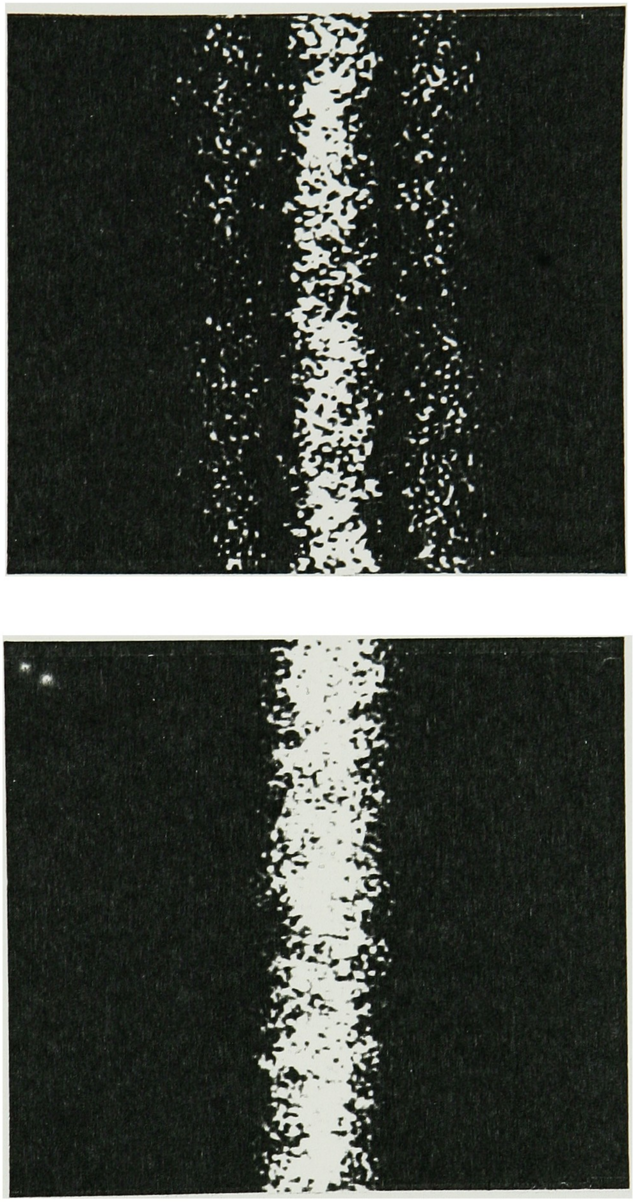


FIGURE 2 Degraded Line Image, Filtered and Unfiltered

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2. Jerke, John M., Hartman, Arie W., Nyyssonen, Diana, Rosberry, Fred W., Swing, Richard E., Swyt, Dennis A., and Young, Russell D.: "The Accurate Line Width Measurements at the National Bureau of Standards." Institute for Basic Standards, National Bureau of Standards, Washington, D. C. 20234

APPENDICES

APPENDIX A

FILTER SELECTION FOR BINARY LINES

ANALYSIS OF CLEAR LINE ON BLACK BACKGROUND

A binary line can be modeled as follows:

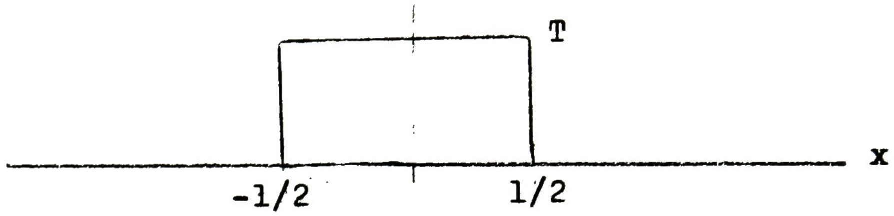

FIGURE 3 Mathematical Model of Clear Line on Black Background

T is the transmission level of the line, l is the line width, and k is the aperture width.

$$f(x) = T\ \mathrm{rect}(x/l) \tag{1}$$

$$f(\nu) = T\int_{-l/2}^{l/2} \exp(-i2\pi\nu x)dx \tag{2}$$

$$f(\nu) = T\ \frac{\exp(-i2\pi\nu x)}{-i2\pi\nu x}\Bigg|_{-l/2}^{l/2} \tag{3}$$

$$f(\nu) = T\ \frac{\exp(-i2\pi\nu l/2) - \exp(-i2\pi\nu l/2)}{-i2\pi\nu} \tag{4}$$

$$\sin x = \frac{\exp(ix) - \exp(-ix)}{2i}$$

$$f(\nu) = \frac{T\ \sin(\pi\nu l)}{\pi\nu} \tag{5}$$

$$\mathrm{sinc}\ x = \frac{\sin(\pi x)}{\pi x}$$

$$f(\nu) = lT\ \mathrm{sinc}(\nu l) \tag{6}$$

let A=1T

$$f(\nu) = A\ \mathrm{sinc}(\nu 1) \tag{7}$$

So that the image spectrum of a binary line on a black background is specified by a single sinc function.

The filtered image is given by the inverse Fourier transform of the product of the image spectrum and the spatial filter. A bandpass spatial filter can be modeled as follows:

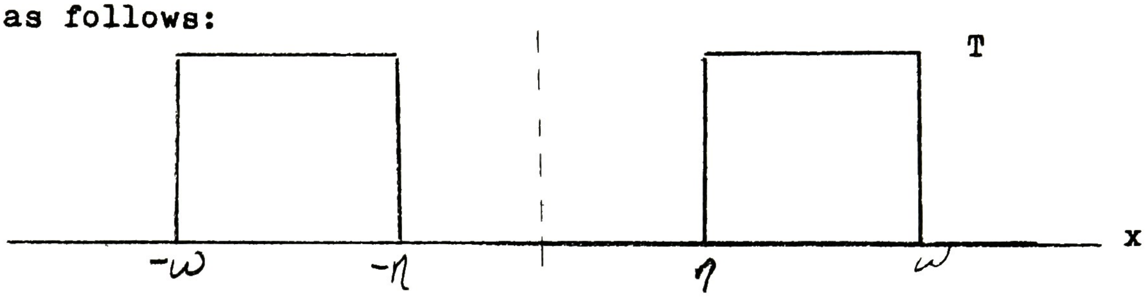

FIGURE 4 Mathematical Model of Bandpass Spatial Filter

η is the lower cutoff frequency and ω the upper cutoff frequency, such that the filtered image may be represented by:

$$f(x) = \int_{-\omega}^{\omega} f(\nu)\ \exp((i2\nu\pi x/m)d\nu - \int_{-\eta}^{\eta} f(\nu)\ \exp(i2\pi\nu x/m)d\nu \tag{8}$$

$$f(x) = A\int_{-\omega}^{\omega} \mathrm{sinc}(\nu 1)\ \exp(i2\pi\nu x/m\ d\nu$$

$$- A\int_{-\eta}^{\eta} \mathrm{sinc}(\nu 1)\ \exp(i2\pi\nu x/m)d\nu \tag{9}$$

where x is adjusted by m, the magnification.

$$\text{sinc } x = \frac{\sin(\pi x)}{\pi x} = \frac{\exp(i\pi x) - \exp(-i\pi x)}{2i\pi x}$$

$$f(x) = A\int_{-\omega}^{\omega} \frac{(\exp(i\pi\nu l) - \exp(-i\pi\nu l))\exp(i2\pi\nu x/m)d\nu}{i2\pi\nu l}$$

$$- A\int_{-\eta}^{\eta} \frac{(\exp(i\pi\nu l) - \exp(-i\pi\nu l))\exp(i2\pi\nu x/m)d\nu}{i2\pi\nu l} \qquad (10)$$

$$f(x) = A\int_{-\omega}^{\omega} \frac{(\exp(i\pi\nu l(2x/ml + 1) - \exp(-i\pi\nu l(2x/ml - 1)))d\nu}{(2i)\pi\nu l}$$

$$- A\int_{-\eta}^{\eta} \frac{(\exp(i\pi\nu l(2x/ml + 1) - \exp(-i\pi\nu l(2x/ml - 1)))d\nu}{(2i)\pi\nu l} \qquad (11)$$

Once in this form, it can be evaluated as a series of sine integrals. The sine Integral may be evaluated as follows:

$$\int_{-a_2}^{a_1} \frac{\sin x dx}{x} = \int_0^{a_1} \frac{\sin x dx}{x} - \int_0^{-a_2} \frac{\sin x dx}{x} = S_i(a_1) - S_i(-a_2)$$

$$= S_i(a_1) + S_i(a_2)$$

$$f(x) = A\int \frac{\exp(i\pi\omega l(2x/ml + 1)) - \exp(-i\pi\omega l(2x/ml - 1)d\omega}{i2\pi\omega l}$$

$$- A\int \frac{\exp(-i\pi\omega l(2x/ml + 1)) - \exp(i\pi\omega l(2x/ml - 1)(-d\omega)}{-i2\pi\omega l}$$

$$- A\int \frac{\exp(i\pi\eta l(2x/ml + 1)) - \exp(-i\pi\eta l(2x/ml - 1)d\eta}{i2\pi\eta l}$$

$$+ A\int \frac{\exp(-i\pi\eta l(2x/ml + 1)) - \exp(i\pi\eta l(2x/ml - 1)(-d\eta)}{-i2\pi\eta l} \qquad (12)$$

let $B = (2x/ml + 1)$ & let $C = (2x/ml - 1)$

$$f(x) = A\int \frac{B\,\exp(i\pi\omega lB) - \exp(-i\pi\omega lB)\,d\omega}{2i(\pi\omega lB)}$$

$$+ A\int \frac{C\,\exp(i\pi\omega lC) - \exp(-i\pi\omega lC)\,d\omega}{2i(\pi\omega lC)}$$

$$- A\int \frac{B\,\exp(i\pi\eta lB) - \exp(-i\pi\eta lB)\,d\eta}{2i(\pi\eta lB)}$$

$$- A\int \frac{C\,\exp(i\pi\eta lC) - \exp(-i\pi\eta lC)\,d\eta}{2i(\pi\eta lC)} \qquad (13)$$

$$f(x) = A\left(B\int \frac{\sin(\pi\omega lB)\,d\omega}{\pi\omega lB} + C\int \frac{\sin(\pi\omega lC)\,d\omega}{\pi\omega lC} \right.$$

$$\left. - B\int \frac{\sin(\pi\eta lB)\,d\eta}{\pi\eta lB} - C\int \frac{\sin(\pi\eta lC)\,d\eta}{\pi\eta lC} \right) \qquad (14)$$

$$f(x) = A\left(B\,S_i(\pi\omega lB) + C\,S_i(\pi\omega lC) - B\,S_i(\pi\eta lB) - C\,S_i(\pi\eta lC) \right) \qquad (15)$$

The obserable image illuminance is given by the squared modulus of $f(x)$; $I(x) = |f(x)|^2$. Also, the distribution may be simplified if it is normalized to the object edge, such that $\xi = 2x/ml$.

$B = (\xi + 1)$ & $C = (\xi - 1)$

$$I(x) = A^2\left(B\,S_i(\pi\omega lB) + C\,S_i(\pi\omega lC) - B\,S_i(\pi\eta lB) - C\,S_i(\pi\eta lC) \right)^2 \qquad (16)$$

Since the edge is normalized in terms of the line edge, the value of the luminance there will be given by $I(\xi)$ for $= \pm 1$.

$$I(1) = A^2 \left(2\, S_i(2\pi\omega l) - 2\, S_i(2\pi\eta l) \right)^2 \tag{17}$$

The location of the line edge may be marked by a zero luminance value by equating the two sine integrals:

$$I(1) = 0, \quad S_i(2\pi\omega l) = S_i(2\pi\eta l) \tag{18}$$

The smallest spatial filter solution may be obtained by solving this equality for a specific line width l, using the smallest possible solution of the inverse sine integral. This approach will maximize the reconstructed image luminance.

$$\eta = (1/2\pi l)^{\circ} S_i^{-1} \left[S_i(2\pi\omega l) \right] \tag{19}$$

This derivation agrees with that of R. Swing[1] for a given line width defined as l.

The upper cutoff frequency for a diffraction limited lens may be determined as $\omega = (NA)/\lambda$, or imposed with a spatial filter in the transform plane of the lens.

ANALYSIS OF BLACK LINE ON CLEAR BACKGROUND

Such a binary line can be modeled as follows:

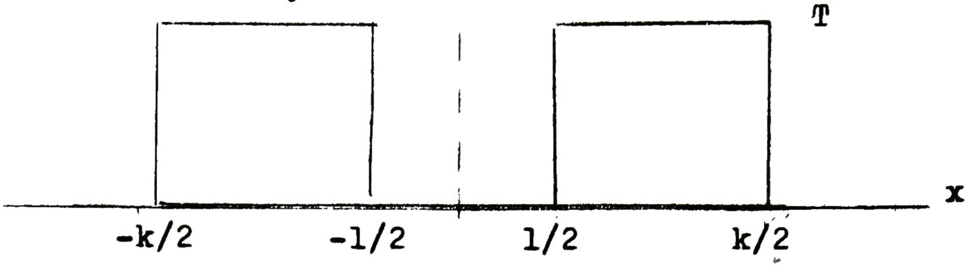

FIGURE 5 Mathematical Model of Black Line on Clear Background

T is the transmission level of the line, l is the line width, and k is the aperture width.

$$f(x) = T\ \mathrm{rect}(x/k) - T\ \mathrm{rect}(x/l) \tag{1}$$

$$f(\nu) = kT\ \mathrm{sinc}(\nu k) - lT\ \mathrm{sinc}(\nu l) \tag{2}$$

So that the image specturm of a binary line on a clear background is specified by the difference of two sinc functions.

After lengthly evaluation,[1] it can be shown that the lower cutoff filter solution is the same as in the previous analysis of a clear binary line by restricting the domain to that of the line image by eliminating terms that describe the imaging of the object aperture.

APPENDIX B

FILTER SELECTION FOR BINARY PLUS LEVEL LINES

ANALYSIS OF CLEAR LINE ON DARK BACKGROUND

This type of binary line may be modeled as follows:

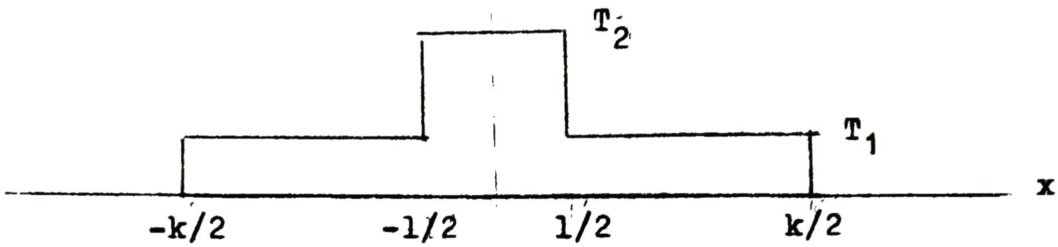

FIGURE 6 Mathematical Model of Clear Line on Dark Background

T_1 and T_2 represent the possible levels of transmittance, l is the line width, and k is the aperture width.

$$f(x) = (T_2 - T_1)\mathrm{rect}(x/l) + (T_1)\mathrm{rect}(x/k) \quad (1)$$

$$f(\nu) = l(T_2 - T_1)\mathrm{sinc}(\nu l) + kT_1\mathrm{sinc}(\nu k) \quad (2)$$

In this case, the image is the sum of two sinc functions, and scaled by the relative transmission levels.

Again, after lengthly analysis[1], the lower cutoff filter solution is the same as before, and the reconstructed filtered image as seen by the eye, is the squared modulus of f(x) and scaled by the various constants.

ANALYSIS OF DARK LINE ON CLEAR BACKGROUND

This may be modeled as follows:

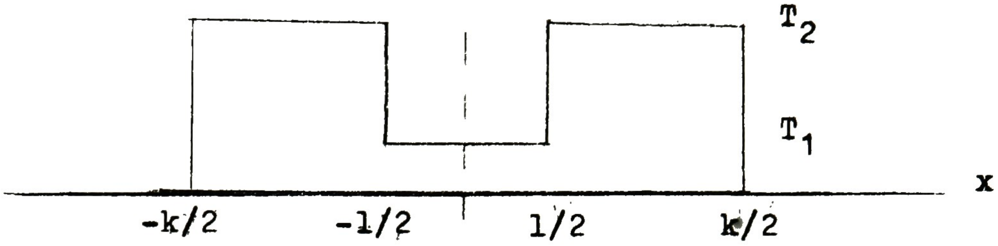

FIGURE 7 Mathematical Model of Dark Line on Clear Background

T_1 and T_2 represent the possible levels of transmittance, l is the line width, and k is the aperture width.

$$f(x) = (T_2 - T_1)\text{rect}(x/k) - T_1\text{rect}(x/l) \tag{1}$$

$$f(\nu) = k(T_2 - T_1)\text{sinc}(\nu k) - lT_1\text{sinc}(\nu l) \tag{2}$$

In this case, the image is the difference of two sinc functions and scaled by the relative transmission levels.

Again, after lengthly analysis[1], the lower cutoff filter solution is the same as before, and the reconstructed filtered image as seen by the eye, is the squared modulus of f(x) and scaled by the various constants.

APPENDIX C

FILTER SELECTION FOR ANNULAR APERTURE LENS

FILTER SELECTION FOR ANNULAR APERTURE LENS

The annular aperture frequency response may be modeled as:

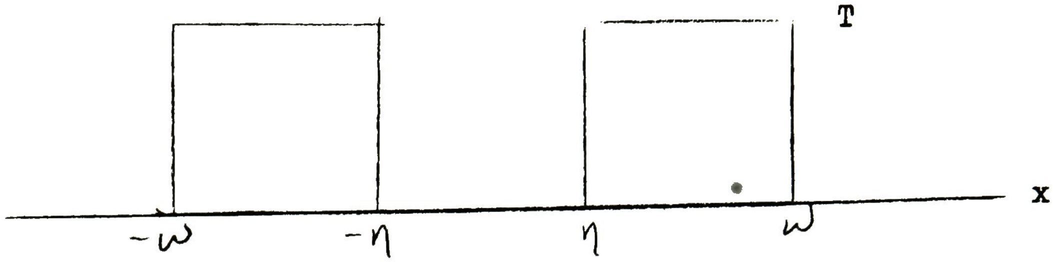

FIGURE 8 Mathematical Model of Annular Aperture Lens Spatial Filter

In this case, the lower as well upper cutoff frequencies, η and ω, may be specified by the lens.

The optimum lower cutoff for accurate line width measurement however, may be specified by the lower cutoff filter equation using higher order solutions of the inverse sine integral.

$$\eta = (1/2\pi\lambda)\ {}^{*}S_i^{-1}\left[S_i(2\pi\omega\lambda)\right] \qquad (1)$$

$* = 0,1,2,3,4...n$ It should be noted that as n goes to infinity, the solution becomes $\pi/2$.

APPENDIX D

PLOTS OF FILTERED IMAGES FOR HIGH CONTRAST LINES

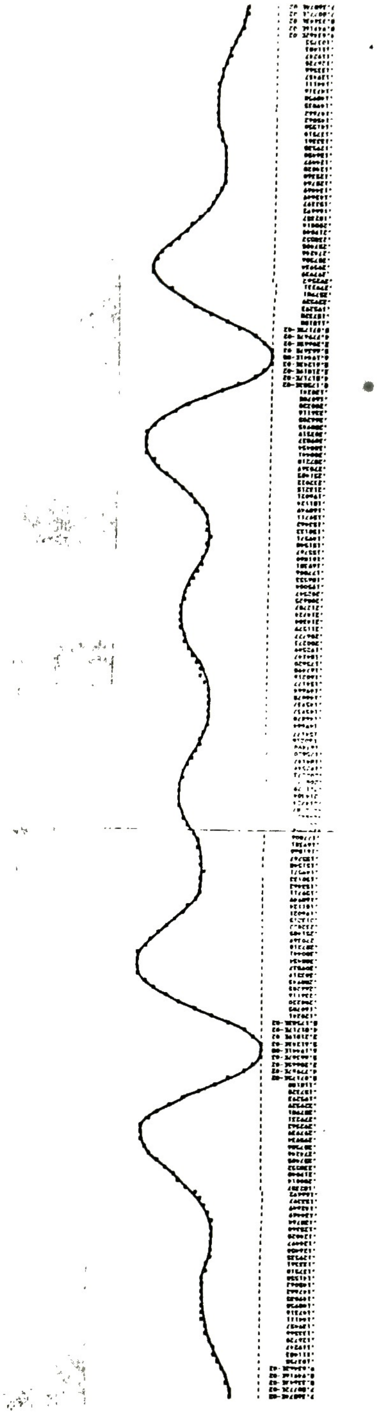

FIGURE 9 Filtered Image Intensity Distribution
for 9.9um with n=30.88 cy/mm optimum

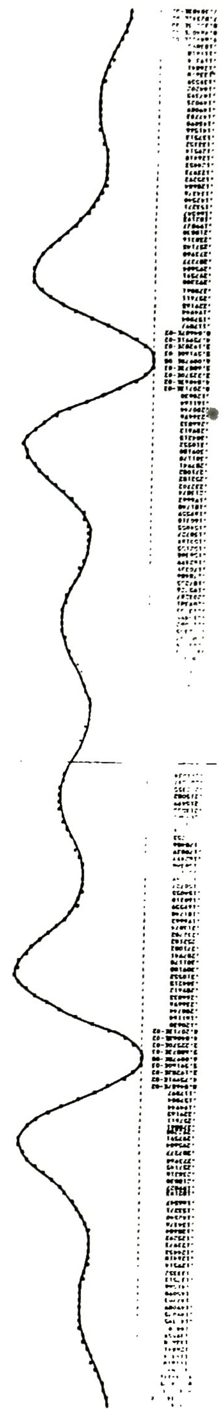

FIGURE 10 Filtered Image Intensity Distribution for 9.9um with n=30.83 cy/mm actual

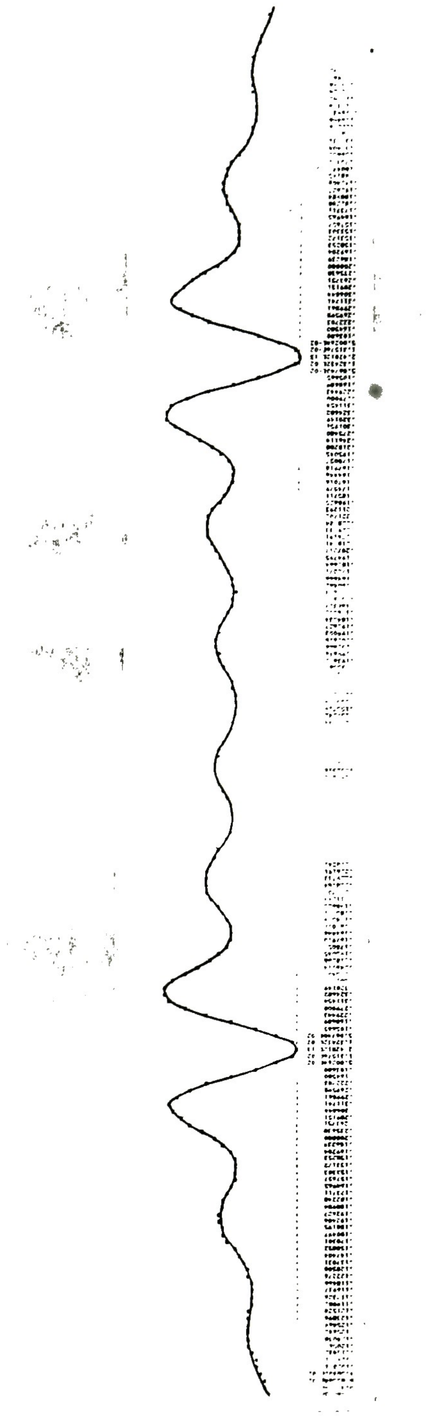

FIGURE 11 Filtered Image Intensity Distribution for 15.2 with n=19.98 cy/mm optimum

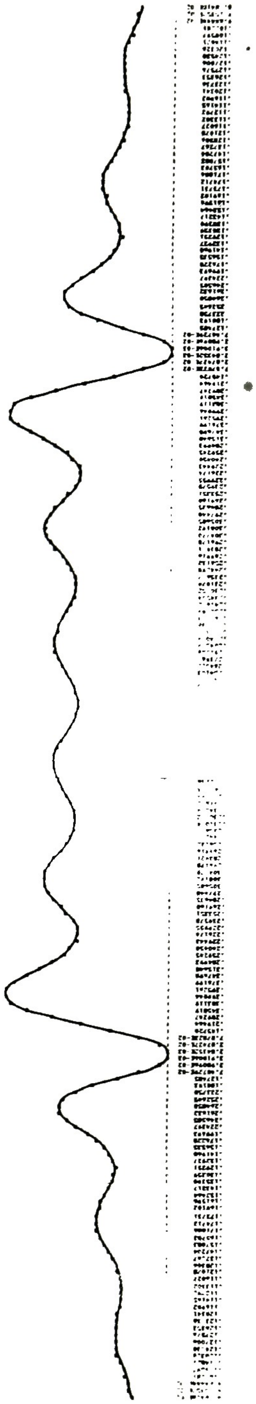

FIGURE 12 Filtered Image Intensity Distribution for 15.2um with n=16.84 cy/mm actual

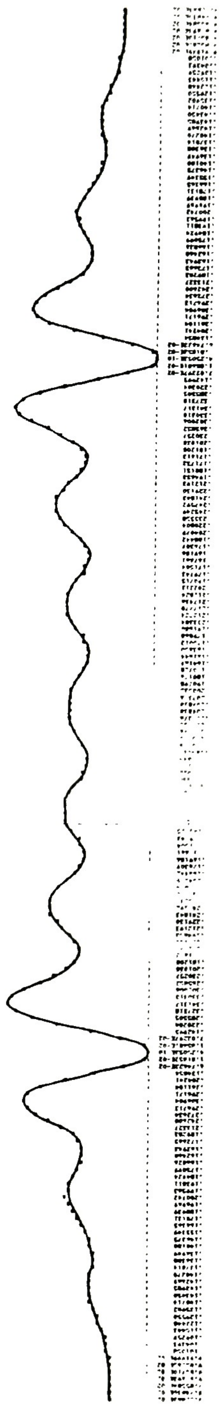

FIGURE 13 Filtered Image Intensity Distribution
for 18.5um with n=16.16 cy/mm optimum

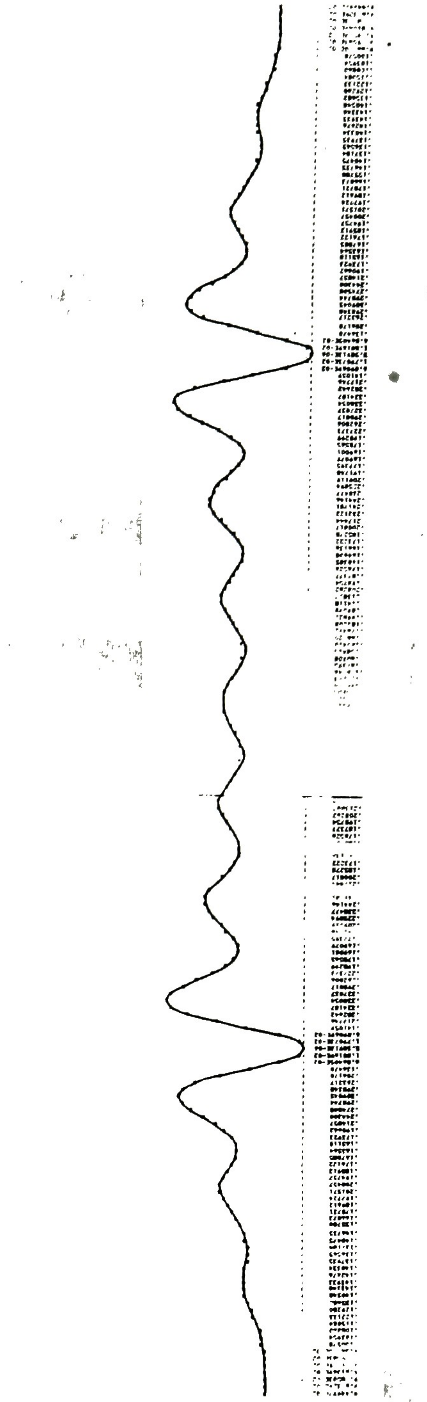

FIGURE 14 Filtered Image Intensity Distribution for 18.5um with n=16.29 cy/mm actual

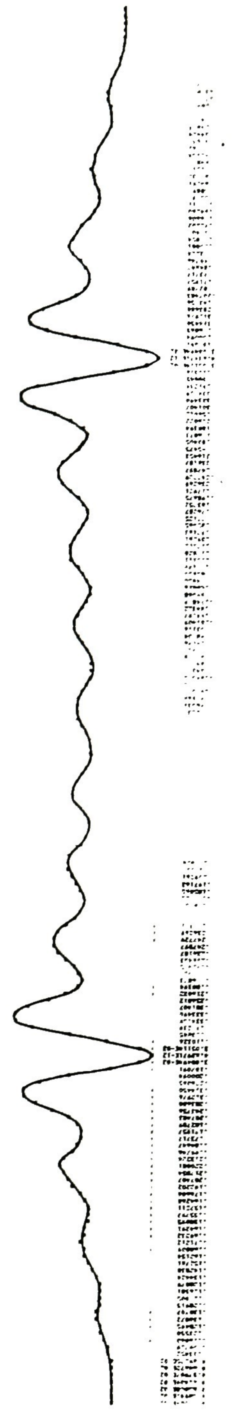

FIGURE 15 Filtered Image Intensity Distribution
for 24.0um with n=12.60 cy/mm optimum

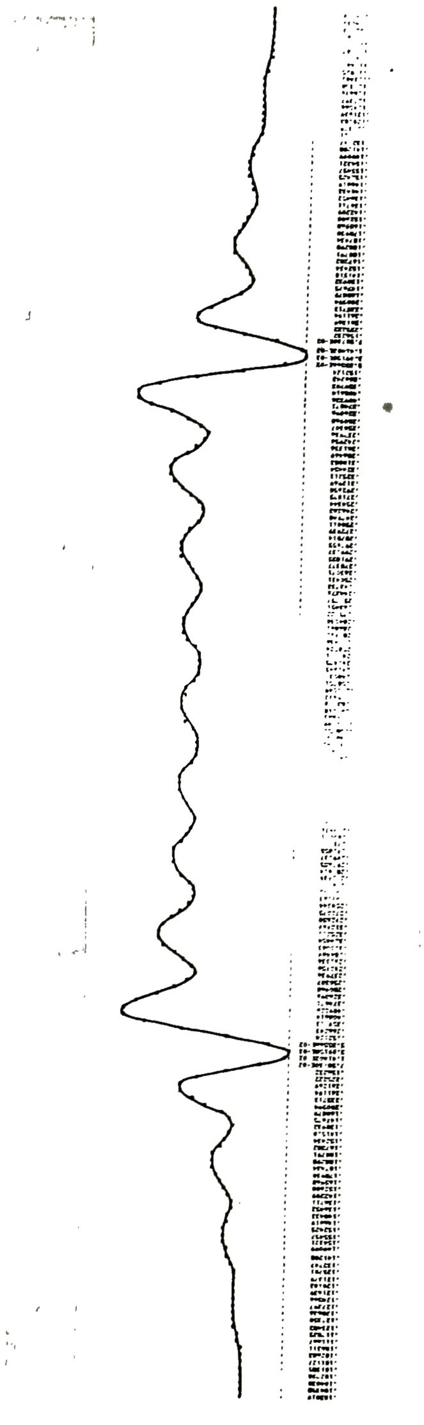

FIGURE 16 Filtered Image Intensity Distribution for 24.0um with n=10.55 cy/mm actual

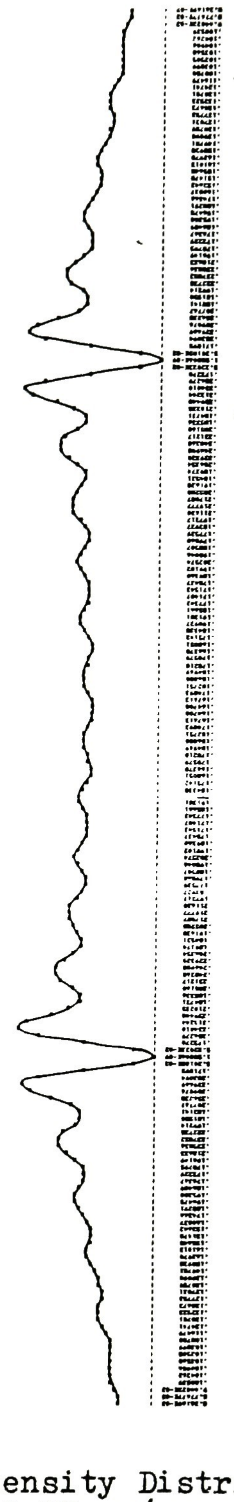

FIGURE 17 Filtered Image Intensity Distribution for 31.0um with n=9.87 cy/mm optimum

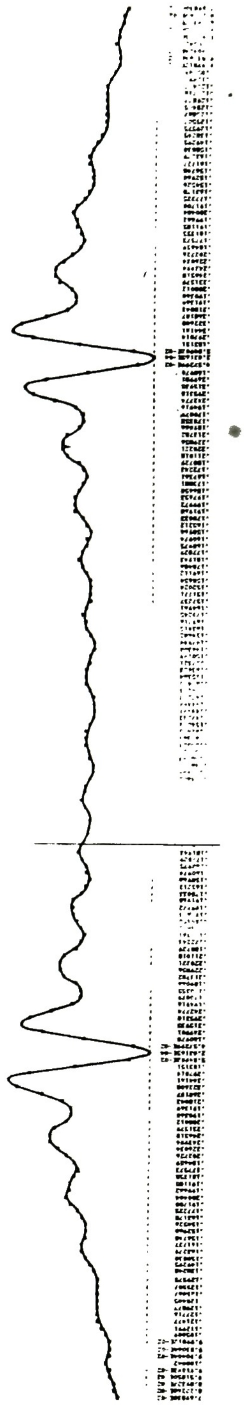

FIGURE 18 Filtered Image Intensity Distribution for 31.0um with n=10.36 cy/mm actual

APPENDIX E

PLOTS OF FILTERED IMAGES FOR VARYING CONTRAST IMAGES

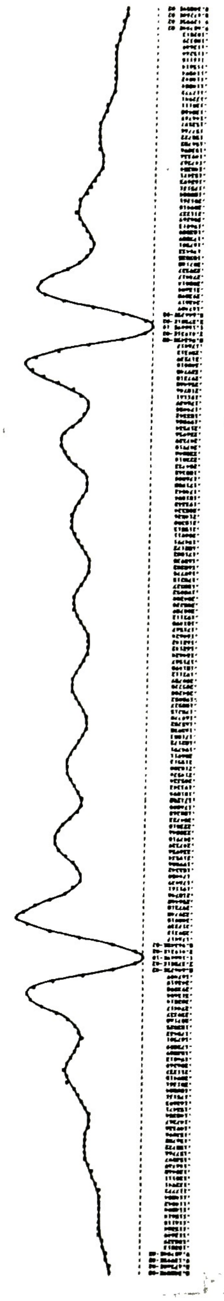

FIGURE 19 Filtered Image Intensity Distribution for 21.3um with n=14.16 cy/mm optimum

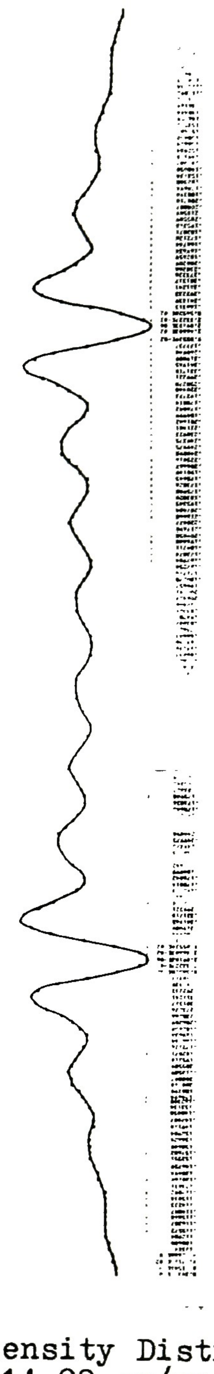

FIGURE 20 Filtered Image Intensity Distribution for 21.3um with n=14.09 cy/mm actual

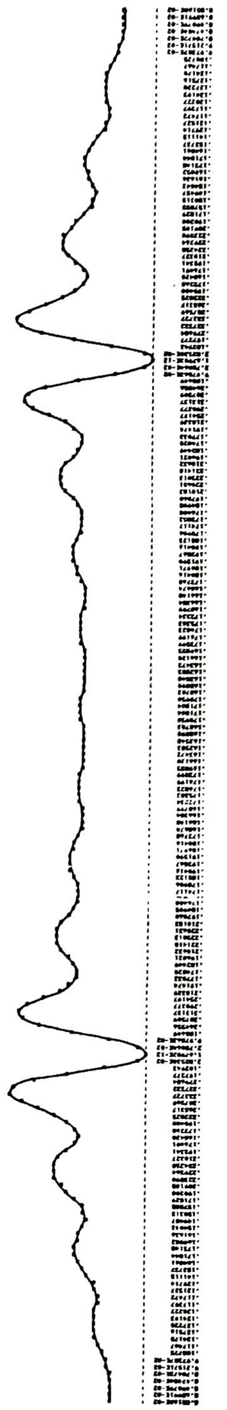

FIGURE 21 Filtered Image Intensity Distribution for 22.6um with n=13.79 cy/mm optimum

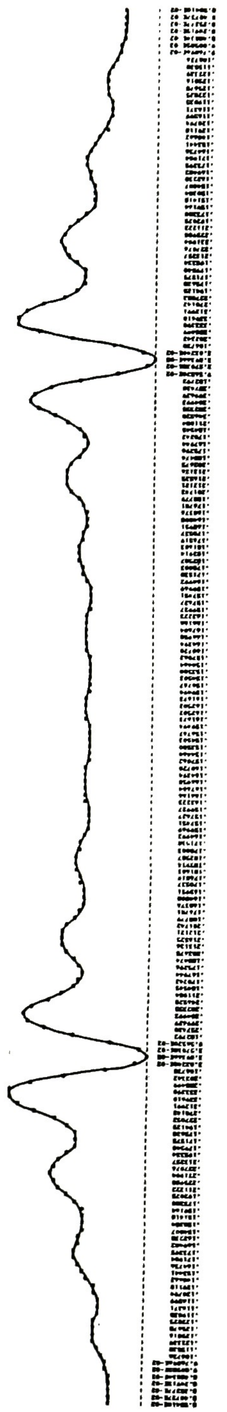

FIGURE 22 Filtered Image Intensity Distribution for 22.6um with n=14.09 cy/mm actual

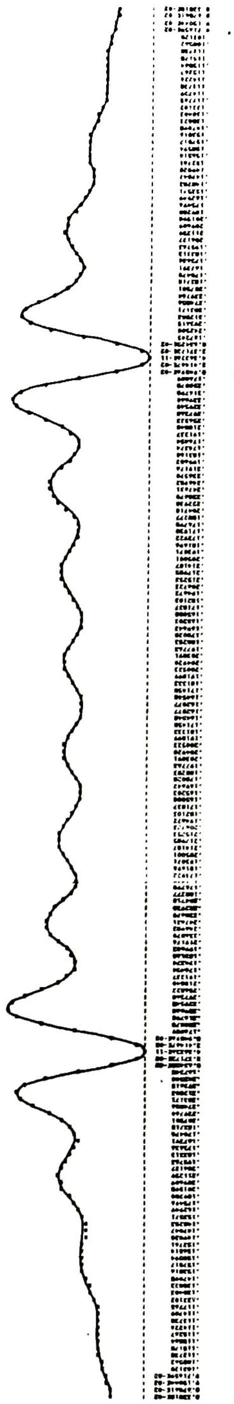

FIGURE 23 Filtered Image Intensity Distribution for 20.8um with n=14.45 cy/mm optimum

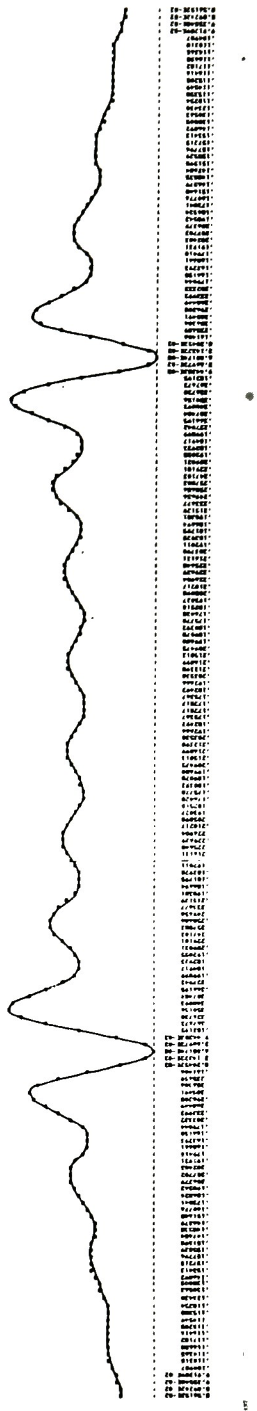

FIGURE 24 Filtered Image Intensity Distribution for 20.8um with n=14.09 cy/mm. actual

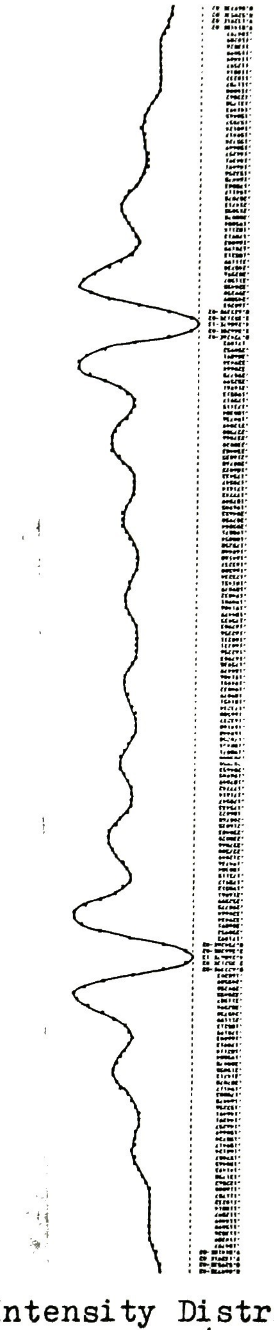

FIGURE 25 Filtered Image Intensity Distribution
for 20.5um with n=14.88 cy/mm optimum

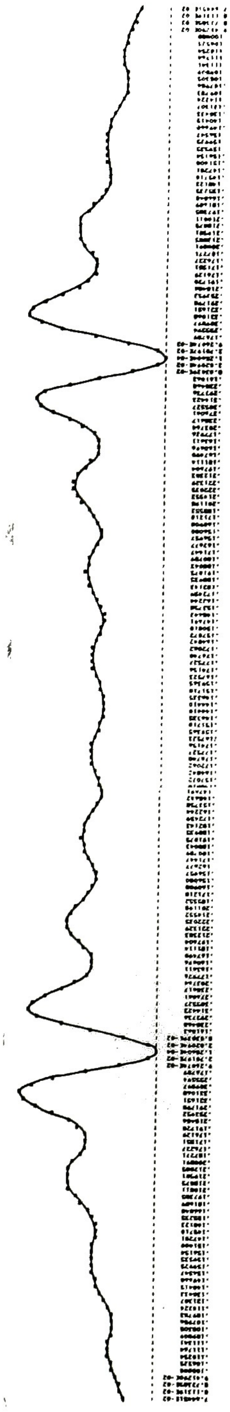

FIGURE 26 Filtered Image Intensity Distribution for 20.5um with n=15.46 cy/mm actual

APPENDIX F

PLOTS OF FILTERED IMAGES FOR DEGRADED LINES

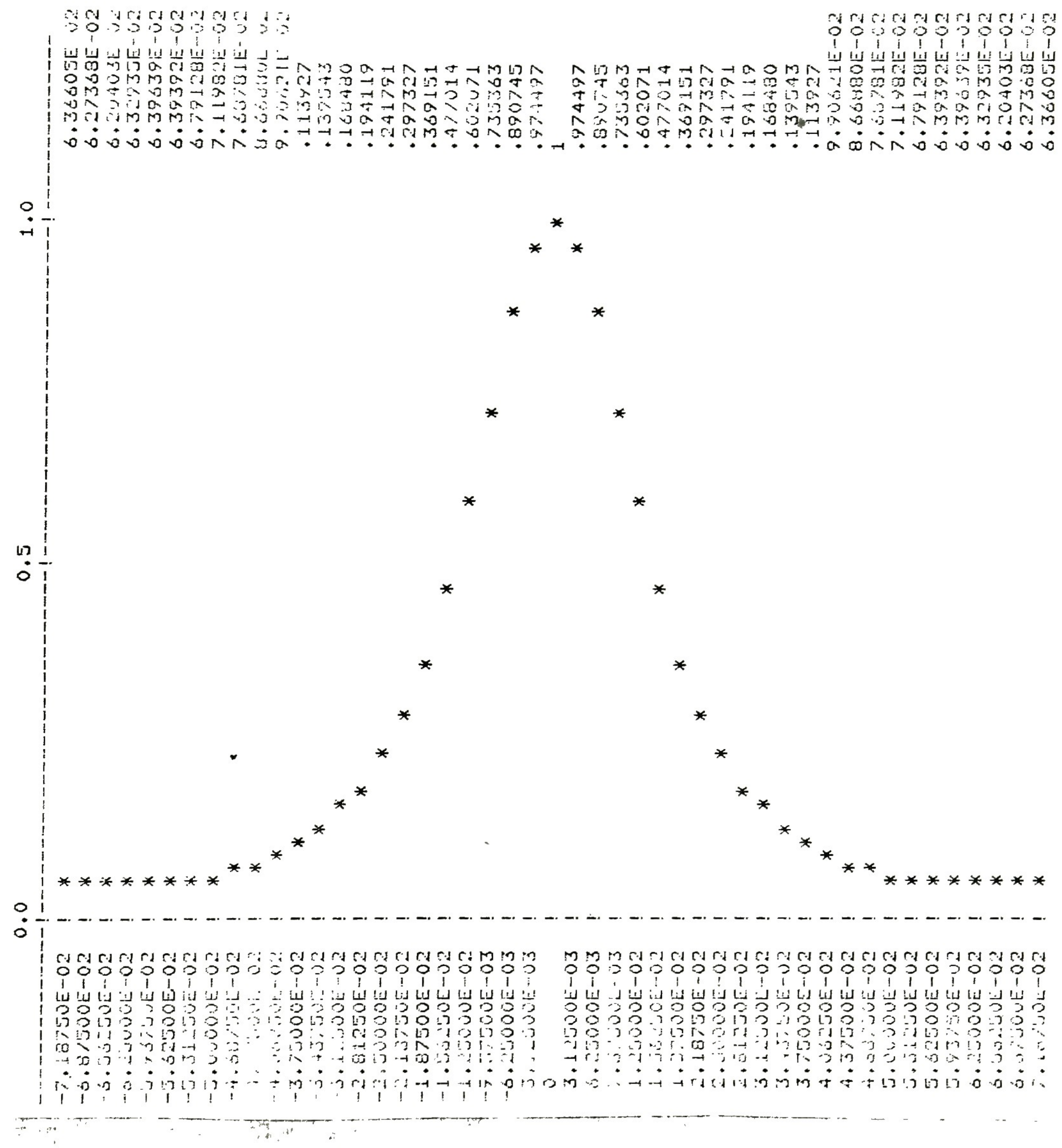

FIGURE 27 Degraded Line Profile for 30.1um

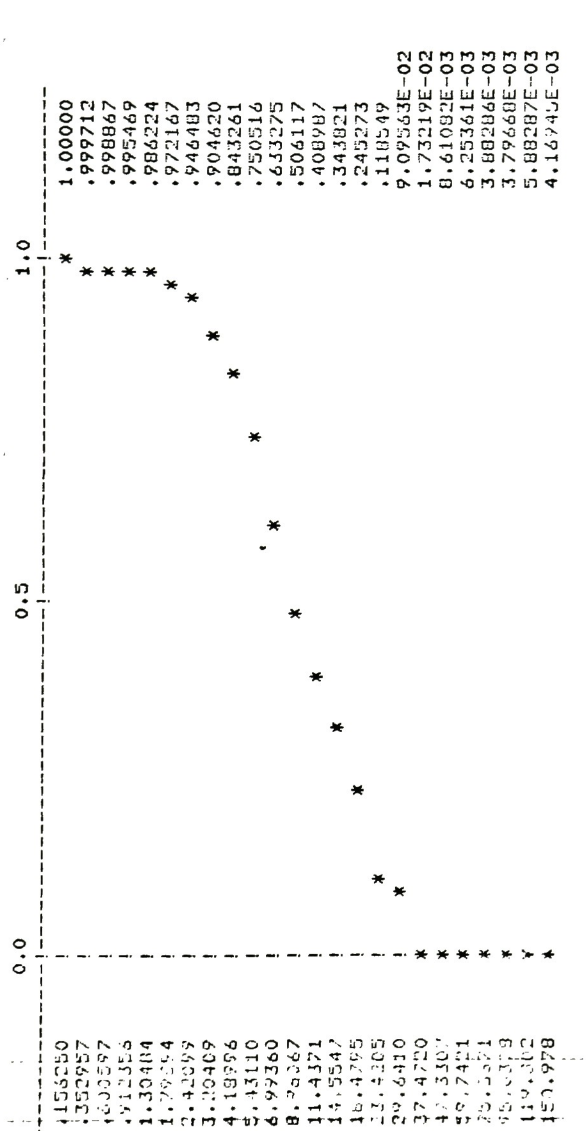

FIGURE 28 Degraded Line Spectrum for 30.1um

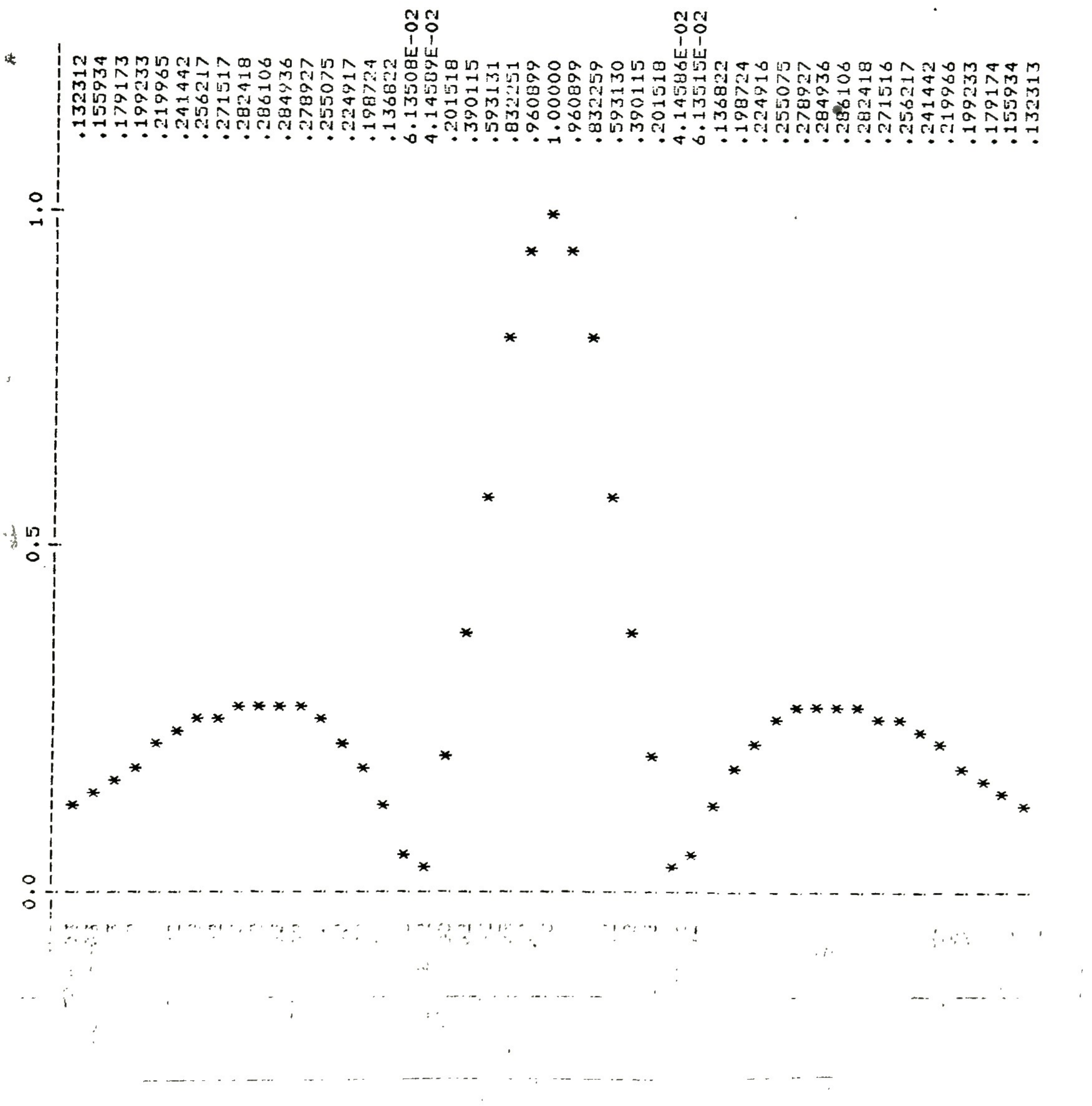

FIGURE 30 Filtered Image Intensity Distribution for 30.1 um with n=8.03 cy/mm actual

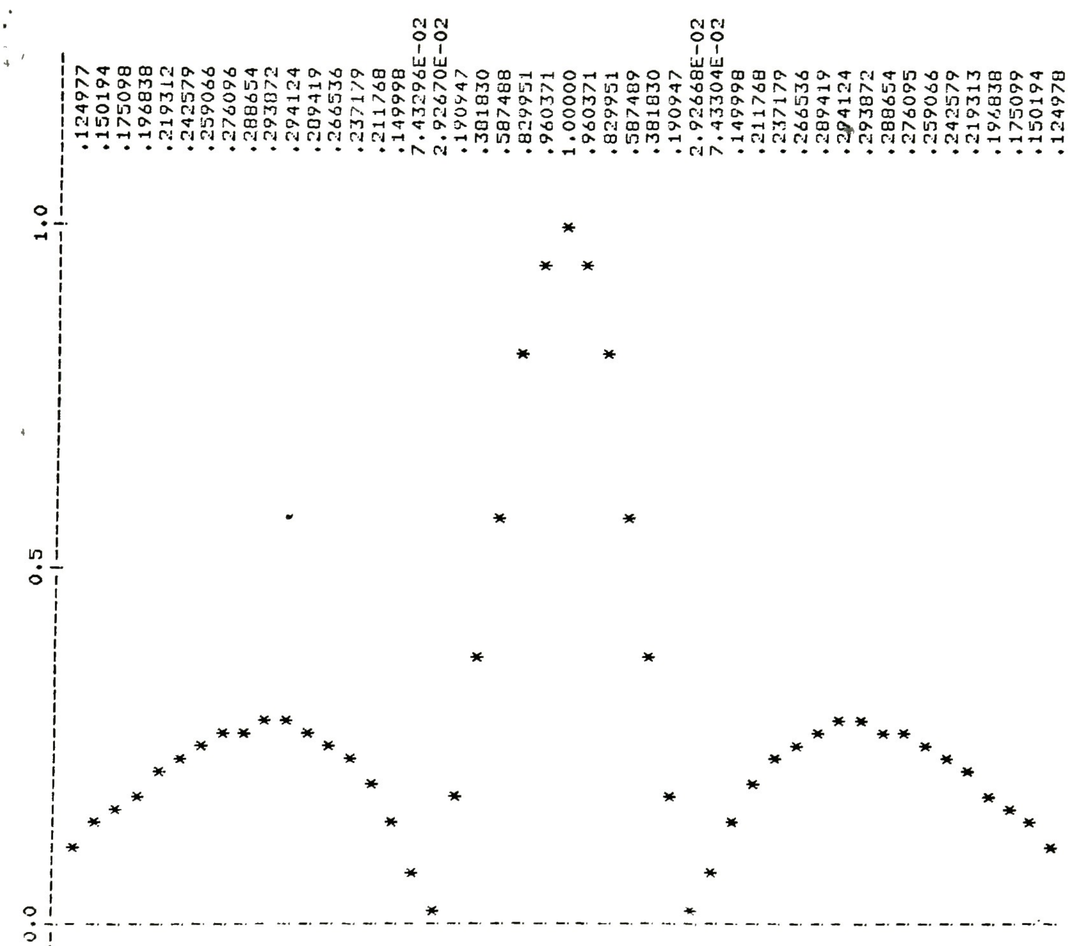

FIGURE 29 Filtered Image Intensity Distribution for 30.1um with n=8.44 cy/mm optimum

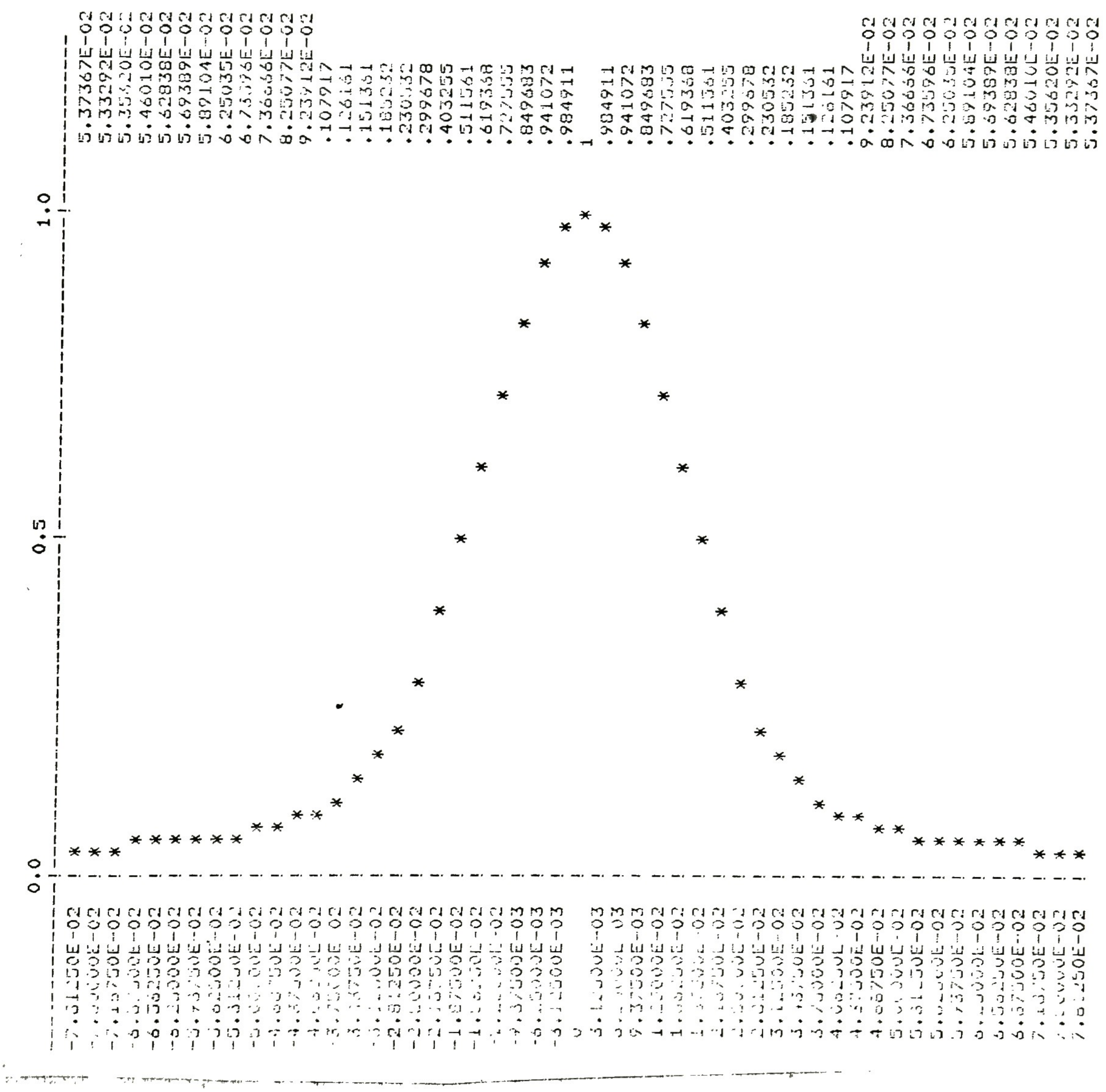

FIGURE 31 Degraded Line Profile for 38.2um

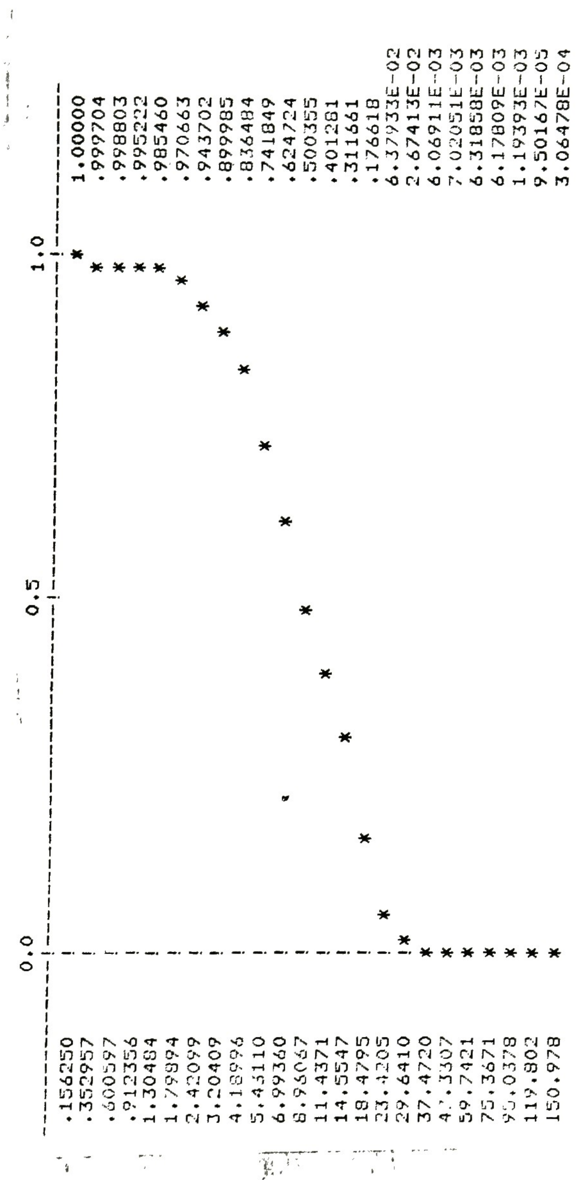

FIGURE 32 Degraded Line Spectrum for 38.2um

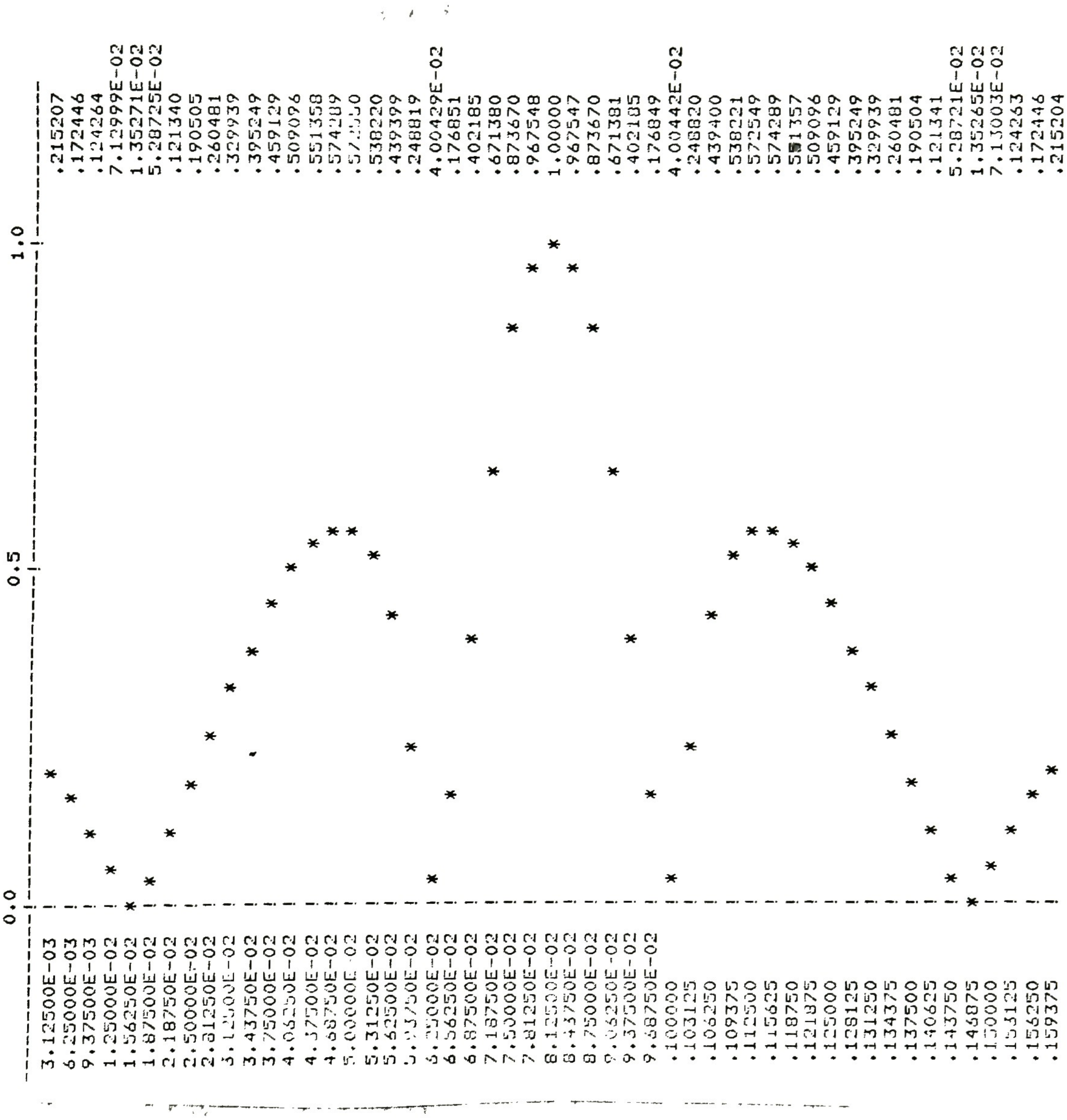

FIGURE 33 Filtered Image Intensity Distribution for 38.2um with n=7.19 cy/mm optimum

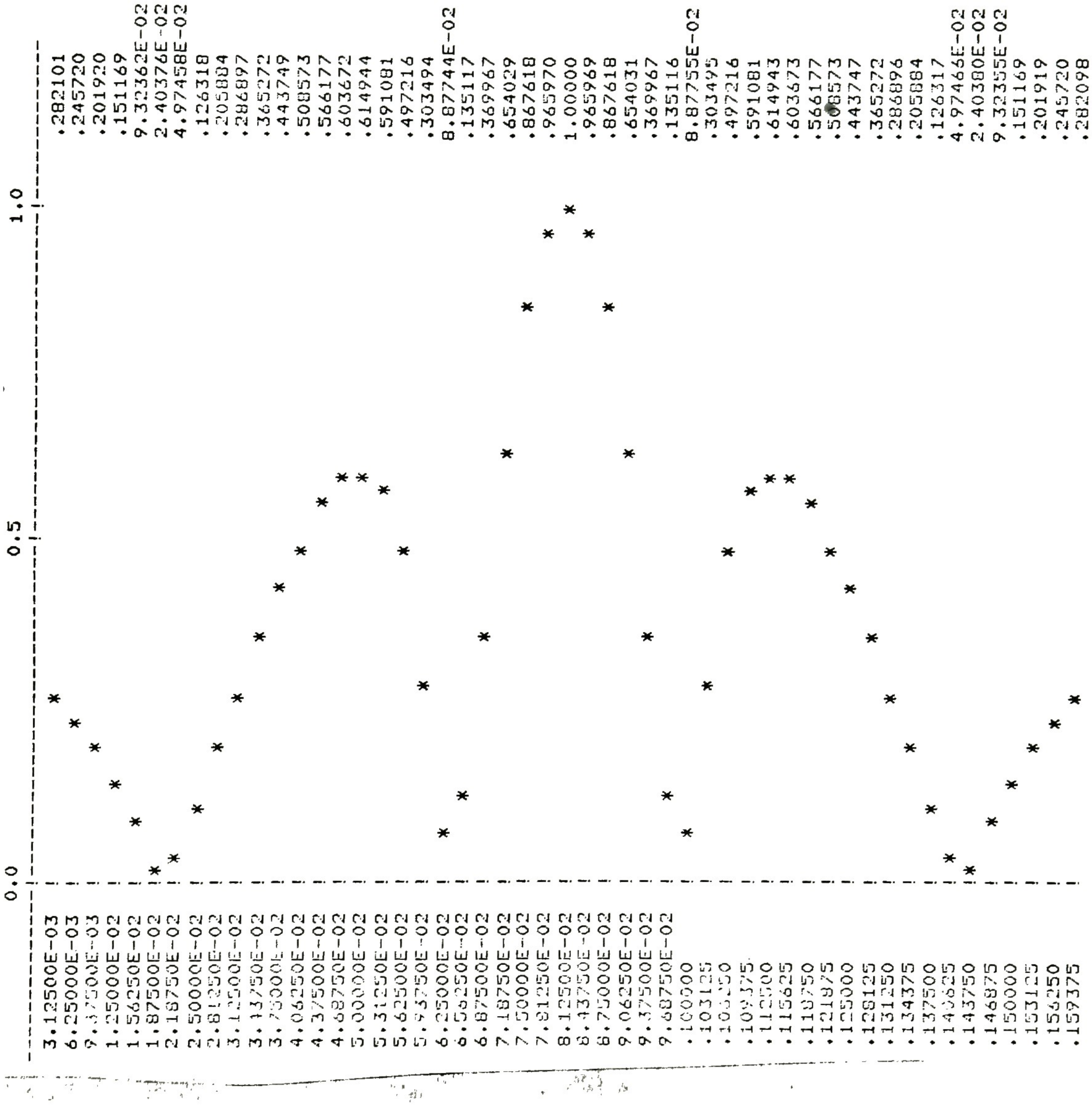

FIGURE 34 Filtered Image Intensity Distribution for 38.2um with n=6.58 cy/mm actual

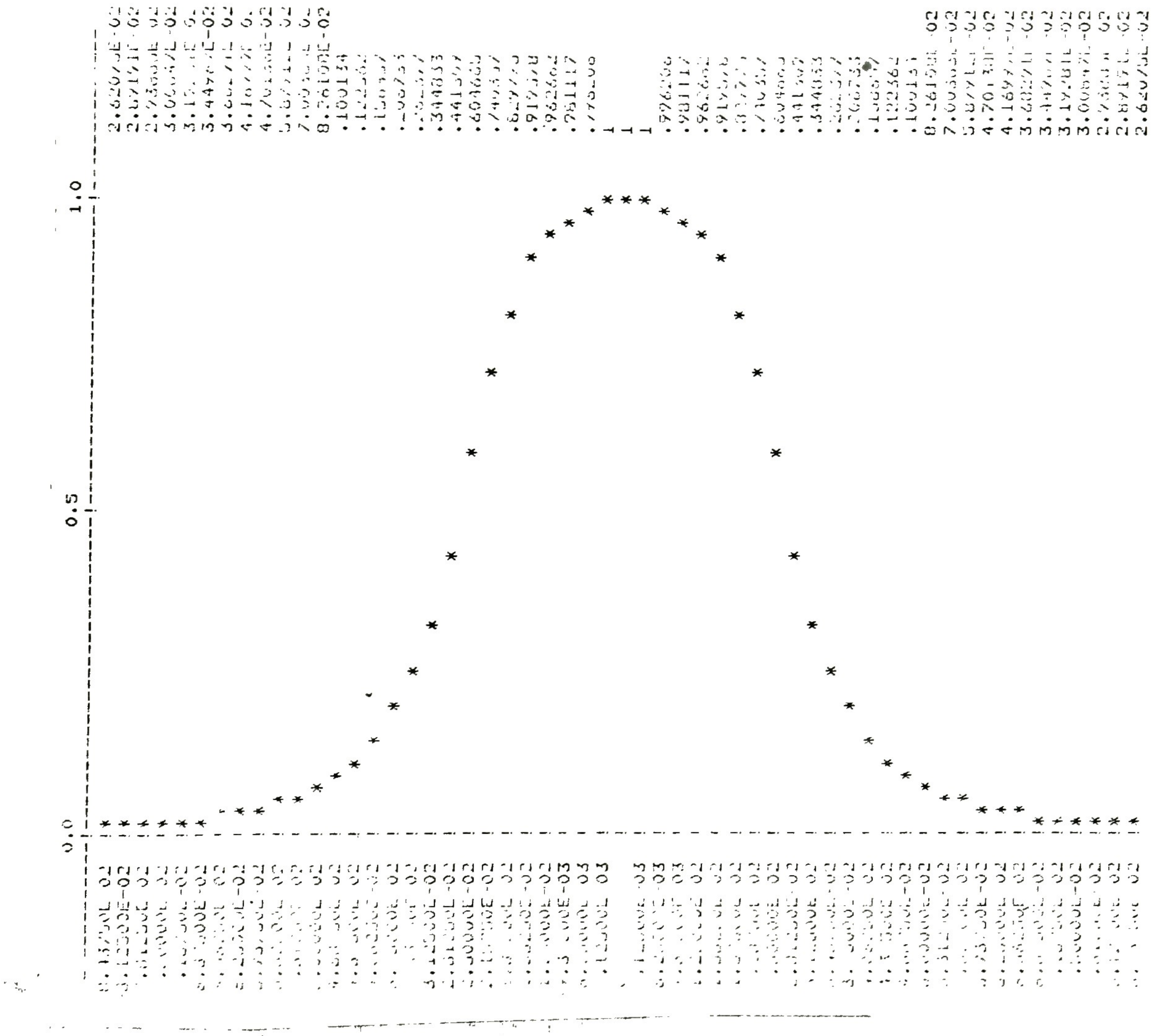

FIGURE 35 Degraded Line Profile for 54.0um

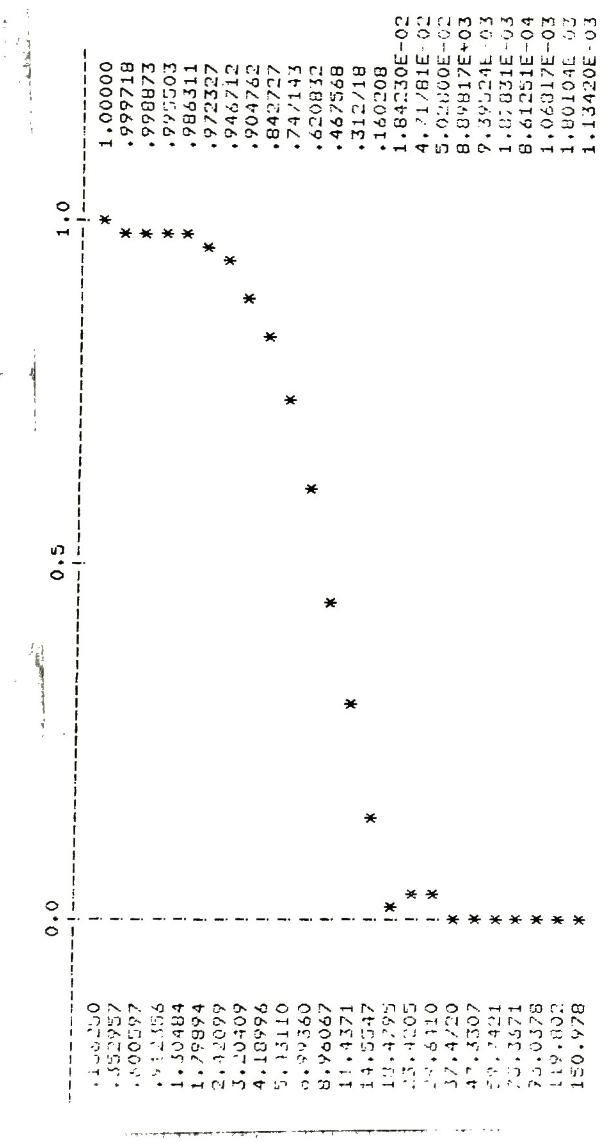

FIGURE 36 Degraded Line Spectrum for 54.0um

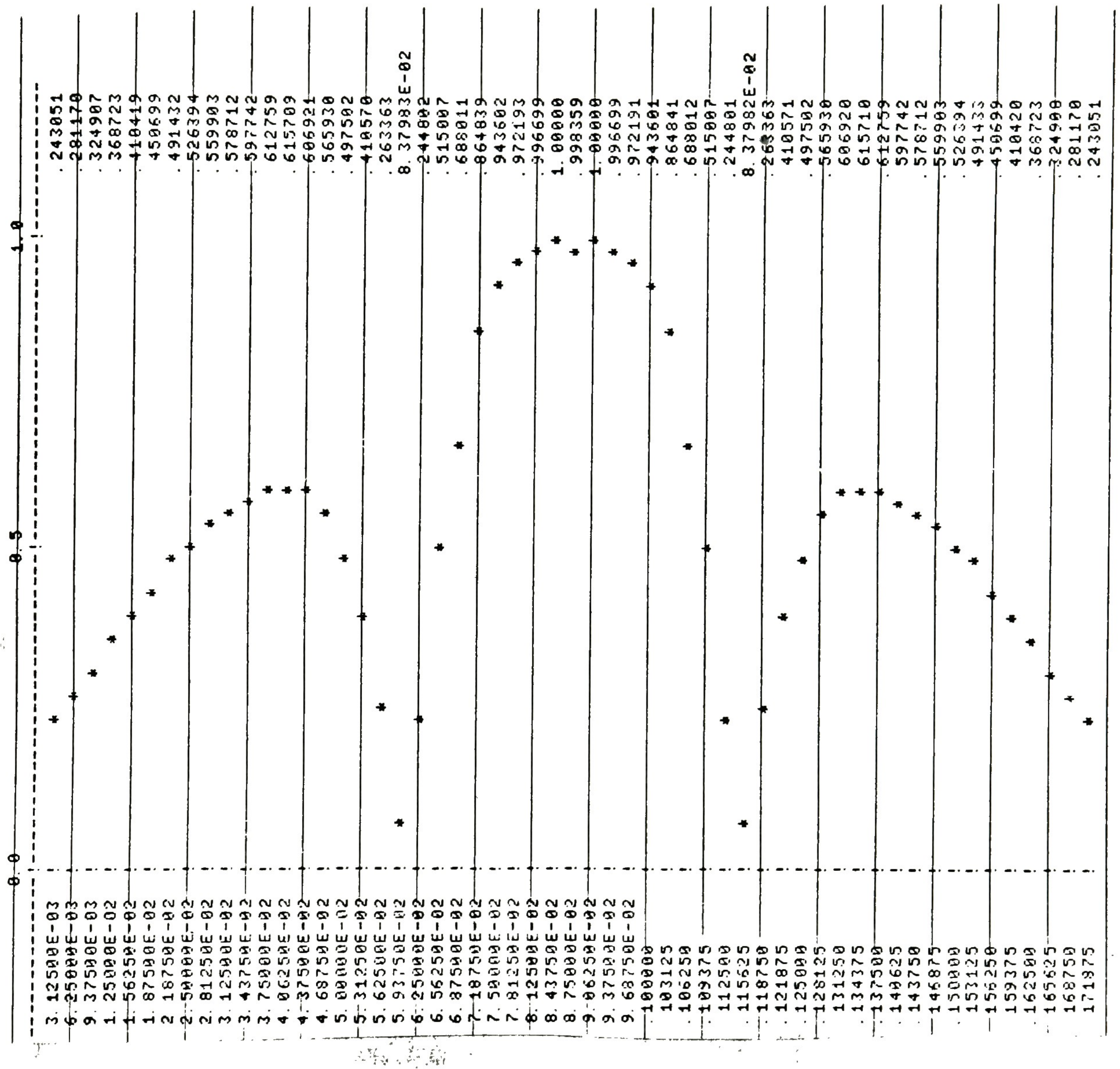

FIGURE 37 Filtered Image Instensity Distribution for 54.0um with n=5.00 cy/mm optimum

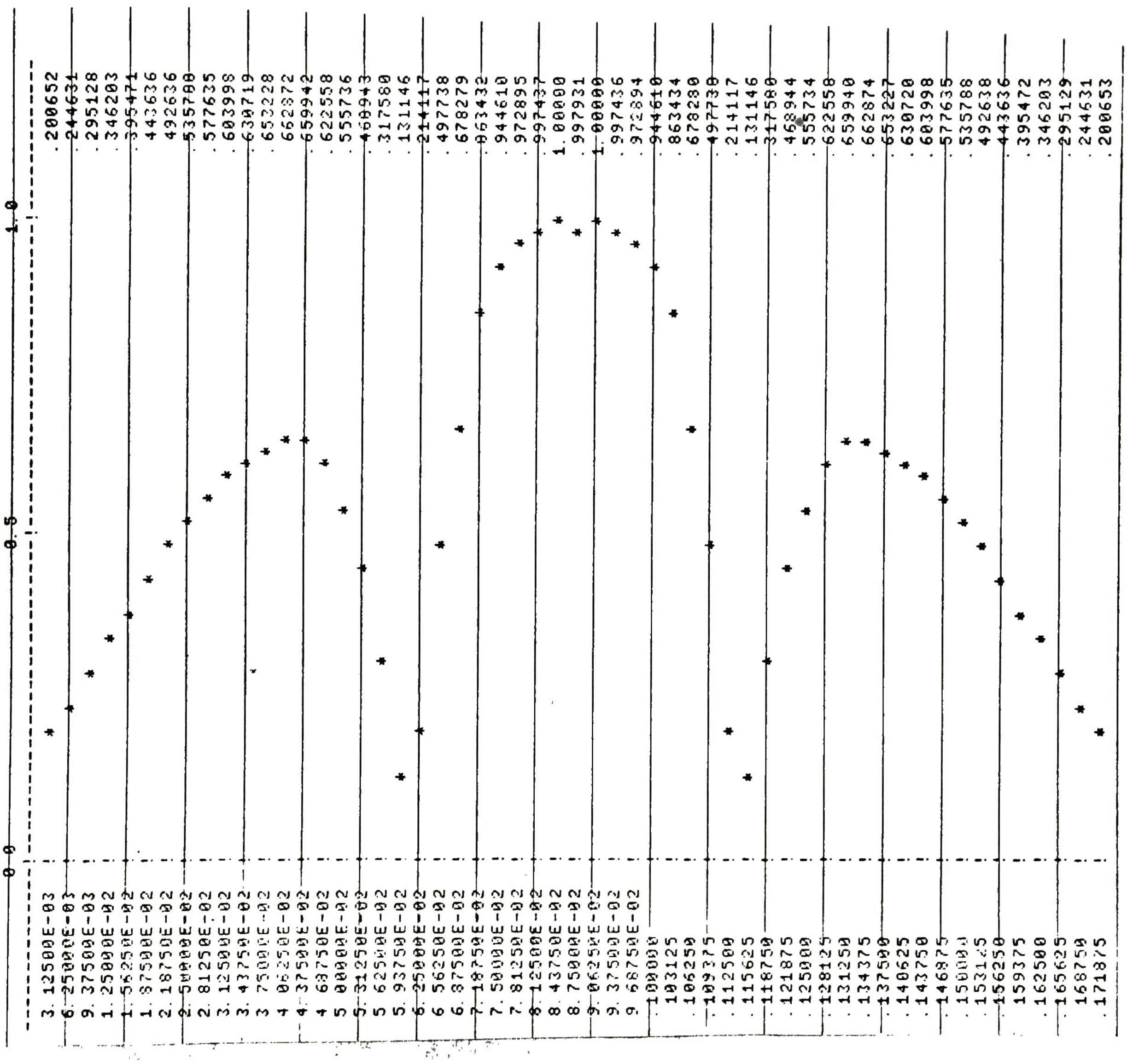

FIGURE 38 Filtered Image Intensity Distribution for 54.0um with n=4.98 cy/mm actual

APPENDIX G

FILTER OPTIMUM AND DATA ANALYSIS PROGRAMS

LININ PROGRAM DESCRIPTION

This program is used for data file input. The file size may be changed by redimensioning of X, and the form is suitable for a Fourier transform program using real numbers.

```
!C LININ
1;'INPUT FILE NAME'&INPUTA$
5 OPENA$TO:1,PRINT,OVER
10 DIMX(512)
20 MATX=ZER
21 ;'INPUT NUMBER OF DATA'&INPUTN
22 MATSIZEX(N+1)
23 X(1)=N
25 ;'LOAD FILE'
30 FORA=2TON+1
35 INPUTZ
40 X(A)=Z
50 NEXTA
60 MATPRINT:1,X
70 CLOSE:1
```

TABLE 4 LININ Program

LINTR PROGRAM DESCRIPTION

This program is used to access a current data file, and read a specified number of points. These records are converted to transmittance, normalized and written out onto another data file.

```
!C LINTR
1 ;'INPUT FILE NAME'&INPUTB$
2 ;'OUTPUT FILE NAME'&INPUTA$
5 OPENA$TO:1,PRINT,OVER
6 OPENB$TO:2,INPUT
10 DIMX(56),Y(56)
15 MATX=ZER&MATY=ZER
19 M=0
20 N=47
22 MATSIZEX(N+1),Y(N+1)
25 MATINPUT:2,Y
30 FORA=2TON+1
40 X(A)=(10^(-Y(A)/100))
45 M=MAX(M,X(A))
50 NEXTA
54 MATX=(1/M)*X
55 X(1)=N
60 MATPRINT:1,X
70 CLOSE:1&CLOSE:2
```

TABLE 5 LINTR Program

ETDIFF PROGRAM DESCRIPTION

This program reads density values from a data file, converts these values to transmittance, numerically differentiates and normalizes the data. S can be adjusted to the specific sample interval.

```
!C ETDIFF
1 ;'INPUT FILE NAME'&INPUTB$
2 ;'OUTPUT FILE NAME'&INPUTA$
3 M=0
5 OPENA$TO:1,PRINT,OVER
6 OPENB$TO:2,INPUT
10 DIMX(512),Y(512)
15 MATX=ZER&MATY=ZER
20 MATINPUT:2,Y
21N=29
25 S=.000625
30 FOR A=1TON
31 IFY(A+1)=0GOTO54
40 X(A)=((10^(-Y(A)/100))-(10^(-Y(A+1)/100)))/S
45 M=MAX(M,X(A))
50 NEXTA
54 MATX=(1/M)*X
60 MATPRINT:1,X
70 CLOSE:1&CLOSE:2
```

TABLE 6 ETDIFF Program

MOVAVE1 PROGRAM DESCRIPTION

This program basically computes data file smoothing via a moving average on density data and then converts to transmittance. Firstly, however it scales the eight bit numerical data file to density by specifing the upper and lower density digitized.

```
!C MOVAVE1
1*SETF4=1 AS DIR STMT FOR WID 72
10 FORZ=1TO10
20 PAGE
100 *MOVING AVERAGE AND DENSITY TO TRANS CONVERSION
110 DIMX(2000),Z(2000)
120J9=FCH(':')
125 READ A$
127 B4='TTY'
130 ;'INPUT FILE:'TAB(0);A$
140 ;'OUTPUT FILE:'TAB(0);B$
150 OPENA$TO:1,INPUT
160 ENDFILE:1,180
170 FORA=1TO1E6\INPUT:1,X(A)\NEXTA
180 N=A
182 LO=0
183 READ L1
185 ;'LOWER DENSITY:'TAB(0);LO
186 ;'UPPER DENSITY:'TAB(0);L1
187FORA=1TON\X(A)=X(A)*(L1-LO)/255+LO\NEXTA
189 W=5
190 ;'MOVING AVERAGE WINDOW WIDTH:'TAB(0);W
200 MO=10\FORA=1TON-1\MO=MIN(MO,X(A))\NEXTA
210 FORA=1TON-1\X(A)=1-10^-(X(A)-MO)\NEXTA
212 MO=10\FORA=1TON-1\MO=MIN(MO,X(A))\NEXTA
213 M1=0
214 FORA=1TON-1\X(A)=X(A)-MO\M1=MAX(M1,X(A))\NEXTA
216 MATX=(1/M1)*X
220 MATZ=ZER
230 FORA=1TON-W+1\FORB=ATOA+W-1\Z(A)=Z(A)+X(B)/W\NEXTB\NEXTA
240 MATSIZEZ(N-W+1)
250 *
260 DIMP(2000)
270P2=2
280 FORA=1TON-W+1\P(A)=Z(A)\NEXTA
290 P1=N-W+1
300 GOSUB3000
320 NEXTZ
 330 CLOSE:1
350 END
400 DATA MDF105,4
410 DATA MDF200,4
420 DATA MDF30,4,MDF39,4,MDF54,4
430 DATA MDF390,3,MDF600 ,3,MDF730,3,MDF945,3,MDF120,3
3000 D$=' '\E$='0.0'\F$='0.5'\G$='1.0'\P7=5
3001 ;'INPUT INCREMENT OF PLOT:'TAB(0);P7
3002 P6=1
3003 ;\;\;
3010 B8=1
3020 P5=0\IFP4<>1GOTO3040
3030 P5=14
3040 GOSUB3200
3050 D$='-'\E$='-!-'
3060 B8=0
3070 GOSUB3200
```

TABLE 7 MOVAVE1 Program

```
3080 Z3=0
3090 FORJ=P6TOP1STEPP7
3100 Z1=INT(P(J)*(56-P5))
3110 IFZ1=0THEN3150
3120 ;J*P2;TAB(15)'!'TAB(0);TAB(P(J)*(56-P5)+15)'*'TAB(75-P5);P(J)
3130 IFO1=1GOTO3170
3140 GOTO3180
3150 ;J*P2;TAB(15)'*'TAB(75-P5);P(J)
3160 IFO1<>1GOTO3180
3170 Z3=Z3+.1
3180 NEXT J
3190 ;\;\;\;\;\RETURN
3200 B9=0
3210 FORA=1TO13\;D$TAB(0)\NEXTA
3220 IFB9=1GOTO3320
3230 FORB=1TO2
3240 IFB8=0GOTO3270
3250 IFB<>2GOTO3270
3260 E$=F$
3270 ;E$TAB(0)\FORA=1TO25-P5/2\;D$TAB(0)\NEXTA
3280 NEXTB\B9=1
3290 IFB8=0GOTO3310
3300 E$=G$
3310 ;E$TAB(0)\GOTO3210
3320 ;''\RETURN
```

TABLE 7 MOVAVE1 Program (Cont'd.)

MDC PROGRAM DESCRIPTION

This program is introduced to remove the effect of the microdensitometer spread function from the microdensitometer generated data by matrix deconvolution.

```
!C MDC
1;'INPUT FUNCTION FILE NAME'\INPUTA$
2 ;'OUTPUT FUNCTION FOLE NAME'\INPUTB$
3;'OUTPUT FILENAME'\INPUTC$
4 OPENA$TO:1,INPUT\OPENB$TO:2,INPUT\OPENC$TO:3,PRINT,OVER
6 X=6\G=Y(1)
20 DIMX(30),Y(56),F(55,55),G(55,1),H(55,1),I(55,55),J(55,1)
21 DIMZ(55)
30 MATX=ZER\MATY=ZER\MATF=ZER\MATG=ZER\MATH=ZER\MATI=ZER\MATJ=ZER
31 MATZ=ZER
35 MATINPUT:1,X\MATINPUT:2,Y
36 X=6\G=Y(1)
40 FORA=1TO6\Z(A)=X(3+((A-1)*5))\NEXTA
200 N=G\J=N-X+1\GOSUB400
210 MATI=INV(F)\MATH=I*G
220 FORA=1TOJ\;H(A,1)\NEXTA
230 MATPRINT:3,H
240 CLOSE:1\CLOSE:2\CLOSE:3
250 MATJ=F*H
260 MATPRINTJ,G
330 END
400 MATSIZEF(N,N),G(N,1),H(N,1),I(N,N),J(N,1)
420 FORA=1TOG\G(A,1)=Y(A+1)*100\NEXTA
500 FORA=1TON\Q=A
510 FORB=1TOA
520 F(A,B)=Z(Q)*100\Q=Q-1\NEXTB\NEXTA
530 RETURN
```

TABLE 8 MCD Program

SYMAV PROGRAM DESCRIPTION

This program is used to average three data files and symmetrize the result about its maximum.

```
!C SYMAV
10 ;'INPUT 3 FILE NAMES TO BE AVERAGED'
11 I=0\J=0\K=0\L=0
15 MATZ=ZER\MATM=ZER\MATN=ZER
20 FORA=1TO3
30 INPUTX$
40 OPENX$TO:A,INPUT
50 NEXTA
55 INPUTN
56 N1=INT(N/2)
60 DIMA(56),B(56),C(56),Z(56)
62 DIMM(27),N(27)
65 MATSIZEA(N+1),B(N+1),C(N+1),Z(N+1)
67 MATSIZEM(N1),N(N1)
70 MATINPUT:1,A\MATINPUT:2,B\MATINPUT:3,C
80 ;'OUTPUT FILE NAME'\INPUTX$
90 OPENX$TO:4,PRINT,OVER
190 MATZ=Z+A\MATZ=Z+B\MATZ=Z+C
200 MATZ=(1/3)*Z
201 FORA=2TOINT((N+1)/2)\I=I+1\M(I)=Z(A)\NEXTA
202 FORA=N+1TON-N1+2STEP-1\J=J+1\N(J)=Z(A)\NEXTA
203 MATM=M+N\MATM=(1/2)*M
204 FORA=2TOINT((N+1)/2)\K=K+1\Z(A)=M(K)\NEXTA
205 FORA=N+1TON-N1+2STEP-1\L=L+1\Z(A)=M(L)\NEXTA
207 FORA=2TON+1\M=MAX(M,Z(A))\NEXTA
208 FORA=2TON+1\Z(A)=Z(A)/M\NEXTA
210 MATPRINTZ
220 MATPRINT:4,Z
230 FORA=1TO4\CLOSE:A\NEXTA
```

TABLE 9 SYMAV Program

FRPUT PROGRAM DESCRIPTION

This program was used to construct a data file suitable for entry to a Fourier transform program using both real and imaginary data.

```
!C FRPUT
100 ;'INPUT FILE NAME'TAB(0)\INPUTA$
110 OPENA$TO:1,PRINT,OVER
120 DIMX(2048,2)
130 MATX=ZER
140 ;'INPUT FOURIER TRANSFORM FILE SIZE AS AN INTEGER POWER OF TWO'TAB(0
)\INPUTN
150 ;'IF DATA IS COMPLEX, TYPE 1'TAB(0)\INPUTC
160 ;'INPUT THE FOLLOWING:'
170 ;'     1)  NUMBER OF DATA POINTS'TAB(0)\INPUTN3
180 ;'     2)  SAMPLE INTERVAL'TAB(0)\INPUTN4
190 ;'     3)  MOST NEGATIVE ORDINATE'TAB(0)\INPUTN5
200 ;'     4)  MOST POSITIVE ORDINATE'TAB(0)\INPUTN6
210 MATSIZEX(N,2)
220 ;'LOAD FILE'
230 FORA=N5TON6STEPN4
240 N1=A/N4+N
250 N2=INT((N1/N-INT(N1/N))*N+1E-6)
260 N2=N2+1
270 IFC<>1GOTO320
280 ;'ENTER "X + IY" DATA AS:  X,Y'
290 INPUTZ1,Z2
300 X(N2,2)=Z2
310 GOTO340
320 INPUTZ1
330 X(N2,1)=Z1
340 NEXTA
350 MATPRINT:1,X
360 CLOSE:1
```

TABLE 10   FRPUT Program

REV PROGRAM DESCRIPTION

This is an FFT program written in FORTRAN to minimize run time.

```
!C REV
      DIMENSIONXR(2048),XI(2048)
      N5=2048
      N6=11
      REWIND 105
      READ(105,4)(XR(N),XI(N),N=1,2048)
4     FORMAT(2G)
      CALL FFT(XR,XI,N5,N6)
      WRITE(108,3)(XR(N),XI(N),N=1,2048)
3     FORMAT(2G)
      END
      SUBROUTINE FFT(XREAL,XIMAG,N,NU)
      DIMENSIONXREAL(2048),XIMAG(2048)
       N2=N/2
       NU1=NU-1
       K=0
       DO 100 L=1,NU
102    DO 101 I=1,N2
       P=IBITR(K/2**NU1,NU)
      ARG=6.283185*P/FLOAT(N)
      C=COS(ARG)
      S=SIN(ARG)
      K1=K+1
      K1N2=K1+N2
      TREAL=XREAL(K1N2)*C+XIMAG(K1N2)*S
      TIMAG=XIMAG(K1N2)*C-XREAL(K1N2)*S
      XREAL(K1N2)=XREAL(K1)-TREAL
       XIMAG(K1N2)=XIMAG(K1)-TIMAG
      XREAL(K1)=XREAL(K1)+TREAL
      XIMAG(K1)=XIMAG(K1)+TIMAG
101   K=K+1
      K=K+N2
      IF(K.LT.N) GO TO 102
      K=0
      NU1=NU1-1
100   N2=N2/2
      DO 103 K=1,N
      I=IBITR(K-1,NU)+1
      IF(I.LE.K) GO TO 103
      TREAL=XREAL(K)
      TIMAG=XIMAG(K)
       XREAL(K)=XREAL(I)
      XIMAG(K)=XIMAG(I)
      XREAL(I)=TREAL
      XIMAG(I)=TIMAG
103   CONTINUE
      RETURN
      END
      FUNCTION IBITR(J,NU7)
      J1=J
      IBITR=0
      DO 200 I=1,NU7
      J2=J1/2
      IBITR=IBITR*2+(J1-2*J2)
200   J1=J2
      RETURN
      END
```

TABLE 11 REV Program

REV1 PROGRAM DESCRIPTION

This program iteratively selects the optimum filter for a degraded line using two subroutines, Filter and FFT.

```
!C REV1
      DIMENSIONXR(2048),XI(2048)
      DIMENSIONE(2240)
      REAL WID,WIDFR,N3
      INTEGER WID1
      N5=2048
      N6=11
      N4=47
      N3=AINT(350/.15625)
      WID=30.349;WID1=WID/3.125;WIDFR=WID1-AINT(WID1)
      IF(WIDFR.GT..5) GO TO 99
      WID1=AINT(WID1)
      GO TO 99
99    WID1=AINT(WID1)+1
      WID1=18
      OUTPUT WID1
      DO 20 K9=21,N3
      OUTPUT K9
      REWIND 105
      READ(105,1)(XR(N),XI(N),N=1,2048)
1      FORMAT(2G)
      OUTPUT XR(1024),XI(1024)
      CALL FILTER(K9,N5,XR,XI,N3)
      CALL FFT(XR,XI,N5,N6)
      OUTPUT WID1
      E(K9)=(XR(WID1)**2+XI(WID1)**2)**.5
      E(20)=1E6
      OUTPUT E(K9),E(K9-1)
      IF(E(K9).GT.E(K9-1)) GO TO 202
20    CONTINUE
202   K9=K9-1
      REWIND 105
      READ(105,4)(XR(N),XI(N),N=1,2048)
4     FORMAT(2G)
      OUTPUT XR(1024),XI(1024)
      CALL FILTER(K9,N5,XR,XI,N3)
      CALL FFT(XR,XI,N5,N6)
      WRITE(108,2) K9
2     FORMAT(G)
      WRITE(108,3)(XR(N),XI(N),N=1,2048)
3     FORMAT(2G)
      END
      SUBROUTINE  FILTER(N1,N9,XRE,XIM,NN3)
      DIMENSIONXRE(2048),XIM(2048)
      DO 10 A=1,N1
10    XRE(A)=0;XIM(A)=0
      N8=N9-N1+1
      DO 11 A=N8,N9
11    XRE(A)=0;XIM(A)=0
      RETURN
      SUBROUTINE FFT(XREAL,XIMAG,N,NU)
      DIMENSIONXREAL(2048),XIMAG(2048)
       N2=N/2
       NU1=NU-1
       K=0
```

TABLE 12 REV1 Program

```
      DO 100 L=1,NU
102   DO 101 I=1,N2
      P=IBITR(K/2**NU1,NU)
      ARG=6.283185*P/FLOAT(N)
      C=COS(ARG)
      S=SIN(ARG)
      K1=K+1
      K1N2=K1+N2
      TREAL=XREAL(K1N2)*C-XIMAG(K1N2)*S
      TIMAG=XIMAG(K1N2)*C+XREAL(K1N2)*S
      XREAL(K1N2)=XREAL(K1)-TREAL
      XIMAG(K1N2)=XIMAG(K1)-TIMAG
      XREAL(K1)=XREAL(K1)+TREAL
      XIMAG(K1)=XIMAG(K1)+TIMAG
101   K=K+1
      K=K+N2
      IF(K.LT.N) GO TO 102
      K=0
      NU1=NU1-1
100   N2=N2/2
      DO 103 K=1,N
      I=IBITR(K-1,NU)+1
      IF(I.LE.K) GO TO 103
      TREAL=XREAL(K)
      TIMAG=XIMAG(K)
      XREAL(K)=XREAL(I)
      XIMAG(K)=XIMAG(I)
      XREAL(I)=TREAL
      XIMAG(I)=TIMAG
103   CONTINUE
      RETURN
      END
      FUNCTION IBITR(J,NU7)
      J1=J
      IBITR=0
      DO 200 I=1,NU7
      J2=J1/2
      IBITR=IBITR*2+(J1-2*J2)
200   J1=J2
      RETURN
      END
```

TABLE 12 REV1 Program (Cont'd.)

LOGO PROGRAM DESCRIPTION

This program computes mean and standard deviation of line width by breaking down line width data pairs. It also plots the corresponding histogram.

```
!C LOGO
100 I=1
105 X=1\F5=1
110 ;'INPUT FILE NAME'\INPUTA$
120 ;'OUTPUT FILE NAME'\INPUTB$
130 ;'INPUT NUMBER OF RECORDS'\INPUTN
140 OPENA$TO:1,INPUT
150 OPENB$TO:2,PRINT,OVER
160 DIMX(1000)\MATSIZEX(N)
170 DIMZ(500)
175 DIMY(500)
180 FORA=1TON\INPUT:1,X(A)\NEXTA
190 B,B0,L,L0,L5=0
200;'THRESHOLD VALUE'TAB(0)\INPUTT\IFT<>0THEN210\T=100
205 IFF6=1GOTO550
206 IFF5=1GOTO370
210 I=1,L0,L5,L6,L7=0
220 L0=0
240 IFX(A)<>0THEN270\C=C+1\IFC>2THEN250\GOTO450
250 L5=0\L6=1
260 GOTO450
270 C=0
280 L=0
290 IFX(A)<TTHEN310\*T IS THRESHOLD VALUE
300 L=1\*L IS LOGICAL VARIABLE
310 IFL7=0THEN340
320 IFL6=0THEN330\L6=0\GOTO340
330 IFL=L0THEN450\*L0 IS LOGICAL VALUE OF PREVIOUS DATA POINT
340 B=X(A)
350 IFL5=0THEN410\*L5 DETERMINES WHETHER DATA PAIR EXISTS
360 Z(I)=ABS(B-B0)
370 INPUTK0,K1
371 FORA=K0TOK1
372 INPUTY(A)
373 FORB=XTOY(A)
374 Z(B)=A
375 NEXTB
376 X=Y(A)+1
377 NEXTA
378 ;X;A;Y(A)
380 I=I+1
390 L5=0
400 GOTO440
410 B0=B
420 L5=1
430 L7=1
440 L0=L
450 *
470 MATPRINT:2,Z
480 CLOSE:1\CLOSE:2
500;'HISTOGRAM OF DATA,0 OR 1,'TAB(0)
510INPUTS\IFS=0THEN550
515;\;\;'HISTOGRAM OF DATA'\;\;
520R0=0\GOSUB1000
550;'HISTOGRAM OF LINE WIDTH DETERMINATIONS'TAB(0)
560INPUTS\IFS=0THEN600
570;\;\;'HISTOGRAM OF LINE WIDTH DETERMINATIONS'\;\;
575N=X-2
580R0=1\GOSUB1000
```

TABLE 13 LOGO Program

```
599;
600;'STANDARD DEVIATION OF DETERMINATION'
605S0,S1=0
610 FORA=1TOX-1
620S0=S0+Z(A),S1=S1+Z(A)^2
630NEXTA
635 N0=X-2
640S3=SQR((N0*S1-S0^2)/(N0*(N0-1)))
650;'S ='S3
651;\;'N ='N0' DATA PAIRS'
652;\;'MEAN ='S0/N0
660END
1000 *
1010*
1040FORA=1TON-1
1045IFR0=0THEN1050\K5=Z(A)\GOTO1055
1050 K5=X(A)
1055 *
1070 NEXTA
1080 FORA=K0TOK1
1090 ;A''TAB(10)''TAB(0)
1100 IFY(A+1)<>0THEN1110\GOTO1140
1110 FORB=1TOY(A+1)
1120 ;'*'TAB(0)
1130 NEXTB
1140 ;
1150 NEXTA
1160 RETURN
```

TABLE 13 LOGO Program (Cont'd.)

LIPLOT PROGRAM DESCRIPTION

This program plots linear plots in the spatial domain.

```
!C LIPLOT
1;'INPUT N+1'TAB(0)\INPUTN
90;'INPUT FILE'TAB(0)\INPUTA$
91;\;\;\;
100 DIMM(56)
105 MATSIZEM(N)
110 OPENA$TO:1,INPUT
120 MATINPUT:1,M
130 ;'              0.0                          0.5
  1.0'
140 ;'--------------!--------------------------!----------------------
---!--------------'
160 FORJ=2TON
165 J9=(J-1-N/2)*.003125
166 Z=INT(M(J)*55)
167IFZ=0THEN175
168 IFZ<0THEN177
170 ;J9;TAB(15)'!'TAB(0);TAB(M(J)*55+15)'*'TAB(75);M(J)
171 GOTO179
175 ;J9;TAB(15)'*'TAB(75);M(J)
176 GOTO179
177 ;J9;TAB(M(J)*55+15)'*'TAB(0);TAB(15)'!'TAB(75);M(J)
179 *
180 NEXT J
190 CLOSE:1
200;\;\;\;-
205 FORA=2TON\IFM(A)>=.5THEN210\NEXTA
210 R=(M(A)-.5)/(M(A)-M(A-1))
215 R1=(A-1-N/2)*.003125-(A-2-N/2)*.003125
220 W=R*R1+ABS(A-1-N/2)*.003125
222 W=2*W*1E3
225 ;USING 230,W
230 :      LINEWIDTH IN MICROMETERS IS  #####.######
```

TABLE 14 LIPLOT Program

LPLOT PROGRAM DESCRIPTION

This program plots log plots in the spatial domain.

```
!C LPLOT
90;'INPUT FILE'TAB(0)\INPUTA$
91;\;\;\;
100DIMM(512)
110 OPENA$TO:1,INPUT
120 MATINPUT:1,M
130 ;'              0.0                        0.5
  1.0'
140 ;'---------------!---------------------------!-----------------------
---|-------------'
150 N=67\T=.000625*512
151 N=100
155 P=0
160 FOR J=1 TO N STEP10**P
165 J9=J/T
166Z=INT(M(J)*55)
167IFZ=0THEN175
170 ;J9;TAB(15)'!'TAB(0);TAB(M(J)*55+15)'*'TAB(75);M(J)
171 GOTO178
175;J9;TAB(15)'*'TAB(75);M(J)
178 ;
179 P=P+.1
180 NEXT J
190 CLOSE:1
```

TABLE 15 LPLOT Program

FPLOT PROGRAM DESCRIPTION

This program plots linear plots in the frequency domain.

```
!C FPLOT
100 ;'INPUT FILE NAME'TAB(0)\INPUTC$
120 OPENC$TO:1,INPUT
140 DIMX(2048,2),A(1024)
150 N=2048
160 ;'INPUT NUMBER OF SAMPLES TO BE PLOTED'TAB(0)\INPUTN7
170 ;'INPUT SAMPLE INTERVAL'TAB(0)\INPUTF
190 MATSIZEX(N7,2),A(N7)
200 MATINPUT:1,X\CLOSE:1
440 MATX=(F)*X
450 ;'              0.0                         0.5                    -
  1.0'
460 ;'--------------!---------------------------!---------------------
---!-------------'
469 M9=0
470 FORJ=1TON7
480 IF J>=N/2 THEN 510
490 A(J)=(X(J,1)**2+X(J,2)**2)**.5
491 M9=MAX(A(J),M9)
500 NEXT J
510 MATA=(1/M9)*A
529 Z3=0
530 FORJ=1TON7
535 Z1=INT(A(J)*55)
536 IFZ1=0THEN545
540 ;J/N/F;TAB(15)'!'TAB(0);TAB(A(J)*55+15)'*'TAB(75);A(J)
541GOTO550
545 ;J/N/F;TAB(15)'*'TAB(75);A(J)
550 NEXT J
999 END
```

TABLE 16   FPLOT Program

FLPLOT PROGRAM DESCRIPTION

This program plots log plots in the frequency domain.

```
!C FLPLOT
100 ;'INPUT FILE NAME'TAB(0)\INPUTC$
120 OPENC$TO:1,INPUT
140 DIMX(2048,2),A(1024)
150 N=2048
160 ;'INPUT NUMBER OF SAMPLES TO BE PLOTED'TAB(0)\INPUTN7
170 ;'INPUT SAMPLE INTERVAL'TAB(0)\INPUTF
190 MATSIZEX(N7,2),A(N7)
200 MATINPUT:1,X\CLOSE:1
440 MATX=(F)*X
450 ;'              0.0                         0.5
  1.0'
460 ;'---------------!---------------------------!-----------------------
---!-------------'
469 M9=0
470 FORJ=1TON7
480 IF J>=N/2 THEN 510
490 A(J)=(X(J,1)**2+X(J,2)**2)**.5
491 M9=MAX(A(J),M9)
500 NEXT J
510 MATA=(1/M9)*A
528 P=0
529 Z3=0
530 FORJ=1TON7STEP10**P
535 Z1=INT(A(J)*55)
536 IFZ1=0THEN545
540 ;J/N/F;TAB(15)'!'TAB(0);TAB(A(J)*55+15)'*'TAB(75);A(J)
541GOTO550
545 ;J/N/F;TAB(15)'*'TAB(75);A(J)
550 P=P+.1
551 NEXTJ
999 END
```

TABLE 17 FLPLOT Program

APPENDIX H

R. SWING PROGRAMS

R. SWING COMPUTER PROGRAMS DESCRIPTION

1) LINFIL (determines values for the optimum filter, calculates points on either side of line-edge)
2) IMCALC (calculates filtered and unfiltered images, in a spread about one line-edge or from the origin out to twice the line-edge location)
3) CALCO (calculates exact position of zero, for non-optimum filter use; determines apparent line width)
4) ROOTIT (determines correct line width from estimates made on non-optimum filter use)
5) SINER (a subroutine of LINFIL and IMCALC; calculates values of the inverse sine integral)
6) SININT (a subroutine of LINFIL and IMCALC; calculates values of the sine integral)
7) COSINT (a subroutine of IMCALC; calculates values of the cosine integral)
8) SINSEC (computes second order solutions to the inverse sine integral)
9) IMPACH (a patch routine for iterative use of IMCALC)

```
!C LINFIL
001 * RICHARD E. SWING, 213.11, X2159, PROGRAM: LINFIL
002 *
003 * TO OPERATE PROPERLY, THIS PROGRAM REQUIRES THAT TWO
004 * OTHER PROGRAMS BE AVAILABLE IN THE SYSTEM.  THESE ARE
005 * NAMED 'SINER' (TO ESTABLISH THE OPTIMUM VALUE FOR LOWER
006 * CUTOFF FREQUENCY) AND 'SININT' (TO CALCULATE VALUES
007 * OF THE SINE-INTEGRAL).
008 *
010 * INSTRUCTIONS FOR USING THE PROGRAM ARE PRINTED AS REQUIRED.
011 *
029 *
030 DIM T(10)
031 Z9 = 0
032 PRINT
038 PRINT 'SUPPLY, IN THE ORDER NAMED, VALUES FOR:'
40 PRINT '    1) LINE-WIDTH (MICROMETERS)'
042 PRINT '    2) WAVELENGTH (NANOMETERS)'
044 PRINT '    3) TRANSFORM LENS NUMERICAL APERTURE'
046 PRINT '    4) UPPER CUTOFF FREQUENCY (CYCLES/MM)'
050 PRINT
052 PRINT
054 INPUT W,L,N,S
055 PRINT
056 A = 3.14159
60 S1 = (W*S)/(10**3)
066 D1 = 0.02
068 D2 = 1/(4*(A**2))
069 E = 2*A*S1
070 GOSUB 1000
071 GOSUB 3000
072 S5 = (S4/W)*(10**3)
076 GOSUB 600
080 K1 = 47
082 K2 = 55
096 FOR J   K1 TO K2
100 E = A*S1*(D1*(J-1)+1)
102 GOSUB 1000
106 E4 = 2*E1
120 E = A*S1*(D1*(J-1)-1)
130 GOSUB 1000
132 E4 = E4-2*E1
152 E = A*S4*(D1*(J-1)+1)
157 GOSUB 1000
158 E4 = E4-2*E1
172 E = A*S4*(D1*(J-1)-1)
182 GOSUB 1000
184 E4 = E4+2*E1
202 E6 = (E4**2)*D2
208 T(J-46) = E6
220 PRINTUSING 222,D1*(J-1),E6,E4*(1/(2*A))
222 :  ########.##      -########.#####      -########.#####
224 NEXT J
228 GOSUB 720
230 IF H = 1 GOTO 076
234 PRINT
238 PRINT 'TO CALCULATE WITH NEW PARAMETERS, TYPE 1'
242 PRINT 'TO TE
```

TABLE 18   LINFIL Program

```
244 PRINT
246 INPUT F
248 IF F = 1 GOTO 032
250 IF F = 2 GOTO 999
254 PRINT
256 GOTO 238
600 FOR J = 1 TO 5
602 PRINT
604 NEXT J
606 PRINT 'NORMALIZED LINE-IMAGE WITH BAND-PASS FILTERING'
608 PRINT
610 PRINTUSING 612,S5
612 :  LOWER CUTOFF IS    ########.###
614 PRINTUSING 616,S
616 :  UPPER CUTOFF IS    ########.##
620 PRINT
622 PRINTUSING 624,W
624 :     LINE-WIDTH (MICROMETERS) IS    ########.##
626 PRINTUSING 628,L
628 :     WAVELENGTH (NANOMETERS) IS     ########.##
630 PRINTUSING 632,N
632 :     LENS NUMERICAL APERTURE IS     ########.###
634 PRINT
636 PRINT
638 PRINTUSING 640
640 :           X                  I(X)                  R(X)
642 PRINT
644 RETURN
720 PRINT
722 PRINT
724 PRINTUSING 726,T(5),T(4)-T(6),T(3)-T(7),T(2)-T(8)
726 :-########.#####     -########.#####     -########.#####     -########.
#####
728 PRINT
730 PRINT 'TO CONTINUE ADJUSTMENT AT LINE-EDGE,'
732 PRINT 'TYPE 1; OTHERWISE TYPE 2.'
734 PRINT
736 INPUT H
738 IF H > 2 GOTO 728
740 IF H = 2 GOTO 760
742 PRINT
744 PRINT 'SUPPLY VALUES (>0) FOR LOWER AND UPPER CUTOFF'
746 PRINT 'FREQUENCIES (CYCLES/MM), IN THAT ORDER.'
748 PRINT
750 INPUT F1,F2
751 IF F1 = 0 GOTO 742
752 S4 = (F1*W)/(10**3)
754 S1 = (F2*W)/(10**3)
756 S = F2
758 S5 = F1
760 RETURN
999 END
1000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
1010 *
1020 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
1030 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM THE MAIN
1040 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
1050 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
```

TABLE 18   LINFIL Program (Cont'd.)

```
1060 *
1070 A1 = 1/18
1080 A2 = 1/600
1090 A3 = 1/35280
1100 A4 = 1/3265920
1110 B1 = 38.027264
1120 B2 = 265.187033
1130 B3 = 335.677320
1140 B4 = 38.102495
1150 B5 = 40.021433
1160 B6 = 322.624911
1170 B7 = 570.236280
1180 B8 = 157.105423
1190 C1 = 42.242855
1200 C2 = 302.757865
1210 C3 = 352.018498
1220 C4 = 21.821899
1230 C5 = 48.196927
1240 C6 = 482.485984
1250 C7 = 1114.97885
1260 C8 = 449.690326
1270 IF ABS(E) > 1.2 GOTO 1300
1280 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
1290 GOTO 1370
1300 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
1310 Z2 = (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
1320 Z3 = (1/E)*(Z1/Z2)
1330 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
1340 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
1350 Z6 = (1/(E**2))*(Z4/Z5)
1360 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
1370 RETURN
3000;
3010 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SINER
3020 *
3030 * THIS IS A SUBROUTINE USED BY THE PROGRAM NAMED 'LINFIL'.
3040 * IT ACCEPTS A VALUE OF THE SINE-INTEGRAL AND RETURNS ITS
3050 * INTERPOLATED INVERSE ARGUMENT DIVIDED BY 2*PI.
3060 * THAT VALUE PROVIDES AN ESTIMATE OF THE LOWER CUTOFF
3070 * FREQUENCY NEEDED FOR CALCULATION BY 'LINFIL'.
3080 *
3090 DIM W(156)
3100 IF Z9 = 1 GOTO 03140
3110 FOR J = 1 TO 155
3120 READ W(J)
3130 NEXT J
3140 E1 = (INT(E1*(10**6)+5))/(10**6)
3150 K = 1
3155 ONSGN(E1-W(K))+2GOTO3200,3180,3160
3160 K = K+1
3170 GOTO 3155
3180 B = (1.60 + (K-1)*(0.01))/(2*A)
3190 GOTO 3230
3200 B = ((E1-W(K-1))/(W(K)-W(K-1)))*(0.01)
3210 S4 = (B+(1.60+(K-2)*(0.01)))/(2*A)
3220 Z9 = 1
3230 RETURN
```

TABLE 18 LINFIL Program (Cont'd.)

```
3240 DATA 1.38918,1.39541,1.40159,1.40774,1.41384,1.41990,1.42592
3250 DATA 1.43190,1.43784,1.44374,1.44959,1.45540,1.46118,1.46690
3260 DATA 1.47259,1.47823,1.48384,1.48939,1.49491,1.50039,1.50582
3270 DATA 1.51121,1.51655,1.52186,1.52712,1.53233,1.53751,1.54264
3280 DATA 1.54773,1.55277,1.55778,1.56273,1.56765,1.57252,1.57735
3290 DATA 1.58214,1.58688,1.59158,1.59623,1.60084,1.60541,1.60994
3300 DATA 1.61442,1.61886,1.62325,1.62760,1.63191,1.63617,1.64039
3310 DATA 1.64457,1.64870,1.65279,1.65683,1.66083,1.66479,1.66871
3320 DATA 1.67258,1.67640,1.68019,1.68393,1.68762,1.69128,1.69487
3330 DATA 1.69845,1.70198,1.70546,1.70889,1.71229,1.71564,1.71894
3340 DATA 1.72221,1.72543,1.72861,1.73174,1.73483,1.73788,1.74089
3350 DATA 1.74385,1.74677,1.74965,1.75249,1.75528,1.75803,1.76074
3360 DATA 1.76340,1.76603,1.76861,1.77115,1.77365,1.77611,1.77852
3370 DATA 1.78089,1.78322,1.78551,1.78776,1.78997,1.79214,1.79426
3380 DATA 1.79635,1.79839,1.80039,1.80236,1.80428,1.80616,1.80800
3390 DATA 1.80980,1.81156,1.81329,1.81497,1.81661,1.81821,1.81978
3400 DATA 1.82130,1.82278,1.82423,1.82564,1.82701,1.82834,1.82963
3410 DATA 1.83086,1.83210,1.83327,1.83441,1.83552,1.83658,1.83761
3420 DATA 1.83860,1.83955,1.84047,1.84135,1.84219,1.84300,1.84377
3430 DATA 1.84450,1.84520,1.84586,1.84649,1.84708,1.84764,1.84816
3440 DATA 1.84865,1.84910,1.84952,1.84991,1.85026,1.85058,1.85086
3450 DATA 1.85111,1.85133,1.85151,1.85166,1.85178,1.85186,1.85192
3460 DATA 1.85194
3470 END
```

TABLE 18 LINFIL Program (Cont'd.)

```
!C IMCALC
001 * RICHARD E. SWING, 213.11, X2159, PROGRAM: IMCALC
002 *
003 * TO OPERATE PROPERLY, THIS PROGRAM REQUIRES THAT TWO
004 * OTHER PROGRAMS BE AVAILABLE IN THE SYSTEM. THESE ARE
005 * NAMED 'SININT' AND 'COSINT' , AND CALCULATE VALUES
006 * OF THE SINE-INTEGRAL AND COSINE-INTEGRAL, RESPECTIVELY.
7 ;'IF YOU WISH TO SAVE PLOT FILE, TYPE 1'
8 INPUTL2
9 ;'IF YOU WISH TABULAR LISTING, TYPE 1'\INPUTL3
10 ;'IF YOU WISH PLOT,TYPE1'\INPUTP\IFL2<>1GOTO30
11 ;'INPUT FILE NAME'\INPUTA$
12 OPENA$TO:2,PRINT,OVER
30 DIM T(10),I(101)
032 FOR J = 1 TO 5
034 PRINT
036 NEXT J
037 F3 = 1
038 PRINT 'SUPPLY, IN THE ORDER NAMED, VALUES FOR:'
040 PRINT '    1) LINE-WIDTH (MICROMETERS)'
042 PRINT '    2) UPPER BAND-PASS FREQUENCY CUTOFF'
044 PRINT '    3) UPPER BAND-PASS OFFSET'
046 PRINT '    4) LOWER BAND-PASS FREQUENCY CUTOFF'
047 PRINT '    5) LOWER BAND-PASS OFFSET'
048 PRINT '    6) FULL IMAGE (1) OR REGION ABOUT EDGE (2)'
049 PRINT '    7) WAVELENGTH (NANOMETERS), NUMERICAL APERTURE'
50 ;\;\INPUTW,S,D,S5,E3,G,L,N
51 ;'DO YOU WISH TO SPECIFY D-MIN AND D-MAX OF THE LINE?'TAB(0)\INPUTA$
52 IFA$<>'Y'GOTO56
53 ;'INPUT D-MIN AND D-MAX'
54 INPUTT2,T1
055 PRINT
56 A=3.141592654
058 S1 = (W*S)/(10**3)
060 S2 = (W*D)/(10**3)
062 S3 = (W*E3)/(10**3)
064 S4 = (W*S5)/(10**3)
066 D1 = 0.02
068 D2 = 1/(4*(A**2))
69 1FA$<>'Y'GOTO75
70 D2=D2*((10**-T2)**2-(10**-T1)**2)**2
075 IF S5 = 0 GOTO 762
076 GOSUB 600
078 IF G = 1 GOTO 086
080 K1 = 47
082 K2 = 55
084 GOTO 096
086 K1 = 1
088 K2 = 101
096 FOR J = K1 TO K2
100 E = A*(S1+S2)*(D1*(J-1)+1)
102 GOSUB 1000
104 GOSUB 2000
106 E4 = E1
108 E5 = E2
110 E = A*(S1-S2)*(D1*(J-1)+1)
112 GOSUB 1000
```

TABLE 19   IMCALC Program

```
114 GOSUB 2000
116 E4 = E4+E1
118 E5 = E5-E2
120 E = A*(S1+S2)*(D1*(J-1)-1)
122 IF ABS(E) > 0 GOTO 128
124 E2 = 0
126 GOTO 130
128 GOSUB 2000
130 GOSUB 1000
132 E4 = E4-E1
134 E5 = E5-E2
136 E = A*(S1-S2)*(D1*(J-1)-1)
138 IF ABS(E) > 0 GOTO 144
140 E2 = 0
142 GOTO 146
144 GOSUB 2000
146 GOSUB 1000
148 E4 = E4-E1
150 E5 = E5+E2
152 E = A*(S4+S3)*(D1*(J-1)+1)
153 IF ABS(E) > 0 GOTO 156
154 E2 = 0
155 GOTO 157
156 GOSUB 2000
157 GOSUB 1000
158 E4 = E4-E1
160 E5 = E5-E2
162 E = A*(S4-S3)*(D1*(J-1)+1)
163 IF ABS(E) > 0 GOTO 166
164 E2 = 0
165 GOTO 167
166 GOSUB 2000
167 GOSUB 1000
168 E4 = E4-E1
170 E5 = E5+E2
172 E = A*(S4+S3)*(D1*(J-1)-1)
174 IF ABS(E) > 0 GOTO 180
176 E2 = 0
178 GOTO 182
180 GOSUB 2000
182 GOSUB 1000
184 E4 = E4+E1
186 E5 = E5+E2
188 E = A*(S4-S3)*(D1*(J-1)-1)
190 IF ABS(E) > 0 GOTO 196
192 E2 = 0
194 GOTO 198
196 GOSUB 2000
198 GOSUB 1000
199 E4 = E4+E1
200 E5 = E5-E2
201 IF F3 = 2 GOTO 204
202 E6 = ((E4**2)+(E5**2))*D2
203 GOTO206
204 E6 = (((E4/(2*A))-1)**2)+(E5**2)*D2
206 IFL3<>1GOTO223
220 PRINTUSING 222,D1*(J-1),E6
222 :    ########.##            ########.#####
223 F(J)=E6
224 NEXT J
```

TABLE 19 IMCALC Program (Cont'd.)

```
225 IFL2<>1GOTO226\MATPRINT:2,F
226 IFF<>1GOTO232
228 GOSUB3000
232 FORJ=1TO5\;\NEXTJ
234 ;'IF YOU WISH ANOTHER PLOT OF THE SAME DATA, TYPE 1'\INPUTP1
236 IF P1<>1GOTO238
237 GOSUB3000
238 PRINT 'TO CALCULATE WITH NEW PARAMETERS, TYPE 1;'
239 PRINT 'OTHERWISE, TYPE 2.'
240 PRINT
242 INPUT F
243 IF F > 2 GOTO 238
244 IF F = 2 GO TO 999
246 GOTO7
600 FOR J = 1 TO 5
602 PRINT
604 NEXT J
606 PRINT 'NORMALIZED LINE-IMAGE WITH BAND-PASS FILTERING'
608 PRINT
610 PRINTUSING 612,S5,E3
612 :  LOWER CUTOFF IS ########.##    LOWER OFFSET IS ########.##
614 PRINTUSING 616,S,D
616 :  UPPER CUTOFF IS ########.##    UPPER OFFSET IS ########.##
620 PRINT
622 PRINTUSING 624,W
624 :     LINE-WIDTH (MICROMETERS IS    ########.##
626 PRINTUSING 628,L
628 :     WAVELENGTH (NANOMETERS) IS    ########.##
630 PRINTUSING 632,N
632 :     LENS NUMERICAL APERTURE IS    ########.###
634 PRINT
636 PRINT
637 IFL3<>1GOTO642
638 PRINTUSING 640
640 :               X                        I(X)
642 PRINT
644 RETURN
762 PRINT
764 PRINT 'UNFILTERED LINE IMAGE WILL BE LISTED.'
766 PRINT '    FOR CLEAR LINE, DARK BACKGROUND, TYPE 1.'
768 PRINT '    FOR DARK LINE, CLEAR BACKGROUND, TYPE 2.'
770 PRINT
772 INPUT F3
774 IF F3 > 2 GOTO 762
776 GOTO 076
998 IFL2<>1GOTO999\CLOSE:2
999 END
1000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
1010 *
1020 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
1030 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM THE MAIN
1040 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
1050 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
```

TABLE 19   IMCALC Program (Cont'd.)

```
1060 *
1070 A1 = 1/18
1080 A2   1/600
1090 A3 = 1/35280
1100 A4 = 1/3265920
1110 B1 = 38.027264
1120 B2 = 265.187033
1130 B3 = 335.677320
1140 B4 = 38.102495
1150 B5 = 40.021433
1160 B6 = 322.624911
1170 B7 = 570.236280
1180 B8 = 157.105423
1190 C1 = 42.242855
1200 C2 = 302.757865
1210 C3 = 352.018498
1220 C4 = 21.821899
1230 C5 = 48.196927
1240 C6 = 482.485984
1250 C7 = 1114.97885
1260 C8 = 449.690326
1270 IF ABS(E) > 1.2 GOTO 1300
1280 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
1290 GOTO 1370
1300 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
1310 Z2 = (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
1320 Z3 = (1/E)*(Z1/Z2)
1330 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
1340 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
1350 Z6 = (1/(E**2))*(Z4/Z5)
1360 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
1370 RETURN
1380 END
2000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: COSINT
2010 *
2020 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
2030 * COSINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM
2040 * THE MAIN PROGRAM AND RETURNS THE VALUE 'E2'.  THE
2050 * PROGRAM IS USED WITH THE PROGRAM NAMED 'IMCALC.'
2060 *
2070 A1 = 0.577216
2080 A2 = 1/4
2090 A3 = 1/96
2100 A4 = 1/4320
2110 A5 = 1/322560
```

TABLE 19 IMCALC Program (Cont'd.)

```
2120 A6 = 1/36288000
2130 B1 = 38.027264
2140 B2 = 265.187033
2150 B3 = 335.677320
2160 B4 = 38.102495
2170 B5 = 40.021433
2180 B6 = 322.624911
2190 B7 = 570.236280
2200 B8 = 157.105423
2210 C1 = 42.242855
2220 C2 = 302.757865
2230 C3 = 352.018498
2240 C4 = 21.821899
2250 C5 = 48.196927
2260 C6 = 482.485984
2270 C7 = 1114.97885
2280 C8 = 449.690326
2290 IF ABS(E) > 1.2 GOTO 2330
2300 E2 = A1+LOG(ABS(E))-(A2*(E**2))+(A3*(E**4))
2310 E2 = E2-(A4*(E**6))+(A5*(E**8))-(A6*(E**10))
2320 GOTO 2400
2330 Z1 = (E**8)+(B1*(E**6))+(B2*(E**4))+(B3*(E**2))+B4
2340 Z2 = (E**8)+(B5*(E**6))+(B6*(E**4))+(B7*(E**2))+B8
2350 Z3 = (1/E)*(Z1/Z2)
2360 Z4 = (E**8)+(C1*(E**6))+(C2*(E**4))+(C3*(E**2))+C4
2370 Z5 = (E**8)+(C5*(E**6))+(C6*(E**4))+(C7*(E**2))+C8
2380 Z6 = (1/(E**2))*(Z4/Z5)
2390 E2 = Z3*SIN(E)-Z6*COS(E)
2400 RETURN
2410 END
3000 DIMU(101),F(101)
3010 ;'INPUT INCREMENT OF PLOT, 1 TO 20'
3020 INPUT L1
3030 ;'INPUT SCALE OF PLOT, 20-100'
3040 INPUTS
3050 IFL=2GOTO3170
3060 ;\;\;\;\;
3070 FORA=0TO100STEPL1
3080 IFINT(F(101-A)*S)<1GOTO3100
3090 ;F(101-A);TAB(15)'!'TAB(0);TAB(F(101-A)*S+15)'*'\GOTO3110
3100 ;F(101-A);TAB(F(101-A)*S+15)'*'
3110 NEXTA
3120 FORA=1TO101STEPL1
3130 IFINT(F(A)*S)<1GOTO3150
3140 ;F(A);TAB(15)'!'TAB(0);TAB(F(A)*S+15)'*'\GOTO3160
3150 ;F(A);TAB(F(A)*S+15)'*'
3160 NEXTA
3170 RETURN
```

TABLE 19 IMCALC Program (Cont'd.)

```
!C CALCO
001 * RICHARD E. SWING, 213.11, X2159, PROGRAM: CALCO
002 *
020 FOR J=1 TO 3
025 PRINT
030 NEXT J
035 PRINT 'STATE VALUES OF X0, C, R(X0), R(X0+C),R(X0+2C)'
040 PRINT 'AND LINE-WIDTH (MICROMETERS), IN THAT ORDER:'
045 PRINT
050 INPUT X,C,B1,B2,B3,L
055 B = B1/(ABS(B3))
060 A = 2*C*B/(1+B)
065 Z1 = X+A
070 Z2 = (B1+B3)/2
080 L1 = L*Z1
090 L2 = ((L1-L)*100)/L
100 PRINT
105 PRINT
110 PRINTUSING 115,Z1
115 :     Z = ########.#####
120 PRINTUSING 125,Z2,B2
125 :     R(X0+C) = -########.#####    TRUE VALUE IS -########.#####
130 PRINT
135 PRINTUSING 140,L1
140 :     APPARENT LINE WIDTH IS ########.###
145 PRINTUSING 150,L,L2
150 :     INPUT WIDTH IS ########.###    SO % ERROR IS -########.##
155 PRINT
160 PRINT
165 PRINT 'TO CONTINUE, TYPE 1;'
170 PRINT 'OTHERWISE TYPE 2.'
175 PRINT
180 INPUT T
185 IF T > 2 GOTO 155
190 IF T = 1 GOTO 020
999 END
```

TABLE 20 CALCO Program

```
!C ROOTIT
001 * RICHARD E. SWING, 213.11, X2159, PROGRAM: ROOTIT
002 *
003 * THE PROGRAM NAMED 'SININT' MUST BE AVAILABLE IN THE
004 * SYSTEM FOR EXECUTION OF ROOTIT.
005 *
020 FOR J = 1 TO 5
024 PRINT
028 NEXT J
032 PRINT 'SUPPLY, IN ORDER NAMED, VALUES FOR:'
036 PRINT '    1) UPPER CUTOFF FREQUENCY (CYCLES/MM)'
040 PRINT '    2) LOWER CUTOFF FREQUENCY (CYCLES/MM)'
044 PRINT '    3) OPTIMUM FILTER LINE-WIDTH (MICROMETERS)'
048 PRINT '    4) ZERO-POINT FOR IMAGE DISTRIBUTION'
050 PRINT '    5) TEST LINE-WIDTH (MICROMETERS)'
052 PRINT
056 PRINT
060 INPUT D1,D2,D3,D4,D5
064 PRINT
068 D6 = 3.14159
072 G1 = (D3*D1*D6*(D4+1))/(10**3)
076 G2 = (D6*D1*(D4+1))/(10**3)
080 G3 = (D3*D1*D6*(D4-1))/(10**3)
084 G4 = (D6*D1*(D4-1))/(10**3)
088 G5 = (D3*D2*D6*(D4+1))/(10**3)
092 G6 = (D6*D2*(D4+1))/(10**3)
096 G7   (D3*D2*D6*(D4-1))/(10**3)
100 G8 = (D6*D2*(D4-1))/(10**3)
120 PRINT
124 PRINT
128 PRINTUSING 132
132 :              D                         F(D)
136 PRINT
148 Q = 0
150 FOR J = 1 TO 57
151 D7 = 0.04
152 E3 = (J-29)*D7
154 E = G1+2*G2*E3
158 GOSUB 1000
162 E2 = E1
166 E = G3+2*G4*E3
170 GOSUB 1000
174 E2 = E2-E1
178 E = G5+2*G6*E3
182 GOSUB 1000
186 E2 = E2-E1
190 E = G7+2*G8*E3
192 GOSUB 1000
194 E2 = E2+E1
195 IF Q = 0 GOTO 200
196 PRINTUSING 197,E3,E2
197 :     -########.#####          -########.#####
198 GOTO 206
200 PRINTUSING 204,E3,E2
204 :     -########.#####          -########.#####
206 IF Q = 1 GOTO 300
208 NEXT J
```

TABLE 21   ROOTIT Program

```
230 PRINT
234 PRINT
238 PRINT 'IF DETAIL ONE-AT-A-TIME CALCULATIONS ARE'
242 PRINT 'DESIRED, TYPE 1; OTHERWISE TYPE 2.'
246 PRINT
250 INPUT T
254 IF T > 2 GOTO 230
258 IF T = 2 GOTO 999
262 PRINT
266 PRINT 'SPECIFY VALUE OF D (INCLUDE SIGN IF NEGATIVE).'
270 PRINT
274 INPUT E3
278 Q = 1
282 GOTO 154
300 PRINT
304 PRINT 'CONTINUE ?  YES (1)......NO (2).'
308 PRINT
312 INPUT S
316 IF S = 1 GOTO 262
320 IF S = 2 GOTO 400
322 PRINT
323 PRINT
324 GOTO 300
400 PRINT
401 L = (((D3+2*E3)-D5)*100)/D5
402 PRINT
403 PRINT
404 PRINT
408 PRINTUSING 412,(D3+2*E3)
412 : CORRECT LINE-WIDTH (MICROMETERS) IS  ########.###
416 PRINT
417 PRINTUSING 418,D5,L
418 :  TEST LINE-WIDTH IS  ########.###        % REL.ERROR IS  -########
.##
419 PRINT
420 PRINT
999 END
1000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
1010 *
1020 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
1030 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM THE MAIN
1040 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
1050 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
1060 *
1070 A1 = 1/18
1080 A2 = 1/600
1090 A3 = 1/35280
1100 A4 = 1/3265920
1110 B1 = 38.027264
1120 B2 = 265.187033
1130 B3 = 335.677320
1140 B4 = 38.102495
```

TABLE 21   ROOTIT Program (Cont'd.)

```
1150 B5   40.021433
1160 B6 = 322.624911
1170 B7 = 570.236280
1180 B8 = 157.105423
1190 C1 = 42.242855
1200 C2 = 302.757865
1210 C3 = 352.018498
1220 C4 = 21.821897
1230 C5 = 48.196927
1240 C6 = 482.485984
1250 C7 = 1114.97885
1260 C8 = 449.690326
1270 IF ABS(E) > 1.2 GOTO 1300
1280 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
1290 GOTO 1370
1300 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
1310 Z2 = (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
1320 Z3 = (1/E)*(Z1/Z2)
1330 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
1340 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
1350 Z6 = (1/(E**2))*(Z4/Z5)
1360 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
1370 RETURN
1380 END
```

TABLE 21   ROOTIT Program (Cont'd.)

```
!C SINER
3000 GOTO 075
3010 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SINER
3020 *
3030 * THIS IS A SUBROUTINE USED BY THE PROGRAM NAMED 'LINFIL'.
3040 * IT ACCEPTS A VALUE OF THE SINE-INTEGRAL AND RETURNS ITS
3050 * INTERPOLATED INVERSE ARGUMENT DIVIDED BY 2*PI.
3060 * THAT VALUE PROVIDES AN ESTIMATE OF THE LOWER CUTOFF
3070 * FREQUENCY NEEDED FOR CALCULATION BY 'LINFIL'.
3080 *
3090 DIM W(156)
3100 IF Z9 = 1 GOTO 03140
3110 FOR J = 1 TO 155
3120 READ W(J)
3130 NEXT J
3140 E1 = (INT(E1*(10**6)+5))/(10**6)
3150 K = 1
3155 ONSGN(E1-W(K))+2GOTO3200,3180,3160
3160 K = K+1
3170 GOTO 3155
3180 B = (1.60 + (K-1)*(0.01))/(2*A)
3190 GOTO 3230
3200 B = ((E1-W(K-1))/(W(K)-W(K-1)))*(0.01)
3210 S4 = (B+(1.60+(K-2)*(0.01)))/(2*A)
3220 Z9 = 1
3230 RETURN
3240 DATA 1.38918,1.39541,1.40159,1.40774,1.41384,1.41990,1.42592
3250 DATA 1.43190,1.43784,1.44374,1.44959,1.45540,1.46118,1.46690
3260 DATA 1.47259,1.47823,1.48384,1.48939,1.49491,1.50039,1.50582
3270 DATA 1.51121,1.51655,1.52186,1.52712,1.53233,1.53751,1.54264
3280 DATA 1.54773,1.55277,1.55778,1.56273,1.56765,1.57252,1.57735
3290 DATA 1.58214,1.58688,1.59158,1.59623,1.60084,1.60541,1.60994
3300 DATA 1.61442,1.61886,1.62325,1.62760,1.63191,1.63617,1.64039
3310 DATA 1.64457,1.64870,1.65279,1.65683,1.66083,1.66479,1.66871
3320 DATA 1.67258,1.67640,1.68019,1.68393,1.68762,1.69128,1.69489
3330 DATA 1.69845,1.70198,1.70546,1.70887,1.71229,1.71564,1.71894
3340 DATA 1.72221,1.72543,1.72861,1.73174,1.73483,1.73788,1.74089
3350 DATA 1.74385,1.74677,1.74965,1.75249,1.75528,1.75803,1.76074
3360 DATA 1.76340,1.76603,1.76861,1.77115,1.77365.1.77611,1.77852
3370 DATA 1.78089,1.78322,1.78551,1.78776,1.78997,1.79214,1.79426
3380 DATA 1.79635,1.79839,1.80039,1.80236,1.80428,1.80616,1.80800
3390 DATA 1.80980,1.81156,1.81329,1.81497,1.81661,1.81821,1.81978
3400 DATA 1.82130,1.82278,1.82423,1.82564,1.82701,1.82834,1.82963
3410 DATA 1.83088,1.83210,1.83327,1.83441,1.83552,1.83658,1.83761
3420 DATA 1.83860,1.83955,1.84047,1.84135,1.84219,1.84300,1.84377
3430 DATA 1.84450,1.84520,1.84586,1.84649,1.84708,1.84764,1.84816
3440 DATA 1.84865,1.84910,1.84952,1.84991,1.85026,1.85058,1.85086
3450 DATA 1.85111,1.85133,1.85151,1.85166,1.85178,1.85186,1.85192
3460 DATA 1.85194
3470 END
```

TABLE 22 SINER Program

```
!C SININT
1000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
1010 *
1020 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
1030 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM THE MAIN
1040 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
1050 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
1060 *
1070 A1 = 1/18
1080 A2 - 1/600
1090 A3 = 1/35280
1100 A4 = 1/3265920
1110 B1 = 38.027264
1120 B2 = 265.187033
1130 B3 = 335.677320
1140 B4 = 38.102495
1150 B5 = 40.021433
1160 B6 = 322.624911
1170 B7 = 570.236280
1180 B8 = 157.105423
1190 C1 = 42.242855
1200 C2 = 302.757865
1210 C3 = 352.018498
1220 C4 = 21.821899
1230 C5 = 48.196927
1240 C6   482.485984
1250 C7 = 1114.97885
1260 C8 = 449.690326
1270 IF ABS(E) > 1.2 GOTO 1300
1280 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
1290 GOTO 1370
1300 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
1310 Z2 = (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
1320 Z3 = (1/E)*(Z1/Z2)
1330 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
1340 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
1350 Z6 = (1/(E**2))*(Z4/Z5)
1360 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
1370 RETURN
1380 END
```

TABLE 23 SININT Program

```
2000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: COSINT
2010 *
2020 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
2030 * COSINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM
2040 * THE MAIN PROGRAM AND RETURNS THE VALUE 'E2'.  THE
2050 * PROGRAM IS USED WITH THE PROGRAM NAMED 'IMCALC.'
2060 *
2070 A1 = 0.577216
2080 A2 = 1/4
2090 A3 = 1/96
2100 A4 = 1/4320
2110 A5 = 1/322560
2120 A6 = 1/36288000
2130 B1 = 38.027264
2140 B2 = 265.187033
2150 B3 = 335.677320
2160 B4 = 38.102495
2170 B5 = 40.021433
2180 B6   322.624911
2190 B7 = 570.236280
2200 B8 = 157.105423
2210 C1 = 42.242855
2220 C2 = 302.757865
2230 C3 = 352.018498
2240 C4 = 21.821899
2250 C5 = 48.196927
2260 C6 = 482.485984
2270 C7 = 1114.97885
2280 C8 = 449.690326
2290 IF ABS(E) > 1.2 GOTO 2330
2300 E2 = A1+LOG(ABS(E))-(A2*(E**2))+(A3*(E**4))
2310 E2 = E2-(A4*(E**6))+(A5*(E**8))-(A6*(E**10))
2320 GOTO 2400
2330 Z1 = (E**8)+(B1*(E**6))+(B2*(E**4))+(B3*(E**2))+B4
2340 Z2 = (E**8)+(B5*(E**6))+(B6*(E**4))+(B7*(E**2))+B8
2350 Z3   (1/E)*(Z1/Z2)
2360 Z4 = (E**8)+(C1*(E**6))+(C2*(E**4))+(C3*(E**2))+C4
2370 Z5 = (E**8)+(C5*(E**6))+(C6*(E**4))+(C7*(E**2))+C8
2380 Z6 = (1/(E**2))*(Z4/Z5)
2390 E2 = Z3*SIN(E)-Z6*COS(E)
2400 RETURN
```

TABLE 24   COSINT Program.

```
!C SINSEC
3000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SINSEC
3010 *
3020 * THIS IS A SUBROUTINE USED BY THE PROGRAM NAMED 'LINFIL'.
3030 * IT ACCEPTS A VALUE OF THE SINE-INTEGRAL AND RETURNS ITS
3040 * INTERPOLATED SECOND-ORDER INVERSE ARGUMENT DIVIDED BY
3050 * 2*P1.  THAT VALUE PROVIDES AN ESTIMATE OF THE LOWER
3060 * CUTOFF FREQUENCY (SECOND-ORDER) NEEDED FOR CALCULATION
3070 * BY 'LINFILL'.
3080 *
3090 DIM R(60)
3100 S7 = (INT(E1*(10**6)+5))/(10**6)
3110 K = 0
3120 FOR J=0TO50
3130 E = 3.14 + (J+(50*K))*(0.01)
3140 GOSUB3290
3150 R(J) = (INT(E1*(10**6)+5))/(10**6)
3160 NEXT J
3170 I = 0
3180 ON(S7-R(I))GOTO3190,3230,3250
3190 I = I+1
3200 IF I < 50 GOTO 03180
3210 K = K+1
3220 GOTO 03120
3230 S4 = (3.14 + (I+(50*K))*(0.01))/(2*A)
3240 GOTO 03270
3250 B = (R(I-1)-S7)/(R(I-1)-R(I))
3260 S4 = (3.14 + ((I-1)+(50*K)+B)*(0.01))/(2*A)
3270 RETURN
3280 END
3290 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
3300 *
3310 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
3320 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM THE MAIN
3330 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
3340 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
3350 *
3360 A1   1/18
3370 A2 = 1/600
3380 A3 = 1/35280
3390 A4 = 1/3265920
3400 B1 = 38.027264
3410 B2 = 265.187033
3420 B3 = 335.677320
3430 B4 = 38.102495
```

TABLE 25   SINSEC Program

```
3440 B5 = 40.021433
3450 B6 = 322.624911
3460 B7 = 570.236280
3470 B8 = 157.105423
3480 C1 = 42.242855
3490 C2 = 302.757865
3500 C3 = 352.018498
3510 C4 = 21.821899
3520 C5 = 48.196927
3530 C6   482.485984
3540 C7 = 1114.97885
3550 C8 = 449.690326
3560 IF ABS(E) > 1.2 GOTO 3590
3570 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
3580 GOTO 3660
3590 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
3600 Z2 = (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
3610 Z3 = (1/E)*(Z1/Z2)
3620 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
3630 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
3640 Z6 = (1/(E**2))*(Z4/Z5)
3650 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
3660 RETURN
3670 END
```

TABLE 25 SINSEC Program (Cont'd.)

```
!C IMPACH
032 PRINT
034 *
036 E7 = 1
038 E8 = 1
040 E9 = 1
042 *
044 *
046 *
047 *
048 *
049 *
066 D1 = 0.002
080 K1 = 491
082 K2 = 511
220 PRINTUSING 222,D1*(J-1),E6*E9,E4*(1/(2*A))*E8,E5*(1/(2*A))*E7
222 :  ########.###      ########.#####     ########.#####     #######
#.#####
612 :  LOWER CUTOFF IS ########.###     LOWER OFFEST IS ########.##
640 :          X              I(X)            R(X)             IM(X)
```

TABLE 26   IMPACH Program

APPENDIX I

R. SWING PROGRAMS ADAPTED FOR THE XEROX SIGMA 9

```
!C LINFILC
001 * RICHARD E. SWING, 213.11, X2159, PROGRAM: LINFIL
002 *
003 * TO OPERATE PROPERLY, THIS PROGRAM REQUIRES THAT THREE
004 * OTHER PROGRAMS BE AVAILABLE IN THE SYSTEM.  THESE ARE
005 * NAMED 'SINER' AND 'SINSEC' (TO ESTABLISH THE OPTIMUM
006 * VALUE FOR LOWER CUTOFF FREQUENCY) AND 'SININT' (TO CAL-
007 * CULATE VALUES OF THE SINE-INTEGRAL).
008 *
010 * INSTRUCTIONS FOR USING THE PROGRAM ARE PRINTED AS REQUIRED.
011 *
029 *
030 DIM T(10)
032 PRINT
038 PRINT 'SUPPLY, IN THE ORDER NAMED, VALUES FOR:'
040 PRINT '    1) LINE-WIDTH (MICROMETERS)'
042 PRINT '    2) WAVELENGTH (NANOMETERS)'
044 PRINT '    3) TRANSFORM LENS NUMERICAL APERTURE'
046 PRINT '    4) UPPER CUTOFF FREQUENCY (CYCLES/MM)'
047 PRINT '    5) FIRST (1) OR SECOND (2) ORDER FILTER'
050 PRINT
052 PRINT
054 INPUT W,L,N,S,F7
055 PRINT
56 A=3.14159
59 *****2A*SIGMA-S*****
60 S1=(W*S)/(10**3)
066 D1 = 0.02
068 D2 = 1/(4*(A**2))
069 E = 2*A*S1
70 GOSUB1000
071 IF F7 = 2 GOTO 074
72 GOSUB2000
073 GOTO 075
74 GOSUB3000
75 *****SIGMA-1*****
76 S5=(S4/W)*(10**3)
77 GOSUB600
080 K1 = 47
082 K2 = 55
96 FORJ2=K1TOK2
100 E = A*S1*(D1*(J2-1)+1)
102 GOSUB1000
106 E4 = 2*E1
120 E = A*S1*(D1*(J2-1)-1)
130 GOSUB1000
132 E4 = E4-2*E1
152 E = A*S4*(D1*(J2-1)+1)
157 GOSUB1000
158 E4 = E4-2*E1
172 E = A*S4*(D1*(J2-1)-1)
182 GOSUB1000
184 E4 = E4+2*E1
202 E6 = (E4**2)*D2
208 T(J2-46) = E6
220 ;USING 222,D1*(J2-1),E6,E4*(1/(2*A))
222 :  -########.##      -########.#####      -########.#####
224 NEXT J2
228 GOSUB 720
```

TABLE 27   LINFILC Program

```
230 IF H = 1 GOTO 076
234 PRINT
238 PRINT 'TO CALCULATE WITH NEW PARAMETERS, TYPE 1'
242 PRINT 'TO TERMINATE CALCULATIONS, TYPE 2.'
244 PRINT
246 INPUT F
248 IF F = 1 GOTO 032
250 IF F = 2 GOTO 999
254 PRINT
256 GOTO 238
599 *****HEADING SUBROUTINE*****
600 FORJ=1TO5
602 PRINT
604 NEXT J
606 PRINT 'NORMALIZED LINE-IMAGE WITH BAND-PASS FILTERING'
608 PRINT
610 ;USING 612,S5,F7
612 :  LOWER CUTOFF IS  -########.###        (#)
614 ;USING 616,S
616 :  UPPER CUTOFF IS  -########.##
620 ;
622 ;USING 624,W
624 :     LINE-WIDTH (MICROMETERS) IS  -########.##
626 ;USING 628,L
628 :     WAVELENGTH (NANOMETERS) IS   -########.##
630 ;USING 632,N
632 :     LENS NUMERICAL APERTURE IS   -########.###
634 PRINT
636 PRINT
638 ;USING 640
640 :              X                  I(X)                 R(X)
642 PRINT
644 RETURN
720 PRINT
722 PRINT
724 ;USING 726,T(5),T(4)-T(6),T(3)-T(7),T(2)-T(8)
726 :       -########.#####     -########.#####      ########.#####     -
########.#####
728 PRINT
730 PRINT 'TO CONTINUE ADJUSTMENT AT LINE-EDGE,'
732 PRINT 'TYPE 1; OTHERWISE TYPE 2.'
734 PRINT
736 INPUT H
738 IFH>2GOTO728
740 IF H = 2 GOTO 760
742 PRINT
744 PRINT 'SUPPLY VALUES (>0) FOR LOWER AND UPPER CUTOFF'
746 PRINT 'FREQUENCIES (CYCLES/MM), IN THAT ORDER.'
748 PRINT
750 INPUT F1,F2
751 IF F1 = 0 GOTO 742
752 S4 = (F1*W)/(10**3)
754 S1 = (F2*W)/(10**3)
756 S = F2
758 S5 = F1
760 RETURN
999 END
```

TABLE 27   LINFILC Program (Cont'd.)

```
!C CIMCALPACH
100 * RICHARD E. SWING, 213.11, X2159, PROGRAM: IMCALC
110 *
120 * TO OPERATE PROPERLY, THIS PROGRAM REQUIRES THAT TWO
130 * OTHER PROGRAMS BE AVAILABLE IN THE SYSTEM. THESE ARE
140 * NAMED 'SININT' AND 'COSINT' , AND CALCULATE VALUES
150 * OF THE SINE-INTEGRAL AND COSINE-INTEGRAL, RESPECTIVELY.
160 ;'IF YOU WISH TO SAVE PLOT FILE, TYPE 1'
170 INPUTL2
180 ;'IF YOU WISH TABULAR LISTING, TYPE 1'\INPUTL3
190 ;'IF YOU WISH PLOT,TYPE1'\INPUTP\IFL2<>1GOTO220
200 ;'INPUT FILE NAME'\INPUTA$
210 OPENA$TO:2,PRINT,OVER
220 DIM T(10),I(101)
230 PRINT
240 *
250 E7 = 1
260 F3 = 1
270 E8 = 1
280 E9 = 1
290 W=V(2)\D=0\S5=X\E3=0\G=2
300 L=632.8
310 N=.2632
320 D3=D3
330 *
340 *
350 PRINT
360 PRINT
380 PRINT
390 A=3.141592654
400 S1 = (W*S)/(10**3)
410 S2 = (W*D)/(10**3)
420 S3 = (W*E3)/(10**3)
430 S4 = (W*S5)/(10**3)
440 D1 = 0.002
450 D2 = 1/(4*(A**2))
460 IF S5 = 0 GOTO 1590
470 GOSUB 1360
480 IF G = 1 GOTO 0520
490 K1 = 491
500 K2   511
510 GOTO 0540
520 K1    1
530 K2 = 101
540 FOR J = K1 TO K2
550 E = A*(S1+S2)*(D1*(J-1)+1)
```

TABLE 28   CIMCALPACH Program

```
1040 E5   E5+E2
1050 E = A*(S4-S3)*(D1*(J-1)-1)
1060 IF ABS(E) > 0 GOTO 1090
1070 E2 = 0
1080 GOTO 1100
1090 GOSUB 2080
1100 GOSUB 1690
1110 E4   E4+E1
1120 E5 - E5-E2
1130 IF F3 = 2 GOTO 1160
1140 E6   ((E4**2)+(E5**2))*D2
1150 GOTO1170
1160 E6 = (((E4/(2*A))-1)**2)+(E5**2)*D2
1170 IFL3<>1GOTO1200
1180 PRINTUSING 1190,D1*(J-1),E6*E9,E4*(1/(2*A))*E8,E5*(1/(2*A))*E7
1190 :-########.#####   -########.#####   -########.#####   -########.#####
1200 F(J-490)=E6
1201 M=MIN(M,E6*E9)
1202 IFE6*E9<>MGOTO1204
1203 X=D1*(J-1)\Q1=E4*(1/(2*A))*E8\I=1\GOTO1210
1204 IFI<>1GOTO1206
1205 Q2=E4*(1/(2*A))*E8\I=2\GOTO1210
1206 IFI<>2GOTO1210
1207 Q3=E4*(1/(2*A))*E8\I=0
1210 NEXT J
1220 IFL2<>1GOTO1230\MATPRINT:2,F
1230 IFP<>1GOTO1250
1240 GOSUB2500
1250 FORJ=1TO5\;\NEXTJ
1260 ;'IF YOU WISH ANOTHER PLOT OF THE SAME DATA, TYPE 1'\INPUTP1
1270 IF P1<>1GOTO1290
1280 GOSUB2500
1290 PRINT 'TO CALCULATE WITH NEW PARAMETERS, TYPE 1;'
1300 PRINT 'OTHERWISE, TYPE 2.'
1310 PRINT
1320 INPUT F
1330 IF F > 2 GOTO 1290
1340 IFF=2GOTO1675
1350 GOTO160
1360 FOR J = 1 TO 5
1370 PRINT
1380 NEXT J
1390 PRINT 'NORMALIZED LINE-IMAGE WITH BAND-PASS FILTERING'
1400 PRINT
1410 PRINTUSING 1420,S5,E3
1420 :  LOWER CUTOFF IS ########.###    LOWER OFFEST IS ########.##
1430 PRINTUSING 1440,S,D
1440 :  UPPER CUTOFF IS ########.##     UPPER OFFSET IS ########.##
```

TABLE 28 CIMCALPACH Program (Cont'd.)

```
1450 PRINT
1460 PRINTUSING 1470,W
1470 :     LINE-WIDTH (MICROMETERS IS     ########.##
1480 PRINTUSING 1490,L
1490 :     WAVELENGTH (NANOMETERS) IS     ########.##
1500 PRINTUSING 1510,N
1510 :     LENS NUMERICAL APERTURE IS     ########.###
1520 PRINT
1530 PRINT
1540 IFL3<>1GOTO1570
1550 PRINTUSING 1560
1560 :          X                I(X)                R(X)                IM(X)
1570 PRINT
1580 RETURN
1590 PRINT
1600 PRINT 'UNFILTERED LINE IMAGE WILL BE LISTED.'
1610 PRINT '     FOR CLEAR LINE, DARK BACKGROUND, TYPE 1.'
1620 PRINT '     FOR DARK LINE, CLEAR BACKGROUND, TYPE 2.'
1630 PRINT
1640 INPUT F3
1650 IF F3 > 2 GOTO 1590
1660 GOTO 0470
1670 IFL2<>1GOTO1680\CLOSE:2
1675 CHAINLINK'CCALCO'
1680 END
1690 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
1700 *
1710 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
1720 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM THE MAIN
1730 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
1740 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
1750 *
1760 A1 = 1/18
1770 A2 = 1/600
1780 A3 = 1/35280
1790 A4   1/3265920
1800 B1 = 38.027264
1810 B2 = 265.187033
1820 B3 = 335.677320
1830 B4 = 38.102495
1840 B5 = 40.021433
1850 B6 = 322.624911
1860 B7 = 570.236280
1870 B8 = 157.105423
1880 C1 = 42.242855
1890 C2 = 302.757865
1900 C3 = 352.018498
```

TABLE 28 CIMCALPACH Program (cont'd.)

```
1910 C4 = 21.821899
1920 C5 = 48.196927
1930 C6 = 482.485984
1940 C7 = 1114.97885
1950 C8 = 449.690326
1960 IF ABS(E) > 1.2 GOTO 1990
1970 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
1980 GOTO 2060
1990 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
2000 Z2   (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
2010 Z3 = (1/E)*(Z1/Z2)
2020 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
2030 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
2040 Z6 = (1/(E**2))*(Z4/Z5)
2050 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
2060 RETURN
2070 END
2080 * RICHARD E. SWING, 213.11, X2159, PROGRAM: COSINT
2090 *
2100 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
2110 * COSINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM
2120 * THE MAIN PROGRAM AND RETURNS THE VALUE 'E2'.  THE
2130 * PROGRAM IS USED WITH THE PROGRAM NAMED 'IMCALC.'
2140 *
2150 A1   0.577216
2160 A2 = 1/4
2170 A3 = 1/96
2180 A4   1/4320
2190 A5 = 1/322560
2200 A6 = 1/36288000
2210 B1 = 38.027264
2220 B2 = 265.187033
2230 B3 = 335.677320
2240 B4 = 38.102495
2250 B5 = 40.021433
2260 B6 = 322.624911
2270 B7 = 570.236280
2280 B8 = 157.105423
2290 C1 = 42.242855
2300 C2 = 302.757865
2310 C3 = 352.018498
2320 C4 = 21.821899
2330 C5 = 48.196927
2340 C6 = 482.485984
2350 C7 = 1114.97885
```

TABLE 28   CIMCALPACH Program (Cont'd.)

```
2360 C8 = 449.690326
2370 IF ABS(E) > 1.2 GOTO 2410
2380 E2 = A1+LOG(ABS(E))-(A2*(E**2))+(A3*(E**4))
2390 E2 = E2-(A4*(E**6))+(A5*(E**8))-(A6*(E**10))
2400 GOTO 2480
2410 Z1    (E**8)+(B1*(E**6))+(B2*(E**4))+(B3*(E**2))+B4
2420 Z2 = (E**8)+(B5*(E**6))+(B6*(E**4))+(B7*(E**2))+B8
2430 Z3 = (1/E)*(Z1/Z2)
2440 Z4 = (E**8)+(C1*(E**6))+(C2*(E**4))+(C3*(E**2))+C4
2450 Z5    (E**8)+(C5*(E**6))+(C6*(E**4))+(C7*(E**2))+C8
2460 Z6 = (1/(E**2))*(Z4/Z5)
2470 E2    Z3*SIN(E)-Z6*COS(E)
2480 RETURN
2490 END
2500 DIMU(101),F(101)
2510 ;'INPUT INCREMENT OF PLOT, 1 TO 20'
2520 INPUT L1
2530 ;'INPUT SCALE OF PLOT, 20-100'
2540 INPUTS
2550 S=S*100
2560 IFL=2GOTO2680
2570 ;\;\;\;\;
2580 FORA=0TO100STEPL1
2590 IFINT(F(101-A)*S)<1GOTO2610
2600 ;F(101-A);TAB(15)'!'TAB(0);TAB(F(101-A)*S+15)'*'\GOTO2620
2610 ;F(101-A);TAB(F(101-A)*S+15)'*'
2620 NEXTA
2630 FORA=1TO101STEPL1
2640 IFINT(F(A)*S)<1GOTO2660
2650 ;F(A);TAB(15)'!'TAB(0);TAB(F(A)*S+15)'*'\GOTO2670
2660 ;F(A);TAB(F(A)*S+15)'*'
2670 NEXTA
2680 RETURN
```

TABLE 28 CIMCALPACH Program (Cont'd.)

```
!C OPTLIN
8 ;'SUPPLY THE FOLLOWING:'
10 DIMV(100),S(100)
15 N=100
31 Z9=0
40 ;'            1) LINE-WIDTH  (MICROMETERS):'TAB(0)\INPUTV(2)
42 ;'            2) LOWER CUTOFF FREQUENCY (CYCLES/MM)'TAB(0)\INPUTX
46 ;'            3) UPPER cUTOFF FREQUENCY (CYcLES/MM)'TAB(0)\INPUTS
50 ;\;\;
055 PRINT
60 I=2
65 GOSUB2000
70 FORI=3TON
80 IFS(I-1)>XTHEN110
90 IFS(I-1)<XTHEN140
100 GOTO500
110 L(I)=1\IFL(I)<>L(I-1)GOTO250
120 V(I)=V(I-1)*2
130 GOTO160
140 T(I)=1\IFT(I)<>T(I-1)GOTO250
150 V(I)=V(I-1)/2
160 GOSUB2000
170 NEXTI
250 FORI=ITON
260 IFS(I-1)>XTHEN290
270 IFS(I-1)<XTHEN310
280 GOTO500
290 V(I)=V(I-1)+ABS(V(I-2)-V(I-1))/2
300 GOTO320
310 V(I)=V(I-1)-ABS(V(I-2)-V(I-1))/2
320 GOSUB2000
330 NEXTI
500 ;USING 510,X
510 :      LOWER CUTOFF FREQUENCY (CYCLES/MM)       -########.#####
520 ;USING530,V(I-1)
530 :      OPTIMUM FILTER LINE-WIDTH (MICROMETERS)  -########.#####
540 ;USING550,S(I-1)
550 :      CORRESPONDING LOWER CUTOFF IS            -########.#####
600 D3=V(I-1)
950 CHAINLINK'CIMCALPACH'
999 END
1000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
1010 *
1020 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
1030 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM THE MAIN
1040 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
1050 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
1060 *
1070 A1 = 1/18
1080 A2 = 1/600
1090 A3 = 1/35280
1100 A4 = 1/3265920
1110 B1 = 38.027264
1120 B2 = 265.187033
1130 B3   335.677320
```

TABLE 29   OPTLIN Program

```
1140 B4 - 38.102495
1150 B5   40.021433
1160 B6   322.624911
1170 B7 = 570.236280
1180 B8 = 157.105423
1190 C1 = 42.242855
1200 C2 = 302.757865
1210 C3 = 352.018498
1220 C4 = 21.821899
1230 C5 = 48.196927
1240 C6 = 482.485984
1250 C7 = 1114.97885
1260 C8 = 449.690326
1270 IF ABS(E) > 1.2 GOTO 1300
1280 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
1290 GOTO 1370
1300 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
1310 Z2 = (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
1320 Z3 = (1/E)*(Z1/Z2)
1330 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
1340 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
1350 Z6 = (1/(E**2))*(Z4/Z5)
1360 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
1370 RETURN
2000 A = 3.14159
2010 S1 = (V(I)*S)/(10**3)
2020 D1   0.02
2030 D2 = 1/(4*(A**2))
2040 E = 2*A*S1
2050 GOSUB 1000
2060 GOSUB 3000
2070 S(I)=(S4/V(I))*(10**3)
2080 RETURN
3000 *
3010 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SINER
3020 *
3030 * THIS IS A SUBROUTINE USED BY THE PROGRAM NAMED 'LINFIL'.
3040 * IT ACCEPTS A VALUE OF THE SINE-INTEGRAL AND RETURNS ITS
3050 * INTERPOLATED INVERSE ARGUMENT DIVIDED BY 2*PI.
3060 * THAT VALUE PROVIDES AN ESTIMATE OF THE LOWER CUTOFF
3070 * FREQUENCY NEEDED FOR CALCULATION BY 'LINFIL'.
3080 *
3090 DIM W(156)
3100 IF Z9 = 1 GOTO 03140
3110 FORJ=1TO155
3120 READ W(J)
3130 NEXT J
3140 E1 = (INT(E1*(10**6)+5))/(10**6)
3150 K=1
3155 ONSGN(E1-W(K))+2GOTO3200,3180,3160
3160 K = K+1
3170 GOTO 3155
3180 B = (1.60 + (K-1)*(0.01))/(2*A)
3190 GOTO 3230
3200 B = ((E1-W(K-1))/(W(K)-W(K-1)))*(0.01)
3210 S4 = (B+(1.60+(K-2)*(0.01)))/(2*A)
3220  Z9=1
3230 RETURN
```

TABLE 29 OPTLIN Program (Cont'd.)

```
3240 DATA 1.38918,1.39541,1.40159,1.40774,1.41384,1.41990,1.42592
3250 DATA 1.43190,1.43784,1.44374,1.44959,1.45540,1.46118,1.46690
3260 DATA 1.47259,1.47823,1.48384,1.48939,1.49491,1.50039,1.50582
3270 DATA 1.51121,1.51655,1.52186,1.52712,1.53233,1.53751,1.54264
3280 DATA 1.54773,1.55277,1.55778,1.56273,1.56765,1.57252,1.57735
3290 DATA 1.58214,1.58688,1.59158,1.59623,1.60084,1.60541,1.60994
3300 DATA 1.61442,1.61886,1.62325,1.62760,1.63191,1.63617,1.64039
3310 DATA 1.64457,1.64870,1.65279,1.65683,1.66083,1.66479,1.66871
3320 DATA 1.67258,1.67640,1.68019,1.68393,1.68762,1.69128,1.69489
3330 DATA 1.69845,1.70198,1.70546,1.70889,1.71229,1.71564,1.71894
3340 DATA 1.72221,1.72543,1.72861,1.73174,1.73483,1.73788,1.74089
3350 DATA 1.74385,1.74677,1.74965,1.75249,1.75528,1.75803,1.76074
3360 DATA 1.76340,1.76603,1.76861,1.77115,1.77365,1.77611,1.77852
3370 DATA 1.78089,1.78322,1.78551,1.78776,1.78997,1.79214,1.79426
3380 DATA 1.79635,1.79839,1.80039,1.80236,1.80428,1.80616,1.80800
3390 DATA 1.80980,1.81156,1.81329,1.81497,1.81661,1.81821,1.81978
3400 DATA 1.82130,1.82278,1.82423,1.82564,1.82701,1.82834,1.82963
3410 DATA 1.83088,1.83210,1.83327,1.83441,1.83552,1.83658,1.83761
3420 DATA 1.83860,1.83955,1.84047,1.84135,1.84219,1.84300,1.84377
3430 DATA 1.84450,1.84520,1.84586,1.84649,1.84708,1.84764,1.84816
3440 DATA 1.84865,1.84910,1.84952,1.84991,1.85026,1.85058,1.85086
3450 DATA 1.85111,1.85133,1.85151,1.85166,1.85178,1.85186,1.85192
3460 DATA 1.85194
3470 END
```

TABLE 29 OPTLIN Program (Cont'd.)

```
!C CCALCO
001 * RICHARD E. SWING, 213.11, X2159, PROGRAM: CALCO
002 *
10 DIMV(100)
15 D3=D3
020 FOR J=1 TO 3
025 PRINT
030 NEXT J
35 ;'INPUT VALUES OF X0,R(X0),R(X0+C),R(X0+2C)'
40 L=W
49 INPUTX,B1,B2,B3
50 C=.002
055 B = B1/(ABS(B3))
060 A = 2*C*B/(1+B)
065 Z1 = X+A
070 Z2 = (B1+B3)/2
080 W1 = W*Z1
090 W2 = ((W1-W)*100)/W
100 PRINT
105 PRINT
110 PRINTUSING 115,Z1
112 Z8=Z1
115 :    Z - ########.#####
120 PRINTUSING 125,Z2,B2
125 :    R(X0+C) = -########.#####    TRUE VALUE IS -########.#####
130 PRINT
135 PRINTUSING 140,W1
140 :    APPARENT LINE WIDTH IS ########.###
145 PRINTUSING 150,W,W2
150 :    INPUT WIDTH IS ########.###    SO % ERROR IS -########.##
950 CHAINLINK'CROOTIT'
999 END
```

TABLE 30   CCALCO Program

```
!C CROOTIT
001 * RICHARD E. SWING, 213.11, X2159, PROGRAM: ROOTIT
002 *
003 * THE PROGRAM NAMED 'SININT' MUST BE AVAILABLE IN THE
004 * SYSTEM FOR EXECUTION OF ROOTIT.
005 *
020 FOR J = 1 TO 5
024 PRINT
028 NEXT J
50 D3=D3
60 D1=S\D2=S5
61 D4=Z8\D5=W
064 PRINT
068 D6 = 3.14159
072 G1 = (D3*D1*D6*(D4+1))/(10**3)
076 G2 = (D6*D1*(D4+1))/(10**3)
080 G3 = (D3*D1*D6*(D4-1))/(10**3)
084 G4 = (D6*D1*(D4-1))/(10**3)
088 G5 = (D3*D2*D6*(D4+1))/(10**3)
092 G6 = (D6*D2*(D4+1))/(10**3)
096 G7 = (D3*D2*D6*(D4-1))/(10**3)
100 G8 = (D6*D2*(D4-1))/(10**3)
120 PRINT
124 PRINT
128 PRINTUSING 132
132 :             D                          F(D)
136 PRINT
148 Q = 0
150 FOR J = 1 TO 57
151 D7 = 0.04
152 E3 = (J-29)*D7
154 E = G1+2*G2*E3
158 GOSUB 1000
162 E2 = E1
166 E   G3+2*G4*E3
170 GOSUB 1000
174 E2 = E2-E1
178 E   G5+2*G6*E3
182 GOSUB 1000
186 E2 = E2-E1
190 E : G7+2*G8*E3
192 GOSUB 1000
194 E2 = E2+E1
195 IF Q = 0 GOTO 200
196 PRINTUSING 197,E3,E2
197 :     -########.#####         -########.#####
198 GOTO 206
```

TABLE 31   CROOTIT Program

```
200 PRINTUSING 204,E3,E2
204 :    -########.#####        -########.#####
206 IF Q = 1 GOTO 300
208 NEXT J
230 PRINT
234 PRINT
238 PRINT 'IF DETAIL ONE-AT-A-TIME CALCULATIONS ARE'
242 PRINT 'DESIRED, TYPE 1; OTHERWISE TYPE 2.'
246 PRINT
250 INPUT T
254 IF T > 2 GOTO 230
258 IF T = 2 GOTO 999
262 PRINT
266 PRINT 'SPECIFY VALUE OF D (INCLUDE SIGN IF NEGATIVE).'
270 PRINT
274 INPUT E3
278 Q = 1
282 GOTO 154
300 PRINT
304 PRINT 'CONTINUE ?  YES (1)......NO (2).'
308 PRINT
312 INPUT S
316 IF S = 1 GOTO 262
320 IF S   2 GOTO 400
322 PRINT
323 PRINT
324 GOTO 300
400 PRINT
401 L = (((D3+2*E3)-D5)*100)/D5
402 PRINT
403 PRINT
404 PRINT
408 PRINTUSING 412,(D3+2*E3)
412 : CORRECT LINE-WIDTH (MICROMETERS) IS  ########.###
416 PRINT
417 PRINTUSING 418,D5,L
418 :  TEST LINE-WIDTH IS  ########.###        % REL.ERROR IS  -########.##
419 PRINT
420 PRINT
999 END
1000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
1010 *
1020 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
1030 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR 'E' FROM THE MAIN
1040 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
1050 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
1060 *
```

TABLE 31   CROOTIT Program (Cont'd.)

```
1070 A1 = 1/18
1080 A2 = 1/600
1090 A3 = 1/35280
1100 A4 = 1/3265920
1110 B1 = 38.027264
1120 B2 = 265.187033
1130 B3 = 335.677320
1140 B4 = 38.102495
1150 B5 = 40.021433
1160 B6 = 322.624911
1170 B7 = 570.236280
1180 B8 = 157.105423
1190 C1 = 42.242855
1200 C2 = 302.757865
1210 C3 = 352.018498
1220 C4 = 21.821899
1230 C5 = 48.196927
1240 C6 = 482.485984
1250 C7 = 1114.97885
1260 C8 = 449.690326
1270 IF ABS(E) > 1.2 GOTO 1300
1280 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
1290 GOTO 1370
1300 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
1310 Z2 = (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
1320 Z3 = (1/E)*(Z1/Z2)
1330 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
1340 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
1350 Z6 = (1/(E**2))*(Z4/Z5)
1360 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
1370 RETURN
1380 END
```

TABLE 31 CROOTIT Program (Cont'd.)

```
!C SINERC
2000 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SINER
2010 *
2020 * THIS IS A SUBROUTINE USED BY THE PROGRAM 'LINFIL'.
2030 * IT ACCEPTS A VALUE OF THE SINE-INTEGRAL AND RETURNS ITS
2040 * INTERPOLATED FIRST-ORDER INVERSE ARGUMENT DIVIDED BY
2050 * 2*P1.  THAT VALUE PROVIDES AN ESTIMATE OF THE LOWER
2060 * CUTOFF FREQUENCT (FIRST-ORDER) NEEDED FOR CALCULATION
2070 * BY 'LINFIL'.
2080 *
2090 DIM W(60)
2100 S7 = (INT(E1*(10**6)+5))/(10**6)
2110 K = 0
2120 FORJ=0TO50
2130 E = 1.60+(J+(50*K))*(0.01)
2140 GOSUB2280
2150 W(J) = (INT(E1*(10**6)+5))/(10**6)
2160 NEXT J
2170 I = 0
2180 ON(S7-W(I))GOTO2250,2230,2190
2190 I = I+1
2200 IF I < 50 GOTO 02180
2210 K = K+1
2220 GOTO 02120
2230 S4 = 1.60 +(1.60+(I+(50*K))*(0.01))/(2*A)
2240 GOTO 02270
2250 B   (S7-W(I-1))/(W(I)-W(I-1))
2260 S4 = (1.60 +((I-1)+(50*K)+B)*(0.01))/(2*A)
2270 RETURN
2280 * RICHARD E. SWING, 213.11, X2159, PROGRAM: SININT
2290 *
2300 * THIS IS A SUBROUTINE FOR COMPUTING VALUES OF THE
2310 * SINE-INTEGRAL.  IT REQUIRES A VALUE FOR "E" FROM THE MAIN
2320 * PROGRAM AND RETURNS THE VALUE 'E1'.  THE PROGRAM IS
2330 * USED WITH THE PROGRAMS NAMED 'LINFIL' AND 'IMCALC'
2340 *
2350 A1 = 1/18
2360 A2   1/600
2370 A3 = 1/35280
2380 A4 = 1/3265920
2390 B1 = 38.027264
2400 B2 = 265.187033
2410 B3 = 335.677320
```

TABLE 32   SINERC Program

```
2420 B4 = 38.102495
2430 B5 - 40.021433
2440 B6 = 322.624911
2450 B7 = 570.236280
2460 B8 = 157.105423
2470 C1 = 42.242855
2480 C2 = 302.757865
2490 C3 = 352.018498
2500 C4   21.821899
2510 C5   48.196927
2520 C6   482.485984
2530 C7 = 1114.97885
2540 C8 = 449.690326
2550 IF ABS(E) > 1.2 GOTO 2580
2560 E1 = E-(A1*(E**3))+(A2*(E**5))-(A3*(E**7))+(A4*(E**9))
2570 GOTO 2650
2580 Z1 = (E**8)+B1*(E**6)+B2*(E**4)+B3*(E**2)+B4
2590 Z2 = (E**8)+B5*(E**6)+B6*(E**4)+B7*(E**2)+B8
2600 Z3 = (1/E)*(Z1/Z2)
2610 Z4 = (E**8)+C1*(E**6)+C2*(E**4)+C3*(E**2)+C4
2620 Z5 = (E**8)+C5*(E**6)+C6*(E**4)+C7*(E**2)+C8
2630 Z6 = (1/(E**2))*(Z4/Z5)
2640 E1 = (3.14159/2)*SGN(E)-Z3*COS(E)-Z6*SIN(E)
2650 RETURN
2660 END
```

TABLE 32 SINERC Program (Cont'd.)

APPENDIX J

LINE WIDTH MEASUREMENT HISTOGRAMS

FOR HIGH CONTRAST EDGES

```
71    ********
72    ***************************
73    ***********************************
74    *****************************
75    *
76    *
```

Filtered Image

```
62    *
63
64
65    *
66
67
68    **
69
70
71    *
72    ****
73    *****
74    ****
75    ****
76    ****
77    *********
78    ***********
79    **********
80    *********
81    *****
82    ******
83    **
84    **
```

Unfiltered Image

TABLE 33 Line Width Measurement Histograms for 9.9um

```
113     ***
114     ******
115     ***********************************
116     ***********************************
117     ****************
118     **
119
120
121
122     *
123
124     **
```

Filtered Image

```
112     **
113     **
114     *****
115     *******
116     ***************
117     **************
118     *********
119     **********
120     **********
121     **********
122     ******
123     ****
124
125     *
126     *
127     ****
```

Unfiltered Image

TABLE 34   Line Width Measurement Histograms for 15.2 um

```
137     *
138     **
139     *****
140     ***********************
141     ****************************
142     ****************************
143     *******
144     *
145
146
147
148
149     *****
```

Filtered Image

```
134     *
135
136     *
137
138     **
139     ***
140     ****
141     *****
142     *******
143     **********
144     *************
145     *******************
146     **********
147     ***
148     ************
149     ***
150     ***
151     ******
152     *
```

Unfiltered Image

TABLE 35   Line Width Measurement Histograms for 18.5um

```
184     ***
185     ***************************************************
186     ****************************************
187
188     *
189     ********
```

Filtered Image

```
176     *
177     ***
178
179     *
180     ***
181     ******
182     *********
183     *************
184     ******************
185     *****
186     *************
187     **********
188     **********
189     ******
190     **
191     *
192     **
193
194
195     *
```

Unfiltered Image

TABLE 36   Line Width Measurement Histograms for 24.0um

```
224    *
225
226
227
228    *
229    *****
230    **********
231    *********************************
232    *************************************
233    *********
234    ****
```

Filtered Image

```
223    *
224
225
226    **
227    *****
228    ****
229    *****
230    *******
231    **********
232    ****************
233    ***************
234    **************
235    ***********
236    ******
237    **
238    *
239    *
240    **
```

Unfiltered Image

TABLE 37   Line Width Measurement Histograms for 31.0um

APPENDIX K

LINE WIDTH MEASUREMENT HISTOGRAMS FOR VARYING CONTRAST EDGES

```
      141     *******
      142     *************************************************************
***************
      143     ******************
      144     **
```

Filtered Image

```
      139     *
      140     *
      14i     ***
      142     *******
      143     ****************
      144     ******************************
      145     ***********************
      146     **************
      i47     **
      i48     **
      149     *
```

Unfiltered Image

TABLE 39 Line Width Measurement Histograms for 22.6um

```
138    *
139    ********************************************
140    ******************************************************
141    **
```

Filtered Image

```
136    **
137    **
138    *************
139    **************
140    ***********************
141    *****************
142    *******************
143    *******
144    ***
145    *
146
147    *
```

Unfiltered Image

TABLE 38 Line Width Measurement Histograms for 21.3um

133	*****
134	**************************************
135	**
136	****
137	*

Filtered Image

129	*
130	*
131	***
132	******
133	*************
134	****************
135	**********************
136	*************
137	************
138	*******
139	******

Unfiltered Image

TABLE 40 Line Width Measurement Histograms for 20.8um

```
134     *
135     ***
136     *******
137     **************************************************************
138     *************************************
139     *
```

Filtered Image

```
132     *
133
134     ***
135     *
136     ********
137     ****************
138     *********************
139     ************************
140     ***********
141     ************
142     ***
```

Unfiltered Image

TABLE 41   Line Width Measurement Histograms for 20.5um

APPENDIX L

LINE WIDTH MEASUREMENT HISTOGRAMS FOR DEGRADED LINE IMAGES

```
123     **
124     ***
125     ****************
126     ***********************
127     ********************
128     *******************
129     ***********
130     ******
131     ***
132     *
```

Filtered Image

```
101     *
102     *
103
104
105
106
107
108
109     **
110     **
111
112     **
113     ***
114     **
115     ****
116     ***
117     ******
118     *********
119     ***
120     ********
121     ******
122     *******
123     ********
124     ********
125     ****
126     ***
127     ****
128     *****
129     *****
130     *
131
132     **
133
134
135     *
```

Unfiltered Image

TABLE 42 Line Width Measurement Histograms for 30.1um

```
125      *********
126      *************************
127      ****************************
128      ****************************
129      ********
130      *****
131      **
```

Filtered Image

```
120      *
121      **
122      ****
123      *****
124      ****
125      *******
126      *********
127      ***************
128      ************
129      **************
130      **********
131      *********
132      ****
133
134      *
135      **
136      *
137
138      *
```

Unfiltered Image

TABLE 43 Line Width Measurement Histograms for 38.2um

```
126      **
127      ***
128      ************************
129      *****************************************
130      ********************************
131      *****
132
133      *
```

Filtered Image

```
119      *
120
121
122      **
123      ******
124      *******
125      *************
126      ***********
127      ***********
128      **************
129      *****************
130      ********
131      ******
132      *
133      **
134
135      *
136      *
137      *
```

Unfiltered Image

TABLE 44 Line Width Measurement Histograms for 54.0um