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# EXPERIMENTS IN SPATIAL COHERENT OPTICAL FILTERING

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# EXPERIMENTS IN SPATIAL COHERENT OPTICAL FILTERING


Rudolph K. Larsen
Data Techniques Branch
Electronics Division


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# EXPERIMENTS IN SPATIAL COHERENT OPTICAL FILTERING

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## ABSTRACT

Coherent Optical Techniques provide a means of processing entire pictures in parallel. Experiments were performed demonstrating the effectiveness of spatial frequency filtering in a Coherent Optical Data Processing System.

The experiments were performed by the author, a Goddard co-op student from Pratt Institute. During the period when these experiments were performed, he was assigned to the Computer Technology Section of the Data Techniques Branch for a five month work tour ending June 1971.

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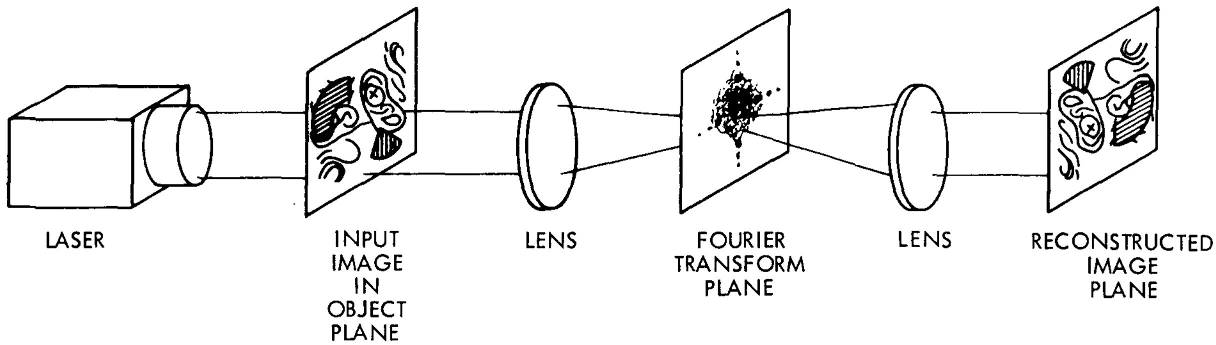


Figure 1. Coherent Optical Data Processor

## MATHEMATICAL BACKGROUND

The following is a brief math discussion of the relationship between the Object Plane, containing a particular target area, the resultant Fourier Transform Plane and the Reconstructed Image Planes. It will prove helpful in understanding the techniques applied in coherent optical data processing used to perform the experiments described in the second half of this report.

One of the most common waveshapes in electronics is the rectangular pulse. In this case, its constant amplitude depends on only one dimension, that is, time. Now consider a two dimensional rectangular pulse having a constant amplitude and of length a and width b as shown in Figure 2.

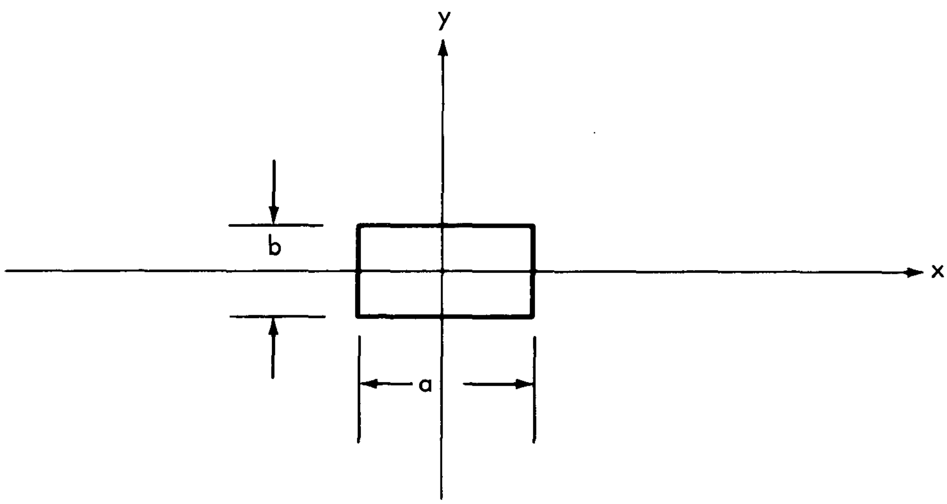


Figure 2. Two Dimensional Rectangular Pulse

# EXPERIMENTS IN SPATIAL COHERENT OPTICAL FILTERING

## INTRODUCTION

Future unmanned spacecraft will offer scientists a vantage point from space to study large areas of the earth and the planets for extended periods of time. Such spacecraft will be gathering huge amounts of pictoral data far surpassing the capacity of any telemetry link. A system will be needed whereby an orbiting spacecraft or planetary probe can be automatically selective in its choice of surface areas for observation and can process the image data in real time to telemeter back only desired information about the surface areas.

Most image processing techniques to date involve large digital computers requiring long run times to process even low resolution images. The only way of doing real time high resolution image processing involves parallel processing techniques whereby an image is processed at once, in tact, and not broken down sequentially into digitized bits of data.

Optical techniques, both coherent and non-coherent offer ways to do parallel image processing. In particular, coherent optics using laser technology has yielded promising techniques for processing images in the "spatial frequency" domain much the same as spectrum analysis techniques are used to process time varying signals.

A system involving such techniques is called the coherent Optical Data Processor. It basically consists of three components aligned in tandem, a laser and two lenses, as shown in Figure 1. At the output of the laser and at the focal points of the two lenses exists respectively, the Object Plane, Fourier Transform Plane, and Reconstructed Image Plane. Using coherent optics the first lens yields a filterable two dimensional Fourier transform of any pattern placed at the system's input. The second lens uses this filtered transform to form a Reconstructed Image which emphasizes target areas.

In the first part of this paper, an insight is given into the characteristics of a two dimensional Fourier Transform Plane based on mathematical illustrative examples. Types of spatial filters which can pick out areas or an image with certain spatial frequency characteristics are then discussed. In the second part of this paper, experiments are described and results are shown demonstrating the abilities of spatial frequency filtering techniques in picking out target areas in a field of image noise.

The spectial analysis of an electronic pulse yields a function of the form $\frac{\sin \omega}{\omega}$ when the Fourier transform is taken. A similar result would be expected in a two dimensional analysis of the rectangular function.

The Fourier transform of a two dimensional function f (x, y) is

$$F\,(u,v) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,\ y)\ e^{j(ux\ +\ vy)}\ dx\,dy$$

where, u, v represent coordinates of spatial frequency in the Fourier transform plane. If the rectangular function is of unity amplitude, in a background (remainder of the x -y plane) of zero amplitude, the integral is confined between its limits $-\frac{a}{2}$ to $+\frac{a}{2}$ and $-\frac{b}{2}$ to $+\frac{b}{2}$

giving,

$$F\,(u,v) = \int_{-\frac{a}{2}}^{+\frac{a}{2}}\int_{-\frac{b}{2}}^{+\frac{b}{2}} 1 \cdot e^{j(ux\ +\ vy)}\ dx\,dy$$

Solving this double integral yields,

$$F\,(u,v) = ab\left(\frac{\sin\frac{au}{2}}{\frac{au}{2}}\right)\left(\frac{\sin\frac{bv}{2}}{\frac{bv}{2}}\right) \qquad \text{EQ 1.}$$

Equation 1 shows that there are $\frac{\sin \omega}{\omega}$ terms along both the horizontal and vertical axis of the Fourier transform plane, i.e.,

$\frac{\sin\frac{au}{2}}{\frac{au}{2}}$ on the u axis and $\frac{\sin\frac{bv}{2}}{\frac{bv}{2}}$ on the v axis. Equation 1 is plotted in Figure 3. The concentric rectangles represent levels of equal light intensity similar to contour mapping of terrain.

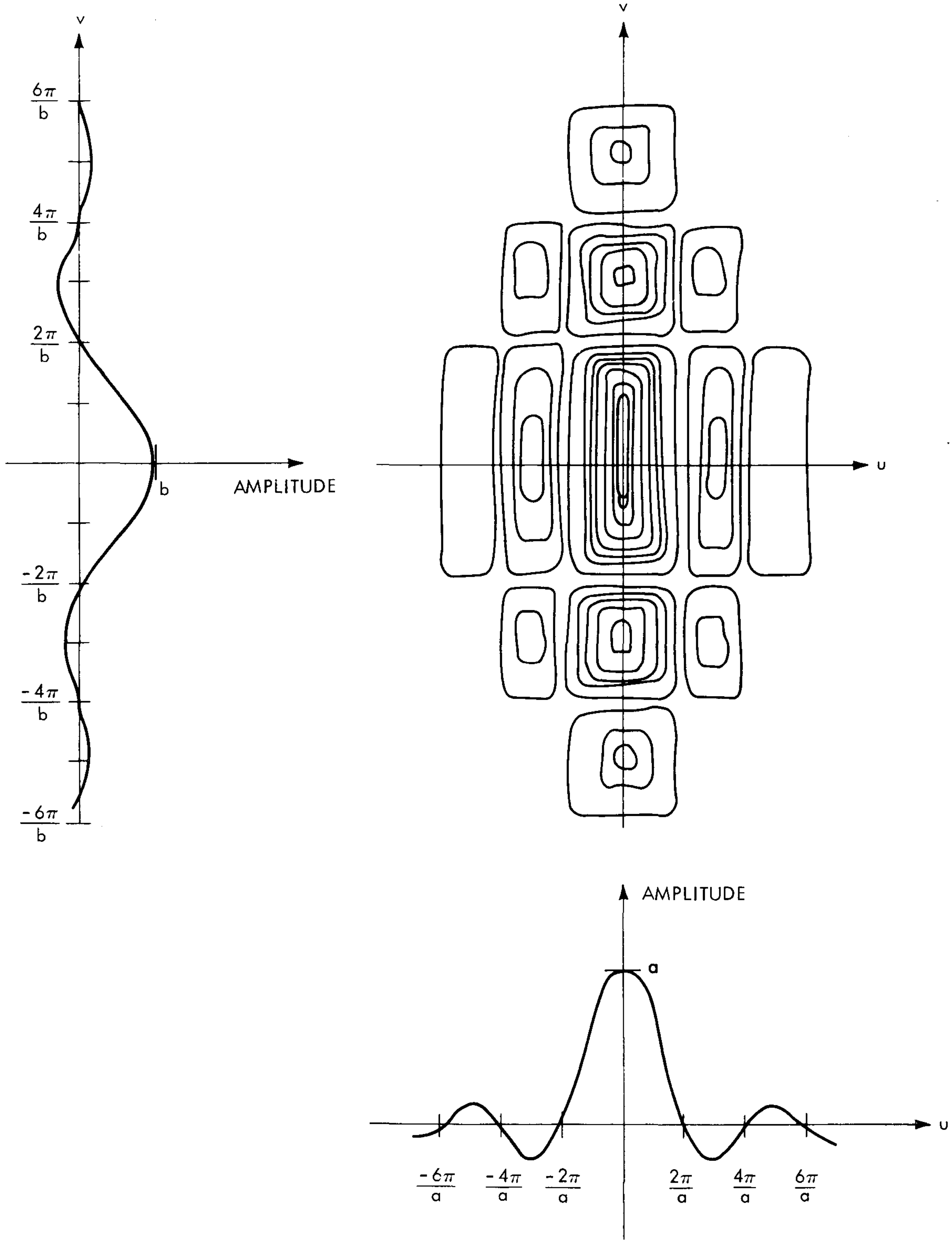


Figure 3. Graphical Representation of Two Dimensional Fourier Transform of Rectangular Pulse

Examining the $\frac{\sin \omega}{\omega}$ functions on each axis will aid in understanding how the size of the rectangular pulse function in the object plane affects the location and size of the bright areas in the Fourier transform plane. Looking again at Equation 1 and observing the function along the u axis ($v=0$), one sees that the envelope is simply $\frac{2}{au}$ which is inversely proportional to the dimension "a". Thus, as the dimension "a" is made smaller, the envelope decays much closer in. The same can be said of the function along the x-axis where the envelope spread is inversely proportional to the dimension "b". Thus, with "a" and "b" small, the Fourier transform is spread out. As "a" and "b" are made larger, the transform is confined closer to the center of the u, v plane.

If the rectangle was elongated to a horizontal bar by increasing the dimension "a" , analysis of Equation 1 shows that the envelope along the horizontal axis would decrease. However, the envelope along the vertical axis would remain unchanged. This creates a vertical pattern which is perpendicular to the rectangular bar. If the "b" dimension were elongated forming a vertical bar, the envelope along the v axis would shrink forming a horizontal pattern.

Thus, conclusions can be said concerning the Fourier Transform's relationship to the original rectangular function. If the rectangle were symmetrical in x and y, i.e., "a" was equal to "b", the Fourier transform is symmetrical since the envelopes along both the u and v directions decay at the same rate. If the rectangle is elongated in the horizontal direction, the Fourier transform will be elongated in the vertical direction. If the rectangle is elongated in the vertical direction, the Fourier transform will be elongated in the horizontal direction. Generally, symmetrical functions yield symmetrical Fourier transforms. Elongated functions yield elongated Fourier transforms but at $90^{\circ}$ to the function.

One further comment may be made about Equation 1. The location of the maxima of the $\frac{\sin \omega}{\omega}$ functions are proportional to $\frac{a}{2}$ in the u direction and $\frac{b}{2}$ in the v direction. Thus, by noting these spacings, one has a measure of the dimensions of the rectangle.

A more useful example is shown in Figure 4, where there are 5 parallel horizontal bars. Using the principle of superposition the Fourier transform can be taken separately for each of these bars and summed forming the Fourier transform of the field of five bars. The result is given by

$$F(u, v) = ab\left(\frac{\sin \frac{au}{2}}{\frac{au}{2}}\right)\left(\frac{\sin \frac{bv}{2}}{\frac{bv}{2}}\right)(2 \cos cv + 2 \cos 2cv + 1)$$

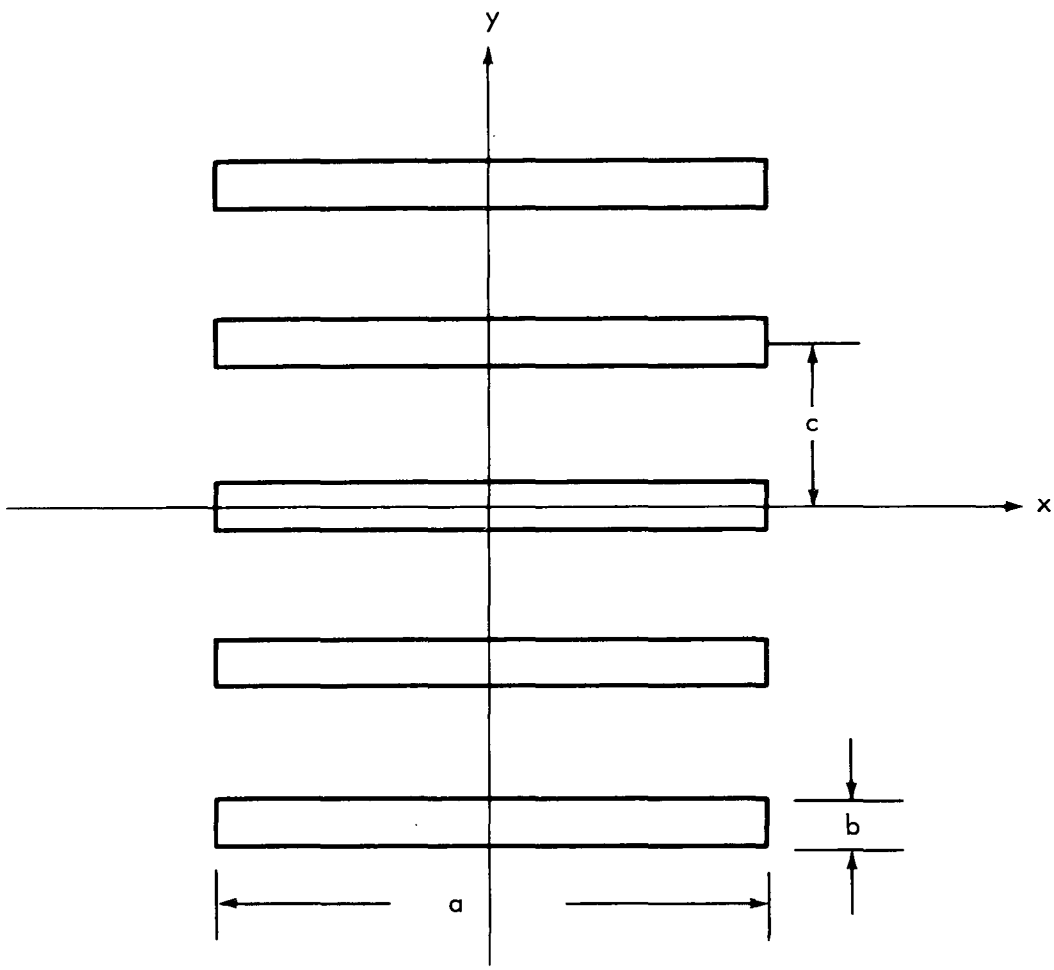


Figure 4. Five Parallel Horizontal Bars

This equation is plotted along the u and v axis in Figure 5. (In this Figure $C=2b$). On the u axis one has the same $\frac{\sin\omega}{\omega}$ function as in Equation 1, whose envelope decays inversely proportional to the length of the bars. Along the v axis, peaks appear. The spacing between these peaks is inversely proportional to the spacing "c" between the bars and is therefore proportional to the "spatial frequency" of the bars. The center peak represents the "D.C." component. The first peak away from the center (in both directions) represents the fundamental "spatial frequency", the second peak, the first harmonic and so on. As more bars are added in the original function, more terms are added to the summation in the Fourier transform causing the peaks to become narrower in the v direction. Thus if one examines one of the peaks, as plotted in Figure 5, the width of the peak in the u direction is an inverse measure of the length of the bars. The width in the v direction is a measure (also inversely) of the number of bars in the original pattern or function.

Two general conclusions can now be drawn concerning the Fourier Transform Plane. First: the radial distance from the center of the Fourier Transform Plane is a measure of the "spatial frequencies" contained in the original function. This is illustrated by the spacing "c" in Figure 4 and the corresponding location of the peaks in the Fourier transform. The smaller "c" is, the higher the spatial frequency and the further out the peaks will be. Second, if information is confined at a given angle in the Fourier Transform Plane, there is an elongated structure in the original function along a direction perpendicular to this angle.

The relationship between a two dimensional pattern and its Fourier transform has been described. An inverse Fourier transform can then easily be taken to reconstruct the original pattern. However, should certain areas of the Fourier transform function be purposely masked before the inverse is applied to it, the reconstructed pattern will undergo a controllable modification.

Two general conclusions were just drawn about the Fourier Transform Plane of an object which can be applied here. Spatial frequency is dependent on the radial distance from the center and orientation is dependant on the angle at which the frequency information lies. Thus, circular masks would be frequency dependant and rotating slits or wedges would be orientation dependant. Spatial frequency filters are analogs to electronic filters. Placed in the Fourier Transform Plane, a circular aperature would be a low pass filter while an opaque disc would pass high frequencies. Combined they would form a transparent ring which would act as a band pass filter. Ring thickness would determine the bandpass while its radius would determine the frequency range.

Since orientation is dependant on the angle of inclination about the center, rotating slits or wedges could be used to pass or block all frequencies along a given angle. Wedge thickness would govern range of angles involved. Combining both ring and wedge filters would yield a highly selective filter capable of choosing a narrow band of spatial frequencies along a given angle of inclination.

These filters can be used to mask the Fourier transform of the horizontal bars just discussed. An Inverse Fourier transform can then be taken with the newly masked transform as its input function. Obviously, the reconstructed image will no longer be identical to the original object. However, the results can be predicted. Low and high pass frequency filters will allow most of the image to reconstruct if the fundamental and few basic harmonics are allowed to pass. The most interesting frequency filter, though, is the bandpass. If it passes the

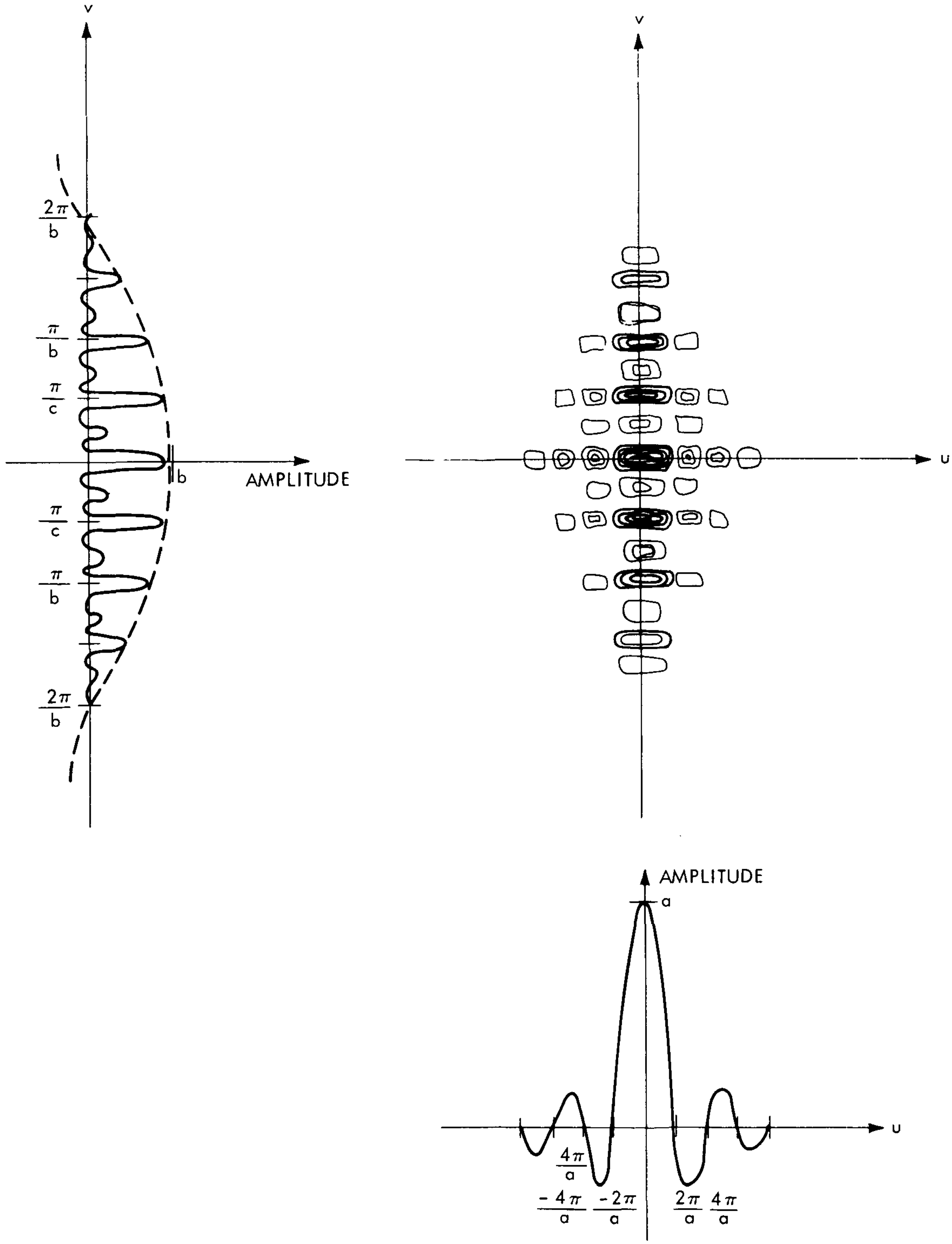


Figure 5. Graphical Representation of Two Dimensional Fourier Transform of Parallel Bars

fundamental frequency (Figure 5) a reconstructed image will appear, not as discrete bars but as an area varying sinusoidally in intensity. Furthermore, it will occupy the exact location of the original object.

Should two identical sets of parallel bars be placed in the Object Plane but at different angles to each other the bandpass filter will not separate them in Reconstructed Image Plane. However, since their Fourier Transform will be localized along distinct angles from one another, wedge filters blocking the D.C. component can be used. The wedge filter will pass all the frequencies of one set and only this set will appear in the Reconstructed Image Plane.

Now that the theory has been explained concerning spatial frequency and analyses using the Fourier transform, the experiments performed in perfecting the techniques are described.

## EXPERIMENTS

The main object of the experiments was to locate simple geometric targets such as groups of equally spaced parallel lines from fields of background patterns using simple coherent optical filtering techniques. The targets have "localized" Fourier transforms which can be passed using simple filters while the remainder of the Fourier transform plane is blocked. The experiments consisted of three phases. Each phase yielded a series of pictures of the Reconstructed Image Plane showing the results of placing various filters in the Fourier transform plane.

The initial phase of experiments sought to obtain an understanding of the spatial frequency spectrum of the "elbow" and "pie" patterns shown in Figure 6-A in a background of thin-lined random direction noise. Band pass filters were made by painting glass, and parallel razor edged slits were used for orientation filters. Although these tests were crude they demonstrated the feasibility of locating the targets.

The second phase of the experiments utilized a more precisely made series of ring and wedge filters. These were fabricated using photographic techniques and their dimensions correspond to those of a set of electronically controlled ring and wedge filters presently in the process of procurement. Once the techniques of pinpointing the objects from a light noise background such as the random thin lines, was established a much "heavier" noise background was added to the "pie" and "elbow" region as shown in Figure 11-A.

Finally, the third phase of the experiments called for locating very small target areas of parallel equally spaced lines in a background of similar parallel lines,

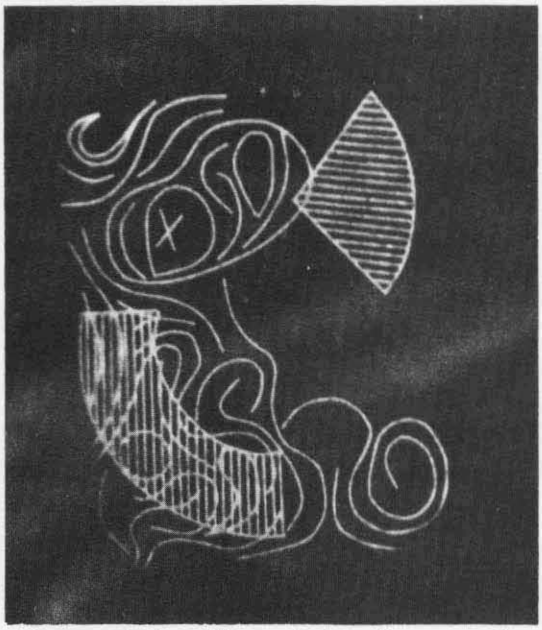

Figure 6-A Elbow & Pie Patterns in Light Noise

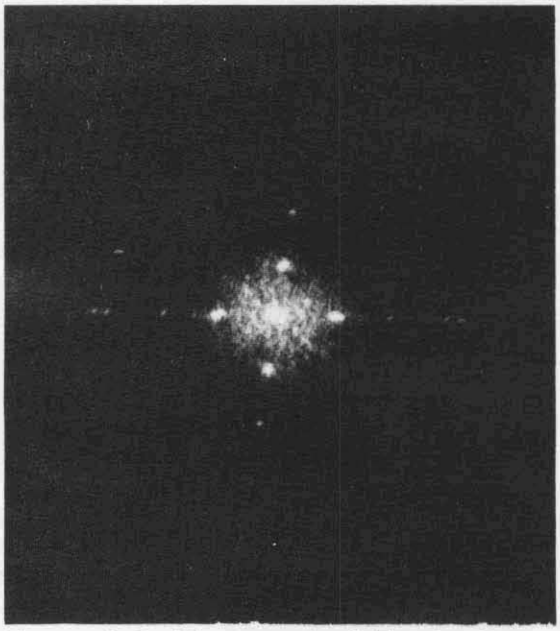

Figure 6-B Photograph of Fourier Transform of Patterns in Figure 6-A

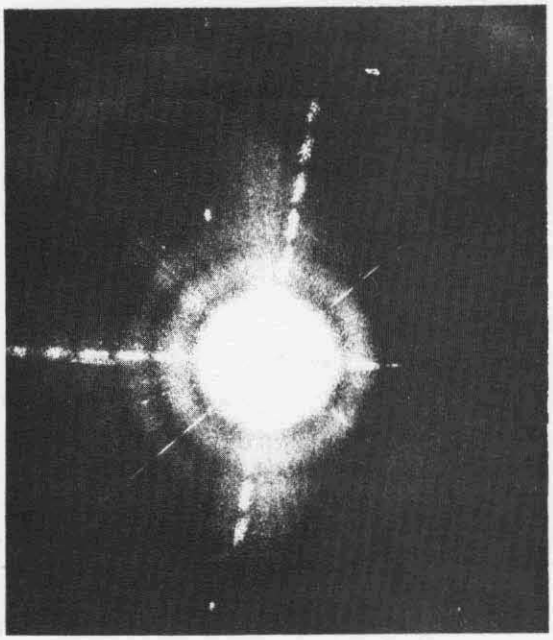

Figure 6-C Over Exposed Photograph of Same Fourier Transform

many of which were in the same direction but were of random frequency as shown in Figure 12-A. This was done to test the feasibility of frequency band-pass filtering alone since much of the noise was in the same direction as the target.

PHASE I

Figure 6-A shows the reconstructed image with the Optical Data Processing System discussed earlier, when no filtering is done in the Fourier transform plane. The "slice of pie" shaped area consists of bars running horizontally, while the "elbow" is made up of vertical bars. Noise is represented by the abstract pattern running through the elbow from the upper left to lower right and in various areas of the image.

Figure 6-B is a photograph of the Fourier transform of Figure 6-A. The four bright first harmonic spots around the D.C. component carry the basic information of location and frequency of the two target patterns. Figure 6-C is an over exposed photograph of the Fourier transform plane. The two nearly perpendicular lines consist of higher order harmonics of the "pie" and "elbow". The concentric circular patterns represent the omnidirectional harmonics of the noise.

A transparent ring was made by simply scratching black paint off a glass slide. It was placed directly in the Fourier transform plane, permitting only the ring of light emcompassing the four dots to pass through. In effect, it allowed only a narrow band of spatial frequencies to pass. The resultant reconstructed image is shown in Figure 7-A. Note that the ring filter is omnidirectional. Hence, it would also pass all harmonic frequencies that fall within the narrow bandpass of the filter regardless of source. Figure 7-A shows that the noise contribution was still present but attenuated.

By decreasing exposure time as in Figure 7-B one can see that a no noise threshold could be reached where the "elbow" and "pie" is easily detected. A much greater attenuation of noise was achieved by painting out further areas of the transparent ring filter as shown in Figure 7-C. It has the same exposure time as Figure 7-A and shows that noise components are already attenuated.

The effects of orientation filtering were observed by alligning two parallel razor edges such that the near vertical line of harmonics peaks of Figure 6-C was allowed to pass through the Fourier transform plane. Also the D.C. component was blocked. The reconstructed image is shown in Figure 8-A. The pie shaped area easily stands out along with all horizontal tangents to the background noise. The same occurs for the elbow in Figure 8-B when the razor edges

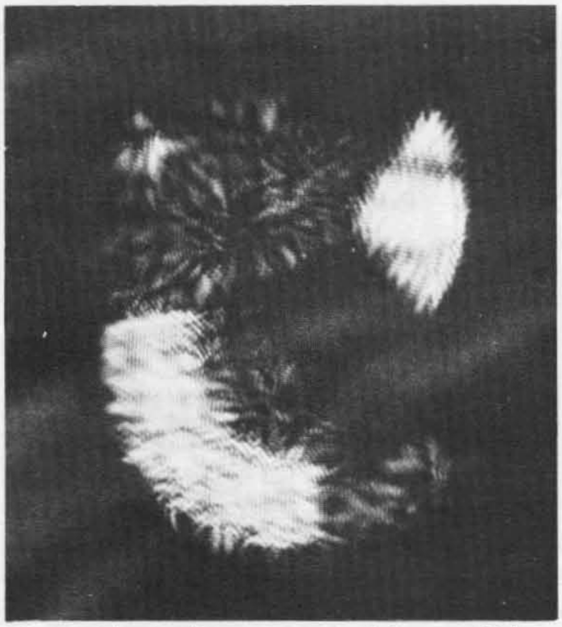

Figure 7-A Reconstructed Image Using Painted Ring Filter

Figure 7-B Reconstructed Image with No-Noise Exposure Threshold Reached



Figure 7-C Reconstructed Image Using Maximum Masking with Paint

Figure 8-A Reconstructed Image Filtered by Razor Slits to Pass Pie

Figure 8-B Reconstructed Image Filtered by Razor Slits to Pass Elbow



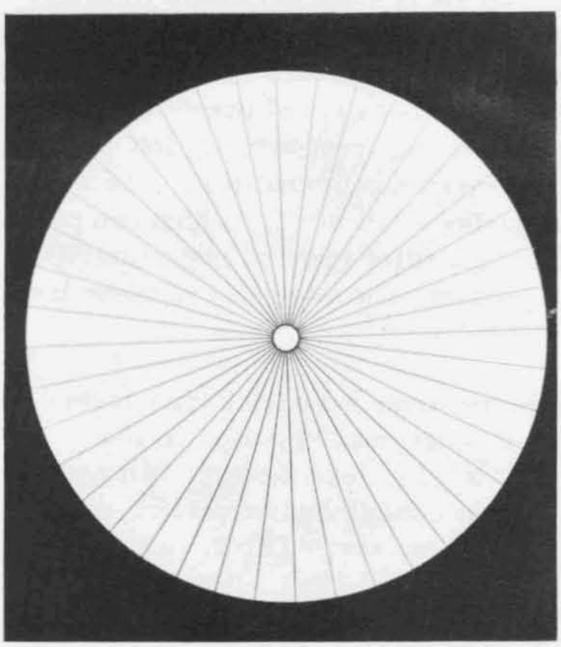

Figure 8-C Geometry of Ring Filters

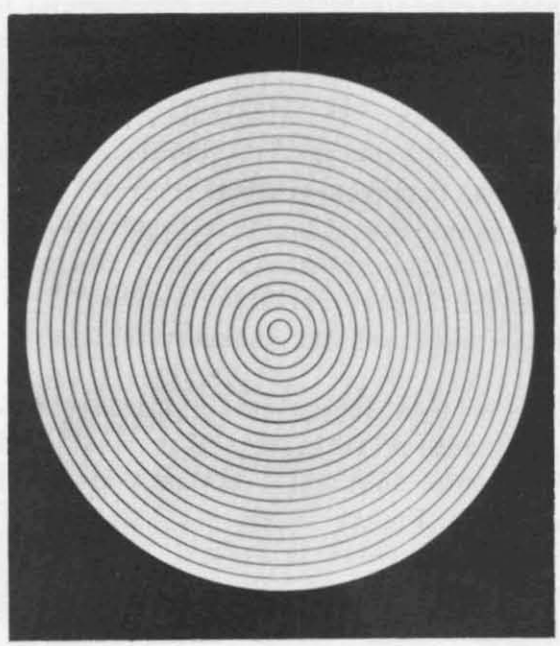

Figure 8-D Geometry of Wedge Filters

were horizontally fixed. The D.C. component carries brightness information of all areas of the object plane. Hence, it was blocked to prevent objects of undesired orientation to appear in the reconstructed image plane.

These initial experiments showed that frequency bandpass ring filtering could easily select the desired targets by passing the fundamental frequencies of those targets. Bandpass filtering could not select one target among several of similar frequencies lying in the passband ring. These filters eliminate all noise except noise whose spatial frequencies lay inside the bandpass ring. Such areas might then be placed below a threshold level of detection. A rotating D.C. blocking slit filter could select areas whose spatial frequencies have similar orientation regardless of frequency. Noise whose spatial frequencies lay outside the selected line of orientation would be completely attenuated. However, some noise patterns have edges in directions which caused much of their Fourier transform energy to lie within the slit so that this energy would pass through full strength. These edges would be reconstructed in the reconstructed image and could not be placed below a threshold of detection. Indeed, some combination of frequency and orientation filtering of the Fourier transform Plane is necessary.

PHASE II

One of the main aims of the second and third phases of the experiments was to predict the usability of an electrically alterable set of ring and wedge filters that are to be developed. To do this a series of ring and wedge filters with the same dimensions as the electrically alterable ones was produced on photographic glass slides. The electrically alterable ring filter consists of twenty concentric rings which can be individually made opaque or transparent forming low pass filters, bandpass filters, high pass filters or various combinations. The wedge filters consist of 40, nine degree wedges covering a full circle, which can be made opaque or transparent. The wedge and ring filters can be placed in the Fourier Transform Plane individually or in tandem. The geometry of these two types of filters are shown in Figures 8-C and 8-D.

Figure 9-A again shows an image reconstructed from a Fourier transform plane with no filtering. Figures 9-B and 9-C were made by passing the horizontal dots and then vertical dots through the nine degree wedge filter as shown in Figure 10-A. Further filtering was accomplished by placing the ring filter shown in Figure 10-B directly behind the wedge filter. The results of this combined filtering is shown in Figures 10-C and 10-D. Note that edges have become ill-defined yet the center of the targets can still be pinpointed and extraneous noise has been completely eliminated.

In a more difficult test of the effectiveness of the combination of the ring and wedge filters, a much heavier noise pattern was developed with approximately

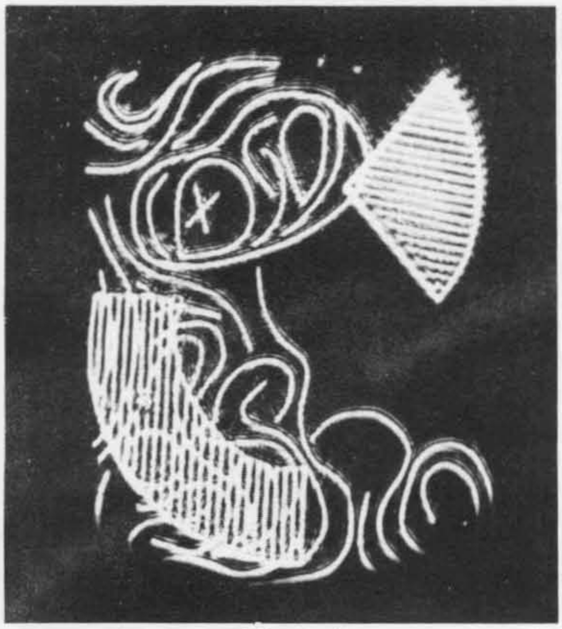

Figure 9-A Unfiltered Reconstructed Image

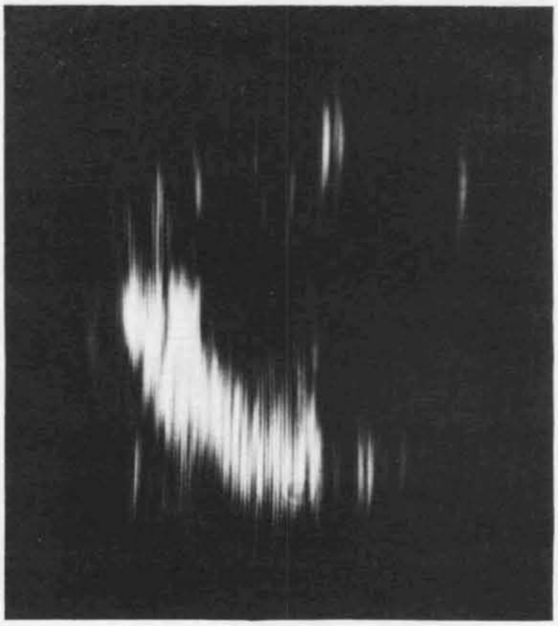

Figure 9-B Reconstructed Image Using Glass Slide Wedge Filters to Pass Elbow



Figure 9-C Reconstructed Image Using Glass Slide Wedge Filters to Pass Pie

ACTUAL SIZE

Figure 10-A Wedge Filter Made from Photographic Glass Slides

ACTUAL SIZE

Figure 10-B Ring Filter Made from Photographic Glass Slides



Figure 10-C Reconstructed Image of Elbow Using Glass Slide Ring and Wedge Filters

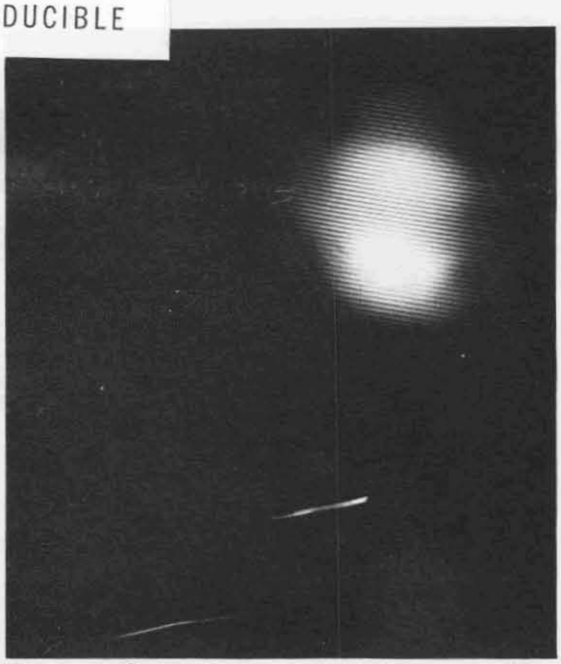

Figure 10-D Reconstructed Image of Pie Using Glass Slide Ring and Wedge Filters

the same D.C. level of brightness as the target areas but of lower frequency. Figure 11-A shows the unfiltered reconstructed image while Figure 11-B demonstrates the effectiveness of the ring filter alone in seeking out the target areas. With wedge filtering added, the two target areas can be selectively choosen as in Figures 11-C and 11-D. Notice that centers of the areas can easily be found and noise has been effectively eliminated.

This second phase of experiments demonstrated the combined effectiveness of the ring and wedge filtering. By sequentially sampling a set of bandpass filters or wedge filters in an automated spacecraft system, the location of different target areas could be pinpointed. Excellent results were exhibited both with a light noise background and the more heavier noise background.

PHASE III

Having demonstrated the effectiveness of locating target areas in random noise patterns, a further test was made to find small target areas within a background of similar structure. Figure 12-A presents such a problem. Note there are four possible target areas. Areas a, b and c are of about the same frequency, while area d, located in the center is of extremely high frequency.

First, the very small area c, was to be detected. A bandpass filter was placed in the Transform Plane passing the frequencies of areas a, b and c as shown in Figure 12-B. All three areas stand out from the background structure. Now a wedge filter was placed in the Transform Plane and used to isolate area c in the Reconstructed Image Plane. However, a $9^{\circ}$ wedge proved too narrow to pass enough information concerning area c. A wider wedge had to be used since for this particular structure, high frequency information is spread out laterally within the ring or bandpass filter. A wedge of about $27^{\circ}$ proved effective in locating the target without passing the other two areas of similar frequency. The target is clearly shown in Figure 12-C.

In the second test, area d was to be detected and it is shown magnified in Figure 13 - A, photographed in the Reconstructed Image Plane with no filtering. Figure 13 - B shows the reconstructed image with a high frequency bandpass filter centered over the frequency spots of the target in the Fourier transform plane. It shows the high frequency components of the background. Figure 13-C illustrates a less exposed photograph of this plane taken at a threshold at which only the target area is recorded on film. Finally, Figure 13-D results when a wedge filter was added in the Fourier transform plane.

The two targets provided experience in varying the size of the bandpass filters and the width of the wedge filters to compensate for changes in the identifying

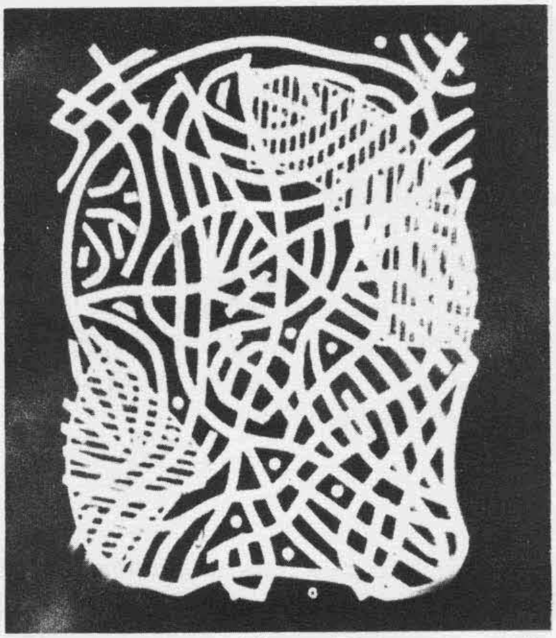

Figure 11-A Unfiltered Reconstructed Image of Elbow and Pie in Heavy Noise

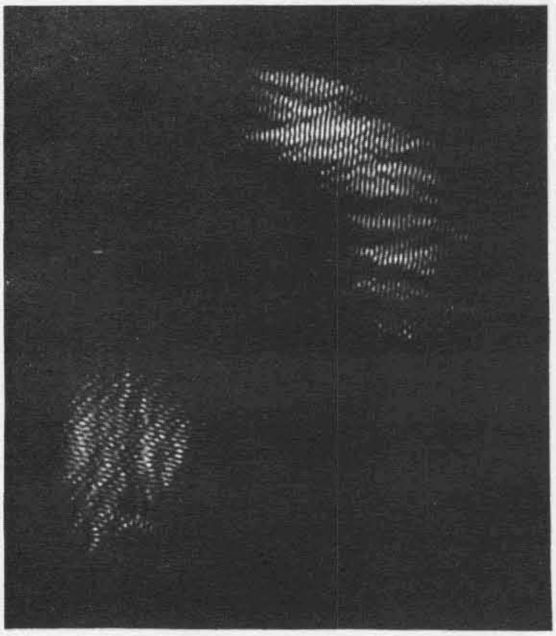

Figure 11-B Reconstructed Image Using the Glass Slide Ring Filter Alone

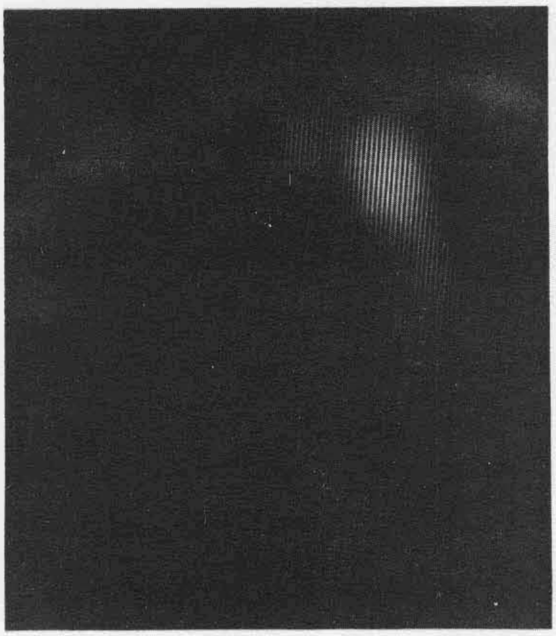

Figure 11-C Reconstructed Image of Elbow Using Glass Slide Ring and Wedge Filters

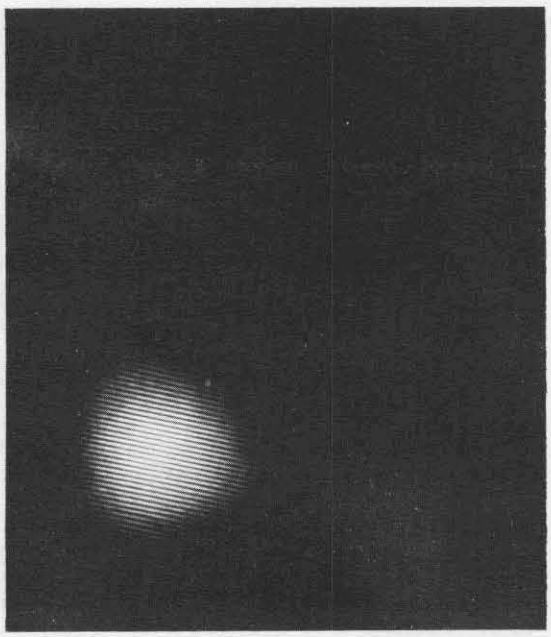

Figure 11-D Reconstructed Image of Pie Using Glass Slide Ring and Wedge Filters

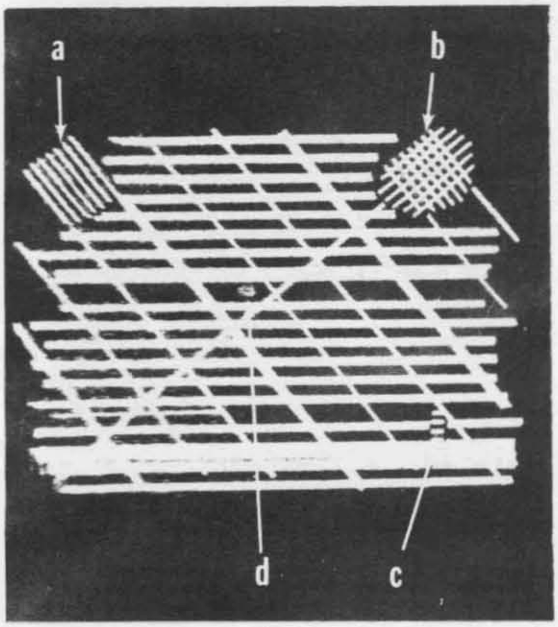


Figure 12-A Unfiltered Reconstructed Image with Small Target Areas in a Background of Similiar Structure

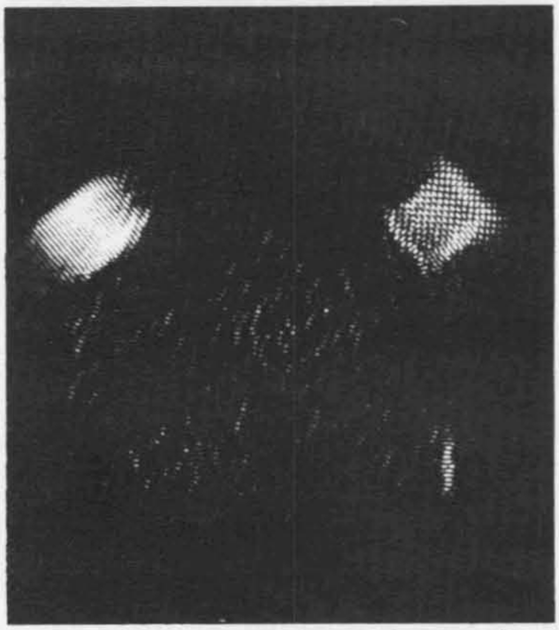

Figure 12-B Reconstructed Image of Figure 12-A Using Frequency Filtering with Glass Slide Ring Filter

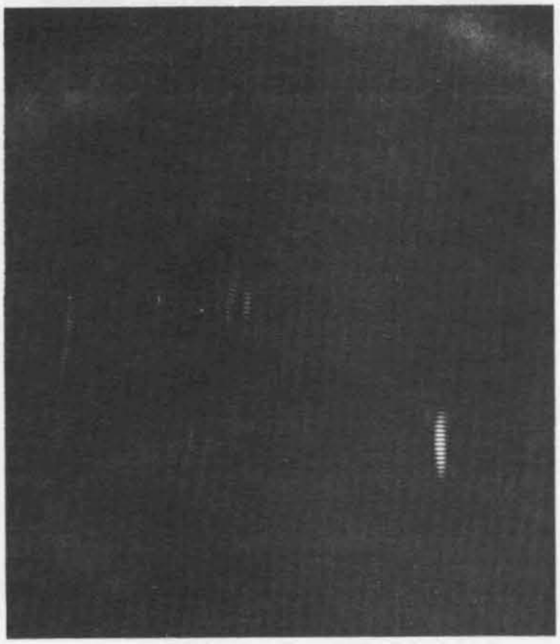

Figure 12-C Reconstructed Image of (12-A) Using both Ring and Wedge Glass Slide Filters

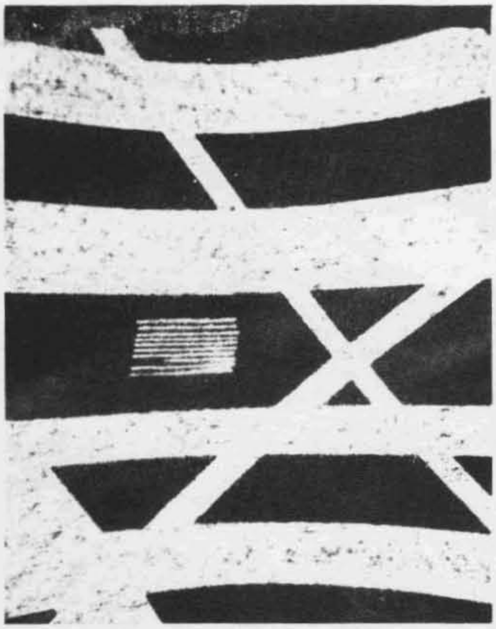

Figure 13-A Magnified Unfiltered Reconstructed Image of Area "d"

Figure 13-B Magnified Reconstructed Image of Area "d" Filtered Using High Frequency Glass Slide Ring Filter



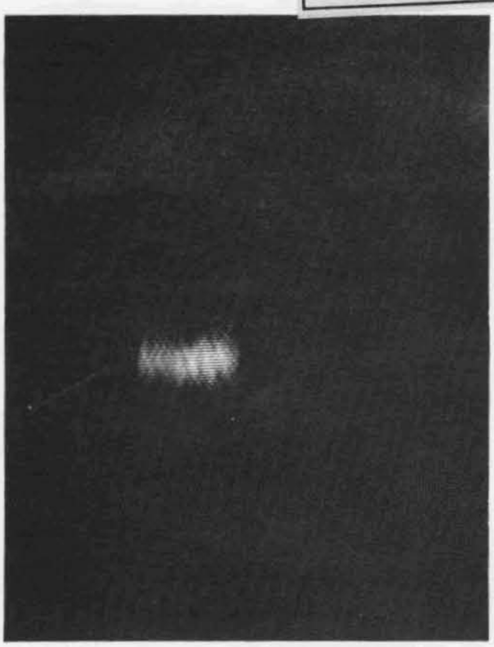

Figure 13-C Same Filtered Image as Figure 13-B, but with Film Exposure Reduced

Figure 13-D Magnified Reconstructed Image of Area "d" Filtered by Both Ring and Wedge Glass Slide Filters

characteristics of target areas. The first target (area c) consisted of very narrow horizontal lines. This tended to enlarge the area in the Fourier transform plane containing information about this area. The ring filter was wide enough to pass the frequency but as just reported the wedge had to be widened enough to get all the information within the ring. The second target contained very high frequencies which were confined to a small spot in the Fourier transform plane. Hence, the bandpass filter used, had to have a high center frequency (large radius) while still maintaining the thiness of its transparent ring (narrow band). Since the frequency of the object was so high with respect to the background noise, bandpass filtering alone provided substantial signal to noise ratio while the added orientation filtering only served to blurr the edges of the target. Hence, the two target areas demonstrated the need for flexibility in filtering and the need for easily alterable filters.

As an added experiment a further property of the Fourier Transform Plane was tested. The heavy noise object pattern was taken and a negative was made of it. It was desired to see whether identical results could be obtained when filtering the Fourier Transform Plane of each of the two objects. Math analysis would predict that only the D.C. component would change in intensity yet location of peaks representing frequency would not shift.

Figures 14-A and 14-B show the complemented objects. The fundamental harmonic dots for Figure 14-A were found in the Fourier Transform Plane and frequency filtered to yield Figure 14-C in the Reconstructed Image Plane. Without changing the location of the frequency filter the complementary object Figure 14-B was placed in the object plane and its frequency filtered Reconstructed Image noted as in Figure 14-D. It was nearly identical to Figure 14-C. Wedge filtering for the "pie"was similarly performed and the results are shown in Figure 15-A and 15-B. Finally, the elbow target area was filtered using the combined ring and wedge filters and the results are shown in Figure 15-C and 15-D. The overall results of this added experiment show that the two object patterns, although complementary, have the same frequency components and can be filtered identically to reveal target areas. This fact can be put to good use. An object pattern containing many bright areas will display a strong D.C. component in the Fourier Transform Plane. Unfortunately spherical aberations in the first lens may cause this D.C. component to lose its sharpness and mask lower frequencies that may be desired for filtering. Hence, by taking the object pattern's negative complement and using it instead, a new Fourier transform will be formed with identical frequency components but with a D.C. component of much lower amplitude.

Additionally this experiment demonstrated that devices that present the negative of an input image are as satisfactory for data processing tasks as devices that present the positive of an input image.

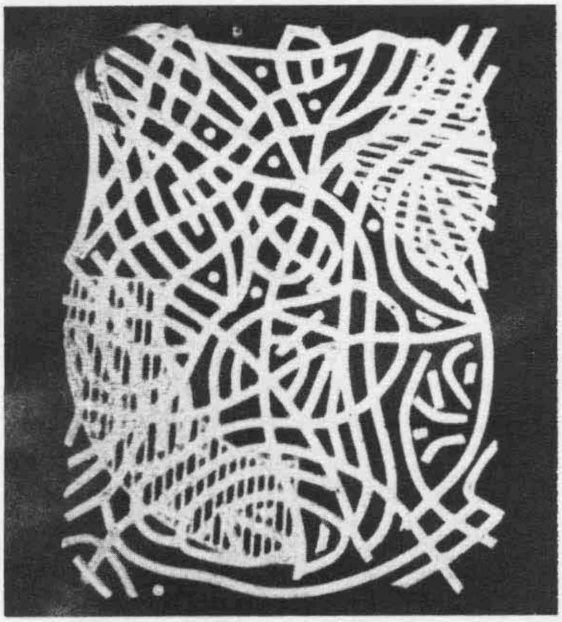

Figure 14-A Unfiltered Reconstructed Image of Elbow and Pie Target Areas in Heavy Noise, White on Black

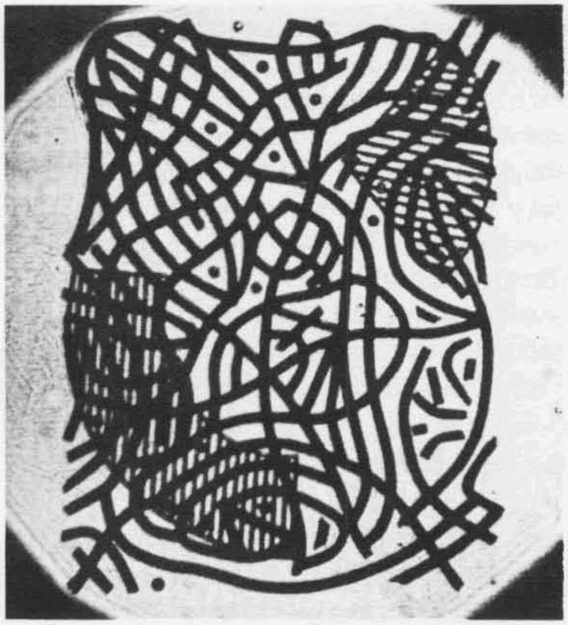

Figure 14-B Complement of Figure 14-A, Black on White

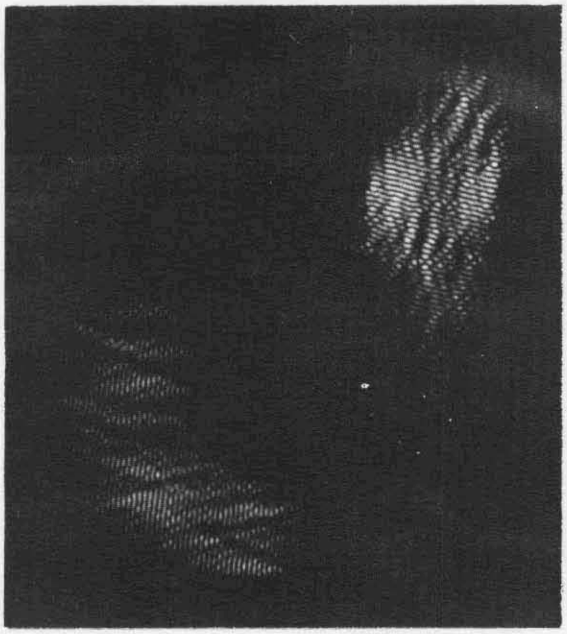

Figure 14-C Frequency Filtered, Reconstructed Image of White on Black Pattern shown in Figure 14-A

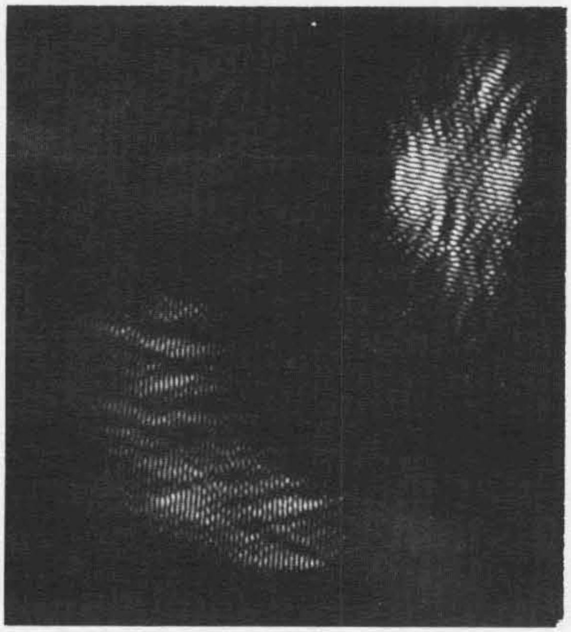

Figure 14-D Frequency Filtered Reconstructed Image of Black on White Complement

Figure 15-A Reconstructed Image but Filtered by Wedge Glass Slide Filter to Reveal Pie Target Area

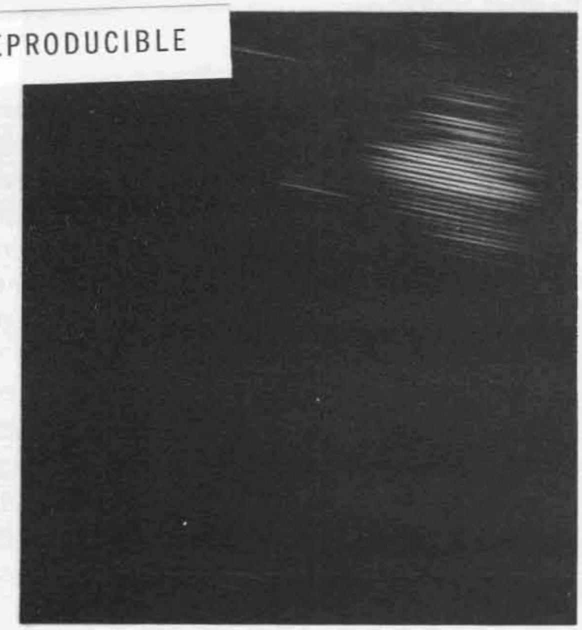

Figure 15-B Identical Filtering Used with Figure 15-A but with Black on White Complement

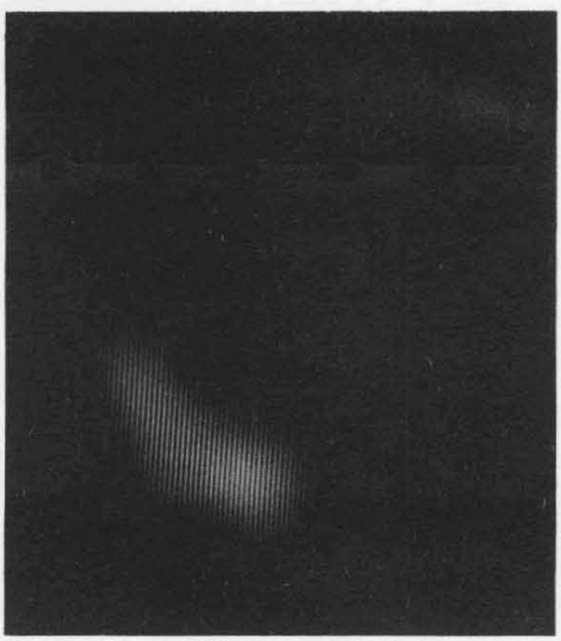

Figure 15-C White on Black Reconstructed Image but Filtered with Both Ring and Wedge Filters to Reveal Elbow Target Area

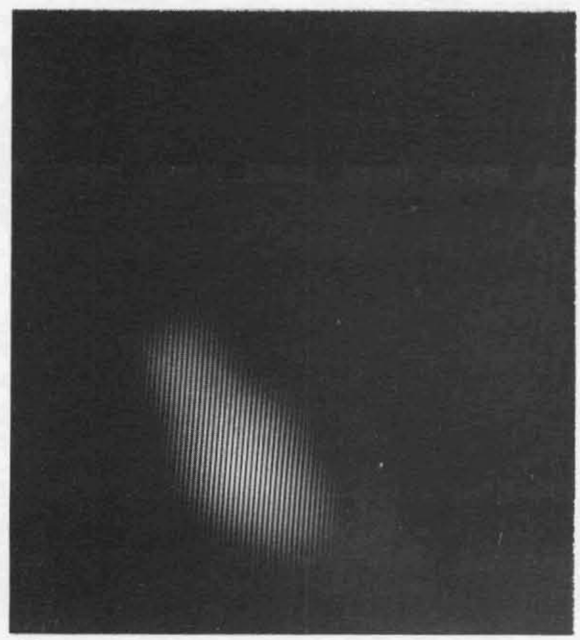

Figure 15-D Identical Filtering Used with Figure 15-C but with Black on White Complement

## CONCLUSIONS

In conclusion, this report has developed the relationship between a two dimensional pattern and the Fourier transform. Then it has shown how areas of this Fourier Transform can be filtered before taking an Inverse Fourier Transform to reconstruct the original image. These mathematical principles can be directly applied to a coherent Optical Data Processing System. The principles were demonstrated in a series of experiments. The first phase demonstrated frequency and orientation filtering to bring out desired target areas in light random noise. The second phase ensured the correctness of dimensions proposed for electronically alterable ring and wedge filters while showing the effectiveness of picking out target areas from heavy random areas. Phase three then successfully tested the ability of the system to pick out small target areas from background noise of similar orientation. The targets of both high and low frequency were sought to test various sizes of ring and wedge filters. An added experiment was performed on both the heavy noise target pattern and its negative complement. This showed the effects of a noisy D.C. component could be avoided.

Overall results of the experiments show a method for processing patterns or pictures containing target areas whose Fourier Transforms are localized along a certain angle and whose harmonic frequencies tend to peak. These target areas can be successfully filtered out from more random background noise patterns. The results, then, point to the development of system capable of analyzing more complex pictures containing such target areas as cultivated fields amongst a background of rough irregular terrain. As further research is performed with the coherent Optical Data Processor more techniques will be developed so that this goal will be realized and applied to the study of the earth and planets by satellite.

## ACKNOWLEDGEMENT

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