[redacted]

May 22, 1970

Attention: John C.

Dear John:

Enclosed for your files are three (3) copies of Activity Summary, [redacted]/2201201-AS-4. Attached to each copy is the Program Plan dated May 20, 1970.

Sincerely,

[redacted]

PSC/c
Enclosures

Approved For Release 2005/11/21 : CIA-RDP78B05171A000500020026-5

 STAT

[redacted]

May 22, 1970

ACTIVITY SUMMARY

To: John C.
From: [redacted] STAT
Subject: Contract Visit to Customer Facility
May 19,20, 1970
[redacted] STAT
STAT Reference: [redacted]/2201201-AS-5

On May 19, 20, 1970 [redacted] STAT
STAT [redacted] conducted a laboratory visit under the above referenced program. The performance of the laboratory program has advanced during the past few weeks to a point where we can begin concluding the initial phase of the effort, namely the initiation and demonstrated activity of the holographic systems. Reference to the lab notebooks will show target detection results with good detection quality. It is now our main interest to put together demonstrative illustrations of the system performance, both for detection and image processing objectives. We are also, at this time, laying out some of the basic objectives for initiation of the partially coherent image processing activity on the Bech optical bench.

The text, The Feynman Lectures on Physics, Vol. II, by Richard P. Feynman et al., Addison-Wesley Publishing Company, was delivered to the laboratory on May 19.

The specifics of our effort during these two days are written up in the laboratory notebook. The Program Plan that outlines work to be accomplished, based on the program status at the close of 20 May, was generated on that day and left with John C. A copy is attached to this activity summary.

The next trip is planned for the week of May 25, 1970, with [redacted] scheduled to be at the laboratory.

PSC/c
Attachment

 [redacted]

Program Plan

To John C.

STAT From [redacted]

Date 20 May, 1970

Subject:- Program Plan for Interim Period.

The status of this program is such that we can now begin final proceedings to conclude the preliminary phase of this program. This preliminary phase included set-up of the holographic interferometer and coherent processor, and activation of these systems for fabricating holographic filters for target detection and image restoration. We have performed these tasks and met these objectives with good results. We now want to put together a set of illustrations and results to enable demonstration of the objectives that we have gained.

To demonstrate the goals that have been attained we can use the specially prepared target for demonstration of target detection, as well as some simulated or de facto operational material for target detection. We also are to demonstrate image restoration and will generate motion blurred imagery for the restoration demonstration. The program is as follows:—

(1) Prepare imagery for demonstration of target detection utility to operational materials and system utility to image processing. Obtain simulated or real reconnaissance imagery with targets of interest for the former. Plus a prepared target for the image processing demonstration.

STAT

Target should be blurred sufficiently to effect spurious resolution of the alph-numeric characters in the target format. Note processing requirements previously discussed and formating of blur target.

(2) Fabricate filters for targets generated in (1) above. Follow directions we discussed to ensure that the expected signal is recorded on the hologram filter. This is essential if filtering is to occur. To accomplish this it may require the filter fabrication step from a specially generated target input, such as a slit for image blur removal or a very high contrast image of a plane. If the diffraction pattern is not apparent on the filter, out beyond the central order of the interferometer point response then the filter is not satisfactory.

(3) Test filters and record data on film.

(4) Print up results of test series including original input, the filter, and the detected output (correlation beam only).

(5) Draft out diagrams that can be used for briefing material. Direct all for display in lab.

(6) Write up sufficient documentation to allow initiated to operate system. In essence this is an operators manual.

Schedule

Task no.	May 20	21	22	25	26	27	28
1		xxxx	xxxx	xxxxx	x		
2		xxxx	xxxx	xxxx	xxxx	x	
3			xxxxx	xxxxx	xxxxx	xxxx	xx
4						xxx	xx
5						xxx	xx ...
6					x	xxxx	xx ..

Lecture Notes

STAT [redacted]

STAT [redacted]/2201201-TM-2

5 May 1970

Fourier Transform Hologram

An interferometer has been set-up on the granite surface plate for fabricating Fourier transform holographic detection filters. The system set-up is described in detail in the lab notebooks and is of the configuration shown below. The laser output is imaged

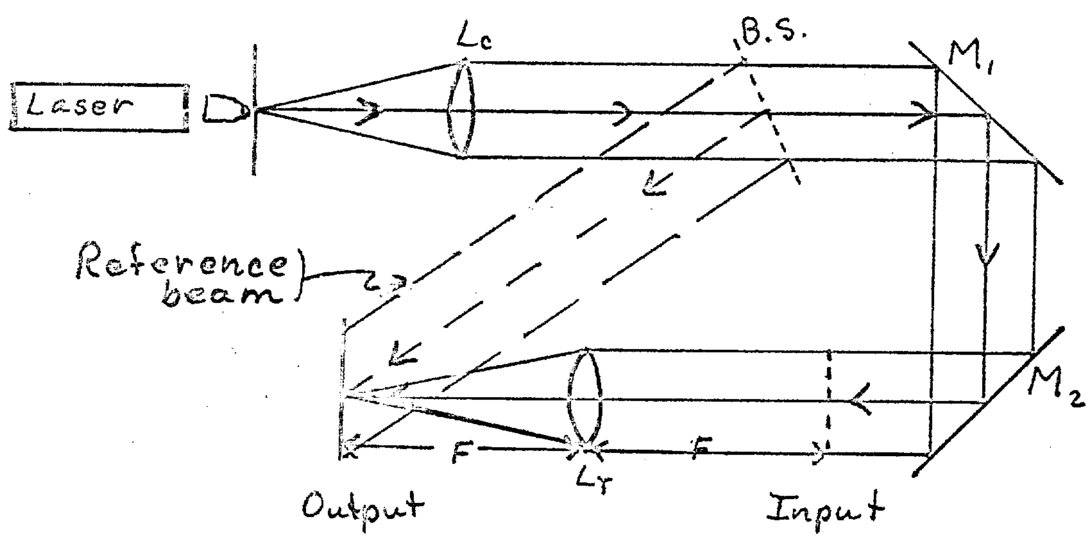

Fig. 1 Interferometer for generating Fourier transform holograms. Lc is the collimating lens, L_T the Fourier transform lens, B.S. the beam splitter and M the mirrors.

through a microscope objective onto a pinhole. The illumination passed by the pinhole is divergent, and that intercepted and passed through the collimating lens is collimated. The pinhole should be small. The output from L_c can be considered ideally collimated only if the pinhole diameter is smaller than the resolution spot (Airy spot) diameter of the collimating lens. The Airy spot diameter D is given by

$$D = 2.44 \frac{\lambda F}{a}$$

where F is the focal length and a the aperture diameter of L_c, and λ is the output wavelength of the laser illumination. The collimating lens in use has F = 446 mm., a ≈ 50 mm., giving D = 13.8 μm. Since this is a diffraction limited value one could estimate that the actual spot size is closer to the source pinhole diameter. Complete collimation is not always required. A small divergence in the wavefront will not be noticeable, especially at the limits that we are discussing here.

The diameter of the collimated beam must be considered from the viewpoint of its application. This diameter specifies the format size that can be illuminated at the input plane of the interferometer. It also defines the format of the output hologram. Since we are using this hologram as a detection filter, the format will determine the aperture function of the coherent processor where the aperture limit specifies the resolution limit of the processor. This resolution limit vs. aperture diameter response is illustrated on the graph shown on page__. Since the Fourier transform lens [illegible] is a 300mm., f/5.6 Schneider Symmar, the lens limiting aperture is approximately 53.5 mm.. Therefore the two inch diameter collimated beam is completely sufficient for this system. It will be found that other components such as the beam splitter and mirrors, and the film and camera at the output of the interferometer, are the primary factors limiting the filter format. We should obtain components that will not limit format; of primary importance is the beam splitter format. The optical glass is thick (as is the nature of high quality

Lens Resolution
(Rayleigh Criterion)

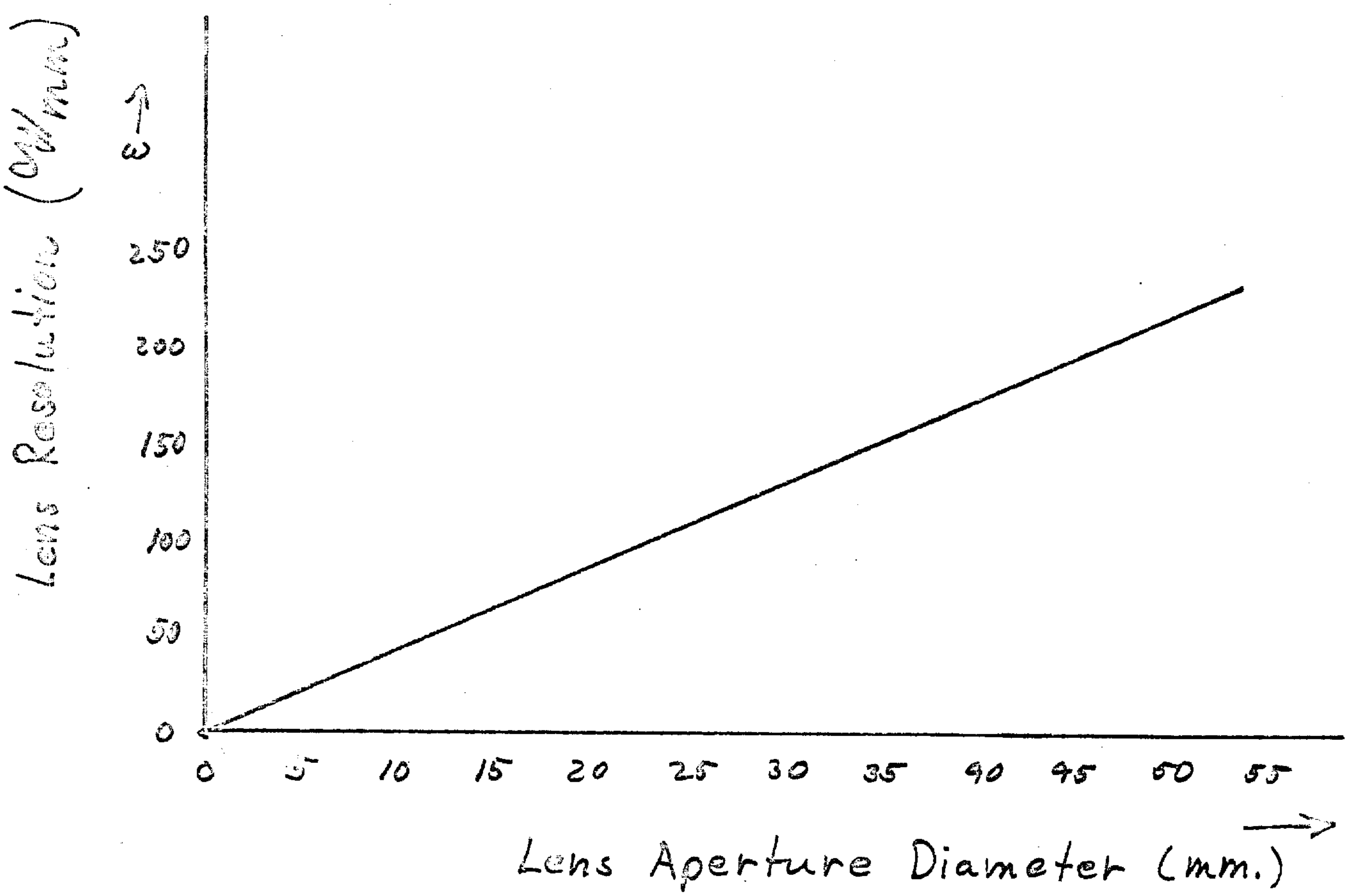

Fig. 2 Graph showing the 300 mm. coherent processor transform lens resolution response with aperture. The aperture is determined by the filter format.

optical flats), and since this component is placed in the beam at an angle (see Fig 1, p. 17) it is necessary to have a larger format than other components.

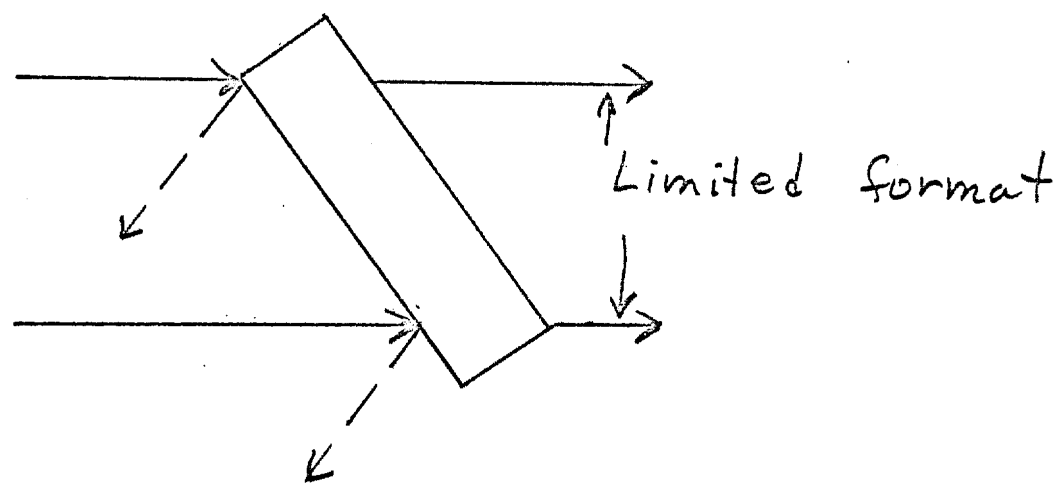

Fig 3. Illustration showing how format of illumination can be limited by the beam splitter.

At present we require only a 1 inch square format for the detection filter.

Reference beam angle

Fig. 1 p 17 shows the reference beam incident on the output of the interferometer at an angle α. This angle sets up an interference pattern between the reference beam and signal beam wavefronts. If both wavefronts are planar, then a straight line sinusoidal output is obtained. The larger the angle α, the higher the frequency of these sinusoidal interference fringes. The fringe frequency is given by

$$n/\text{mm.} = \frac{\tan\alpha}{\lambda}$$

where n is the number of cycles per millimeter. Fig 4, p.24 is a plot of the interference fringes that are gained as a function of the incident angle α. The fringe frequency must be controlled so as not to exceed the resolution of the holographic recording film at the output, but also to be high enough so as to

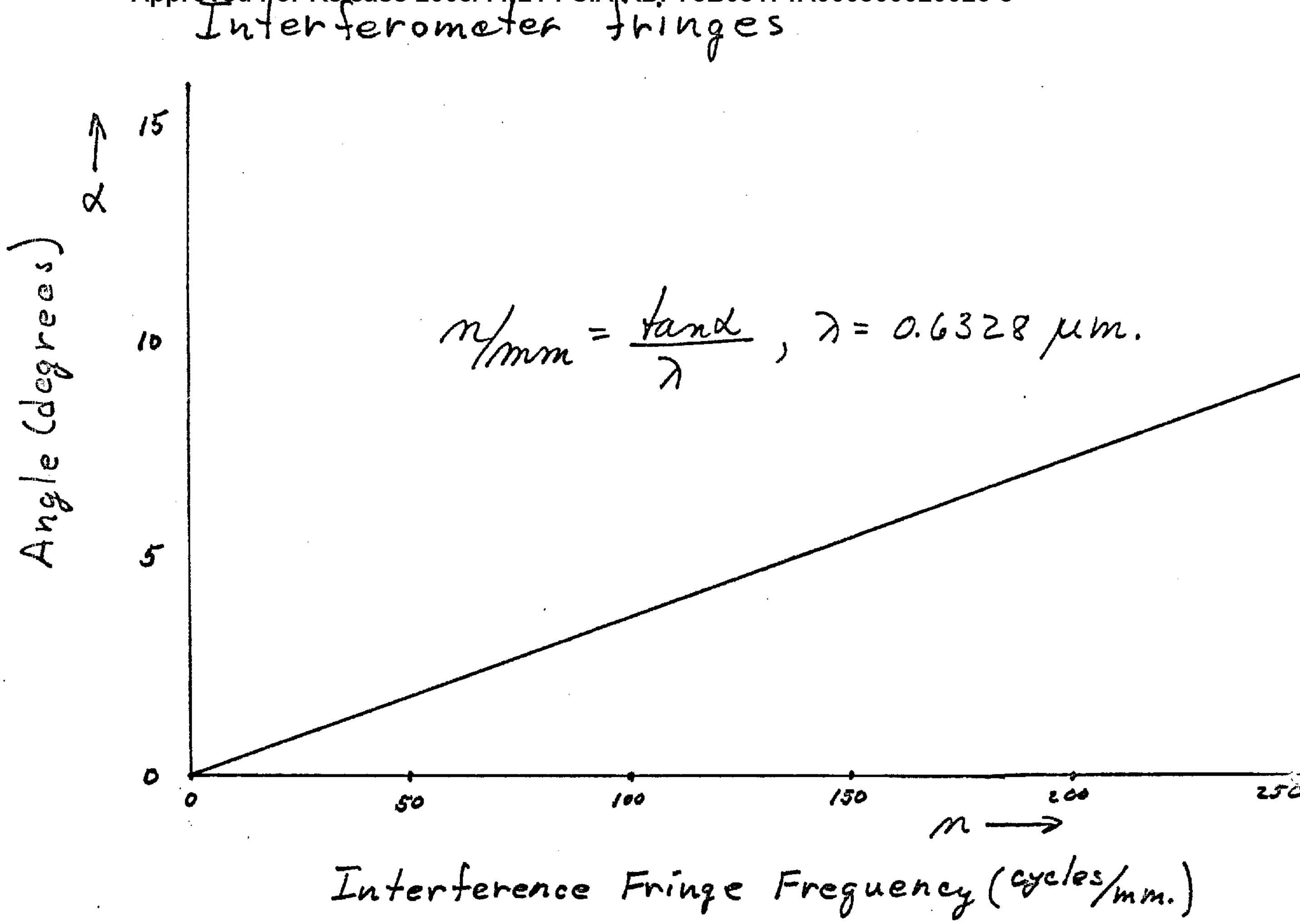

Fig. 4 Graph showing the interference fringe frequency resulting from the angle α between the signal beam and the reference beam in the holographic interferometer.

provide sufficient separation of formats at the output of the coherent processor. Reference to Fig 5 below shows a diagram of the coherent processor. The holographic output

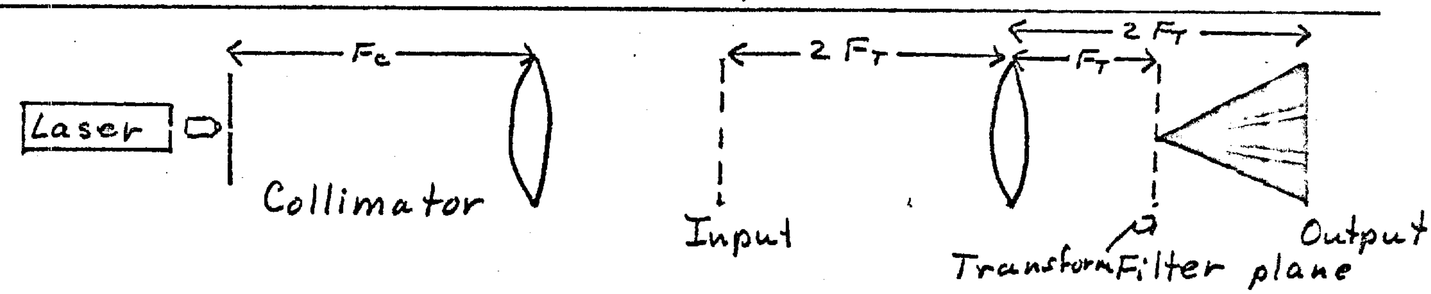

Fig. 5 Coherent processor for holographic target detection.

contains diffracted terms. Only when the diffraction angle is sufficiently large are the output formats separated. Fig 6, p. 26 gives a graph showing the separation of the format centers at the output of the coherent processor for a 300 mm. Schneider Symmar transform lens.

Format Separation

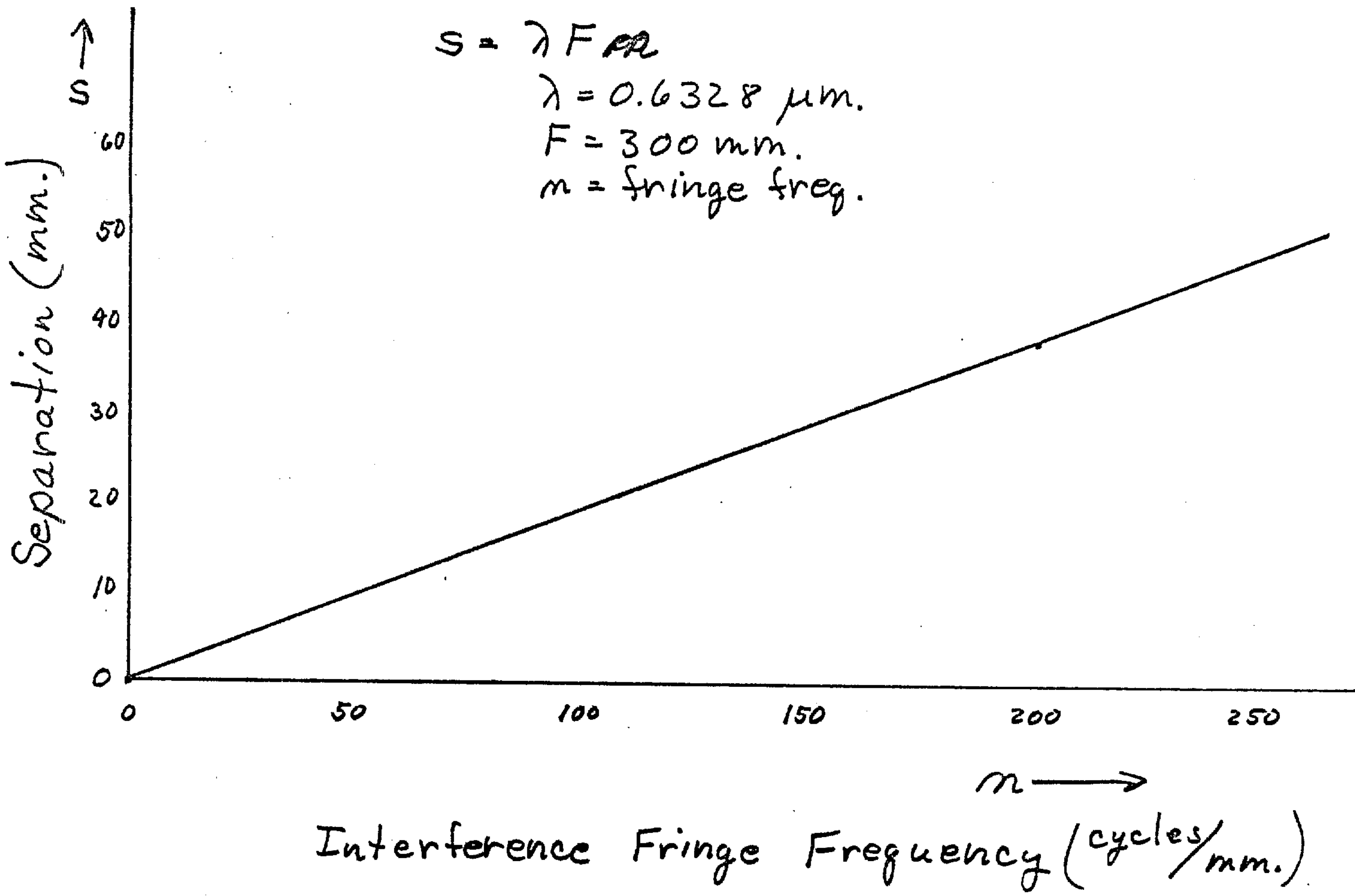

Fig. 6 Graph showing the format separation obtained at the output of the coherent processor with a 300mm. processing lens.

Reference beam amplitude

The amplitude of the reference beam must be controlled from two viewpoints, the first being that the holographic output must be a positive function if the complet information is to be recorded on film, the second being a limitation to the magnitude of the reference beam so that the signal is maintained above film threshold recording limits. The resolution of film is a very sensitive function of signal contrast input, varying as illustrated in Fig 7 below. At low

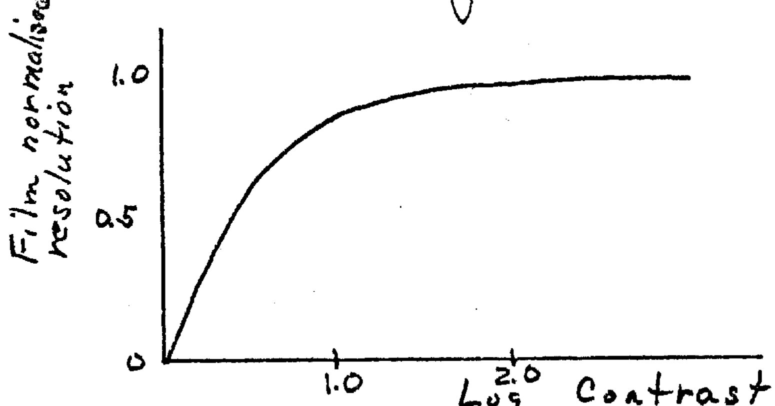

Fig. 7 Film response to contrast input.

contrast the film resolution drops off quickly. So we should be sure to keep the output a positive function, we should try to use the reference beam to effect dynamic range suppression, but we should be careful not to loose resolution of data because of a low contrast signal. The details of these items will be covered when we discuss film and its use in recording holograms and as a holographic filter.

References

VanderLugt, A., Signal Detection by Complex Spatial Filtering IEEE, IT-10, 139(1964)
Vander Lugt, A., Practical Considerations for the Use of Spatial Carrier Frequency Filters, Applied Optics 5, 1760 (1966)
Raso, D.J. Simplified Method to Make Hologram Filters for Target Recognition J. Opt Soc Am 58, 432 (1968)
Vander Lugt, A., A Review of Optical Data Processing Techniques Optica Acta 15, 1 (1968)
Brown + Lohman, Complex Spatial Filtering with Binary Masks Appl. Opt. 5, 967 (1966)
Gabor, D. Character Recognition by Holography Nature 208, 422 (1965)

Optical Fourier Transformation

We have assumed, during the course of previous discussions, that the coherent optical system is capable of performing a Fourier transformation. At this time we should clarify this point because it is the most significant feature applied to image processing. Reference is made to the following texts:-

(1) Radiation and Optics by John M. Stone, McGraw-Hill Book Co. (1963). Chapter 9 discusses the solution to the propagation equation for collimated monochromatic light through a lens for the case of Fraunhofer diffraction whereas Ch. 11 contains a discussion on Fourier Analysis. Note that section 6

of Chapter 11 makes the connection, thereby describing the Fourier transform operation with a lens.

(2) Principles of Optics by Born + Wolf Pergamon Press, N.Y. Note Chapter 8, Section 3, especially equations 36 – 38.

(3) Introduction to Fourier Optics by J. Goodman McGraw-Hill, N.Y. (1968). See Chapters 3, 4 and especially Ch. 5 for a complete analysis and derivation.

In the following paragraphs we present a discussion to describe the Fourier transform operation. We start with the Fresnel Diffraction Integral that gives an expression describing the propagation of a known optical wave $\underline{U_0}(x_0, y_0)$ from plane x_0, y_0 to x, y. The underline denotes a complex quantity. The relationship is:

$$\underline{U}(x,y) = \frac{\exp(jkz)}{j\lambda z} \iint_{-\infty}^{\infty} \underline{U}_0(x_0,y_0) \exp\left\{j\frac{k}{2z}\left[(x-x_0)^2+(y-y_0)^2\right]\right\} dx_0\,dy_0 \quad (1)$$

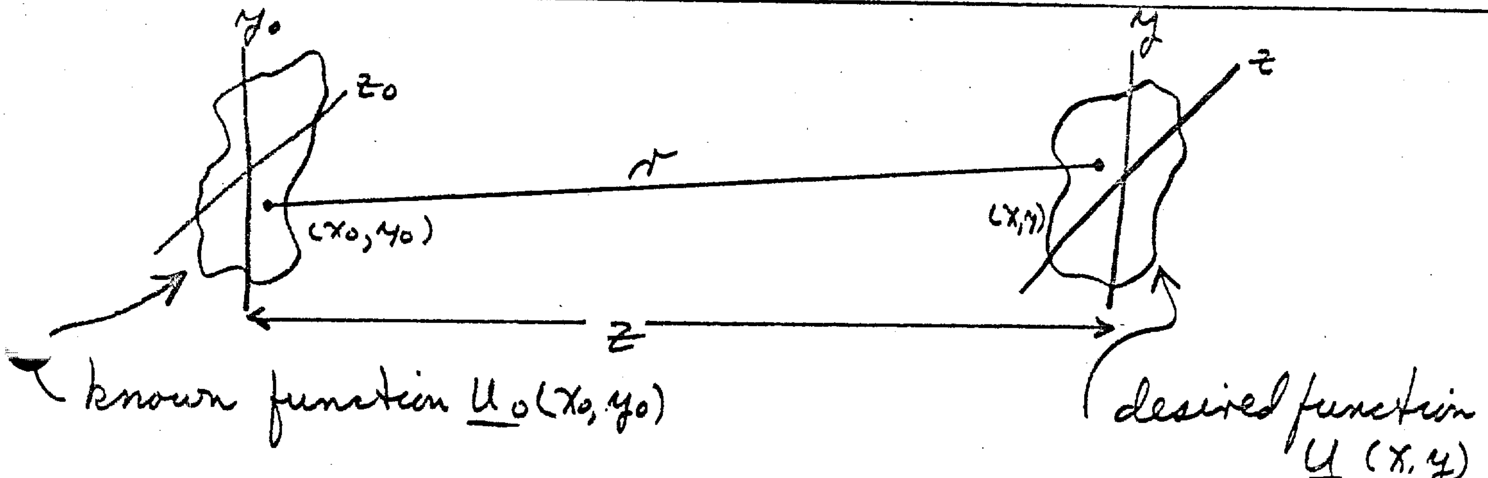

Fig. 8 Wave propagation in the Fresnel region.

The above expression is derived in pages 36 ff. Let us consider the optical set-up shown in Fig 9 below. The transparency of amplitude transmittance $t(x,y)$ is illuminated by

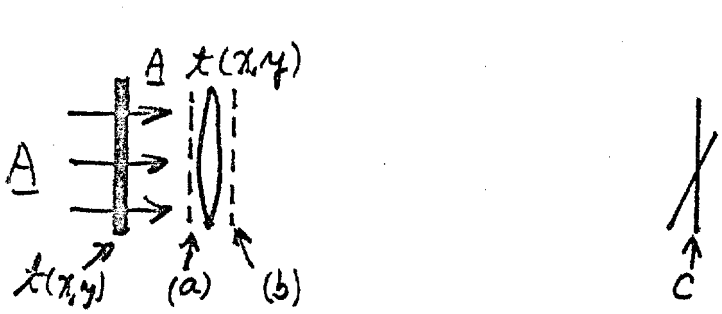

Fig 9 Optical configuration being analyzed

a collimated, monochromatic beam of wavelength λ, described by $\underline{A}$ (a plane wave). Just to the left of the lens (note that the transparency is placed close to the lens) the wavefront is described by

$$\underline{A}\ t(x,y)\ . \qquad (2)$$

The effect of the lens is to multiply the optical wavefront by the factor +

$$\exp\left[-j\frac{k}{2f}(x^2+y^2)\right] \qquad (3)$$

Just to the right of the lens at plane (b) there is

$$\underline{A}\ t(x,y)\ \exp\left[-\frac{jk}{2f}(x^2+y^2)\right] \qquad (4)$$

This is the known disturbance that is propagated from plane (b) to plane (c). We can apply the Fresnel diffraction equation

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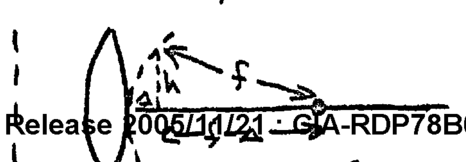
+ footnote
The lens can be described as an optical element that will bring a plane wave to a spherically convergent wave to a point at its focal point. i.e.



Applying the Pythagorean Theorem to the noted triangle to this to determine the wave function at plane (c).

Rewriting eq'n. 1 by expanding the quadratic

$$\underline{U}(x,y) = \frac{\exp(jkz)}{j\lambda z}\iint_{-\infty}^{\infty}\underline{U}_0(x_0,y_0)\Big\{\exp j\frac{k}{2z}\left[x_0^2+y_0^2\right] \exp\frac{jk}{2z}\left[x^2+y^2\right]\exp\frac{jk}{z}(xx_0+yy_0)\Big\}dx_0dy_0 \quad (5)$$

Leaving only terms in x_0 y_0 in the integral

$$\underline{U}(x,y) = \frac{\exp jkz}{j\lambda z}\exp j\frac{k}{2z}(x^2+y^2)\iint_{-\infty}^{\infty}\underline{U}_0(x_0,y_0)\exp\left[j\frac{k}{2z}(x_0^2+y_0^2)\right]\exp\left[j\frac{k}{z}(xx_0+yy_0)\right]dx_0dy_0 \quad (6)$$

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footnote continued fm p. 32
...we obtain

$$f^2 = h^2 + (f-\Delta)^2 = f^2 + \Delta^2 - 2f\Delta$$

$$\Delta < 1$$

$$\Delta = h^2/2f$$

This describes the phase retardation that is introduced to the wavefront as a function of distance from the optical axis. The lens factor is then $\exp(-jk\frac{h^2}{2f})$

We want to evaluate this integral for the known field described by eq'n. 4 and for $z=f$, plane (c) in Fig. 9. Substituting eq'n 4 into eq'n 6 we get

$$\underline{U}(x,y)\Big|_{z=f} = \frac{\exp jkf}{j\lambda f}\exp\left[\frac{jk}{2f}(x^2+y^2)\right] \iint_{-\infty}^{\infty} \underline{A}\, t(x_0,y_0)\exp\left[-\frac{jk}{2f}(x_0^2+y_0^2)\right] \exp\left[j\frac{k}{2f}(x_0^2+y_0^2)\right]\exp\left[\frac{jk}{f}(xx_0+yy_0)\right] dx_0\,dy_0 \tag{7}$$

Simplifying inside the integral we get

$$\underline{U}(x,y)\Big|_{z=f} = \underline{A}\,\frac{\exp jkf}{j\lambda f}\exp\left[\frac{jk}{2f}(x^2+y^2)\right] \underbrace{\iint_{-\infty}^{\infty} t(x_0,y_0)\exp\left[j2\pi\left(\frac{x}{\lambda f}x_0+\frac{y}{\lambda f}y_0\right)\right] dx_0\,dy_0} \tag{8}$$

This is the Fourier transform of the input transparency.

Thus $\underline{U}(x,y)\big|_{z=f}$ is composed of

(1) a complex constant $\frac{A \exp jkf}{j\lambda f}$.

(2) a quadratic phase factor $\exp\left[\frac{jk}{2f}(x^2+y^2)\right]$

(3) a Fourier transform of $t(x,y)$ with transform variables $\left(\frac{x}{\lambda f}, \frac{y}{\lambda f}\right)$.

We have performed this description with the transparency adjacent to the lens, rather than at its front focal plane. We did so in order to simplify the derivation to the fullest extent. Later it can be shown that the quadratic phase factor (#2 above) will disappear when the transparency is f before the lens. The operation requires using the Fresnel Diffraction equation to describe propagation from the transparency to the lens, then the lens factor, and again the Fresnel equation in propagation of the wavefront to the back focal plane of the lens.

The only assumption taken for the above derivation was the Fresnel Diffraction Equation. It is derived here for completeness. This equation is basic to the description of wavefronts through all optical systems.

Fresnel Diffraction Equation.

Consider an optical wavefront as shown in Fig. 10. By Huygens-Fresnel principle, any optical wave propagates as though each point on the wavefront were a point source. Thus each point radiates a spherical wave described

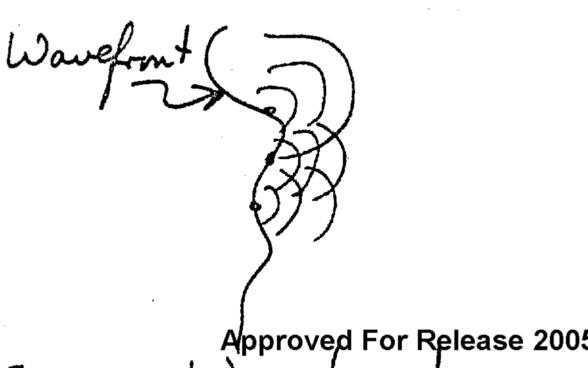
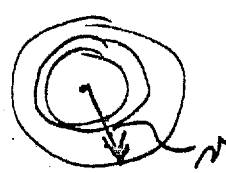


Fig 10 Wavefront propagation

by the equation

$$g(r) = \underline{A}\,\frac{\exp(jkr)}{r} \qquad (9)$$

The form of this equation describing a spherical wave is understandable. The field strength a distand r from the source is given by eq'n 9. The energy density (its magnitude squared) is $|\underline{A}|^2/r^2$.



Over the spherical shell of radius r we get a total radiant energy of

$$\int_{\Sigma} \frac{|\underline{A}|^2}{r^2}\,da = 4\pi r^2 \frac{|\underline{A}^2|}{r^2}$$

$$= 4\pi\,|\underline{A}|^2$$

which is seen to be independent of r. Thus we see a conservation of energy. The term $\exp jkr$ is merely a phase retardation due to the distance r and describes the spherical wave front.