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Computer simulation of a laser designator in the operational environment

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COMPUTER SIMULATION OF A LASER
DESIGNATOR IN THE OPERATIONAL
ENVIRONMENT

by

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December 1989

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This thesis presents a computer simulation program designed to predict the performance of a laser designator in operational environment. It uses aspects of Fourier optical theory, atmospheric modulation transfer function, atmospheric transmittance, and turbulence to analyze the spot size and the power on a target. The guidance system requires the specific power and spot size on a target to track it. So the optimum system for special military purpose can be chosen by the output of this program for a particular atmospheric condition.

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Computer Simulation of a Laser
Designator in the Operational
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by

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ABSTRACT

This thesis presents a computer simulation program designed to predict the performance of a laser designator in an operational environment. It uses aspects of Fourier optical theory, atmospheric modulation transfer function, atmospheric transmittance, and turbulence to analyze the spot size and the power on a target. The guidance system requires the specific power and spot size on a target to track it. So the optimum laser designator for special military purpose can be chosen by the output of this program for a particular atmospheric condition.

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I. INTRODUCTION

A. GENERAL

In recent years as the naval surface combatants become more sophisticated, the use of laser radiation for the detection of targets, and weapon control becomes more important for the navy.

A laser system has several advantages over a microwave system because of its very short wavelength. The advantages are higher resolution, less power requirement and space needed, interception and jamming are difficult, also it can be portable. So, laser guided weapons have been sold by the world's weapon manufacturers to all nations capable of supporting defense forces. But the laser system has a big disadvantage in poor performance in bad weather.

The performance of military laser systems for imaging, target detection, tracking, target designation, warning of missile launch or laser irradiation, optical fuzing, or laser weaponry, is very strongly dependent on the transmission (extinction) and modification of such radiation by atmospheric effects. The extinction depends on absorption and scattering by the molecular constituents of the atmosphere and by the particles suspended in it. The modulation transfer degradation, beam wander, beam broadening and scintillation effects are caused by atmospheric turbulence. Turbulence effects over water as well as over land are a big problem and may be a limiting factor in optical systems.

How to decrease the disadvantage in atmospheric effects and how to select the optimum system within the operational environment are more important to a user, because of the above factors. So a user (such as the Korean navy) must study and research in the area of optical radiation propagation through the atmosphere. In support of this effort, special attention to computer programming of these effects will be devoted to select an optimum laser designator within the operational environment that includes the atmospheric transmittance (extinction) and turbulence. This is the parameter computed for us by the program. The source of this algorithm is based on the program written by Prof. Milne in [Ref. 3].

B.   BACKGROUND

For a laser designator, the predicted beam spot size on the target can be calculated from the atmospheric modulation transfer function (AMTF) and line spread function (LSF) of the laser output pattern and system optics, as described below.

The one–dimensional (single variable) LSF can be generated from the two–dimensional point spread function (PSF) by integrating over one of the two dimensions of a point source image. This one–dimensional LSF is easier to calculate the convolution theorem than the two–dimensional function in computer.

The modulation transfer function (MTF) of the entire system is the AMTF times the Fourier transforms of the LSF of the laser output pattern and of the optics diffraction (also defocus and aberration broadening). This yields the convolution of AMTF, source, and optics. The LSF of the laser

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output pattern is obtained from its radial distribution by integrating over distance y. Then the Fourier transform of the LSF is calculated.

Taking the inverse Fourier transform of the above yields the LSF for the entire system. This LSF can be converted to a radial distribution function by application of the ABEL transform. The fractional energy falling within a given radius is then calculated by integrating with respect to r.

The algorithm, introduced above, can predict the size of a laser spot on a target and the radient energy in the spot for different systems. So, we can compare the systems to determine which one is optimum for our operational environment.

II. THEORY

The first element in the system we are analyzing is, of course, the laser itself.   The radial intensity output of the laser is generally Gaussan and can be expressed by:

$$A = A^0 \exp (-r^2/2\sigma^2)$$

where   A;   maximum   intensity   of   the   laser   source   in watts/steradian

            r;   angular distance from center in μrad

           σ;   angular divergence of the laser source in μrad

This can be calculated for each laser for approximate results and also can be measured directly.   One dimensional line spread function for the source is obtained from the radial intensity output pattern of the laser by integrating to obtain the intensity falling in a vertical slit of width delta x (dx) and a distance x from the center of the pattern as shown in Fig 1 [Ref 1].   A Fourier transform is then used on this LSF to yield the MTF of the laser.

The second element is the optics function.   The optics associated with the laser is basically near diffraction limited.   The Airy function is used to calculate the diffraction point spread function for the laser optics.   From

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[Ref 6], the Airy function for circular aperture diffraction pattern is expressed by the next equation, and illustrated in Fig 2.

$$I(\theta) = I(0) \left[\frac{2\ J_1(k\ a\ \sin\theta)}{k\ a\ \sin\theta} \right]^2$$

where, $J_1(u)$ = first order Bessel function of the first kind

        k = $2\pi/\lambda$

        a = radius of the aperture

(a) Radial distribution of laser output pattern $E(r)$; intensity r; radius

(b) Integration to produce the line spread function intensity vs. x is the area of the hatched strip

(c) Line spread function intensity vs. x
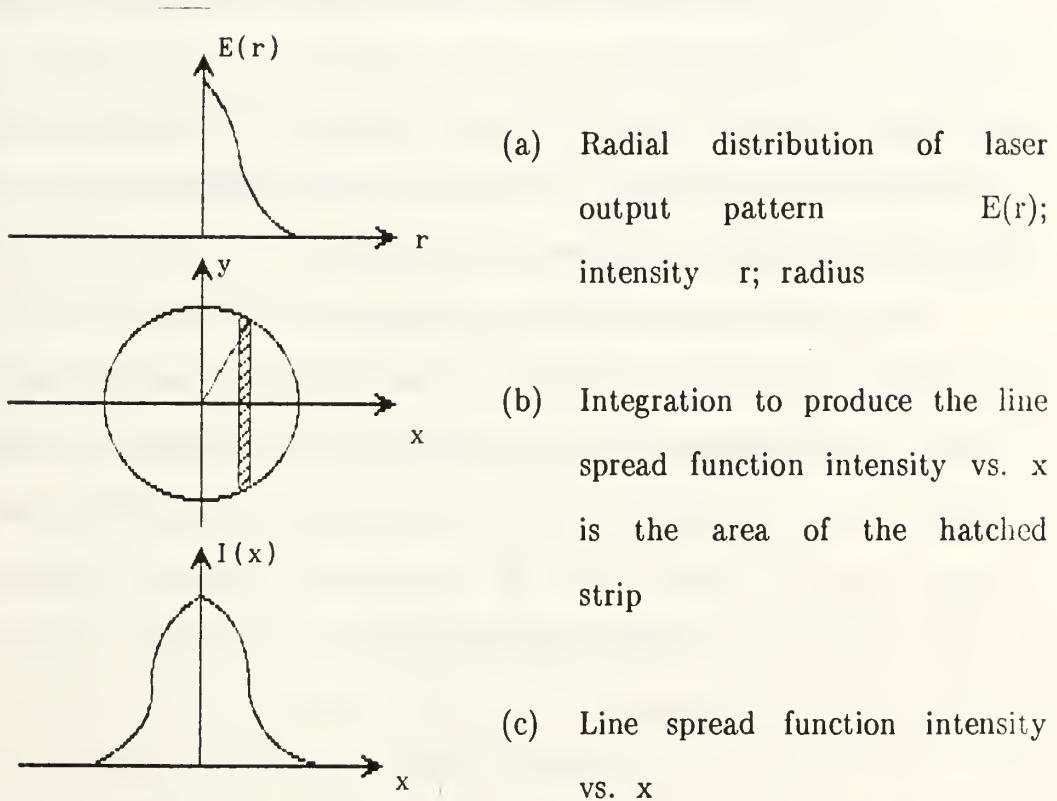
[Fig. 1]   Change from PSF to LSF

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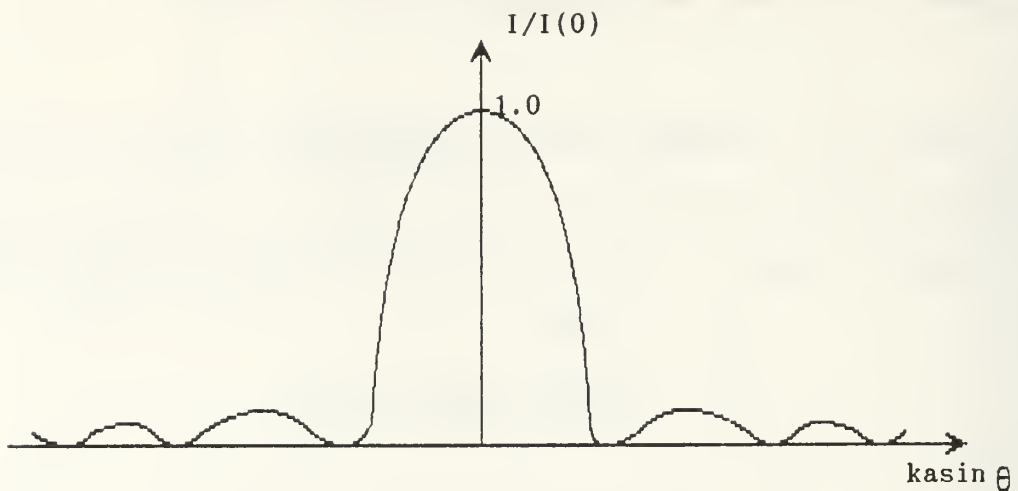
[Fig. 2]   Airy function for circular aperture diffraction pattern

This point spread function is then converted to a line spread function, Fourier transformed to get the MTF and then combined by the convolution theorem into MTF of the laser plus optics.

The third element to be calculated is the effects of atmospheric turbulance on the laser beam.   A properly path–position weighted mean value of C_n becomes the central parameter of interest in calculating the AMTF due to turbulence. C_n and C_t are called respectively the refractive index structure constant and the temperature structure constant, and are related through the equation below.[Ref 1]

$$C_n{}^2 = (\ \frac{79\ P}{T^2}\ 10^{-6}\ )^2\ C_t{}^2$$

$$C_t{}^2\ \cdot\ r^{2/3} = \ <\ (T_{r1} - T_{r2})^2\ >$$

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where $T_{r1}-T_{r2}$; is the temperature difference between two points seperated by a distance r

P ; pressure in millibars

But in the field, the $C_n{}^2$ can be measured directly by optical methods decribed in [Ref 1]. The $C_n{}^2$ is used to predict the MTF of the atmosphere over the path between the laser system and the target. the AMTF is detailed in subsection 3.

The AMTF is then multiplied by the transmittance ($T = e^{(-\mu R)}$, μ = extinction coefficient , R = range)

Now the total effect of the atmosphere, laser itself and optics can be found by the product of the three transform functions.(convolution theorem) The inverse transform then will yield the line spread function of the total system, the LSF as predicted on the target. [Ref 1] describes the process of converting the one dimensional LSF to a circular symmetric point spread function (PSF) using the ABEL transform, detailed in subsection 2.

After obtaining the radial intensity distribution, the size of a laser spot on a target can be predicted. Also the power inside a circle of radius r can then be obtained by integrating the PSF out to r.

A. FOURIER TRANSFORM AND CONVOLUTION

In order to get the total effect of the atmosphere, laser itself and optics, some elements of Fourier theory must be considered. The Fourier transform represents the one dimensional position variable g(y) expressed in

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the spatial frequency domain u(v). The inverse transform repeats the operation in the opposite direction. The forms are commonly represented as shown.

$$u(v) = \int_{-\infty}^{\infty} g(y) \, \exp(-2\pi \, ivy) \, dy = F[g(y)]$$

$$g(y) = \int_{-\infty}^{\infty} u(v) \, \exp(2\pi \, ivy) \, dv = F^{-1}[u(v)]$$

The program calculates the value of the integral at a preset number of points and yields a discrete Fourier transform. A theorem from Fourier theory that allows us to compute the line spread function for one of the elements in the system given is the convolution theorem stated as follows.

If $F[g(y)] = G(v)$, and

$F[h(y)] = H(v)$

then $F[g*h] = GH$ (* represents the convolution)

B.   ABEL TRANSFORM [Ref.1]

In order to get circularly symmetric two–dimensional PSF from one–dimensional LSF the ABEL transform [Griem, 1964; Magnus, 1949] is used in this program referred to above in section II. The one dimensional line spread function can be utilized to calculate the corresponding radial distribution of intensity in the two–dimensional image, provided that the intensity is known to be circularly symmetric, i.e. the intensity $E(r)$ in the image depends only on the radial distance from the center of the image.

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This inversion is called the ABEL transform. For such an image, the line spread function (LSF) is obtained from the radial distribution by integrating the intensity lying within an infinitesmal slit of width dx.

$$I(x) \quad = \quad \int_{-\infty}^{\infty} E(r) \; dy$$

$$= \quad 2 \int_{0}^{R} E(\sqrt{x^2 + y^2}) \; dy$$

where   R is a radius beyond which there is no intensity

The ABEL transform allows us to reverse this process. It is accomplished by carring out the calculation indicated by;

$$E(r) \; = \; - \frac{1}{\pi} \int_{r}^{R} \frac{I'(x) \; dx}{(r^2 - x^2)^{1/2}}$$

where $I(x) = 0$ for $x > R$

$I'(x)$ is the x derivative of $I(x)$

This integral can be carried out by step wise numerical integration with a computer.

C.   MTF OF ATMOSPHERE

The modulation transfer function is a function of the spatial frequency, angular spatial frequency f given in (cycles/radian) or linear spatial

frequency ν given in (cycles/meter). The one—dimensional MTF is directly applicable. Images are, of course, really two—dimensional, and much work has been done in the field of two—dimensional image processing, both analog and digital. However, for many purposes, the one—dimensional form is adequate, and is much more readily handled analytically and in computer processing. We already saw that for circularly symmetric images, the two—dimensional behavior can be obtained from the one—dimensional. The modulation transfer function has the added advantage that for a total optical system the system MTF is the product of the MTF's of the components. So, the MTF of atmosphere can be expressed independently by its own parameters.

There are two limiting situations used in calculating the AMTF. First, the short exposure, or short term MTF is obtained by taking the average of successive LSF in which each LSF is shifted such that the center of the area of each curve has a common origin. Also it discribes images obtained in the limit of time intervals sufficiently short that the turbulence can be considered frozen. The average short term MTF is then the average of the MTF's corresponding to many such images. This procedure, in effect, removes the image wander. Second, the long exposure, or long term MTF is obtained by including the image wander, by not performing a shift in the origin. Also it results simply from taking an integrated image of a sufficiently long time which sees effectively all possible turbulence configurations. It is seen to be the result of image spread (the short term MTF) plus image wander. So the short term LSF is narrower than the long term LSF.

From the [Ref 1] AMTF can be summarized by the following expression.

$$M(f) = \exp\left[-57.64\ \beta\ C_n{}^2\ Z_0\ \lambda^{-1/3}\ f^{5/3}\ [1-\alpha\ (\tfrac{f\lambda}{D})^{1/3}]\right]$$

where λ = wavelength

f = angular spatial frequency(cycles/radian)

D = diameter of optics

Z_0 = range

α = 0 for the L.T. MTF

= 1/2 for the far–field S.T. MTF, $D<<(Z\lambda)^{1/2}$

= 1 for the near–field S.T. MTF, $D\geq(Z\lambda)^{1/2}$

β = 1 for a plane wave

= 3/8 for a spherical wave

III.   PROGRAM DESCRIPTION

This program can be run on IBM personal computers or compatibles under the DOS operating system (version 2.0 or later), and consists of several subroutines, a function and a mainbody.   All program modules are coded in MS's ANSI 77 Fortran Compiler.   The source file is compiled and linked to library with command (FL /G2), then the .EXE file is obtained and this program is ready to be run.

The source file is listed in Appendix A, the typical input data file and module interconnections are listed in Appendix B.

Some input data and modules are added to the program written by Prof. Milne in [Ref. 3] for some parameters to be varied, and for the desired output to be taken.

A.   INPUT DATA

The general input data to this program must be entered interactively from the keyboard or from the input file.   In either case, these data must be determined by the user prior to running this program.   The input data are described and determined briefly below.

1.   IDATE

Time and date of the run, 60 characters, it will be placed in the header of the output file.

2.   INPT

This input indicates the type of laser source function to be used in the program.   If 1 is entered, then a gaussian source function is calculated.   If 2 is entered, then the source function is inputted from the input file.   If 3 is entered, then combination function of source–optics is entered from the input file.

3.   IHEAD(1)

Information about the laser source, 80 characters, it will be placed in the header of the output file.

4.   WAV

Wavelength of the laser in meters, Format E10.4, this input can come from the characteristic of the laser designator determined by the weapon manufacturer.

5.   OBRA

Obscuration ratio, Format F7.5, the ratio of the diameter of the inner mirror to outer mirror.   This data can come from manufacturer also.

6.   RANGE

The distance between the laser designator and the target in meters, Format F7.0.

7.   OPT

Diameter of the optics in meters, Format F7.3.

8.   SQCN

Squared refractive index structure constant in meters$^{(-2/3)}$, Format E10.4.   This input will be the path–weighted integrated value in the operational environment and can be measured directly by optical methods [Ref. 1].

9. SCALE

Angular scale in microradians per point, Format F7.0.

10. EXT

The extinction coefficient of the operational atmosphere in meters^{-1}, Format E10.4, this data can come from Lowtran 6 in NPS IBM 3033AP computer.

11. INOP

Input type of the optics diffraction pattern to be used in the program. If 1 is entered, then the optics diffraction function is calculated. If 2 is entered, then it is entered from the input file.

12. IHEAD(2)

Information about the optics, 80 characters, it will be placed in the header of the output file.

13. A

The maximum intensity of the laser source in watts/steradian, Format E10.4, this data can come from manufacturer also.

14. B

Sigma(standard deviation) of the laser source (gaussian) in microradians, Format E10.4. This data can be determined to measure the angle between the beam center and the line at which the laser's intensity falls to $e^{-1/2}$ of its peak intensity. This data can come from manufacturer also.

15. EXPO

The type of exposure pattern to be taken for output. If 1 is entered, then the long−term (exposure) is taken. If 2 is entered, then the short−term (exposure) is taken.

16.   FRAP

Fraction of total power in watts that is required at the target.

17.   VARY

Selection of the run.   If 1 is entered, then one of input parameters will be varied in program.   If 2 is entered, then fixed value of input parameters will be used in program.

18.   SEL

Selection of the parameter that will be varied in program. SQCN, EXT, RANGE, and OPT can be chosen to be varied.   The maximum and minimum of that value should be entered.   Input Format is same as above 6, 7, 8, and 10.

B.   MODULE DESCRIPTIONS

1.   GETVAR

a.   Module type :   Fortran 77 Subroutine

b.   Usage :   Call GETVAR(min,max,va)

c.   Function :   To get 20 points between minimum and maximum

d.   Interface :

(1)   External references :   Float

(2)   Common data :   None

(3)   Formal arguments :

(a)   Min (real), minimum of the variable.

(b)   Max (real), maximum of the variable.

(c)   Va (real array), 20 values of the variable between minimum and maximum.

(4) Input : Min, Max

(5) Output : Va

2. AIRY

   a. Module type : Fortran 77 Real function

   b. Usage : Y = AIRY (X)

   c. Function : Calculates the value of the Airy function of x. AIRY(x) = 2 * $J_1(x)/x$, where $J_1(x)$ is the Bessel function of order one.

   d. Interface :

   (1) External references : Float, ABS, MAX1

   (2) Common data : None

   (3) Formal arguments :

   (a) X (real), value of the independent variable of the Airy function

   (4) Input : X

   (5) Output : Airy

3. LSF

   a. Module type : Fortran 77 Subroutine

   b. Usage : Call LSF(RG3,k)

   c. Function : Converts a point spread function into a line spread function.

   d. Interface :

   (1) External references : Float, SQRT, IFIX

   (2) Common data : None

   (3) Formal arguments :

   (a) RG3 (real array), this is the PSF on input and the LSF on output.

(b) K (integer), number of points in the array RG3.

(4) Input : RG3, K

(5) Output : RG3

4. AMTF

    a. Module type : Fortran 77 Subroutine

    b. Usage : Call AMTF(j)

    c. Function : Calculates the atmospheric MTF from given value for long—term and short—term, and then the result is multiplied by extinction factor $(e^{-\mu R})$.

    d. Interface :

(1) External references : EXP, COS

(2) Common data : /real/ RG1, RG2. / / WAV, OPT, OBRA, SCALE, RANGE, SQCN, EXT, A, B, IDATE, IHEAD

(3) Formal arguments :

(a) J (integer), if zero on input, then the long term AMTF is calculated; if one on input, then the short term AMTF is calculated.

(4) Input : J, SQCN, RANGE, WAV, EXT, SCALE, OPT

(5) Output : RG2

5. FFT

    a. Module type : Fortran 77 Subroutine

    b. Usage : Call FFT(RG,ID,KA)

    c. Function : Calculates the Fourier transform or inverse Fourier transform of a real—value symmetric function using the Fast Fourier transform (FFT) algorithm.

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d. Interface :

(1) External references : Float, CMPLX, CEXP, CONJG

(2) Common data :   None

(3) Formal arguments :

(a) RG (real), on input, RG is an array of functional values; on output, it is the forward (or inverse) Fourier transform of these functional values.

(b) ID (integer), specifies whether forward (ID = 1) or inverse (ID = 0) Fourier transform is to be calculated.

(c) KA (integer), the largest non–zero term of forward (or inverse) Fourier transform.

(4) Input : RG, ID

(5) Output : RG, KA

6.   BITINV

a. Module type :   Fortran 77 Subroutine

b. Usage :   Call BITINV(K,L,M)

c. Function :   Finds the bit inversion of an M bit number K to L. This is used in the Fourier transform subroutine.

d. Interface :

(1) External references : None

(2) Common data :   None

(3) Formal arguments :

(a) K (integer), the integer whose bit inverse is to be found.

(b) L (integer), the bit inverse of K.

(c) M (integer), the number of bits in the integers K and L.

(4) Input : K, M

(5) Output : L

7. ABEL

a. Module type : Fortran 77 Subroutine

b. Usage : Call ABEL(K)

c. Function : Converts a line spread function (x) to a point spread function (r).

d. Interface :

(1) External references : Float, SQRT, ABS

(2) Common data : /real/ RG1, RG2

(3) Formal arguments :

(a) K (integer), number of points in array RG2 to be processed.

(4) Input : RG2, K

(5) Output : RG2

8. INT

a. Module type : Fortran 77 Subroutine

b. Usage : Call INT(K,TPOW)

c. Function : Integrates the point spread function to find the total power as a function of radius reached around the target and normalizes it.

d. Interface :

(1) External references : Float

(2)   Common data :   /real/ RG1, RG2.   / / WAV, OPT, OBRA, SCALE, RANGE, SQCN, EXT, A, B, IDATE, IHEAD

(3)   Formal arguments :

(a)   K (integer), number of points in array RG2.

(b)   TPOW (real), total integrated power reached around the target.

(4)   Input :   K, RG2, SCALE, RANGE

(5)   Output :   TPOW

9.   OUTIN

a.   Module type :   Fortran 77 Subroutine

b.   Usage :   Call OUTIN(BUF,J,K,L)

c.   Function :   Control the input and output files to read and write the data.

d.   Interface :

(1)   External references :   None

(2)   Common data :   /OI/ LU, LI, IH, IM, IS, IHS, IY, IMO, ID

(3)   Formal arguments :

(a)   BUF (array), array data which are to be read or written.

(b)   J (integer), if −1 on input then call the OPEN subroutine; if 0 on input then call the READF subroutine; if 1 on input then call the WRITF subroutine.

(c)   K (integer), the count number of variable to be varied.

(d)   L (integer), parameter specifying which title is to be printed on output file or which data is to be read from input file.

(4)   Input :   BUF, J, K, L

(5)   Output :   BUF

10.   OPEN

a.   Module type :   Fortran 77 Subroutine

b.   Usage :   Call OPEN

c.   Function :   Open the input and output files.

d.   Interface :

(1)   External references :   None

(2)   Common data :   /OI/ LU, LI, IH, IM, IS, IHS, IY, IMO, ID

(3)   Formal arguments :   None

(4)   Input :   None

(5)   Output :   None

11.   READF

a.   Module type :   Fortran 77 Subroutine

b.   Usage :   Call READF(IER,BUF,L)

c.   Function :   Read the data from input file.

d.   Interface :

(1)   External references :   None

(2)   Common data :   /OI/ LU, LI, IH, IM, IS, IHS, IY, IMO, ID

(3)   Formal arguments :

(a)   IER (integer), error number of reading the input data file.

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(b) BUF (array), array data which are to be read from input data file.

(c) L (integer), if 1 on input then read the information; if 2 on input then read the source function or source–optics function.

(4) Input : L

(5) Output : IER, BUF

12. WRITF

a. Module type : Fortran 77 Subroutine

b. Usage : Call WRITF(IER,BUF,L)

c. Function : Write the data in output file.

d. Interface :

(1) External references : None

(2) Common data : /OI/ LU, LI, IH, IM, IS, IHS, IY, IMO, ID

(3) Formal arguments :

(a) IER (integer), error number of writing the output data file.

(b) BUF (array), array data which are to be written on output data file.

(c) L (integer), parameter specifying which title is to be printed on output file.

(4) Input : BUF, L

(5) Output : IER

13. RESUL

a. Module type : Fortran 77 Subroutine

b.　Usage :　Call RESUL(INU,TPOW,RADIU,POWER,FRAP)

c.　Function :　Calculates the radii on the target and average usable power.

d.　Interface :

(1)　External references : Float

(2)　Common data :　/real/ RG1, RG2.　/ / WAV, OPT, OBRA, SCALE, RANGE, SQCN, EXT, A, B, IDATE, IHEAD

(3)　Formal arguments :

(a)　INU (integer), the count number of variable to be varied.

(b)　TPOW (real), total integrated power reached around the target.

(c)　RADIU (real array), radii on the target which depends on the variable VA.

(d)　POWER (real array), average usable power which depends on the variable VA.

(e)　FRAP (real), function of total power that is required at the target.

(4)　Input :　RG2, FRAP, RANGE, SCALE, TPOW

(5)　Output :　POWER, RADIU

14.　WRITO

a.　Module type :　Fortran 77 Subroutine

b.　Usage :　Call WRITO(VA,RADIU,POWER,ABC)

c.　Function :　Write the data in OUT2. file.

d.　Interface :

(1) External references : None

(2) Common data : /OJ/ SEL, VERY

(3) Formal arguments :

(a) VA (real array), 20 values of the variable between minimum and maximum.

(b) RADIU (real array), radii on the target which depends on the variable VA.

(c) POWER (real array), average usable power which depends on the variable VA.

(d) ABC (array), information that includes the common data / / WAV, OPT, OBRA, SCALE, RANGE, SQCN, EXT, A, B, IDATE, IHEAD.

(4) Input : VA, RADIU, POWER, ABC,SEL

(5) Output : None

IV.   USE OF PROGRAM

The purpose of this simulation is to use the program to predict the atmospheric effects on a laser designator, and to select the optimum laser designator within the operational environment.   This simulation program includes only one leg from a laser designator to a target, but the total infrared system including laser designator must be described before simulating with this program.

The total infrared system including laser designator with definite military mission can be represented by the following block diagram shown in Fig. 3.   The specific function of the blocks are discussed in [Ref. 7].

This total system involves double pass operation from a transmitter (laser designator) to a target and back to the receiver.   The received signal may be used to determine the position, range, or velocity of the target, then the guidance system can be directed at the target.   A target designator system is the first leg of this total system in which the receiver is physically removed from the transmitter.   The most obviously important measure of system performance is the maximum range of operation, or the ratio of received power to transmitted power.   The range equation for this double pass is stated by following expression in [Ref. 7].

$$P_r \; = \; \frac{P_t \; \sigma \; \eta_t \; A_o \; A_t}{4\pi \; \lambda^2 \; R_d^2 \; R_m^2}$$

where P_t = output power of the transmitter (laser designator) in watts.

   P_r = received power of the detector in watts.

   A_t = aperture of the transmitter in meters.

   A_o = aperture of the detector in meters.

   η_t = overall path efficiency (= T_d × T_m × T_o, T_d is atmospheric transmittance from designator to target, T_m is atmospheric transmittance from target to detector, T_o is optical transmittance).

   R_d = distance of designator from target.

   R_m = distance of detector from target.

   σ = optical reflection efficiency of the target (the product of spot area on target and reflection efficiency of target surface and $\cos\theta$).

This equation based on some assumptions, the designator (transmitter) and detector are on different path, so the angle between designator and detector on target is θ, the target acts as a diffuse radiator, and the spot size on the target is smaller than the target size.

From the assumptions, the reflected flux per unit solid angle for a perfectly diffuse reflector is proportional to the cosine of the angle between direction of interest and the normal to the surface, a relationship known as Lambert's cosine law.[Ref. 8]

For the guidance system shown in lower part of Fig. 3, there exists a minimum IR power input from the target necessary for detection. This must be in the form of a target irradiance at the optical receiver in guidance system. The minimum detectable spectral intensity from the target

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depends on the distance between the target and the optical receiver, and minimum spectral power required in the receiver that includes the optical transmission factor and spectral responsivity of detector. So the range equation for guidance system can be constructed to get the minimum detectable spectral intensity from the target by:

$$I_{rt}(\lambda) = \frac{P_r(\lambda) \cdot R^2}{A_0 \cdot e^{-\mu(\lambda) \cdot R}}$$

where $I_{rt}(\lambda)$;   spectral intensity reflected from target (Watts/sr)

         $P_r(\lambda)$;   minimum spectral power required in receiver (Watts)

         A_0 ;   aperture of the detector (m²)

         $\mu(\lambda)$;   spectral extinction coefficient (m⁻¹)

         R   ;   range between target and guidance system

Finally the required spectral intensity on target from the laser designator can be achieved considering the optical reflection efficiency of target.

$$I_{it}(\lambda) = \frac{I_{rt}(\lambda)}{\sigma}$$

where $I_{it}(\lambda)$;   required spectral intensity on target from the laser designator (Watts/sr).

         σ ;   optical reflection efficiency of the target.

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In order to track a target, the tracker or the guidance system must be directed at the target within a certain angle, and the signal to noise ratio of the target signal must be large enough that the tracker can detect the target. Thus the prime military requirement for a laser designator is optical power on the selected target. The required spectral intensity on target must be achieved in a variety of operating conditions.

And now, the first leg of this total system shown in upper part of Fig. 3 can be treated to select the optimum designator in operational environment, and was decribed in Chapter II.
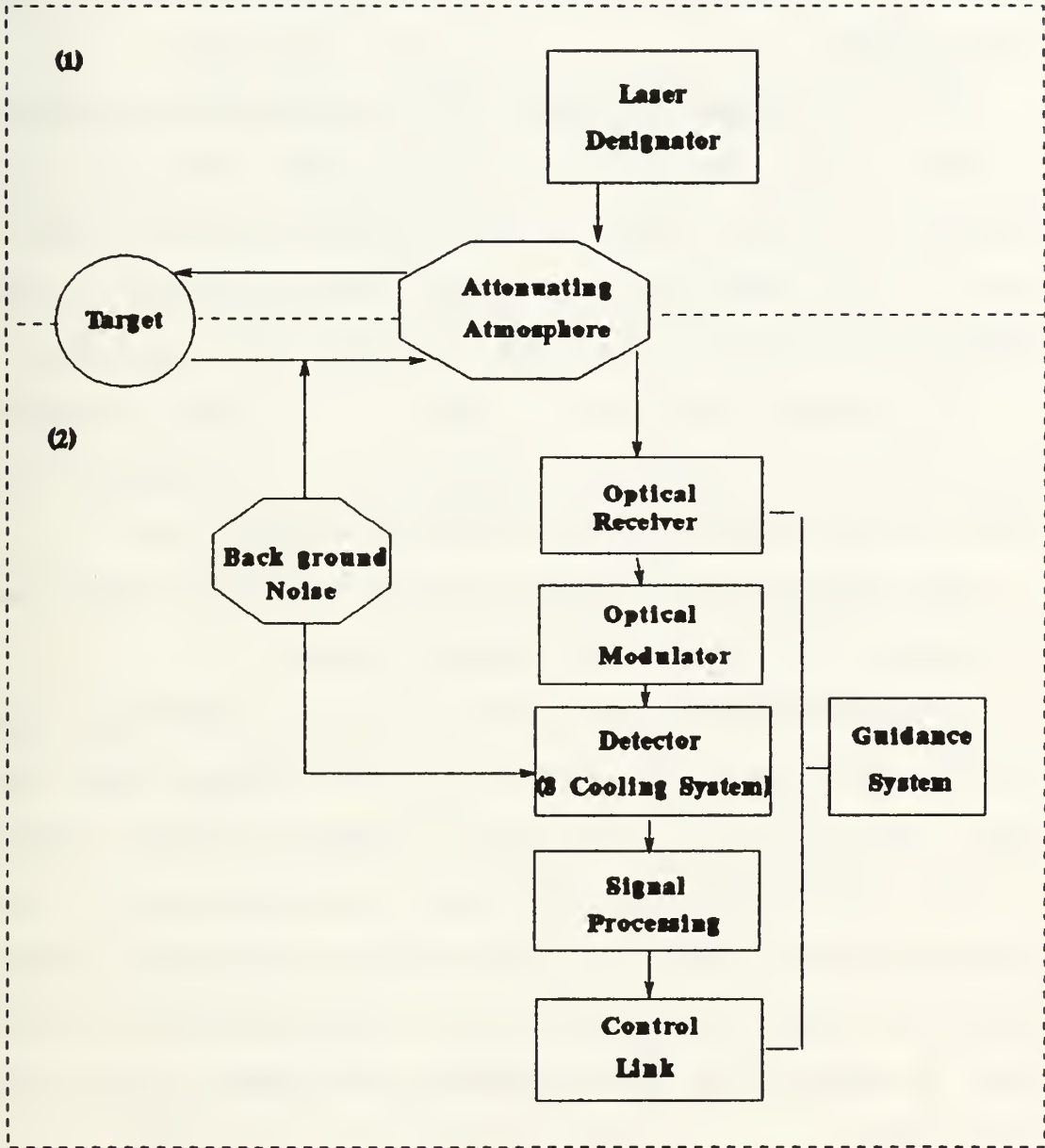
[Fig. 3] Block diagram of total infrared system

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A. METHOD OF SELECTION

The typical values of laser designators and guidance systems are classified and are not allowed to public use. For the purpose of this simulation, the assumed data is to be used or only the method for test is to be explained.

Also the one sigma (1σ) point (40%) of total integrated power is to be used to predict the spot size on target place. The value of sigma represents the inflection points of the Gaussian laser power output (the points at which the curve changes from turning downward to turning upward), and 40% of the output power is included within these points.

The averaged usable power on target is to be used to predict the available power for tracking and guidance system. This power is more useful considering pointing accuracy and tracking stability.

Four parameters, C_n^2, Extinction coefficient, Diameter of optics, Range are available to be varied in this simulation program.

Now some examples of using this method for this simulation program are to be introduced. First, how is the spot size changed when C_n^2 is varied. Second, how is the usable power changed when extinction coefficient is varied. Third, how is the spot size changed when range is varied. Fourth, how can the system parameter be selected when specific operational environment is given (single value of C_n^2). Finally, how can the optimum system be selected when special operational environment is given (various values of C_n^2).

1. TURBULENCE EFFECTS (RUN 1)

    a. Input data

        (1) Wavelength ; 1.06 μm

30

(2)   Obscuration ratio ; 0.00

(3)   Diameter of optics ; 0.95×10^{-1} m

(4)   Scale ; 1.0 μrad/point

(5)   Max. intensity ; 500 watts/steradian

(6)   Sigma ; 1.5 μrad.

(7) C_n^2 ; $8.885 \times 10^{-15} - 2.258 \times 10^{-13}$ m$^{-2/3}$

(8)   Range ; 10 Km

(9)   Extinction coefficient ; 0.5×10^{-4} m^{-1}

(10) Long—term (exposure) is to be taken

(11) One sigma point is to be taken for fractional power on

target

b.   Output ; see Appendix C, A.

2.   EXTINCTION EFFECTS (RUN 2)

a.   Input data ; same as RUN 1 except (7) and (9)

(7) C_n^2 ; 1.0×10^{-14} m$^{-2/3}$

(9)   Extinction coefficient ; $0.5 \times 10^{-5} - 0.5 \times 10^{-3}$ m^{-1}

b.   Output ; see Appendix C, B.

3.   RANGE EFFECTS (RUN 3)

a.   Input data ; same as RUN 1 except (7) and (8)

(7) C_n^2 ; 1.0×10^{-14} m$^{-2/3}$

(8)   Range ; 5 — 15 Km

b.   Output ; see Appendix C, C.

4.   SELECTION OF DIAMETER (RUN 4)

a.   Input data ; same as RUN 1 except (3) and (7)

(3)   Diameter of optics ; $0.25 \times 10^{-1} - 1.25 \times 10^{-1}$ m

(7) C_n^2 ; 1.0×10^{-14} m$^{-2/3}$

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b. Output ; see Appendix C, D.

5. COMPARE TWO SYSTEMS

Here two individual system parameters like (1) through (6) in RUN 1 are to be used for each run. But the environment parameters like (7) through (10) in RUN 1 are to be taken in the same values, because these two systems must be compared in same atmospheric environment.

Also real spectral intensity required on target $[I_{it}(\lambda)]$ instead of one sigma point must be used to determine which one is more optimum for the purpose including tracking or guidance system.

As a result the output will show spot sizes and fractional powers inside a circle for each run, then the user must make a decision which system is the best for their purpose and operational environment.

B. RESULTS & CONCLUSION

This program can be useful in predicting the performance of laser designator in operational environment. It was used to show how the spot size and the averaged usable power are changed when some parameters are varied as shown in above section A.

In Run 1, the C_n^2 was varied. The C_n^2 values were taken for Monterey bay area from Ref. 3. As a result the radius of spot size was changed from 0.24m to 1.36m as well as the averaged usable power was changed from .997 to $.2726 \times 10^{-1}$ watts/sr.

In Run 2, extinction coefficient was varied. The radius of spot size was not changed but the averaged usable power was changed from $.1411 \times 10^{+1}$ to $.9998 \times 10^{-2}$ watts/sr. From the results of Run 1 and Run 2,

it is shown that the performance of a laser designator is affected significantly by atmospheric effects.

In Run 3, range was varied. As a result the radius of spot size was changed from .09 to .465m as well as the averaged usable power was changed from 2.234 to .4551 watts/sr. From the results, the maximum and minimum range can be predicted in specific environment.

It was used to select the optimum diameter of optics as shown in Run 4. The variation was not too big, and over .83cm of diameter the radius of spot size and averaged usable power was not changed. From the results, the optimum diameter of optics can be predicted.

This program can also be used to select the optimum system in special operational environment and purpose like the Pacific Ocean, the Atlantic Ocean, and air—to—air, air—to—surface, surface—to—surface systems.

In the military use, designators are used to mark or designate a target, thereby turning the guidance system into a beacon of reflected energy from target. Given this use, the required power on the target must be achieved over a variety of operating environments. Also laser system user must look at such factors as target size and target cross section, pointing accuracy and tracking stability requirement, as well as atmospheric conditions like turbulence and attenuation. Designators will have energy amplitude stability, side—lobe, and radiation outside the main beam requirements to avoid loss of lock—on or misdirection of seekers sensing the reflected energy. Also no visible light can be emitted and the beam width must be reduced to minimize countermeasure effectiveness.

APPENDIX   A

PROGRAM   LISTING

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C                                                                      C
C             THIS PROGRAM PREDICTS THE PERFORMANCE                    C
C                OF THE LASER DESIGNATOR WITHIN                        C
C        OPERATIONAL ENVIRONMENT TO SELECT THE OPTIMUM SYSTEM.         C
C                                                                      C
C                                                                      C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        INTEGER*2 IDATE,IHEAD,INFO,IH,IM,IS,IHS,IY,IMO,ID,LI,LU,SEL,VARY
        COMMON/REAL/RG1(512),RG2(512)
        COMMON//WAV,OPT,OBRA,SCALE,RANGE,SQCN,EXT,A,B,IDATE(30),IHEAD(80)
        COMMON/OI/LU,LI,IH,IM,IS,IHS,IY,IMO,ID
        COMMON/OJ/SEL,VARY
        DIMENSION INFO(128),ABC(64),VA(20),RADIU(20),POWER(20)
        EQUIVALENCE (WAV,INFO(1)),(INFO(1),ABC(1))
C  DATA INPUT SECTION
        LI=7
        LU=8
        CALL GETDAT(IY,IMO,ID)
        CALL OUTIN(ABC,-1,1,1)
        CALL OUTIN(ABC,0,1,1)
        WRITE(*,1000)(IDATE(I),I=1,30)
  1000 FORMAT(' ENTER TIME AND DATE OF THE RUN - 60 CHARACTERS '/1X,30A2,
      $/)
        READ(*,1030)(IDATE(I),I=1,30)
    10 WRITE(*,1010)
  1010 FORMAT(/' ENTER 1 IF SOURCE IS GAUSSIAN TO BE CALCULATED'/' ENTER
      $2 IF THE SOURCE IS TO BE INPUTTED'/' ENTER 3 IF THE SOURCE-OPTICS
      $FUNCTION IS TO BE INPUTTED    ')
        READ(*,*)INPT
        WRITE(*,1020)(IHEAD(I),I=1,40)
  1020 FORMAT(/' ENTER SOURCE INFORMATION - 80 CHARACTERS'/1X,40A2,/)
        READ(*,1030)(IHEAD(I),I=1,40)
  1030 FORMAT(40A2)
        WRITE(*,1040)WAV
  1040 FORMAT(/' ENTER WAVELENGTH IN METERS',2X,E10.4,/)
        READ(*,*)WAV
        WRITE(*,1050)OBRA
  1050 FORMAT(/' ENTER OBSCURATION RATIO',2X,F7.5,/)
        READ(*,*)OBRA
        WRITE(*,1060)RANGE
  1060 FORMAT(/' ENTER RANGE IN METERS',2X,F7.0,/)
```

```
      READ(*,*)RANGE
      WRITE(*,1070)OPT
1070 FORMAT(/' ENTER DIAMETER OF OPTICS IN METERS',2X,F7.3,/)
      READ(*,*)OPT
      WRITE(*,1080)SQCN
1080 FORMAT(/' ENTER CN SQUARED IN METERS**(-2/3)',2X,E10.4,/)
      READ(*,*)SQCN
      WRITE(*,1090)SCALE
1090 FORMAT(/' ENTER SCALE IN MICRORADIANS PER POINT',2X,F7.2,/)
      READ(*,*)SCALE
      WRITE(*,1100)EXT
1100 FORMAT(/' ENTER EXTINCTION COEFFICIENT IN (1/METERS)',2X,E10.4,/)
      READ(*,*)EXT
      IF(INPT.EQ.3) GO TO 11
      WRITE(*,1015)
1015 FORMAT(/' ENTER 1 IF OPTICS DIFFRACTION PATTERN IS TO BE CALCULATE
     $D'/' ENTER 2 IF OPTICS DIFFRACTION IS TO BE INPUTTED')
      READ(*,*)INOP
      WRITE(*,1110)(IHEAD(I),I=41,80)
1110 FORMAT(/' ENTER OPTICS INFORMATION - 80 CHARACTERS'/2X,40A2,/)
      READ(*,1030)(IHEAD(I),I=41,80)
   11 IF (INPT-2) 12,20,65
C  CALCULATION OF SOURCE PATTERN IF NOT INPUTTED
   12 WRITE(*,1120)A
1120 FORMAT(/' ENTER MAXIMUM OF SOURCE IN WATTS/STERADIAN ',2X,E10.4,/)
      READ(*,*)A
      WRITE(*,1130)B
1130 FORMAT(/' ENTER SIGMA OF GAUSSIAN SOURCE IN MICRORADIANS',2X,E10.4
     $,/)
      READ(*,*)B
      WRITE(*,1140)
1140 FORMAT(/' ENTER 1 IF LONG-TERM(EXPOSURE) IS TO BE TAKEN FOR OUTPUT
     $'/' ENTER 2 IF SHORT-TERM(EXPOSURE) IS TO BE TAKEN FOR OUTPUT')
      READ(*,*) EXPO
      WRITE(*,1150)
1150 FORMAT(/' ENTER THE FRACTION OF TOTAL POWER THAT IS REQUIRED AT TH
     $E TARGET')
      READ(*,*) FRAP
      WRITE(*,1160)
1160 FORMAT(/' ENTER 1 IF ANY VARIABLE IS TO BE VARIED'/' ENTER 2 IF AN
     $Y VARIABLE IS NOT TO BE VARIED ')
      READ(*,*)VARY
      IF(VARY-1) 110,110,100
  110 WRITE(*,1170)
1170 FORMAT(/' 4 VARIABLES CAN BE VARIED IN THIS PROGRAM'/' SELECT THE
     $NUMBER THAT IS TO BE VARIED'//' 1 - SQCN'/' 2 - EXT'/' 3 - RANGE'/
     $' 4 - OPT(DIAMETER)')
      READ(*,*)SEL
      GOTO (120,130,140,150) SEL
  120 WRITE(*,1180)
1180 FORMAT(/' ENTER THE MIN-VALUE OF SQCN')
```

```
      READ(*,*)SQCNL
      WRITE(*,1190)
 1190 FORMAT(/' ENTER THE MAX-VALUE OF SQCN')
      READ(*,*)SQCNH
      CALL GETVAR(SQCNL,SQCNH,VA)
      INU=1
  200 SQCN=VA(INU)
      GO TO 100
  130 WRITE(*,1200)
 1200 FORMAT(/' ENTER THE MIN-VALUE OF EXT')
      READ(*,*)EXTL
      WRITE(*,1210)
 1210 FORMAT(/' ENTER THE MAX-VALUE OF EXT')
      READ(*,*)EXTH
      CALL GETVAR(EXTL,EXTH,VA)
      INU=1
  300 EXT=VA(INU)
      GO TO 100
  140 WRITE(*,1220)
 1220 FORMAT(/' ENTER THE MIN-VALUE OF RANGE')
      READ(*,*)RANGL
      WRITE(*,1230)
 1230 FORMAT(/' ENTER THE MAX-VALUE OF RANGE')
      READ(*,*)RANGH
      CALL GETVAR(RANGL,RANGH,VA)
      INU=1
  400 RANGE=VA(INU)
      GO TO 100
  150 WRITE(*,1240)
 1240 FORMAT(/' ENTER THE MIN-VALUE OF OPT(DIAMETER)')
      READ(*,*)OPTL
      WRITE(*,1250)
 1250 FORMAT(/' ENTER THE MAX-VALUE OF OPT(DIAMETER)')
      READ(*,*)OPTH
      CALL GETVAR(OPTL,OPTH,VA)
      INU=1
  500 OPT=VA(INU)
  100 IF(VARY.EQ.2) INU=20
      WRITE(*,1260) INU,VA(INU)
 1260 FORMAT(/' CONTINUE',2X,I2,2X,E10.4)
      DO 15 I=1,512
      F=SCALE*FLOAT(I-1)
      ARG=F*F/(2.*B*B)
      IF(ARG.GT.70) GO TO 14
      RG1(I)=A*EXP(-ARG)
      K=I
      GO TO 15
   14 RG1(I)=0
   15 CONTINUE
      CALL OUTIN(RG1,1,INU,2)
      GO TO 25
```

```
C   INPUT OF SOURCE PATTERN IF NOT CALCULATED
    20 CALL OUTIN(RG1,0,20,2)
       DO 22 I=1,512
       K=513-I
       IF(RG1(K).NE.0.) GO TO 25
    22 CONTINUE
C   SOURCE PSF IS CONVERTED TO LSF
    25 CALL LSF(RG1,K)
       CALL OUTIN(RG1,1,INU,10)
C   FOURIER TRANSFORM OF SOURCE LSF
       CALL FFT(RG1,1,K)
       CALL OUTIN(RG1,1,INU,18)
       IF(INOP-1)30,30,40
C   CALCULATION OF OPTICS DIFFRACTION PATTERN IF NOT INPUTTED
    30 OBS=OBRA*OBRA
       OB=(1.-OBS)**2
       Q=3.14159E-6*SCALE*OPT/WAV
       DO 34 I=1,512
       R=Q*FLOAT(I-1)
       IF(R.GT.60.) GO TO 32
       RG2(I)=((AIRY(R)-OBS*AIRY(R*OBRA))**2)/OB
       K=I
       GO TO 34
    32 RG2(I)=0.
    34 CONTINUE
       CALL OUTIN(RG2,1,INU,26)
       GO TO 46
C   INPUT OF OPTICS DIFFRACTION IF NOT CALCULATED
    40 CALL OUTIN(RG2,0,20,26)
       DO 44 I=1,512
       K=512-I
       IF(RG2(K).NE.0.) GO TO 46
    44 CONTINUE
C   CONVERSION OF OPTICS DIFFRACTION PATTERN (PSF) TO OPTICS LINE SPREAD
C   LSF
    46 CALL LSF(RG2,K)
       CALL OUTIN(RG2,1,INU,34)
C   FOURIER TRANSFORM OF OPTICS LSF
       CALL FFT(RG2,1,K)
C   NORMALIZATION OF THE FOURIER TRANSFORM OF OPTICS LSF
       DIV=RG2(1)
       DO 57 I=1,512
    57 RG2(I)=RG2(I)/DIV
       CALL OUTIN(RG2,1,INU,42)
C   PRODUCT OF FOURIER TRANSFORM OF SOURCE LSF WITH FOURIER TRANSFORM OF
C   LSF
       DO 64 I=1,512
    64 RG1(I)=RG1(I)*RG2(I)
       CALL OUTIN(RG1,1,INU,50)
       GO TO 66
C   INPUT OF FOURIER TRANSFORM OF SOURCE LSF * FOURIER TRANSFORM OF OPTIC
```

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```
      65 CALL OUTIN(RG1,0,20,50)
C   CALCULATION OF ATMOSPHERIC MODULATION TRANSFER FUNCTION (LONG TERM)
      66 CALL AMTF(0)
         CALL OUTIN(RG2,1,INU,58)
C   PRODUCT OF AMTF WITH FFT OF SOURCE LSF AND FFT OF OPTICS LSF (LONG T
         DO 68 I=1,512
      68 RG2(I)=RG1(I)*RG2(I)
         CALL OUTIN(RG2,1,INU,66)
C   INVERSE FOURIER TRANSFORM OF IMAGE LSF (LONG TERM)
         CALL FFT(RG2,0,K)
         CALL OUTIN(RG2,1,INU,74)
C   CONVERSION OF IMAGE LSF TO PSF (LONG TERM)
         CALL ABEL(K)
         CALL OUTIN(RG2,1,INU,82)
C   CALCULATION OF FRACTION OF POWER TO TARGET INSIDE A CIRCLE OF RADIUS
C   (LONG TERM)
         CALL INT(K,TPOW)
         IF(EXPO.EQ.2) GOTO 72
         CALL RESUL(INU,TPOW,RADIU,POWER,FRAP)
         WRITE(*,1270) TPOW,RADIU(INU),FRAP,POWER(INU)
    1270 FORMAT(/' TOTAL P=',E10.4,2X,'RADIUS=',E10.4,2X,'FRAC=',F5.3,2X,'
         $AVE P=',E10.4)
      72 CALL OUTIN(RG2,1,INU,90)
C   CALCULATION OF ATMOSPHERIC MODULATION TRANSFER FUNCTION (SHORT TERM)
         CALL AMTF(1)
         CALL OUTIN(RG2,1,INU,98)
C   PRODUCT OF AMTF WITH FFT OF SOURCE LSF AND FFT OF OPTICS LSF (SHORT
         DO 74 I=1,512
      74 RG2(I)=RG1(I)*RG2(I)
         CALL OUTIN(RG2,1,INU,106)
C   INVERSE FOURIER TRANSFORM OF IMAGE LSF (SHORT TERM)
         CALL FFT(RG2,0,K)
         CALL OUTIN(RG2,1,INU,114)
C   CONVERSION OF IMAGE LSF TO PSF (SHORT TERM)
         CALL ABEL(K)
         CALL OUTIN(RG2,1,INU,122)
C   CALCULATION OF FRACTION OF POWER TO TARGET INSIDE A CIRCLE OF RADIUS
C   (SHORT TERM)
         CALL INT(K,TPOW)
         IF(EXPO.EQ.1) GOTO 76
         CALL RESUL(INU,TPOW,RADIU,POWER,FRAP)
         WRITE(*,1270) TPOW,RADIU(INU),FRAP,POWER(INU)
      76 CALL OUTIN(RG2,1,INU,130)
         INU=INU+1
         IF(SEL.EQ.1.AND.INU.LT.21) THEN
           GOTO 200
         ELSEIF(SEL.EQ.2.AND.INU.LT.21) THEN
           GOTO 300
         ELSEIF(SEL.EQ.3.AND.INU.LT.21) THEN
           GOTO 400
         ELSEIF(SEL.EQ.4.AND.INU.LT.21) THEN
```

```
      GOTO 500
      ELSE
      GOTO 80
      ENDIF
  80 CALL WRITO(VA,RADIU,POWER,ABC)
      CALL OUTIN(ABC,2,20,1)
      STOP
      END


      SUBROUTINE RESUL(INU,TPOW,RADIU,POWER,FRAP)
      DIMENSION RADIU(20),POWER(20)
      COMMON/REAL/RG1(512),RG2(512)
      COMMON//WAV,OPT,OBRA,SCALE,RANGE,SQCN,EXT,A,B,IDATE(30),IHEAD(80)
      DO 5 I=1,512
      P=RG2(I)/FRAP
      IF(P.GE.1.0) GOTO 7
   5 CONTINUE
   7 RADIU(INU)=RANGE*FLOAT(I)*SCALE*1.E-6
      POWER(INU)=(TPOW*FRAP)/(3.14159*RADIU(INU)**2)
      RETURN
      END


      SUBROUTINE WRITO(VA,RADIU,POWER,ABC)
      INTEGER*2 SEL,VARY
      DIMENSION VA(20),RADIU(20),POWER(20),ABC(64)
      COMMON/OJ/SEL,VARY
      IF(VARY.EQ.2) GOTO 100
      DO 10 I=1,20
      WRITE(9,20) VA(I),RADIU(I),POWER(I)
  20 FORMAT(2X,E10.4,2X,F10.3,2X,E10.4)
  10 CONTINUE
      WRITE(9,30)
  30 FORMAT(2X,' VARIABLE',7X,'RADIUS',3X,'AVERAGE USABLE POWER')
      GOTO (2,3,4,5)SEL
   2 WRITE(9,40)
  40 FORMAT(/,2X,'VARIABLE IS SQCN',/)
      GO TO 200
   3 WRITE(9,50)
  50 FORMAT(/,2X,'VARIABLE IS EXT',/)
      GO TO 200
   4 WRITE(9,60)
  60 FORMAT(/,2X,'VARIABLE IS RANGE',/)
      GO TO 200
   5 WRITE(9,70)
  70 FORMAT(/,2X,'VARIABLE IS OPT(DIAMETER)',/)
      GO TO 200
 100 WRITE(9,80) RADIU(20),POWER(20)
  80 FORMAT(2X,F10.3,2X,E10.4,/)
      WRITE(9,90)
```

```fortran
   90 FORMAT(2X,'RADIUS',6X,'AVERAGE USABLE POWER')
  200 WRITE(9,300)(ABC(I),I=1,64)
  300 FORMAT('WAVELENGTH                   = ',E12.5,' DIAMETER OF OPTICS = ',
     $E12.5,/,'OBSCURATION RATIO       = ',E12.5,' SCALE               = '
     $,E12.5,/,'RANGE                   = ',E12.5,' CN SQUARED          =
     $',E12.5,/,'EXTINCTION COEEFICIENT = ',E12.5,' AMPLITUDE           =
     $ ',E12.5,/,'SIGMA                   = ',E12.5,/,2X,15A4,/,2X,20A4,/
     $,2X,20A4)
      RETURN
      END



      SUBROUTINE GETVAR(MIN,MAX,VA)
      DIMENSION VA(20)
      REAL MIN,MAX,K,L
      K=MAX-MIN
      L=K/19.
      VA(1)=MIN
      DO 10 I=2,19
      VA(I)=VA(1)+L*FLOAT(I-1)
   10 CONTINUE
      VA(20)=MAX
      RETURN
      END



      SUBROUTINE ABEL (K)
C  CONVERTS LINE SPREAD FUNCTION (X) TO POINT SPREAD FUNCTION (R)
      COMMON/REAL/RG1(512),RG2(512)
      G=RG2(1)
      F=G
      RG2(1)=.2*(RG2(1)-RG2(2))
      DO 1 I=1,510
      H=RG2(I+1)
      RG2(I+1)=.4*G+.2*H-.6*RG2(I+2)
      G=H
      IF(ABS(G).GT.1E-6*F) K=I
    1 CONTINUE
      DO 3 I=1,K
      RG2(I)=RG2(I)/(2.*SQRT((FLOAT(I)-.9)**2-(FLOAT(I-1))**2))
      II=I+1
      DO 2 J=II,K
      RG2(I)=RG2(I)+RG2(J)/SQRT((FLOAT(J)-.9)**2-(FLOAT(I-1))**2)
    2 CONTINUE
      RG2(I)=RG2(I)/3.14159
    3 CONTINUE
      K=K+1
      DO 4 I=K,512
    4 RG2(I)=0.
      RETURN
      END
```

```
      FUNCTION AIRY(X)
C  AIRY(X) = 2*J1(X)/X WHERE J1(X) IS THE BESSEL FUNCTION OF ORDER ONE
      IF(X.EQ.0.) GO TO 8
      Z=0
      IF(X.GT.15) GO TO 1
      J=20.+10.*X-X*X/3
      GO TO 2
    1 J=90.+X/2.
    2 IF(X.LT.5.) GO TO 3
      W=1.4*X+60./X
      GO TO 4
    3 W=X+6.
    4 I=MAX1(W,(3.+X/4.))
      DO 6 M=I,J,3
      V=1.E-28
      S=0.
      T=S
      F=1.-4.*(FLOAT(M)/2.-FLOAT(M/2))
      MM=M-2
      DO 5 K=1,MM
      U=2.*FLOAT(M-K)*V/X-T
      T=V
      V=U
      IF((M-K-2).EQ.0) B=U
      F=-F
      FF=1.-F
    5 S=S+V*FF
      U=2.*V/X-T
      S=S+U
      B=B/S
      IF((ABS(B-Z)-ABS(B*1.E-6)).LT.0.) GO TO 7
      Z=B
    6 CONTINUE
    7 AIRY=2.*B/X
      RETURN
    8 AIRY=1.
      RETURN
      END



      SUBROUTINE AMTF(J)
C  THIS SUBROUTINE CALCULATES THE ATMOSPHERIC MODULATION TRANSFER FUNCTI
C  FOR LONG TERM (J=0) AND SHORT TERM (J=1) AND STORES THE RESULT IN RG2
C  THE RESULT IS THEN MULTIPLIED BY EXTINCTION FACTOR EXP(-EXT*RANGE).
      COMMON/REAL/RG1(512),RG2(512)
      COMMON//WAV,OPT,OBRA,SCALE,RANGE,SQCN,EXT,A,B,IDATE(30),IHEAD(80)
      AA=21.6*SQCN*RANGE*WAV**(-.3333333)
      EX=EXP(-EXT*RANGE)
      D=0.
      RG2(1)=EX
      L=0
```

```fortran
      DO 20 I=2,512
      IF(L) 10,5,15
    5 FF=976.56*(I-1)/SCALE
      ARG=AA*(FF**1.666667)
      IF(J.EQ.1) ARG=ARG*(1-(FF*WAV/OPT)**.3333333)
      IF(ARG.GT.13) L=1
      IF((ARG-D).LT.0.) L=-1
      RG2(I)=EX*EXP(-ARG)
      D=ARG
      M=I
      GO TO 20
   10 RG2(I)=RG2(M)*(COS((I-M)*3.14159/M))**2
      IF(I.LT.3*M/2) GO TO 20
      L=1
   15 RG2(I)=0.
   20 CONTINUE
      RETURN
      END


      SUBROUTINE BITINV(K,L,M)
C  FINDS THE BIT INVERSION OF A (M) BIT NUMBER (J) TO (L)
C  THIS IS USED IN THE FOURIER TRANSFORM SUBROUTINE
      J=K
      L=0
      DO 1 I=1,M
      L=L*2
      IF(J.NE.J/2*2) L=L+1
    1 J=J/2
      RETURN
      END


      SUBROUTINE CLOSE(IE1,IE2,IE3)
      INTEGER*2 LU,LI,IH,IM,IS,IHS,IY,IMO,ID,SEL,VARY
      COMMON/OI/LU,LI,IH,IM,IS,IHS,IY,IMO,ID
      CLOSE(LU,IOSTAT=IE1)
      CLOSE(LI,IOSTAT=IE2)
      CLOSE(9,IOSTAT=IE3)
      RETURN
      END


      SUBROUTINE WRITF(IER,BUF,L)
      DIMENSION BUF(512)
      INTEGER*2 LU,LI,IH,IM,IS,IHS,IY,IMO,ID,SEL,VARY
      COMMON/OI/LU,LI,IH,IM,IS,IHS,IY,IMO,ID
    1 FORMAT(1H1)
    2 FORMAT(1X,/,1X,/,'''GAUSSIAN SOURCE FUNCTION''')
    3 FORMAT(2X,5E12.4)
    4 FORMAT(5X,I5,/,1X)
```

```
 10 FORMAT(1X,/,1X,/,'''SOURCE LINE SPREAD FUNCTION''')
 18 FORMAT(1X,/,1X,/,'''FFT OF LINE SPREAD FUNCTION OF SOURCE''')
 26 FORMAT(1X,/,1X,/,'''OPTICS DIFFRACTION PATTERN O(R)''')
 34 FORMAT(1X,/,1X,/,'''OPTIS LINE SPREAD FUNCTION OLSF(X)''')
 42 FORMAT(1X,/,1X,/,'''FFT OF OPTICS LINE SPREAD FUNCTION''')
 50 FORMAT(1X,/,1X,/,'''FFT OF SOURCE * FFT OF OPTICS''')
 58 FORMAT(1X,/,1X,/,'''LONG TERM MTF OF THE ATMOSPHERE''')
 66 FORMAT(1X/,1X/,'''FFT OF IMAGE LINE SPREAD FUNCTION  LONG TERM''')
 74 FORMAT(1X,/,1X,/,'''IMAGE LINE SPREAD FUNCTION  LONG TERM''')
 82 FORMAT(1X,/,1X,/,'''IMAGE POINT SPREAD FUNCTION  LONG TERM''')
 90 FORMAT(1X/,1X,/,'''ENERGY INSIDE CIRCLE OF RADIUS R  LONG TERM''')
 98 FORMAT(1X,/,1X,/,'''SHORT TERM ATMOSPHERIC MTF''')
106 FORMAT(1X/1X/,'''FFT OF IMAGE LINE SPREAD FUNCTION  SHORT TERM''')
114 FORMAT(1X,/,1X,/,'''IMAGE LINE SPREAD FUNCTION SHORT TERM''')
122 FORMAT(1X,/,1X,/,'''IMAGE POINT SPREAD FUNCTION SHORT TERM''')
130 FORMAT(1X/,1X/,'''ENERGY INSIDE CIRCLE OF RADIUS R  SHORT TERM''')
150 FORMAT(2X,2I2,':',I2,':',I2,2X,I2,'-',I2,'-',I4)
    IER=0
    WRITE(LU,1)
    IF(L.EQ.1) GO TO 20
    WRITE(LU,4) L
    WRITE(LU,3) BUF
    J=(L+6)/8
    GO TO (5,7,9,11,13,15,17,19,21,23,25,27,29,31,33,35,37),J
  5 WRITE(LU,2)
    GO TO 38
  7 WRITE(LU,10)
    GO TO 38
  9 WRITE(LU,18)
    GO TO 38
 11 WRITE(LU,26)
    GO TO 38
 13 WRITE(LU,34)
    GO TO 38
 15 WRITE(LU,42)
    GO TO 38
 17 WRITE(LU,50)
    GO TO 38
 19 WRITE(LU,58)
    GO TO 38
 21 WRITE(LU,66)
    GO TO 38
 23 WRITE(LU,74)
    GO TO 38
 25 WRITE(LU,82)
    GO TO 38
 27 WRITE(LU,90)
    GO TO 38
 29 WRITE(LU,98)
    GO TO 38
 31 WRITE(LU,106)
```

```fortran
         GO TO 38
   33 WRITE(LU,114)
         GO TO 38
   35 WRITE(LU,122)
         GO TO 38
   37 WRITE(LU,130)
   38 WRITE(LU,150)IH,IM,IS,IHS,IMO,ID,IY
         RETURN
   20 WRITE(LU,6)(BUF(I),I=1,64)
    6 FORMAT('WAVELENGTH              = ',E12.5,' DIAMETER OF OPTICS = ',
     $E12.5,/,'OBSCURATION RATIO       = ',E12.5,' SCALE              = '
     $,E12.5,/,'RANGE                  = ',E12.5,' CN SQUARED         =
     $',E12.5,/,'EXTINCTION COEEFICIENT = ',E12.5,' AMPLITUDE          =
     $ ',E12.5,/,'SIGMA                 = ',E12.5,/,2X,15A4,/,2X,20A4,/
     $,2X,20A4)
         RETURN
         END


         SUBROUTINE FFT(RG,ID,KA)
C  FOURIER TRANSFORM SUBROUTINE
         IMPLICIT COMPLEX   (C)
         DIMENSION CE(512),CG(1024)
         DIMENSION RG(512)
         DATA IST,TH/0,.006135923/
         CG(1)=RG(1)
         DO 10 I=2,512
         CG(I)=RG(I)
   10 CG(1026-I)=CG(I)
         CG(513)=CG(512)
         IF(IST.NE.0) GO TO 2
         IST=1
         DO 1 I=1,512
         A=TH*FLOAT(I-1)
         C=CMPLX(0.,A)
    1 CE(I)=CEXP(C)
         CE(257)=(0.,1.)
    2 DO 5 M=1,10
         K=2**(10-M)
         L=2**(M-1)
         DO 4 LL=1,L
         KC=LL-1
         CALL BITINV (KC,N,9)
         CD=CE(N+1)
         IF(ID.EQ.1) CD=CONJG(CD)
         KL=2*KC*K+1
         KU=KL+K-1
         DO 3 I=KL,KU
         CA=CG(I)+CG(I+K)*CD
         CG(I+K)=CG(I)-CG(I+K)*CD
    3 CG(I)=CA
```

```fortran
    4 CONTINUE
    5 CONTINUE
      DO 8 I=1,1024
      J=I-1
      CALL BITINV (J,N,10)
      IF(J-N) 6,7,8
    6 N=N+1
      CA=CG(I)/(32.,0.)
      CG(I)=CG(N)
      CG(N)=CA
    7 CG(I)=CG(I)/(32.,0.)
    8 CONTINUE
      DO 20 I=1,512
      RG(I)=CG(I)
      IF(RG(I).GT.1.E-6*RG(1)) KA=I
   20 CONTINUE
      RETURN
      END



      SUBROUTINE INT(K,TPOW)
C  CALCULATES THE FRACTION OF POWER INSIDE A CIRCLE OF RADIUS R
C  OR CALCULATES THE POWER INSIDE A CIRCLE OF RADIUS R
      COMMON/REAL/RG1(512),RG2(512)
      COMMON//WAV,OPT,OBRA,SCALE,RANGE,SQCN,EXT,A,B,IDATE(30),IHEAD(80)
      SR=(SCALE*RANGE)**2
      RG2(1)=.7853982E-12*RG2(1)*SR
      DO 3 I=2,512
      IF(I-K) 1,1,2
    1 RG2(I)=RG2(I-1)+6.28315E-12*RG2(I)*SR*FLOAT(I-1)
      GO TO 3
    2 RG2(I)=RG2(K)
    3 CONTINUE
      TPOW=RG2(512)
      DO 5 I=1,512
    5 RG2(I)=RG2(I)/TPOW
      RETURN
      END



      SUBROUTINE LSF (RG3,K)
C  CONVERTS POINT SPREAD FUNCTION (R) TO LINE SPREAD FUNCTION (X)
      DIMENSION RG3(512)
      DO 2 I=1,K
      Z=RG3(I)
      J=1
    1 R=SQRT(FLOAT((I-1)**2+J*J))
      IR=IFIX(R)
      RI=FLOAT(IR)
      RF=R-RI
      Z=Z+2*((1.-RF)*RG3(IR+1)+RF*RG3(IR+2))
```

```
      J=J+1
      IF (IR.LT.K) GO TO 1
      RG3(I)=Z
    2 CONTINUE
      RETURN
      END


      SUBROUTINE OPEN
      INTEGER*2 LU,LI,IH,IM,IS,IHS,IY,IMO,ID,SEL,VARY
      COMMON/OI/LU,LI,IH,IM,IS,IHS,IY,IMO,ID
      OPEN(7,IOSTAT=IE1,ERR=10,FILE='B:INPUT.DTA',STATUS='OLD')
      OPEN(8,IOSTAT=IE2,ERR=11,FILE='B:OUTPUT.DTA')
      OPEN(9,IOSTAT=IE3,ERR=12,FILE='B:OUT2.DTA')
      RETURN
   10 WRITE(*,13)IE1
   13 FORMAT(' ERROR STOP IN OPENING INPUT FILE ERN = ',I2)
      STOP
   11 WRITE(*,14)IE2
   14 FORMAT(' ERROR STOP IN OPENING OUTPUT1 FILE ERN = ',I2)
      STOP
   12 WRITE(*,15)IE3
   15 FORMAT(' ERROR STOP IN OPENING OUTPUT2 FILE ERN = ',I2)
      END


      SUBROUTINE OUTIN(BUF,J,K,L)
      INTEGER*2 NAME,LU,LI,IH,IM,IS,IHS,IY,IMO,ID,SEL,VARY
      COMMON/OI/LU,LI,IH,IM,IS,IHS,IY,IMO,ID
      DIMENSION BUF(1024)
      CALL GETTIM (IH,IM,IS,IHS)
      IF(J) 20,40,60
   20 CALL OPEN
      RETURN
   40 CALL READF(IER,BUF,L)
      IF(IER.GE.0) RETURN
      WRITE(LU,1005)IER,IN
 1005 FORMAT(' ERROR STOP. READF ERROR. IER = ',I6,'BLOCK # = ',I6)
      STOP
   60 IF(K.LT.20)RETURN
      CALL WRITF(IER,BUF,L)
      IF(J.EQ.2.AND.IER.GE.0) GO TO 70
      IF(IER.GE.0) RETURN
      WRITE(LU,1140)IER,IN
 1140 FORMAT(' ERROR STOP. WRITF ERROR. IER = ',I6,' BLOCK # = ',I6)
      STOP
   70 WRITE(*,1150)
      CALL CLOSE(IE1,IE2,IE3)
 1150 FORMAT('  CALCULATION COMPLETE')
      STOP
      END
```

```fortran
      SUBROUTINE READF(IER,BUF,L)
      INTEGER*2 LU,LI,IH,IM,IS,IHS,IY,IMO,ID,SEL,VARY
      DIMENSION BUF(512)
      COMMON/OI/LU,LI,IH,IM,IS,IHS,IY,IMO,ID
      IF(L.EQ.1) GO TO 20
    1 FORMAT(8F10.5)
      DO 10 I=1,512,8
      K=I+7
      READ(LI,1)(BUF(J),J=I,K)
   10 CONTINUE
      IER=1
      RETURN
   20 READ(LI,2)(BUF(I),I=1,9)
    2 FORMAT(3F10.5)
      READ(LI,3)(BUF(I),I=10,24)
    3 FORMAT(15A4)
      READ(LI,4)(BUF(I),I=25,64)
    4 FORMAT(20A4)
      RETURN
      END
```

APPENDIX B

A. MODULE INTERCONNECTIONS
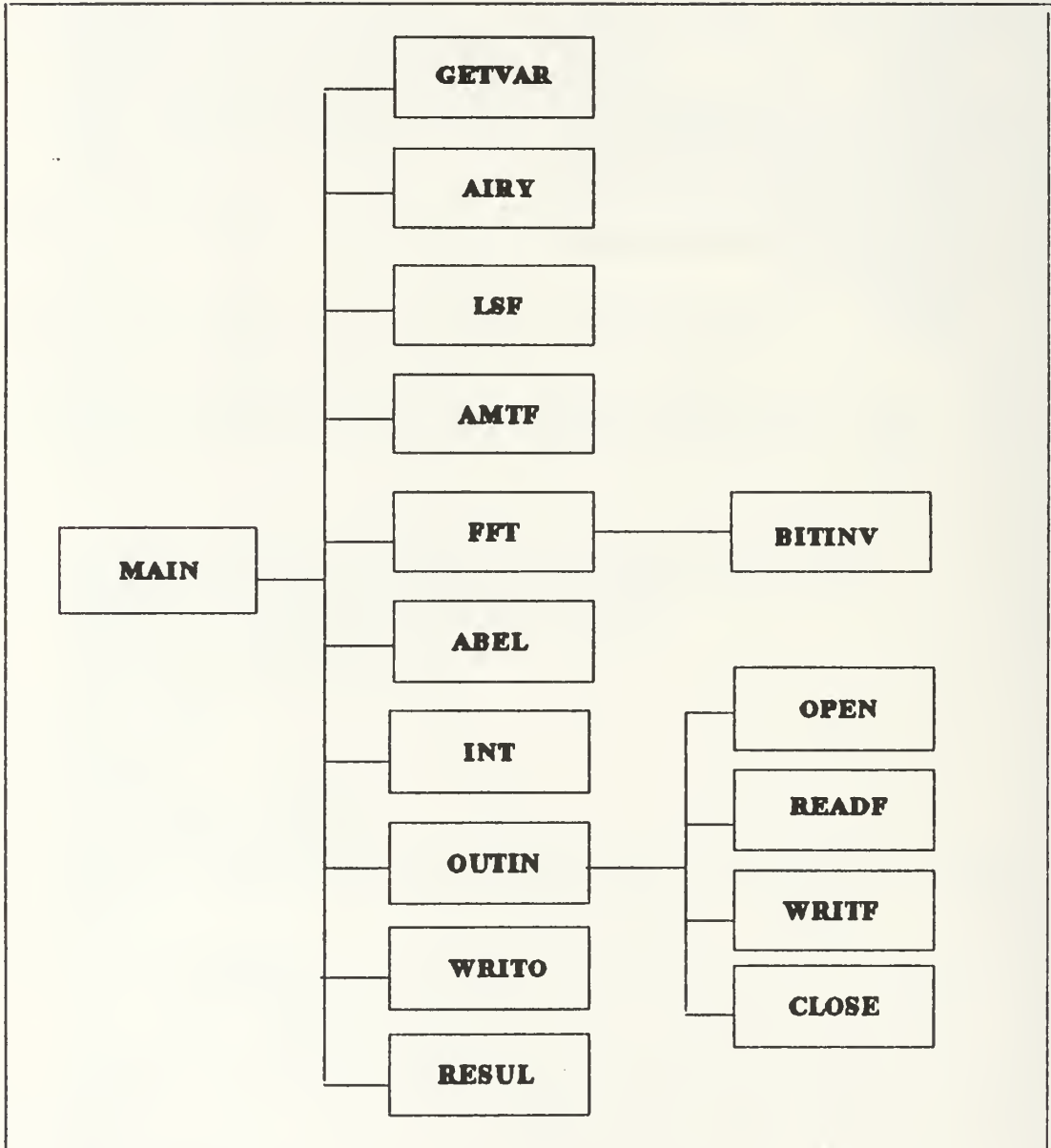
[Fig. 4] Module interconnections

B. INPUT FILE

```
 1.06e-06      0.095      0.000
 1.00000     2000.0   5.00e-14
 0.00005    50000.0     1.5000
HOUR:MIN DATE MONTH YEAR
SECOND LINE OF COMMENTS
THIRD LINE OF COMMENTS
```

1.0	1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	0.8	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0

```
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0     0.0
```

APPENDIX C

OUTPUT OF THE SAMPLE RUNS

A.   OUTPUT OF RUN 1

VARIABLE	RADIUS	AVERAGE USABLE POWER
.8885E-14	.240	.9770E+00
.2030E-13	.360	.4325E+00
.3172E-13	.470	.2527E+00
.4313E-13	.550	.1838E+00
.5455E-13	.630	.1395E+00
.6597E-13	.700	.1125E+00
.7738E-13	.770	.9253E-01
.8880E-13	.830	.7925E-01
.1002E-12	.880	.7015E-01
.1116E-12	.940	.6115E-01
.1231E-12	.990	.5483E-01
.1345E-12	1.040	.4939E-01
.1459E-12	1.080	.4553E-01
.1573E-12	1.130	.4132E-01
.1687E-12	1.170	.3829E-01
.1801E-12	1.210	.3555E-01
.1916E-12	1.250	.3306E-01
.2030E-12	1.290	.3080E-01
.2144E-12	1.320	.2918E-01
.2258E-12	1.360	.2726E-01

VARIABLE IS SQCN

WAVELENGTH	=	.10600E-05	DIAMETER OF OPTICS =		.95000E-01
OBSCURATION RATIO	=	.00000E+00	SCALE	=	.10000E+01
RANGE	=	.10000E+05	CN SQUARED	=	varied
EXTINCTION COEEFICIENT =		.50000E-04	AMPLITUDE	=	.50000E+03
SIGMA	=	.15000E+01			

05:18 19 12 1989
Assumed Gaussian source for simulation
Assumed optics information for run 1

B. OUTPUT OF RUN 2

VARIABLE	RADIUS	AVERAGE USABLE POWER
.5000E-05	.250	.1411E+01
.3105E-04	.250	.1088E+01
.5711E-04	.250	.8383E+00
.8316E-04	.250	.6460E+00
.1092E-03	.250	.4978E+00
.1353E-03	.250	.3837E+00
.1613E-03	.250	.2957E+00
.1874E-03	.250	.2279E+00
.2134E-03	.250	.1756E+00
.2395E-03	.250	.1353E+00
.2655E-03	.250	.1043E+00
.2916E-03	.250	.8037E-01
.3176E-03	.250	.6194E-01
.3437E-03	.250	.4773E-01
.3697E-03	.250	.3678E-01
.3958E-03	.250	.2835E-01
.4218E-03	.250	.2185E-01
.4479E-03	.250	.1683E-01
.4739E-03	.250	.1297E-01
.5000E-03	.250	.9998E-02

VARIABLE IS EXT

WAVELENGTH	=	.10600E-05	DIAMETER OF OPTICS =		.95000E-01
OBSCURATION RATIO	=	.00000E+00	SCALE	=	.10000E+01
RANGE	=	.10000E+05	CN SQUARED	=	.10000E-13
EXTINCTION COEEFICIENT	=	varied	AMPLITUDE	=	.50000E+03
SIGMA	=	.15000E+01			

06:15 19 12 1989
Assumed Gaussian source for simulation
Assumed optics information for run 2

C. OUTPUT OF RUN 3

VARIABLE	RADIUS	AVERAGE USABLE POWER
.5000E+04	.090	.2234E+01
.5526E+04	.105	.1952E+01
.6053E+04	.115	.1901E+01
.6579E+04	.132	.1671E+01
.7105E+04	.149	.1476E+01
.7632E+04	.168	.1309E+01
.8158E+04	.188	.1167E+01
.8684E+04	.200	.1136E+01
.9211E+04	.221	.1016E+01
.9737E+04	.243	.9120E+00
.1026E+05	.257	.8882E+00
.1079E+05	.281	.7997E+00
.1132E+05	.306	.7221E+00
.1184E+05	.320	.7033E+00
.1237E+05	.346	.6368E+00
.1289E+05	.374	.5781E+00
.1342E+05	.389	.5630E+00
.1395E+05	.418	.5124E+00
.1447E+05	.434	.4990E+00
.1500E+05	.465	.4551E+00

VARIABLE IS RANGE

WAVELENGTH	=	.10600E-05	DIAMETER OF OPTICS =		.95000E-01
OBSCURATION RATIO	=	.00000E+00	SCALE	=	.10000E+01
RANGE	=	varied	CN SQUARED	=	.10000E-13
EXTINCTION COEEFICIENT	=	.50000E-04	AMPLITUDE	=	.50000E+03
SIGMA	=	.15000E+01			

   10:58 19 12 1989
   Assumed Gaussian source for simulation
   Assumed optics information for run 3

D.   OUTPUT OF RUN 4

VARIABLE	RADIUS	AVERAGE USABLE POWER
.2500E-01	.330	.5145E+00
.3026E-01	.310	.5840E+00
.3553E-01	.290	.6672E+00
.4079E-01	.280	.7166E+00
.4605E-01	.280	.7173E+00
.5132E-01	.270	.7715E+00
.5658E-01	.270	.7716E+00
.6184E-01	.260	.8321E+00
.6711E-01	.260	.8321E+00
.7237E-01	.260	.8321E+00
.7763E-01	.260	.8321E+00
.8289E-01	.250	.9000E+00
.8816E-01	.250	.9000E+00
.9342E-01	.250	.9000E+00
.9868E-01	.250	.9000E+00
.1039E+00	.250	.9000E+00
.1092E+00	.250	.9000E+00
.1145E+00	.250	.9000E+00
.1197E+00	.250	.9000E+00
.1250E+00	.250	.9000E+00

VARIABLE IS OPT(DIAMETER)

WAVELENGTH	=	.10600E-05	DIAMETER OF OPTICS =	varied
OBSCURATION RATIO	=	.00000E+00	SCALE =	.10000E+01
RANGE	=	.10000E+05	CN SQUARED =	.10000E-13
EXTINCTION COEEFICIENT =		.50000E-04	AMPLITUDE =	.50000E+03
SIGMA	=	.15000E+01		

11:38 19 12 1989
Assumed Gaussian source for simulation
Assumed optics information for run 4

E. GRAPHICAL OUTPUT OF CALCULATION STEPS
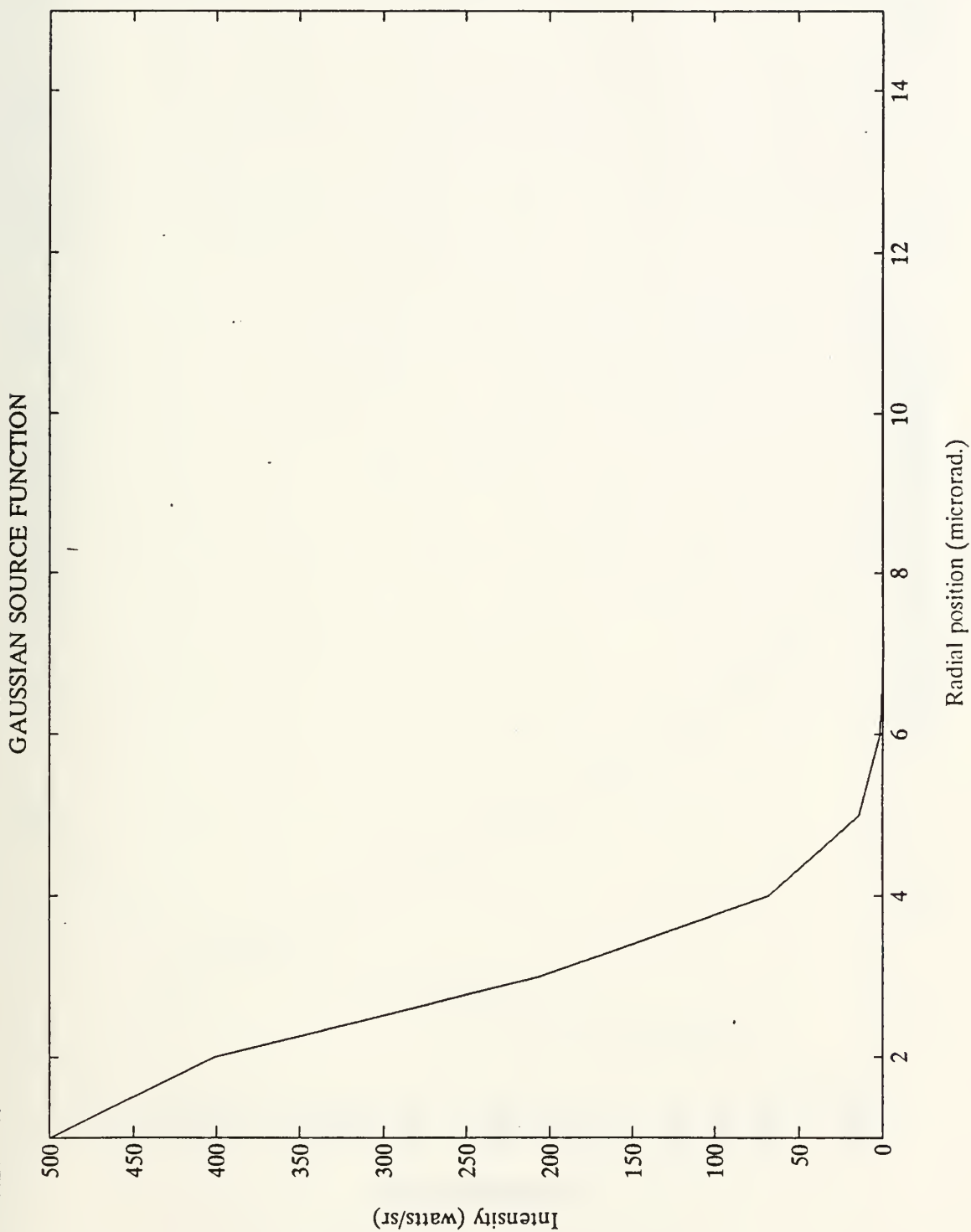
[Fig. 5] Gaussian source function

55
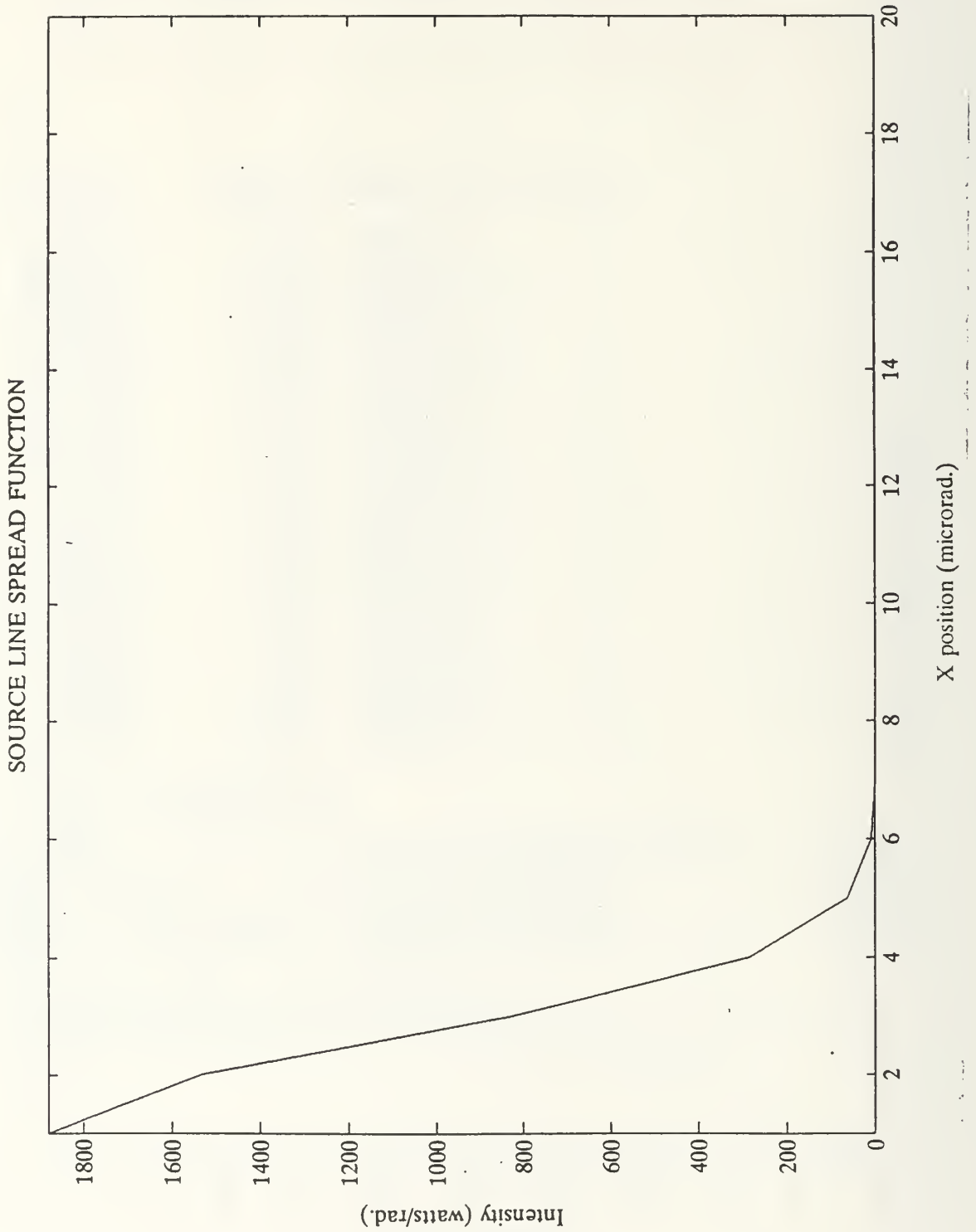
[Fig. 6] Source line spread function

56

[Fig. 7] FFT of source LSF

57

OPTICS DIFFRACTION PATTERN

Intensity (watts/sr)

Radial position (microrad.)
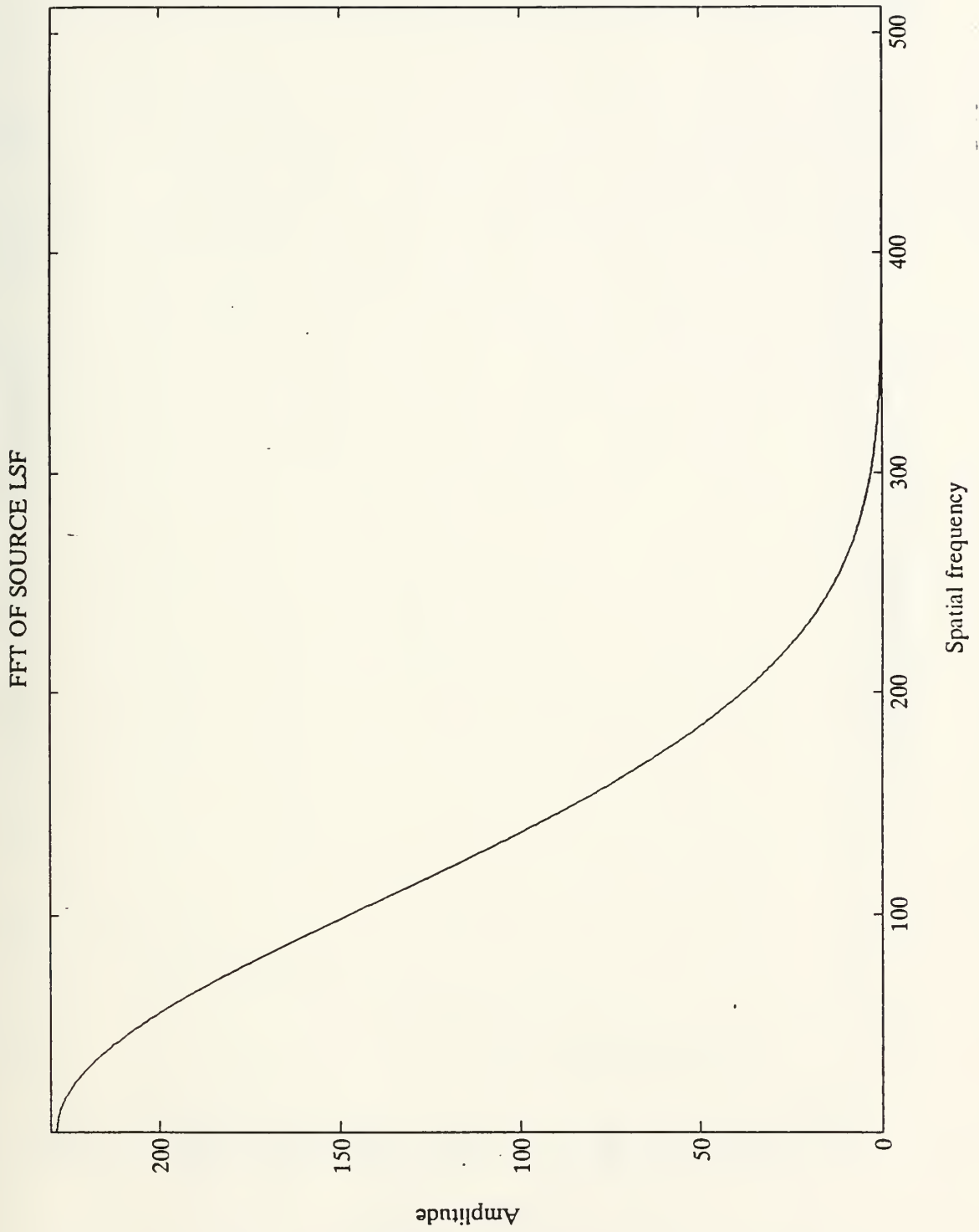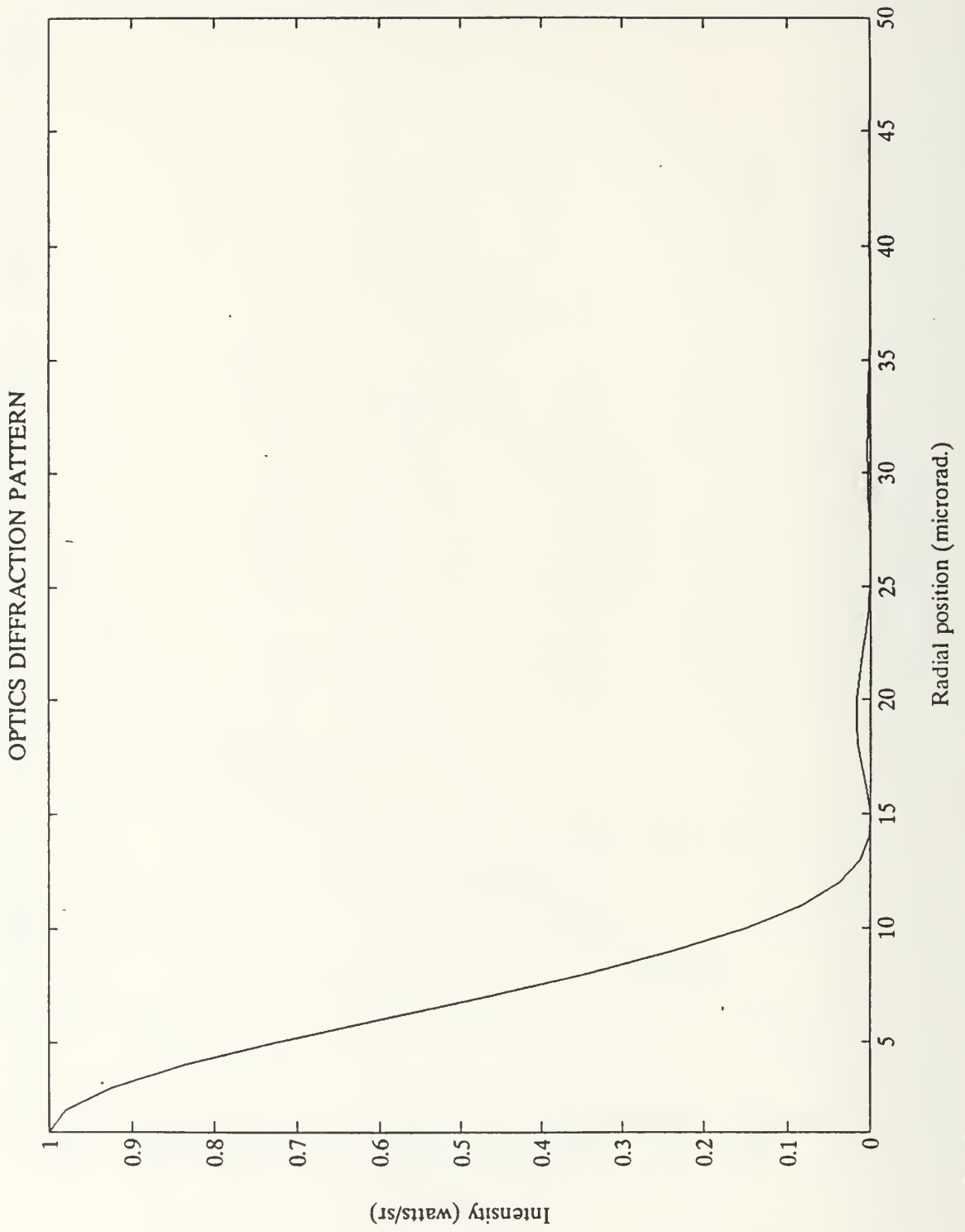
[Fig. 8] Optics diffraction pattern

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OPTICS LINE SPREAD FUNCTION
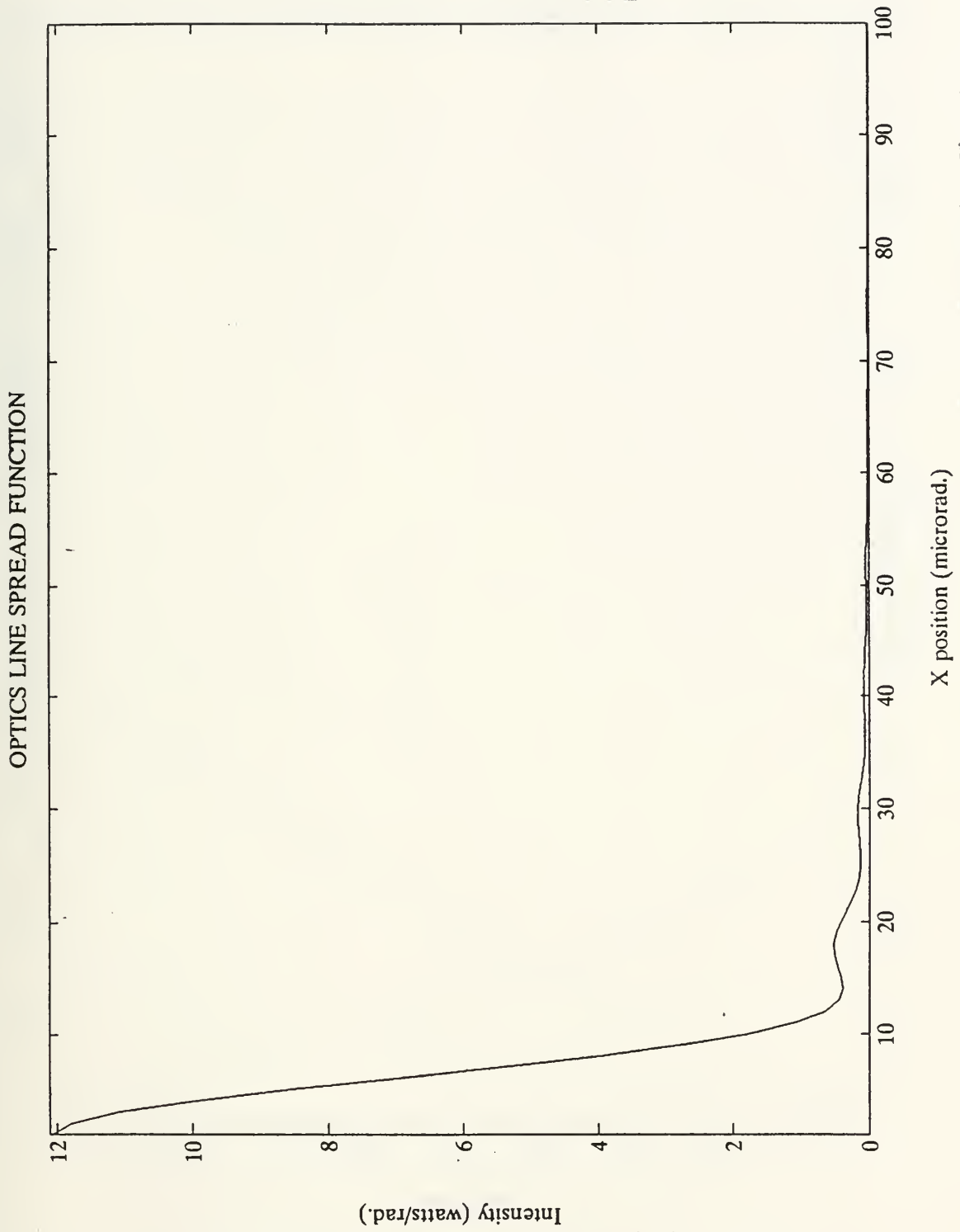
[Fig. 9] Optics line spread function
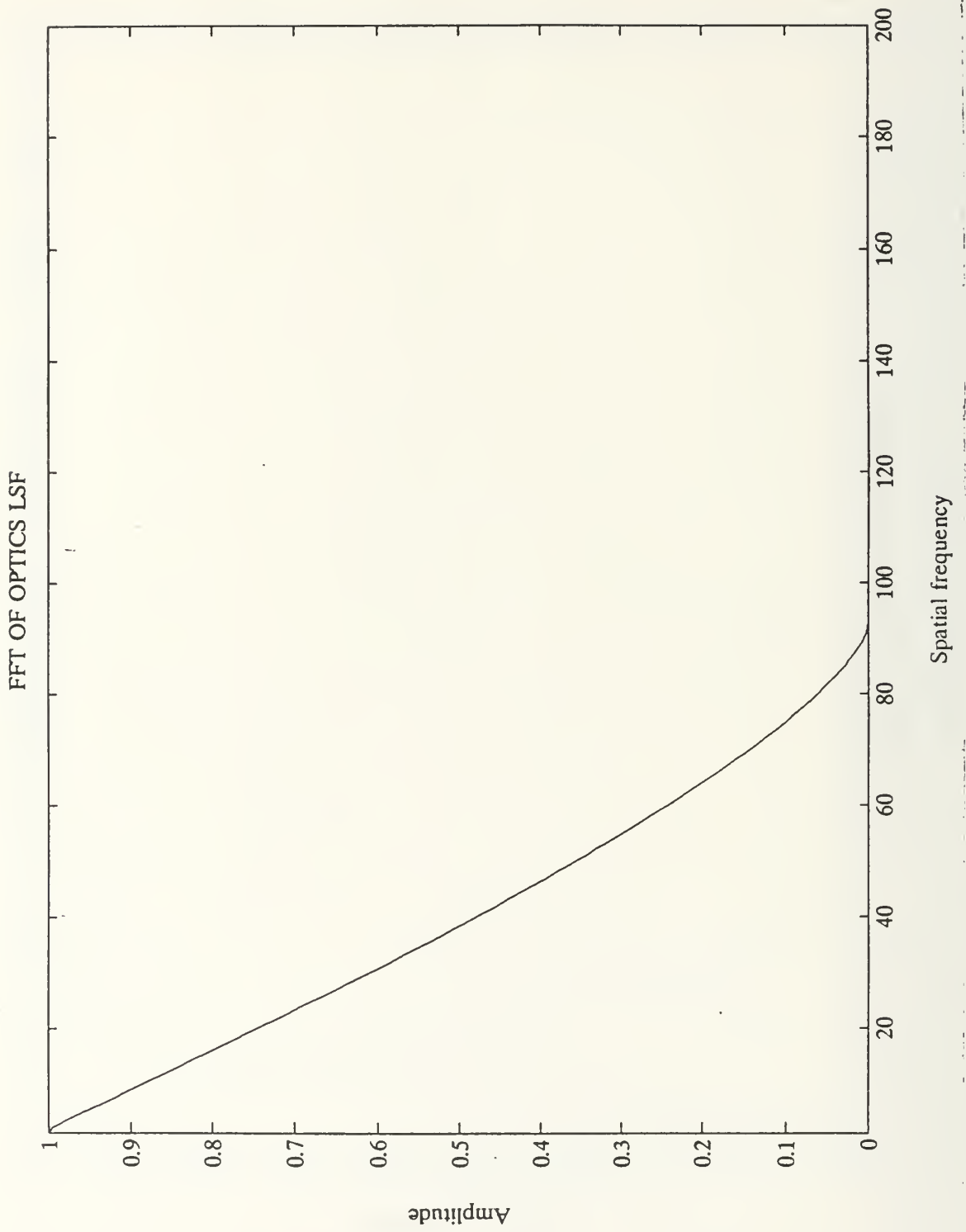
[Fig. 10] FFT of optics LSF

60
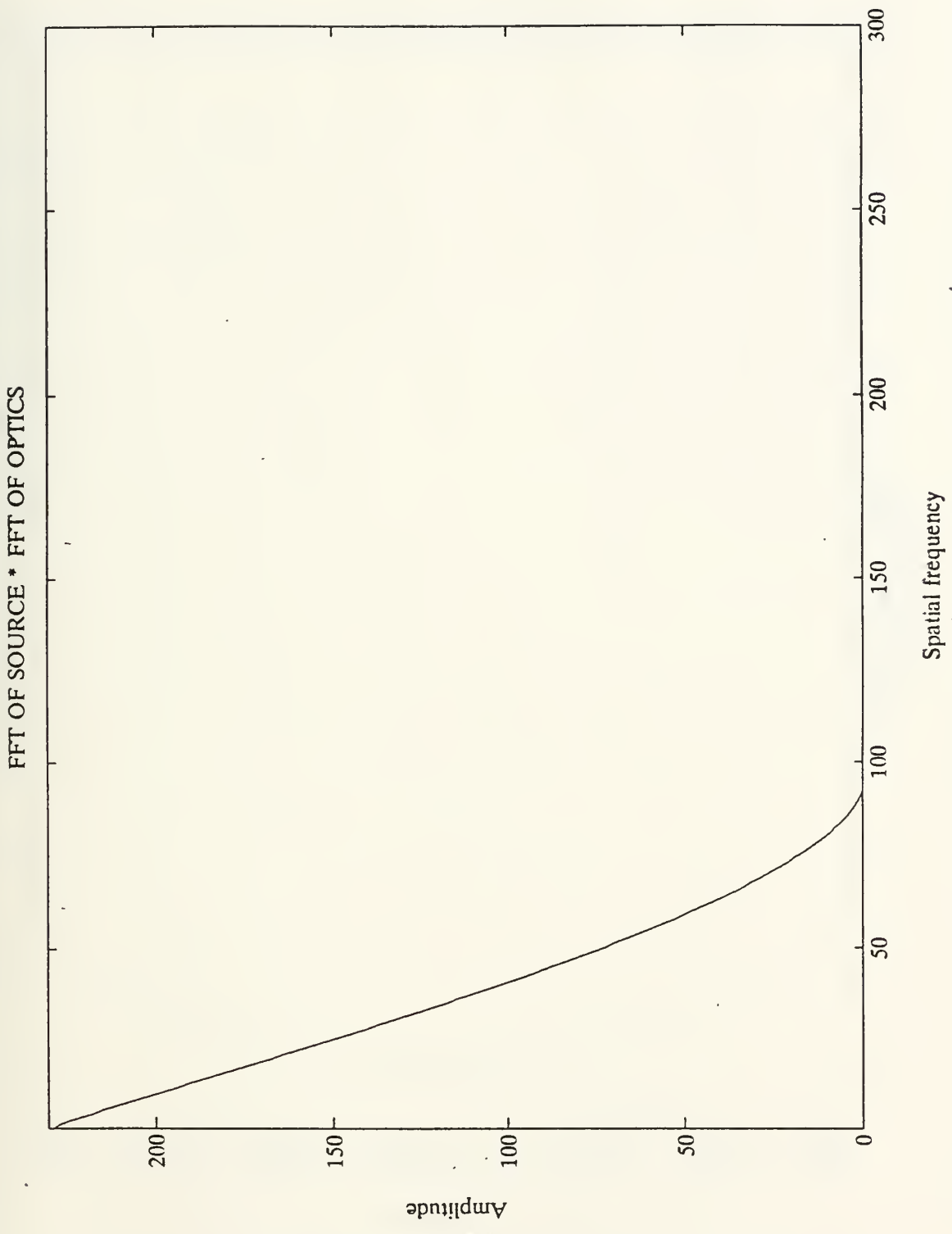
[Fig. 11] FFT of source * FFT of optics
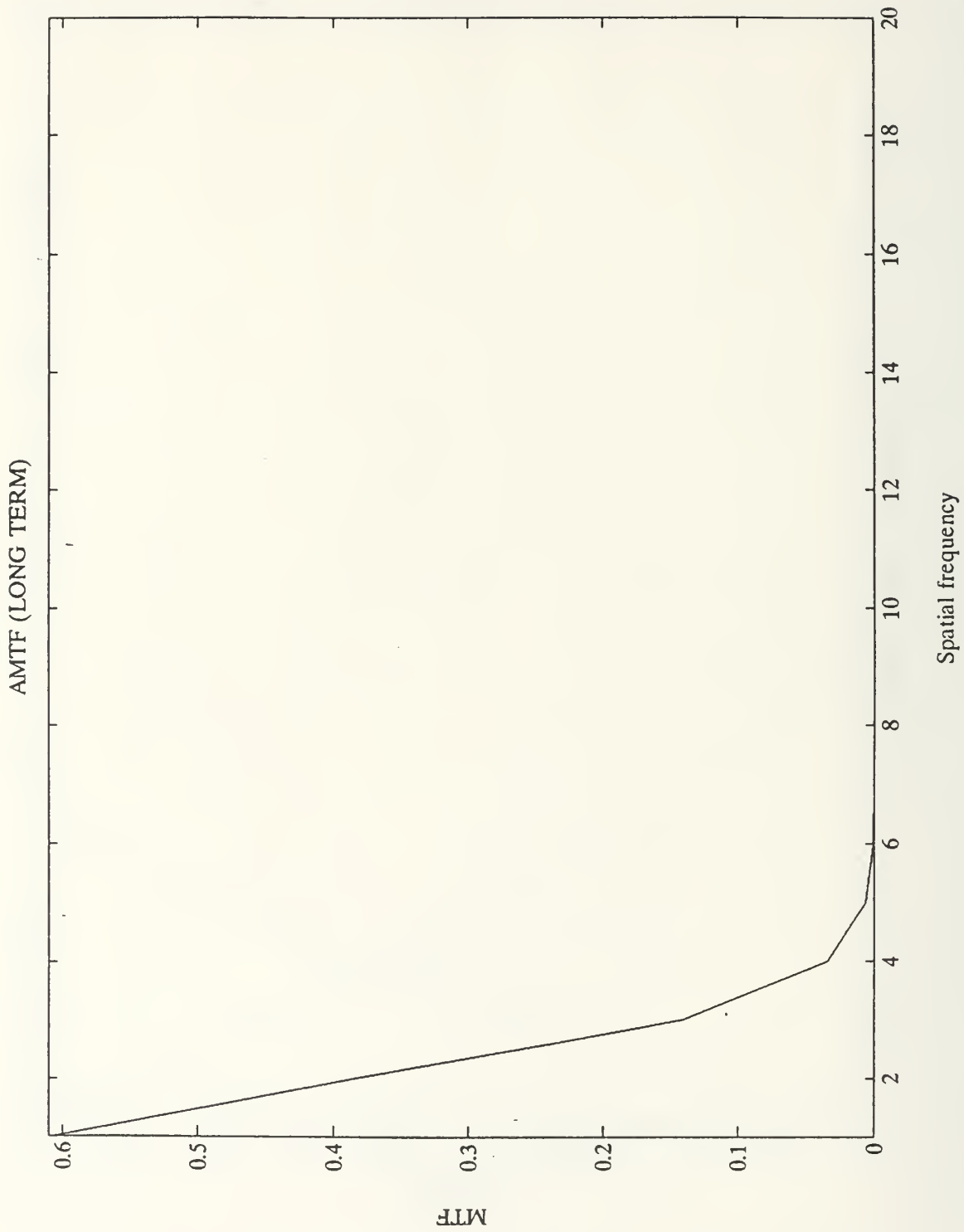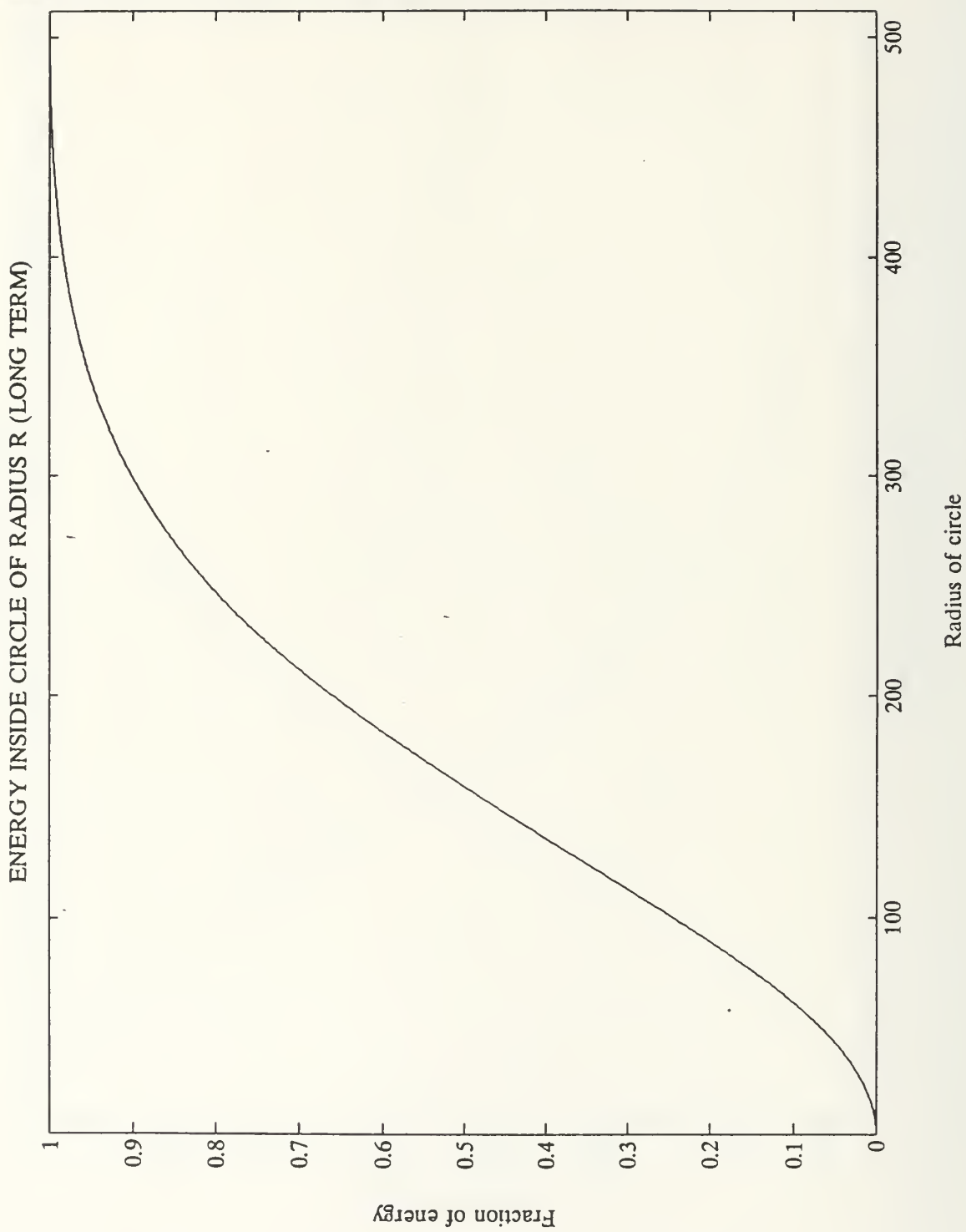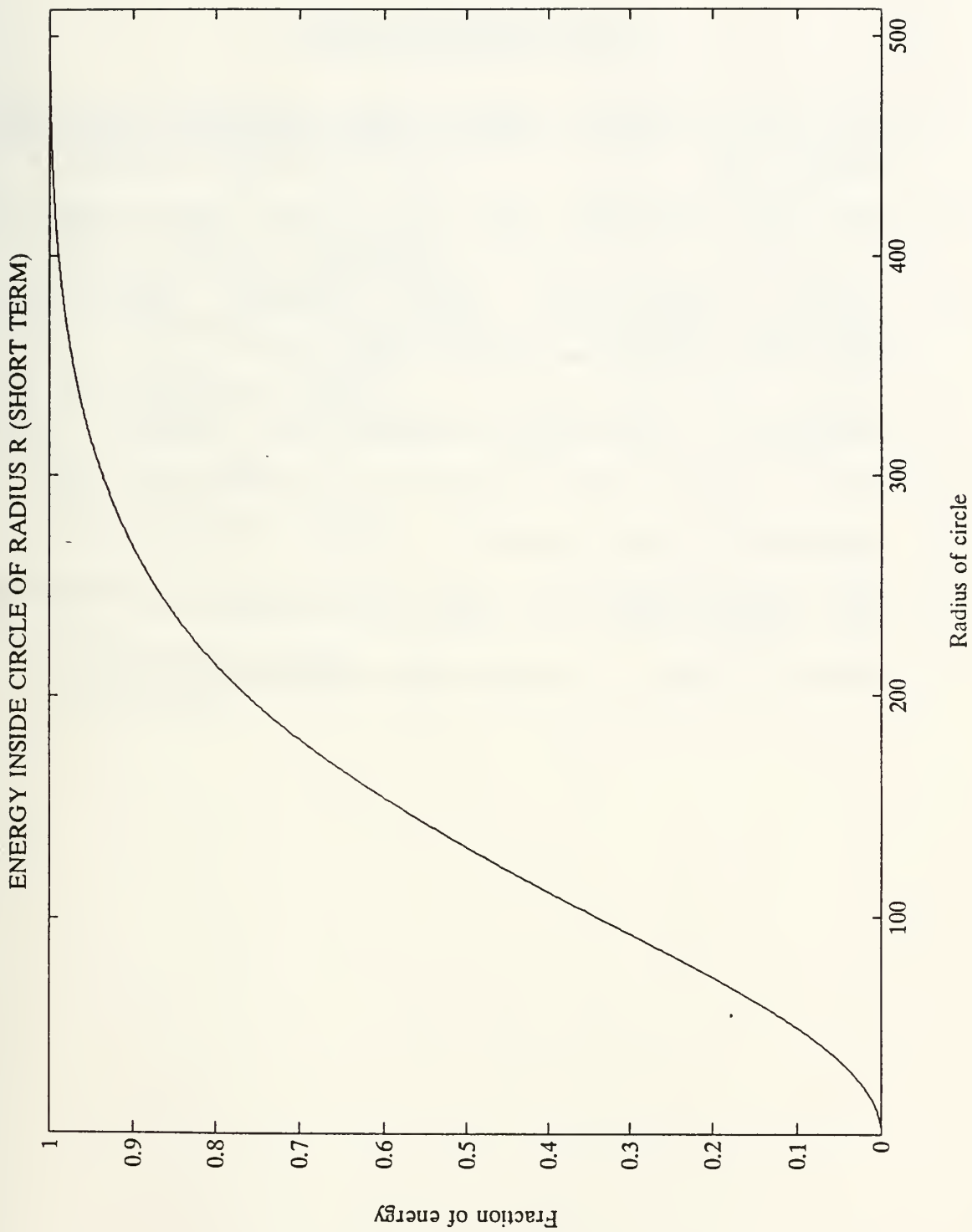
[Fig. 12] AMTF (long term)
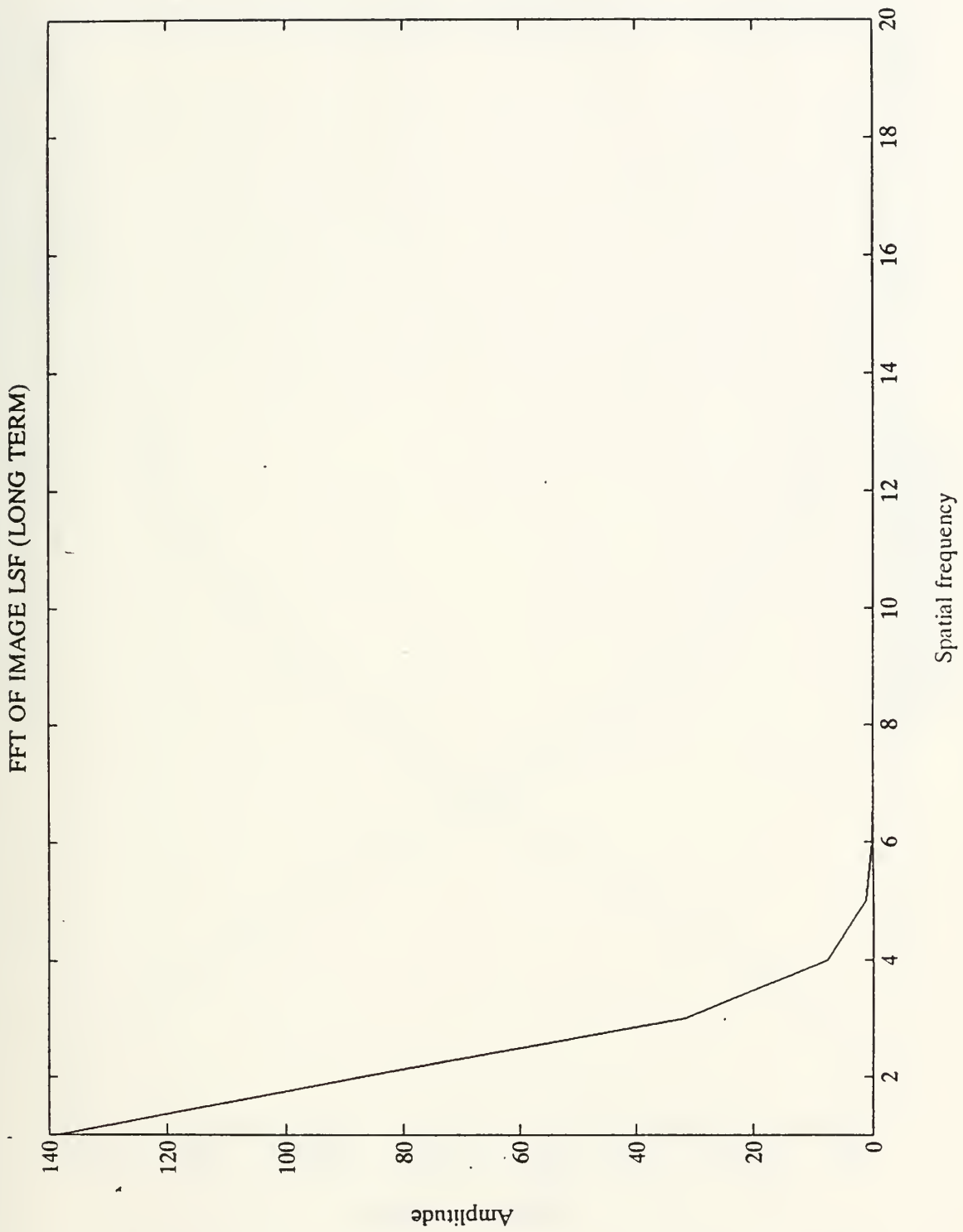
[Fig. 13] FFT of image LSF (long term)
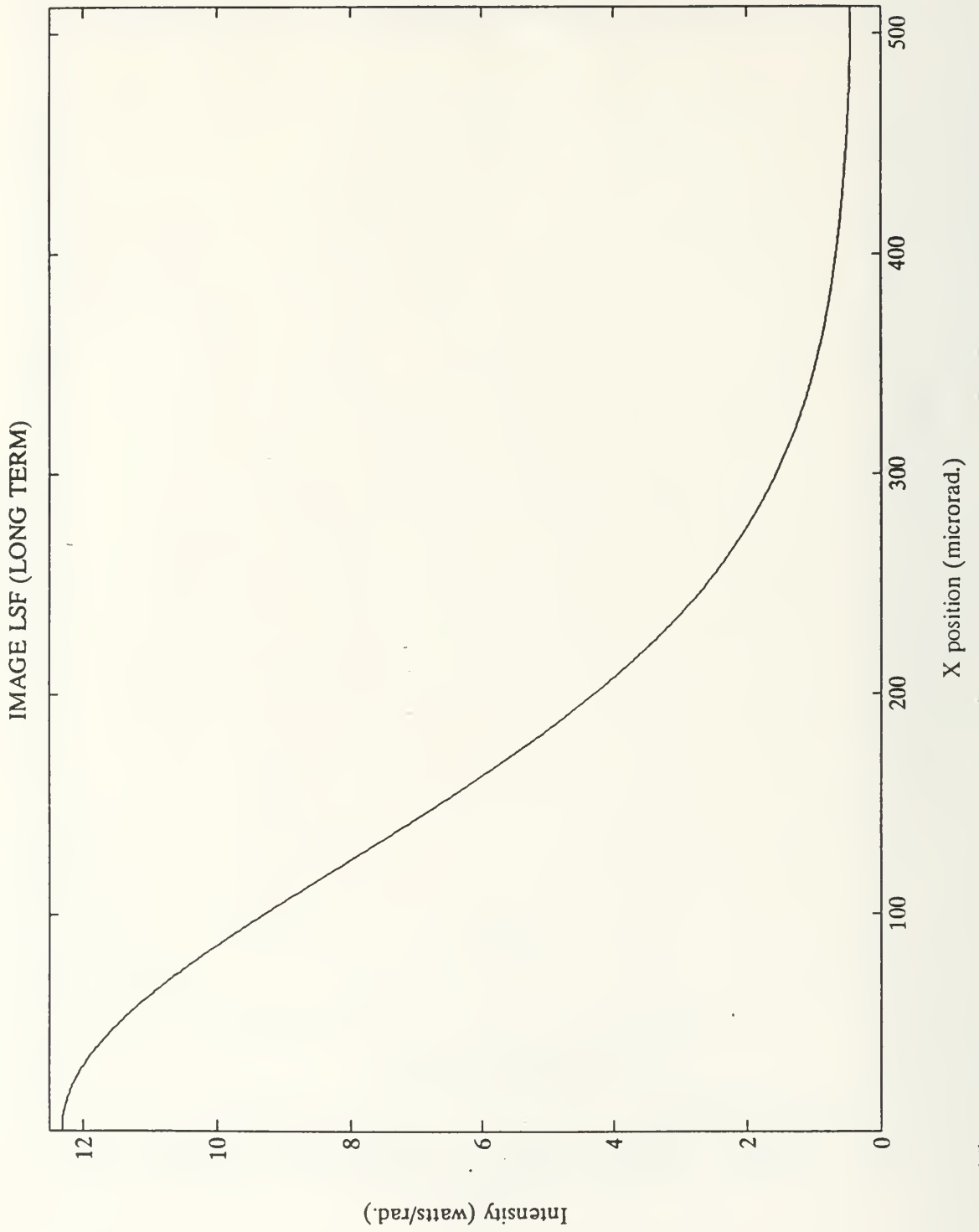
[Fig. 14] Image LSF (long term)

64
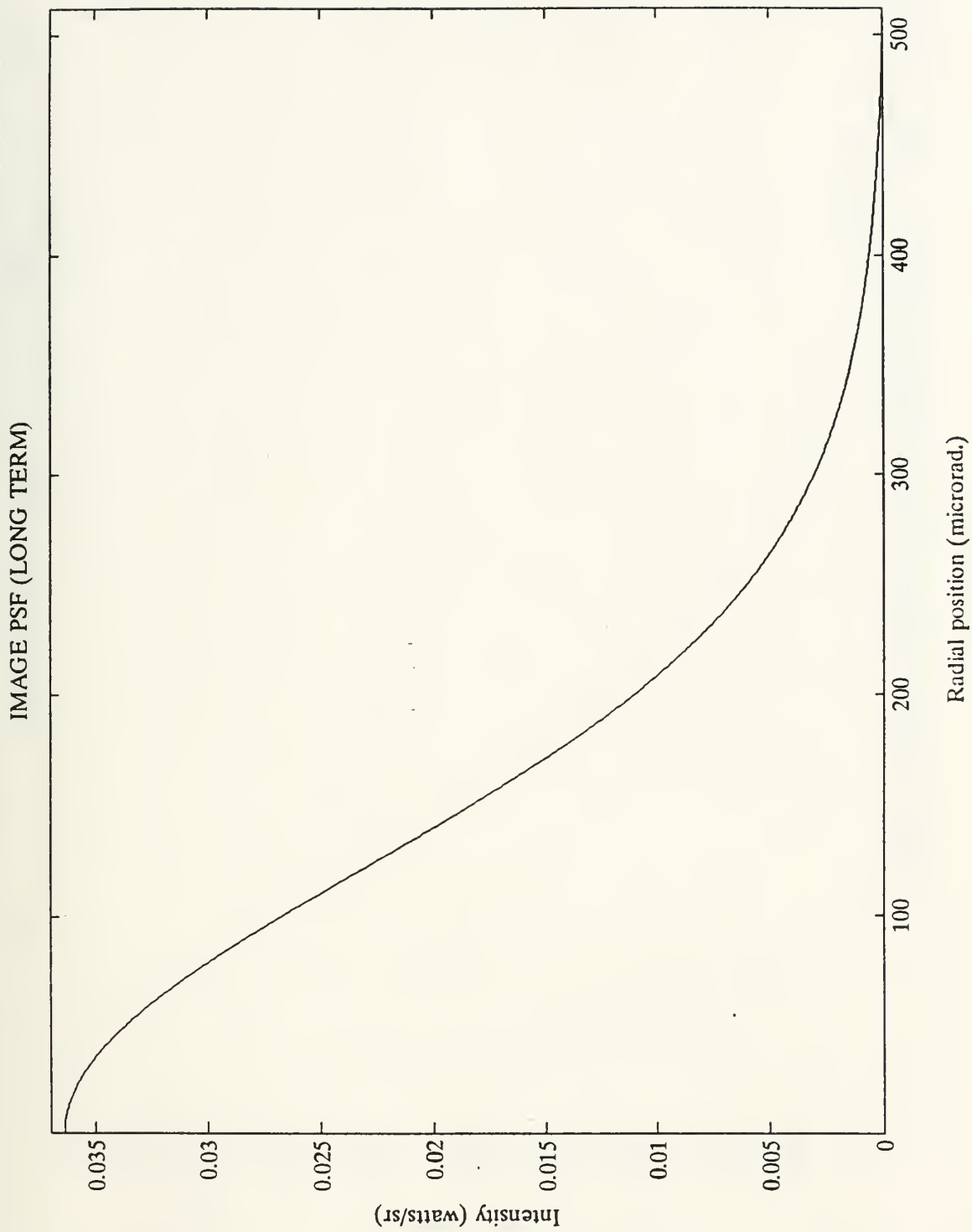
[Fig. 15] Image PSF (long term)

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[Fig. 16] Energy inside circle of radius r (long term)

66
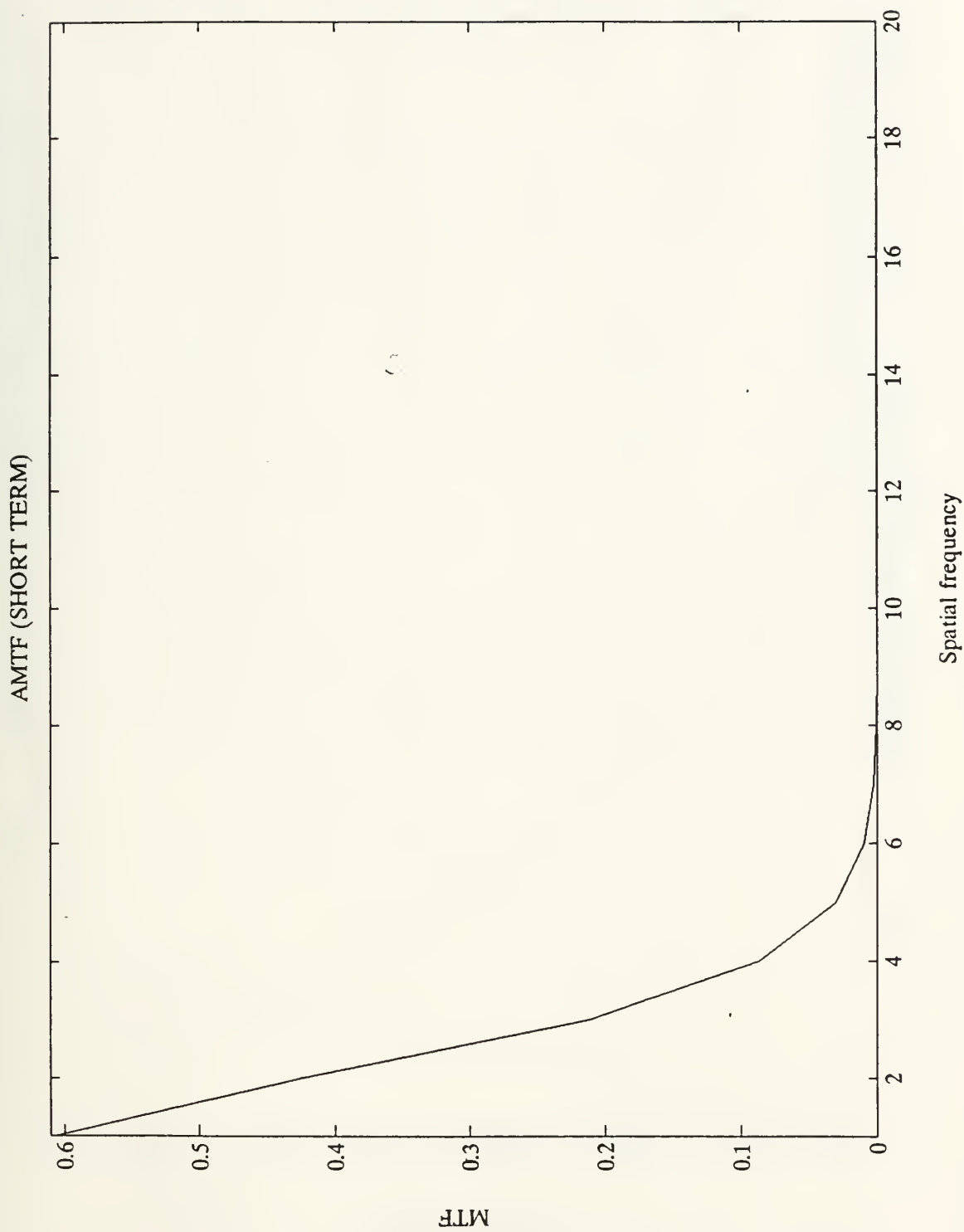
[Fig. 17] AMTF (short term)
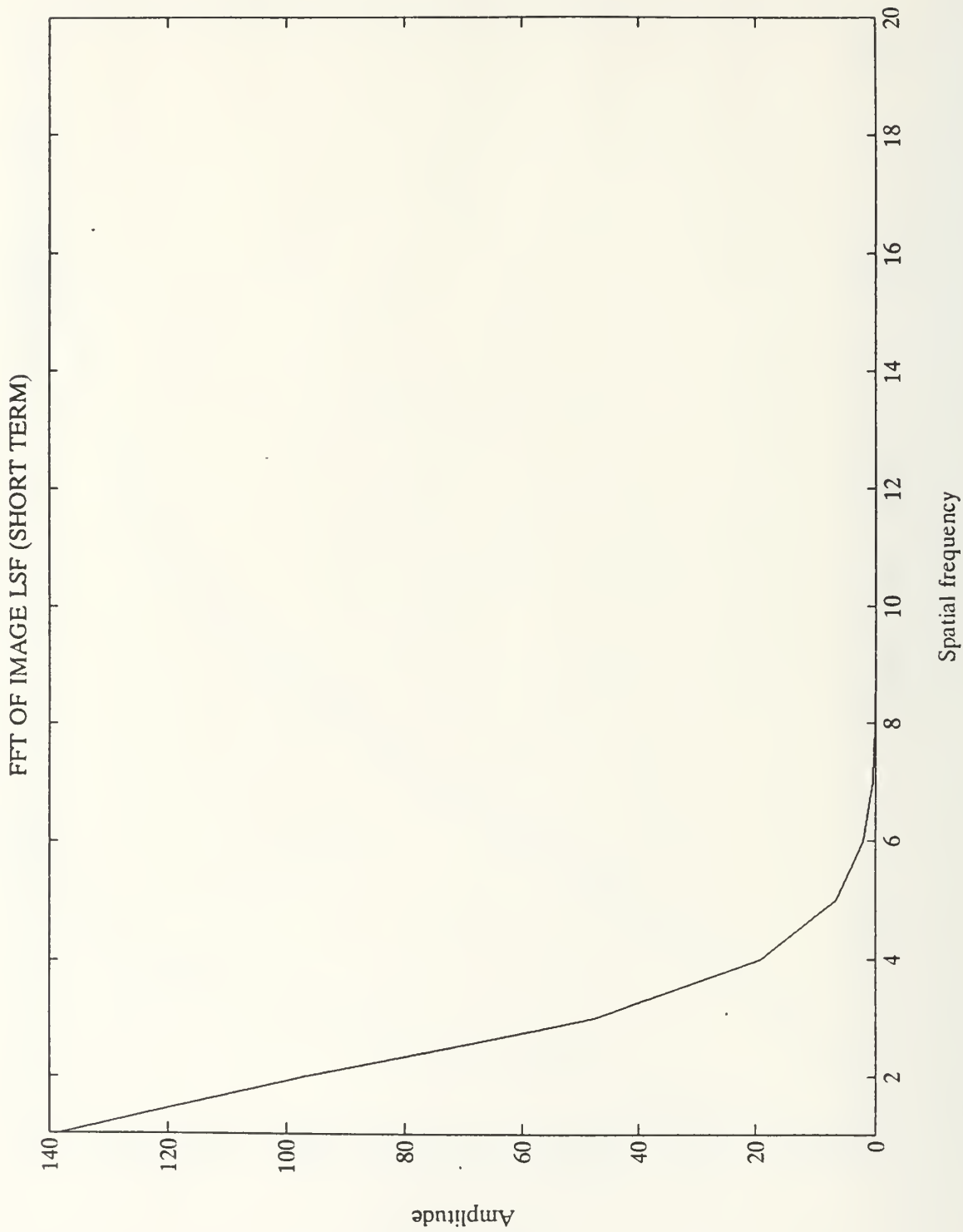
[Fig. 18] FFT of image LSF (short term)
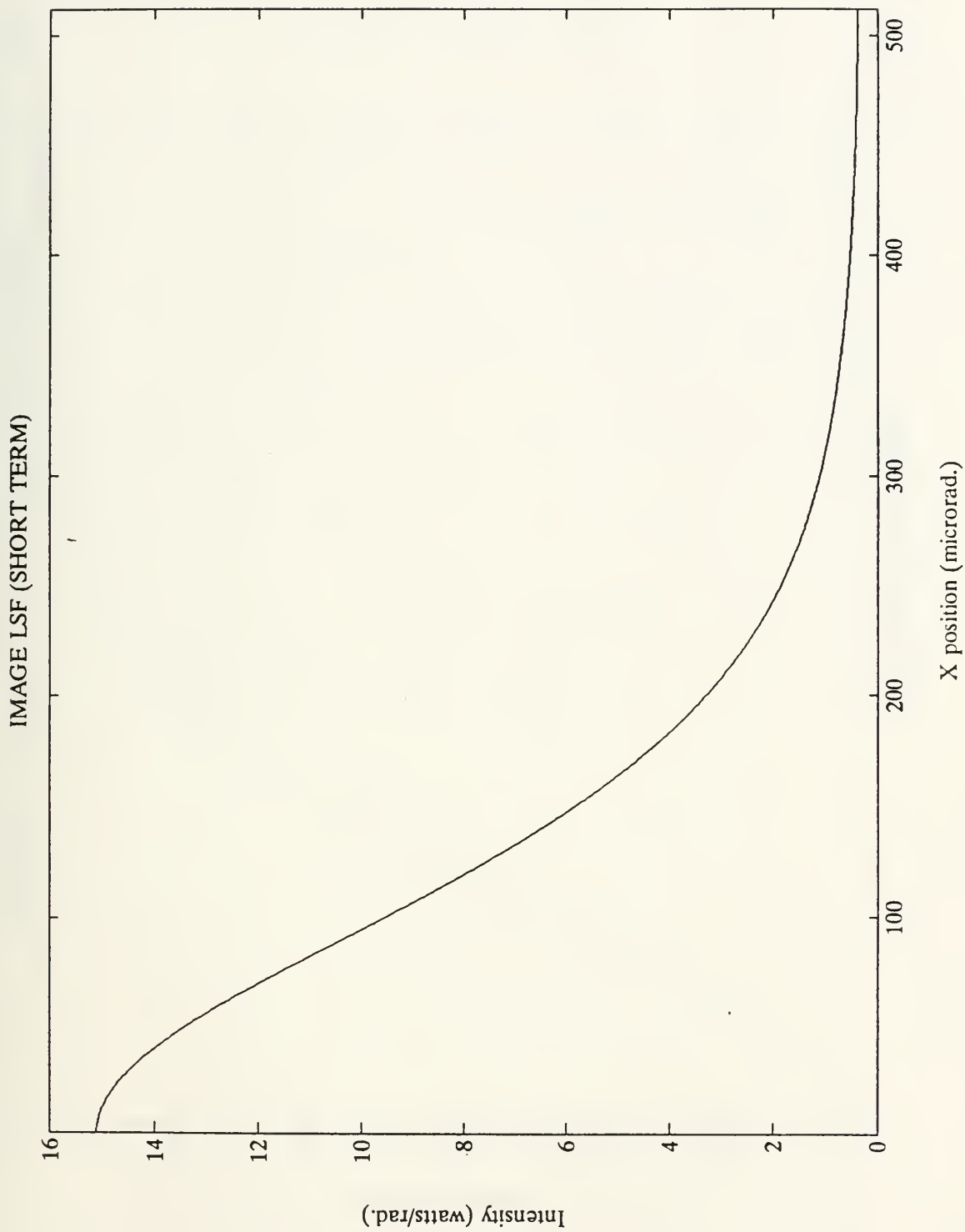
[Fig. 19] Image LSF (short term)

69
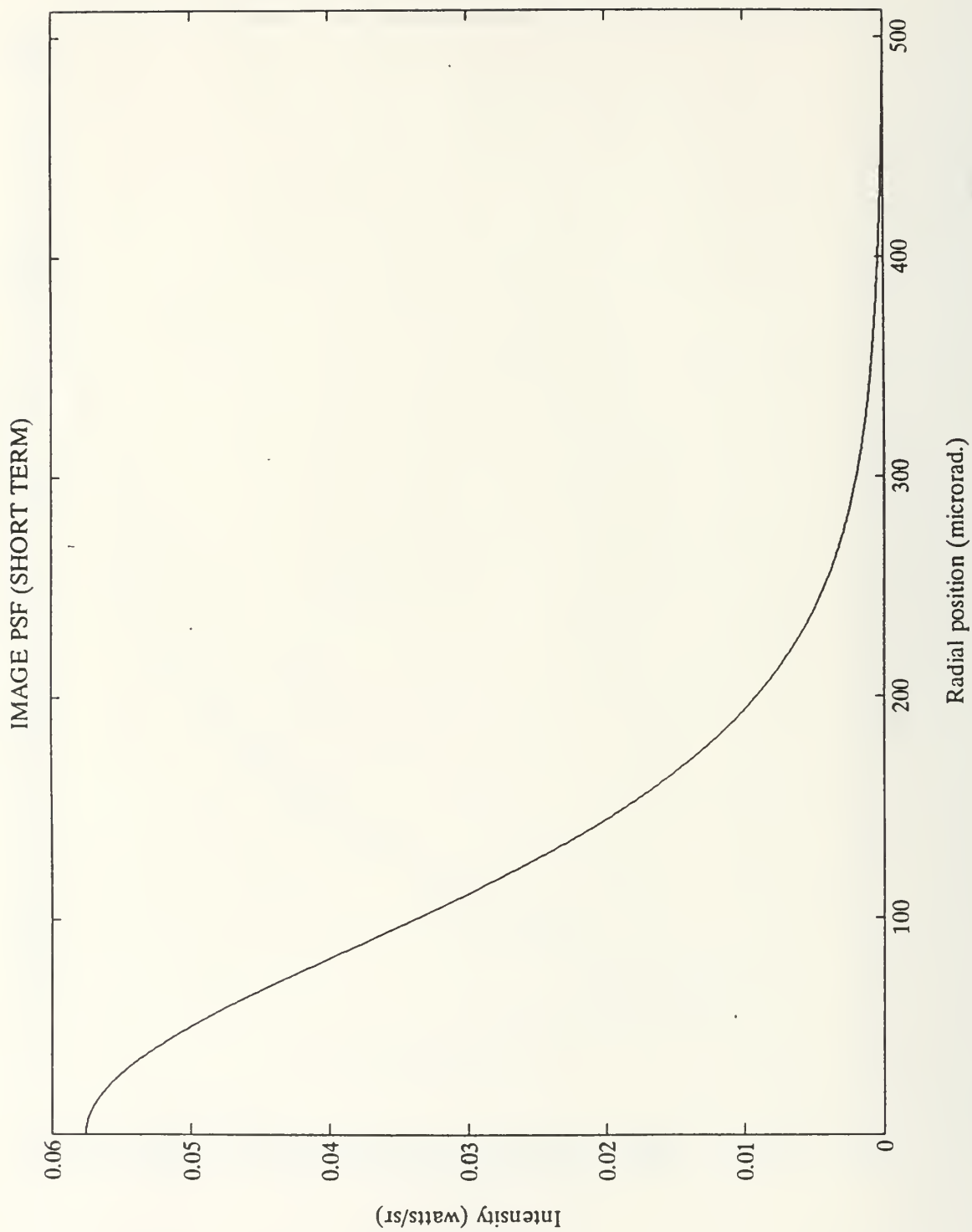
[Fig. 20] Image PSF (short term)

70

[Fig. 21] Energy inside circle of radius r (short term)

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