Reference Manual

Volume II

OPTICAL SCIENCES CENTER
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Reference Manual

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Chapter 4

Diagnostic Analysis/ Graphics

These options provide tools to represent graphically and in listings, those characteristics helpful in diagnosing problems in aberration correction, pupil efficiency, available fields of view, and with Gaussian beam propagation.

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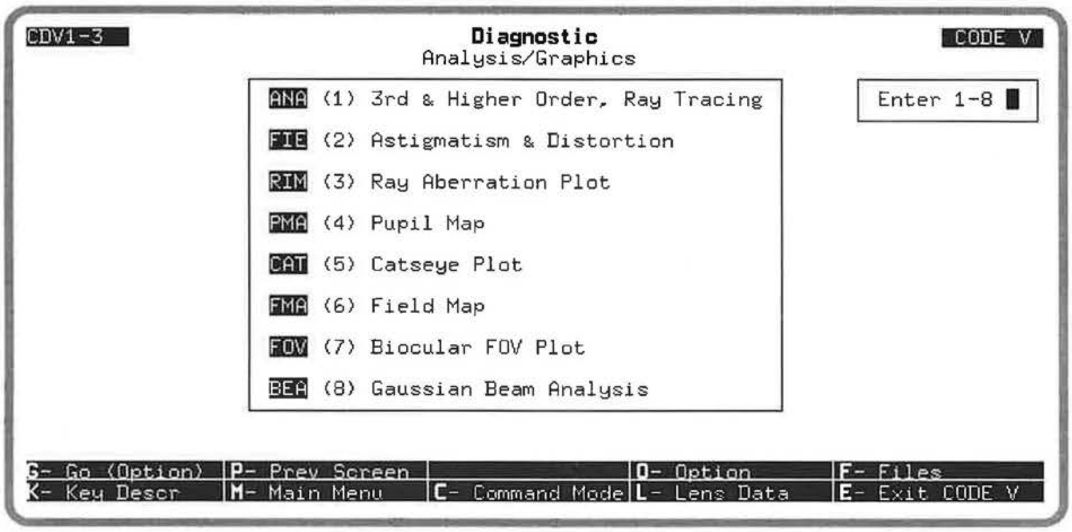
DIAGNOSTIC ANALYSIS/GRAPHICS

OPTION INDEX

SCREENS



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ANALYSIS (**ANA**)

ANA computes simple diagnostic analyses of the optical system including:

- First order traces and third order aberrations
- Pattern ray traces and wave aberrations
- Higher order ray aberration analyses

DEFAULT OPERATION

Listed output is provided for each zoom position for:

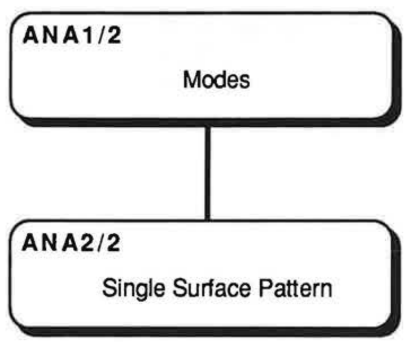
- First order traces with third order transverse aberrations listed at each surface plus image distance, EFL and aberration sums, for the reference wavelength

- Image distance, EFL, and third order sums for each of the other wavelengths and their difference from the reference wavelength

- Tracing of a standard pattern of ray fans at each field, listing image surface ray aberrations and wave aberration (OPD) for each ray, relative to the chief ray. Distortion, entrance and exit angles, and field focus values are given for the chief ray at each field. Rays are traced at each wavelength.

These, and other operations, can be individually selected by command; when such selections are made, the default group is abandoned and only those operations selected will be performed.

SCREEN FLOW DIAGRAM



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```
ANA1/2              Raytrace Analysis                    CODE V
                   Mode/Output Controls

THI Third order      wavelength no.  1  F
    analysis                         2  F
    (F-output all surfaces           3  P
     P-output image surface
     N-No analysis)

RAY Trace ray        wavelength no.  1  Y
    pattern                          2  Y
    (Y/N)?                           3  Y

DEL Real ray interval (pupil frac.)  .2
HIG Higher order analysis (Y/N)?     N

G- Go (Execute) P- Prev Screen  T- Top Screen   O- Option     F- Files
K- Key Descr    M- Main Menu    C- Command Mode L- Lens Data  E- Exit CODE V
```

```
ANA2/2              Ray Trace Analysis                   CODE V
                  Single Surface Pattern

SSP Reference                field no.  1  N
    wavelength trace:                   2  N
    (F-full output                      3  N
     P-partial output
     N-no output)

G- Go (Execute) P- Prev Screen  T- Top Screen   O- Option     F- Files
K- Key Descr    M- Main Menu    C- Command Mode L- Lens Data  E- Exit CODE V
```

COMMAND MNEMONICS (alphabetical)

DEL HIG RAY SSP THI

DATA INPUT DESCRIPTION

Command Syntax		
Screen Prompt	**Explanation**	**Default**
THI [F | P | N]....w,z]		
Third order analysis... (ANA1/2)	Do first order traces and third order analysis. Listing flags for each wavelength/zoom position mean: F - list all surfaces and sums P - list only sums N - no listing If no flags are given, the default pattern is F in the reference wavelength; P in other wavelengths More than one THI command can be given to complete the selection.	THI is included by default only if no commands are given, with F in the reference wavelength; P in other wavelengths.
RAY [Yes | No....w,z]		
Trace ray pattern (Y/N)? (ANA1/2)	Trace rays in pupil pattern according to DEL command, producing fans in +Y,-Y,+X (and -X if no Y-plane symmetry exists). Only focal plane values are given; see SSP for obtaining a more extensive listing. Use Yes|No flags to turn on/off individual wavelengths/zoom positions; more than one RAY command can be given to complete the selection.	RAY is included by default only if no commands are given.
DEL ray_interval_pupil_fraction....z		
Real ray interval (ANA1/2)	Interval between rays in pattern ray tracing (RAY,HIG,SSP commands), in fraction of pupil radius. Rays are traced at relative fractions of the vignetted pupil radii of: 1.0, 1.0-DEL, 1.0-2 * DEL, ... until 1.0-n * DEL < or = DEL. **Range:** 0.01 < value < 1.01; 1.01 eliminates all but chief rays.	0.2000001, giving rays at 1.0, 0.8, 0.6, 0.4 * vignetting in each fan of the pattern.

Continued...

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ANA

Command Syntax		
Screen Prompt	**Explanation**	**Default**
HIG Yes | No		
Higher order analysis (Y/N)? (ANA1/2)	Do higher order analysis of pattern rays (in reference wavelength only), listing the ray equivalents for third order aberration contributions and for fifth plus higher order aberration contributions for each ray as computed from the Aldis theorem; listed also is the ratio of total ray aberration contribution to third order. These contributions for the chief ray and extreme two rays of each fan are listed surface-by-surface at each field; the contributions of the chief ray are removed from all other rays at that field.	No. Not done.
SSP [P | F | N....f,z]		
Reference wavelength trace... (ANA2/2)	Do pattern ray tracing (in reference wavelength only), listing surface by surface coordinates. Listing flags for each field and zoom position mean: F - surface-by-surface listing for all rays P - surface-by-surface listing for chief and extreme rays only N - No listing Use flags to turn on/off individual fields/zoom positions; more than one SSP command can be given to complete the selection.	Not done.

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DISCUSSION OF INPUT AND COMPUTATIONS

When to Use the ANAlysis Option

The ANA option provides several simple diagnostic analysis computations that can be useful in understanding the detailed aberration properties of an optical system. This option represents a logical next step beyond the very simple results of the "Quick Analysis" section of the LDM (FIR, FIO, THO, RSI, SIN). ANA includes multi-wavelength third-order aberrations and their differences; these can help you to analyze chromatic variations of aberrations. It also includes pattern ray tracing (fans) for more comprehensive ray analysis, and higher-order analysis of ray aberrations.

What to Include in LDM Lens Data

Any valid lens system can be analyzed by this option; no additional LDM data is necessary. Note, however, the limited applicability of **THI** and **HIG** data for non-centered systems and for systems with special surfaces (see discussion under Functions of the ANAlysis Option).

Functions of the ANAlysis Option

Default operation of the ANAlysis option is the combination of **THI** plus **RAY** with default **DEL**, excluding **HIG** and **SSP**.

Third Order Analysis

Third order analysis (**THI**) is based on classical aberration theory, in which image defects are expressed as polynomial expansions in object and pupil coordinates.[1] Such a polynomial expansion can be carried to any order (third, fifth, seventh, etc.), but the third order (or Seidel) aberrations are the most widely useful. Surface contributions can aid in understanding the sources as well as the forms of aberration present in a lens design.[2] Because third-order data are calculated in multiple wavelengths (if present), they can also aid in the analysis of the chromatic variation of aberrations; surface-by-surface output for each wavelength is controllable by flags on the **THI** command.

Third order aberrations are calculated from paraxial data (see Technical Notes). Because of this, third order aberrations are strictly valid only for centered systems.

Although third order aberrations will be calculated for any system in CODE V, you should be aware of specific limitations that can limit the accuracy of these calculations. Third order computations are done correctly for centered systems consisting of plane, spherical, and polynomial asphercs. Third order computations for cylindrical surfaces are done for the equivalent spherical-surface in the meridian designated by XZF (in LDM). Third order computations for aspheric toroids are for the equivalent aspheric. For gradient index and diffraction grating surfaces, they are for the aspheric without regard to the index variation or diffraction. Splines generate aberrations of all orders (2,3,4....) and are only treated as a parabola of equivalent power. No effect of decentration is included; therefore, for decentered systems, third order computations may or may not be of value, depending on system structure.

Ray Fans

Ray fans (ray pattern analysis - **RAY** command) are based on real rays and can be useful in understanding the overall aberration properties of an optical system.[3] Ray fans display data for the image surface only (no surface contribution or ray coordinate information). Use **RAY** when you want transverse ray aberrations, OPD, and chief ray properties in tabular form. The **DEL** command controls the spacing and number of rays in the pattern. Note that the RIM option provides similar information in graphical form — plotted ray fans (transverse aberrations or OPD). RIM is usually more convenient for studying aberration forms or for comparing the correction of several optical systems.

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[1]See Born & Wolf, *Principles of Optics* (5th ed.), Pergamon Press, pp. 211-218 for a derivation of the power series expansion.
[2]See W. Smith, *Modern Optical Engineering*, McGraw-Hill, pp. 49-57 for good explanations of the Seidel aberrations.
[3]See W. Smith, pp. 68-71 for a discussion of ray trace curves.

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Use **SSP** when you want tabular information similar to **RAY**, but with the addition of surface by surface ray coordinates for selected (or all) rays. This can produce a large volume of output that would typically be directed to a file for printing and review. For interactive use, tracing individual rays may be more convenient (RSI or SIN commands in the LDM). As with **RAY**, the **DEL** command controls the spacing and hence the number of rays in the pattern.

Higher Order Aberration Analysis

Higher order analysis (**HIG**) provides the surface-by-surface contributions to the ray aberrations and to the combined fifth and higher order aberrations. Higher order analysis strictly applies only to centered systems consisting of plane, spherical, conic, and polynomial aspheric surfaces.

The performance of high quality optical systems is usually limited by aberration residuals higher than third order. Classically, these have been analyzed by special computations of fifth order and seventh order surface-by-surface contributions. An alternate method would be to calculate the surface-by-surface contribution to the ray aberrations (i.e., the sum of all orders); subtracting the third order contributions would then give the fifth and higher order ray aberrations.

At one time such a procedure was impossible because no computational method had been published. However, H. L. Aldis developed a method[4] (now called the Aldis theorem) which permits the calculation of these ray aberration contributions – what we call surface aberrations. The computational scheme is embodied in the **HIG** command.

The computation consists of third order calculations (identical to those in **THI**), the surface aberrations, the difference of these two (giving the higher order contributions) and the ratio of the total ray aberration to the third order aberration. These values can be used in various ways. For example, the higher order contributions reveal the surfaces which are the major sources of aberration tails or higher order astigmatism. If any of these sources are cemented surfaces, then sizeable chromatic variations of the higher order aberrations can be expected. The ratio of total to third order aberration is useful in determining which surfaces can be weakened with the least loss in third order balance; thus the work of achieving third order balance can be shifted from one surface to another with a smaller tendency to produce higher order aberrations.

As with **RAY** and **SSP**, the **DEL** command is used to control the ray pattern spacing and hence the number of rays used in the analysis.

Using Macro-PLUS™ for Fifth Order Analysis

In addition to the built-in capabilities of ANA, Macro-PLUS programs can be used to do other types of analysis. As an example of this, macros for fifth order aberration analysis are supplied with CODE V (through the logical name CV7_MACRO:). The macro FIFTHDEF.SEQ creates a user-defined function (@FIFTH) that evaluates fifth order aberration sums. The macro FORDER.SEQ uses @FIFTH to print the fifth order sums. See the examples in Chapter 11C for more information.

[4]See A. Cox, *A System of Optical Design*, Focal Press, pp. 129-133.

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DESCRIPTION OF OUTPUT

Analysis – Function and Output

A. Third Order Analysis (THIRD) (See Technical Notes for notation) - Table 1

Two first order rays, the paraxial and the paraxial principal rays, are traced from the object through the system to the image. These provide the information necessary to calculate the five monochromatic third order aberration coefficients — spherical aberration, coma, astigmatism, Petzval sum (field curvature), and distortion — and the two first order chromatic aberrations, axial and lateral color. Output, as shown in Table 1, consists of:

1. Paraxial data

   The EFL, image distance, image F/NO and image height are listed.

2. Output for each surface

   Two lines of output are normally printed for each surface. For an aspheric surface, a third line is listed. The first line contains the surface number and the paraxial ray data in the following order:

   Surf. no. Y_s u_s $(ni)_s$ $\overline{Y}_s$ $\overline{u}_s$ $(\overline{ni})_s$

   The second line contains the surface contributions (for the spherical part of the surface if it is an asphere) to the 3rd order transverse aberrations and the Petzval curvature in the following order:

Sph. Ab	Coma	Astigmatism		Dist.	Ax. Col	Lat. Col	Petzval
ΔY	ΔY_T	ΔY_T	ΔX_S	ΔY	$Y_F - Y_c$	$Y_F - Y_c$	ρ

   For an asphere, the third line contains the contributions from the aspheric part of the surface. An extra blank line is added at airspaces in the system so that the printout conveys some sense of the lens construction.

3. Summations

   At the end of the surface output, the summations of the Petzval sum and transverse aberrations are listed.

4. Summations and differences for other wavelengths

   The same first and third order calculations are run in the other wavelengths; sums and differences from the nominal wavelength are listed.

Most systems must be designed to cover a band of radiation rather than a single wavelength. Although the axial and lateral color values already obtained indicate the gross nature of the color correction, many systems eventually are limited by secondary spectrum or chromatic variations of the third order aberrations. To aid in the analysis of these effects, the first and third order calculations run in the other wavelengths and their differences show the chromatic variations. Flags can be used to extend the output to surface contributions, too.

Note that because this option uses paraxial ray trace data to compute the third order surface contributions, it may not apply to non-rotationally symmetric systems (i.e., systems with tilts, decenters, toroidal surfaces, non-zero x field components, etc.).

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Table 1. Third Order Output

Input:
RES CV7_LENS:DBGAUSS
ANA;THI;GO

Double Gauss - U.S. Patent 2,532,751 POSITION 1
Paraxial values and 3rd order transverse aberrations - 587.6 nm
EFL = 100.000000 IMAGE F/NO = 2.000000
IMAGE DISTANCE = 63.137145 IMAGE HEIGHT = 24.932800

SURF	Y(MARG)	U(MARG)	NI(MARG)	Y(CHIEF)	U(CHIEF)	NI(CHIEF)			
	SPH ABER	TAN COMA	TAN ASTIG	SAG ASTIG	PETZVAL	DISTORTION	AX COLOR	LAT COLOR	PETZ CURV
		(U is after refraction)							
EP	25.000000	0.000000		0.000000	0.249328				
1	25.000000	-0.166153	0.435163	-13.929054	0.246704	0.006872			
	-0.972519	-0.046072	-0.517169	-0.516684	-0.516441	-0.008159	-0.301459	-0.004760	-0.006646
2	23.546715	-0.191607	-0.066664	-11.771216	0.360502	0.298042			
	-0.018604	0.249530	-0.958172	-0.214437	0.157431	0.958706	-0.043497	0.194466	0.002026
3	23.489581	-0.374158	0.481693	-11.663721	0.350582	0.026176			
	-0.444231	-0.072422	-0.848045	-0.845421	-0.844110	-0.045942	-0.302564	-0.016442	-0.010863
4	18.840961	-0.375230	-0.602487	-7.308009	0.351586	0.564524			
	-0.018237	0.051264	-0.048034	-0.016011	0.000000	0.015002	0.149394	-0.139981	0.000000
5	17.423732	-0.110962	0.700607	-5.980079	0.395826	0.117283			
	2.099315	1.054292	1.541722	1.424061	1.365231	0.238392	0.487085	0.081539	0.017569
STO	15.747340	-0.110962	-0.110962	0.000000	0.395826	0.395826			
	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
7	14.313583	0.130600	-0.640410	5.114541	0.317880	0.206643			
	2.257732	-2.185525	1.789379	1.319239	1.084170	-0.425683	0.365759	-0.118020	0.013952
8	14.806855	0.129410	0.209698	6.315164	0.314985	0.510404			
	-0.001921	-0.014027	-0.034141	-0.011380	0.000000	-0.027700	0.045033	0.109611	0.000000
9	16.208878	-0.077729	-0.541016	9.727684	0.337906	0.059867			
	-1.495330	0.496402	-0.905289	-0.868669	-0.850359	0.096123	-0.222720	0.024645	-0.010943
10	16.185700	-0.058531	-0.050144	9.828441	0.202118	0.354657			
	0.003387	-0.071860	0.457546	0.118711	-0.050706	-0.839626	0.020613	-0.145793	-0.000653
11	15.784286	-0.250000	-0.500087	11.214600	0.217276	0.039592			
	-1.688550	0.401045	-0.503131	-0.481964	-0.471381	0.038157	-0.200478	0.015872	-0.006066
IMG	0.000000	-0.250000		24.932800	0.217276				
SUM	-0.278960	-0.137372	-0.025332	-0.092554	-0.126164	-0.000729	-0.002834	0.001136	-0.001624

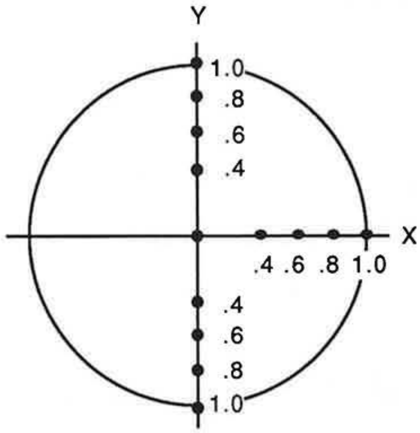
Paraxial values and 3rd order transverse aberrations - 656.3 nm
EFL = 100.043262 IMAGE F/NO = 2.000865
IMAGE DISTANCE = 63.190392 IMAGE HEIGHT = 24.943587

	SPH ABER	TAN COMA	TAN ASTIG	SAG ASTIG	PETZVAL	DISTORTION	AX COLOR	LAT COLOR	PETZ CURV
SUM	-0.280674	-0.128535	-0.030886	-0.096837	-0.129813	-0.000737	-0.000421	0.000945	-0.001670
CHANGES FROM REFERENCE WAVELENGTH									
	-0.001715	0.008837	-0.005554	-0.004284	-0.003648	-0.000007	0.002413	-0.000191	-0.000046

Paraxial values and 3rd order transverse aberrations - 486.1 nm
EFL = 100.032278 IMAGE F/NO = 2.000646
IMAGE DISTANCE = 63.172183 IMAGE HEIGHT = 24.940848

	SPH ABER	TAN COMA	TAN ASTIG	SAG ASTIG	PETZVAL	DISTORTION	AX COLOR	LAT COLOR	PETZ CURV
SUM	-0.266857	-0.158549	-0.009843	-0.081191	-0.116865	-0.001958	-0.008630	0.001486	-0.001503
CHANGES FROM REFERENCE WAVELENGTH									
	0.012103	-0.021177	0.015489	0.011362	0.009299	-0.001228	-0.005796	0.000349	0.000120

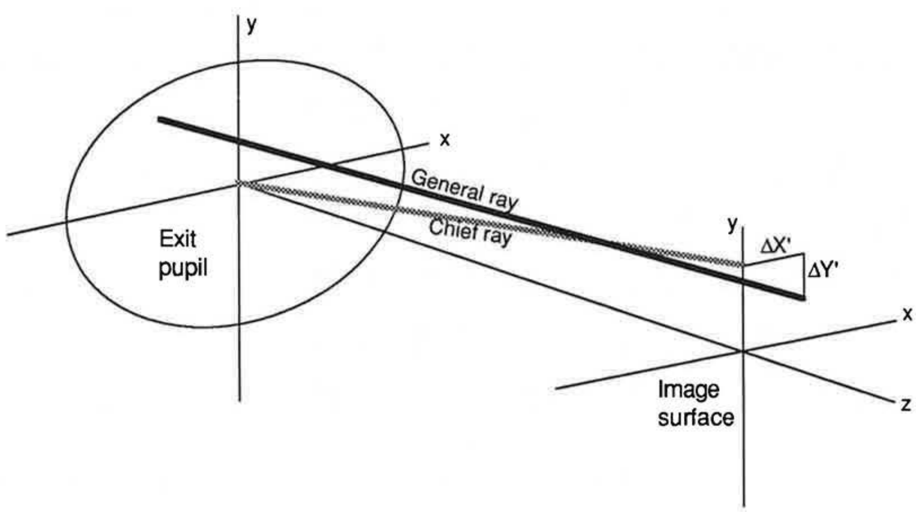
B. Summary of Trace Analysis (**RAY** TRACE) - Table 2



Ray fans are traced according to a standard pupil pattern, in part determined by the LDM data, for the axial field point as well as for each of the previously designated field heights. The normal pupil pattern is shown at the left, where the Y coordinate lies in the meridional plane and the X coordinate is the skew direction; the pupil fractions for X and Y are scaled down appropriately according to the required values of vignetting. The chief ray height in the image surface is subtracted from each of the image surface heights for the ray fans so that the residual aberrations may be listed. Simultaneously, rays are traced in the other wavelengths and the chief ray value for the reference wavelength is also subtracted from these. For the axial bundle of a symmetric system only the X fan is traced; for systems which are bilaterally unsymmetric, a -X fan is also traced at each field.

Table 2 is an example of the output. For each ray the following values are listed:

X Y ΔX' ΔY' OPD



where X and Y are the fractions of the aperture stop surface through which the rays were traced (they will correspond to the entrance pupil fractions only in the absence of pupil aberrations), ΔX' and ΔY' are the X and Y differences of the ray intercept in the image plane from the principal ray and OPD is the wave aberration in wavelength units. If any additional colors are traced, the values of ΔX' and ΔY' and OPD are printed out in the same line. Note that aperture stop coordinates are scaled to the X-vignetting value.

For each chief ray in the reference wavelength, there is given the image plane coordinates (X',Y',Z'), values for distortion, entrance pupil distance, entrance angle and exit angle and X and Y focus values. If any additional colors are traced, the values of ΔX' and ΔY' are listed on the same line.

If a negative edge thickness occurs during the tracing of a ray, the characters -ET are listed after the OPD of the image surface.

Table 2. Ray Trace Analysis Output

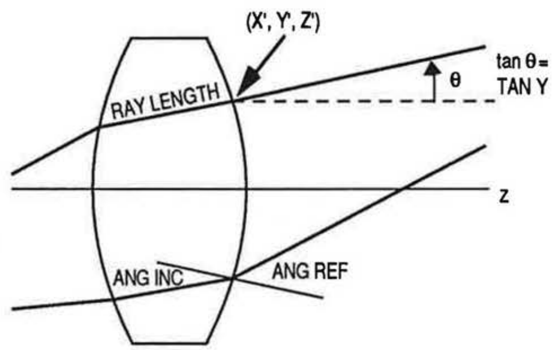
Input:
RES CV7_LENS:DBGAUSS
ANA;RAY;GO

```
    Double Gauss - U.S. Patent 2,532,751                                                      POSITION 1
RELATIVE STOP            587.6 NM                              656.3 NM                       486.1 NM
 COORDINATES       RAY ABERRATIONS                      RAY ABERRATIONS                RAY ABERRATIONS
  X     Y         DELTA X   DELTA Y      OPD          DELTA X   DELTA Y     OPD       DELTA X   DELTA Y      OPD
FOCUS = (  0.000000)
 1.00  0.00      0.055533  0.000000    9.063         0.070008  0.000000    5.572     0.077046  0.000000    7.120
 0.81  0.00     -0.054217  0.000000    7.501        -0.043512  0.000000    5.109    -0.040804  0.000000    6.974
 0.61  0.00     -0.041997  0.000000    3.101        -0.034124  0.000000    1.873    -0.034049  0.000000    2.730
 0.41  0.00     -0.015660  0.000000    0.699        -0.010394  0.000000    0.222    -0.011359  0.000000    0.443

 0.00  0.00     0.000000  17.631651   0.000000     0.000000 -0.000432               0.000000 -0.000083
DISTORTION = -0.0059  PERCENT      EP DIST =   56.825394     ENTRANCE ANGLES = (  0.0000, 10.0000) DEGREES
X-FOCUS, Y-FOCUS = ( -0.162746, -0.082285)                       EXIT ANGLES = (  0.0000,  8.6104) DEGREES

 0.00  0.80      0.000000  0.091908    2.992         0.000000  0.104809    1.191     0.000000  0.097993    1.991
 0.00  0.64      0.000000 -0.016614    4.624         0.000000 -0.007756    3.275     0.000000 -0.010468    4.454
 0.00  0.48      0.000000 -0.031934    2.775         0.000000 -0.026025    2.046     0.000000 -0.026735    2.669
 0.00  0.32      0.000000 -0.020057    1.029         0.000000 -0.016575    0.755     0.000000 -0.016197    0.918

 0.00 -0.29      0.000000 -0.000715    0.045         0.000000 -0.003533   -0.134     0.000000 -0.007051   -0.344
 0.00 -0.43      0.000000 -0.001725   -0.032         0.000000 -0.005268   -0.367     0.000000 -0.012880   -1.032
 0.00 -0.58      0.000000 -0.000755   -0.112         0.000000 -0.004649   -0.630     0.000000 -0.018318   -2.110
 0.00 -0.72      0.000000  0.000530   -0.108         0.000000 -0.003311   -0.827     0.000000 -0.025451   -3.601

 1.00 -0.01      0.197871  0.036922    1.046         0.210005  0.039231   -1.128     0.225687  0.029548   -4.085
 0.81 -0.01     -0.007617 -0.002146    6.775         0.001178 -0.001042    4.760     0.010820 -0.006388    5.143
 0.61  0.00     -0.036750 -0.008886    4.344        -0.030277 -0.008515    3.153    -0.025144 -0.011152    3.706
 0.41  0.00     -0.023800 -0.005829    1.717        -0.019442 -0.005920    1.208    -0.017132 -0.006842    1.444

 0.00  0.00     0.000000  24.927485   0.000000     0.000000 -0.000379               0.000000 -0.000824
DISTORTION = -0.0213  PERCENT      EP DIST =   57.823029     ENTRANCE ANGLES = (  0.0000, 14.0000) DEGREES
X-FOCUS, Y-FOCUS = ( -0.283041, -0.234989)                       EXIT ANGLES = (  0.0000, 11.9013) DEGREES

 0.00  0.60      0.000000 -0.044997    7.278         0.000000 -0.037426    5.891     0.000000 -0.038450    7.684
 0.00  0.48      0.000000 -0.053495    4.846         0.000000 -0.048168    3.983     0.000000 -0.047400    5.106
 0.00  0.36      0.000000 -0.041864    2.568         0.000000 -0.038372    2.127     0.000000 -0.036765    2.672
 0.00  0.24      0.000000 -0.024863    1.003         0.000000 -0.022913    0.839     0.000000 -0.021216    1.030

 0.00 -0.25      0.000000  0.002187    0.276         0.000000  0.000579    0.156     0.000000 -0.006127   -0.146
 0.00 -0.37      0.000000 -0.004526    0.240         0.000000 -0.006239    0.053     0.000000 -0.018222   -0.805
 0.00 -0.50      0.000000 -0.016271   -0.224         0.000000 -0.017678   -0.430     0.000000 -0.036787   -2.327
 0.00 -0.62      0.000000 -0.034795   -1.387         0.000000 -0.035434   -1.515     0.000000 -0.063882   -5.132

 1.00 -0.02      0.355724  0.027680   -9.423         0.365413  0.031592  -10.018     0.390083  0.015443  -18.281
 0.81 -0.01      0.049588 -0.016650    4.484         0.056399 -0.014624    3.013     0.073222 -0.023966    1.411
 0.61 -0.01     -0.024291 -0.019504    4.703        -0.019269 -0.018628    3.641    -0.008910 -0.023727    3.611
 0.41  0.00     -0.027415 -0.011136    2.341        -0.023996 -0.010982    1.839    -0.018309 -0.013406    1.966
```

C. Surface by Surface Listing (**SSP**) - Table 3

For those rays listed in full, the values

X' Y' Z' TAN X TAN Y RAY LENGTH ANG INC ANG REF



for each surface are listed opposite the number of the surface. TAN X is skew direction tangent, TAN Y the meridional direction tangent and the RAY LENGTH is the physical distance along the ray from the preceding surface to the surface. ANG INC and ANG REF are the angles of incidence and refraction. If a negative edge thickness is encountered, the second surface of the intersecting pair is flagged with a -ET following Z'.

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Table 3. Surface-by-Surface Ray Trace

Double Gauss - U.S. Patent 2,532,751 POSITION 1

	X	587.6 NM Y	Z	TAN X	TAN Y	RAY LENGTH	ANG INC (DEG)	ANG REF (DEG)
OBJ	0.000000	0.000000	0.000000	0.000000	0.000000			
1	25.000000	0.000000	5.724766	-0.179754	0.000000	5.724766	25.80	15.61
2	24.176887	0.000000	1.557218	-0.211369	0.000000	4.652500	2.82	4.56
3	22.673351	0.000000	8.372353	-0.429436	0.000000	7.270481	28.60	17.29
4	20.933328	0.000000	0.000000	-0.430895	0.000000	4.409692	23.24	23.31
5	16.150166	0.000000	7.323573	-0.089379	0.000000	12.087208	25.47	43.68
6	15.454416	0.000000	0.000000	-0.089379	0.000000	7.815322	5.11	5.11
7	14.687217	0.000000	-4.337509	0.182676	0.000000	8.617907	38.01	22.55
8	16.169541	0.000000	0.000000	0.180958	0.000000	8.248757	10.35	10.26
9	17.301694	0.000000	-4.577475	-0.050504	0.000000	6.358064	19.38	32.53
10	17.042950	0.000000	0.247574	-0.042288	0.000000	5.129760	1.23	0.76
11	16.860396	0.000000	-2.293694	-0.256834	0.000000	4.320765	17.92	29.90

RELATIVE STOP COORDINATES / RAY ABERRATIONS

X	Y	DELTA X	DELTA Y	OPD
FOCUS = (0.000000)				
1.00	0.00	0.055533	0.000000	9.063
0.81	0.00	-0.054217	0.000000	7.501
0.61	0.00	-0.041997	0.000000	3.101
0.41	0.00	-0.015660	0.000000	0.699

Input:
RES CV7_LENS:DBGAUSS
ANA;SSP;GO

	X	Y	Z	TAN X	TAN Y	RAY LENGTH	ANG INC	ANG REF
OBJ	0.00E+00	-0.18E+12	0.10E-14	0.000000	0.176327			
1	0.000000	-9.869256	0.854065	0.000000	0.175584	0.867240	0.11	0.07
2	0.000000	-8.450162	0.189539	0.000000	0.260052	8.205772	7.39	12.01
		\		\		\		
10	0.000000	7.096739	0.042920	0.000000	0.142317	1.047718	14.34	8.79
11	0.000000	7.994320	-0.508337	0.000000	0.151422	6.370469	0.82	1.33

0.00 0.00 0.000000 17.631651 0.000000
DISTORTION = -0.0059 PERCENT EP DIST = 56.825394 ENTRANCE ANGLES = (0.0000, 10.0000) DEGREES
X-FOCUS, Y-FOCUS = (-0.162746, -0.082285) EXIT ANGLES = (0.0000, 8.6104) DEGREES

	X	Y	Z	TAN X	TAN Y	RAY LENGTH	ANG INC	ANG REF
OBJ	0.00E+00	-0.18E+12	0.10E-14	0.000000	0.176327			
1	0.000000	10.139161	0.901795	0.000000	0.037352	0.915707	20.17	12.30
		\		\		\		
11	0.000000	20.425819	-3.396572	0.000000	-0.040615	3.134317	12.90	21.21

X	Y	DELTA X	DELTA Y	OPD
0.00	0.80	0.000000	0.091908	2.992
0.00	0.64	0.000000	-0.016614	4.624
0.00	0.48	0.000000	-0.031934	2.775
0.00	0.32	0.000000	-0.020057	1.029
0.00	-0.29	0.000000	-0.000715	0.045
0.00	-0.43	0.000000	-0.001725	-0.032
0.00	-0.58	0.000000	-0.000755	-0.112

	X	Y	Z	TAN X	TAN Y	RAY LENGTH	ANG INC	ANG REF
OBJ	0.00E+00	-0.18E+12	0.10E-14	0.000000	0.176327			
1	0.000000	-26.388023	6.418914	0.000000	0.300478	6.517936	17.34	10.62
		\		\		\		
11	0.000000	-3.518299	-0.098138	0.000000	0.334473	6.844911	13.18	21.69

X	Y	DELTA X	DELTA Y	OPD
0.00	-0.72	0.000000	0.000530	-0.108

	X	Y	Z	TAN X	TAN Y	RAY LENGTH	ANG INC	ANG REF
OBJ	0.00E+00	-0.18E+12	0.10E-14	0.000000	0.176327			
1	25.000000	-8.875158	6.491870	-0.182502	0.175523	6.592018	25.80	15.61
		\		\		\		
11	16.984986	7.300176	-2.768317	-0.254715	0.157322	3.842078	17.86	29.80

X	Y	DELTA X	DELTA Y	OPD
1.00	-0.01	0.197871	0.036922	1.046
0.81	-0.01	-0.007617	-0.002146	6.775
0.61	0.00	-0.036750	-0.008886	4.344
0.41	0.00	-0.023800	-0.005829	1.717
		\		

D. Higher Order Analysis (**HIG**) - Table 4

For higher order analysis (**HIG**), the output is as follows:

1. Third order sums and first order properties for reference
2. Surface aberrations

The first two columns are the contributions to the X and Y focal plane ray heights due to the third order aberrations. The second two columns are the corresponding values for the fifth and higher order aberrations (determined from the Aldis theorem). The last two columns are the X and Y ratios of the total to the third order contributions.

The rays traced in this option fit the standard pattern used in ANAlysis. The outer two rays of each group have these six columns listed for each surface; each principal ray does, too. All other rays are represented by the summation of these values in the image surface only.

The chief ray output is an indication of the surface-by-surface contribution to third and higher order distortion. The other rays have had their chief ray dependence effectively removed, making them essentially a breakdown of the aperture dependence of the system aberration. All calculations are performed in the reference wavelength only.

Table 4. Higher Order Analysis

Input:
RES CV7_LENS:DBGAUSS
ANA;HIG;GO

Double Gauss - U.S. Patent 2,532,751

EFL	= 100.000000	IMAGE F/NO	= 2.000000
IMAGE DISTANCE	= 63.137145	IMAGE HEIGHT	= 24.932800

THIRD ORDER	SPH ABER	TAN COMA	TAN ASTIG	PETZ SUM	DISTORTION	AX COLOR	LAT COLOR
TOTALS	-0.278960	-0.137372	-0.025332	-0.001624	-0.000729	-0.002834	0.001136

FIELD 1
TRANSVERSE ABERRATION

RELATIVE STOP COORDINATES X	Y	SURFACE	3RD ORDER X	3RD ORDER Y	HIGHER ORDERS X	HIGHER ORDERS Y	RATIO OF TOTAL/3RD X	RATIO OF TOTAL/3RD Y
		1	0.000000	-0.972519	0.000000	-0.138933	0.000	1.143
		2	0.000000	-0.018604	0.000000	-0.007472	0.000	1.402
		3	0.000000	-0.444231	0.000000	0.001431	0.000	0.997
		4	0.000000	-0.018237	0.000000	-0.007092	0.000	1.389
		5	0.000000	2.099315	0.000000	0.770681	0.000	1.367
		6	0.000000	0.000000	0.000000	0.000000	0.000	0.000
		7	0.000000	2.257732	0.000000	0.346914	0.000	1.154
		8	0.000000	-0.001921	0.000000	-0.002247	0.000	2.170
		9	0.000000	-1.495330	0.000000	-0.273107	0.000	1.183
		10	0.000000	0.003387	0.000000	-0.002466	0.000	0.272
		11	0.000000	-1.688550	0.000000	-0.353217	0.000	1.209
0.000	1.000	TOTAL	0.000000	-0.278960	0.000000	0.334493	0.000	-0.199
		1	0.000000	-0.497930	0.000000	-0.043531	0.000	1.087
		2	0.000000	-0.009525	0.000000	-0.002266	0.000	1.238
		3	0.000000	-0.227446	0.000000	-0.000920	0.000	1.004
		4	0.000000	-0.009337	0.000000	-0.002094	0.000	1.224
		5	0.000000	1.074849	0.000000	0.218083	0.000	1.203
		6	0.000000	0.000000	0.000000	0.000000	0.000	0.000
		7	0.000000	1.155959	0.000000	0.124523	0.000	1.108
		8	0.000000	-0.000984	0.000000	-0.000604	0.000	1.615
		9	0.000000	-0.765609	0.000000	-0.091060	0.000	1.119
		10	0.000000	0.001734	0.000000	-0.000773	0.000	0.554
		11	0.000000	-0.864538	0.000000	-0.112748	0.000	1.130
0.000	0.807	TOTAL	0.000000	-0.142827	0.000000	0.088611	0.000	0.380
0.000	0.609	TOTAL	0.000000	-0.060255	0.000000	0.018258	0.000	0.697
0.000	0.407	TOTAL	0.000000	-0.017853	0.000000	0.002194	0.000	0.877

:
:
(FIELD 2 and FIELD 3 output is similar for chief ray and pattern rays)
:
:

TECHNICAL NOTES

Third-order Calculations

The third-order coefficients are calculated according to the following equations (see MIL-HDBK-141 for comments on a similar scheme):

A. Sign Conventions

All ray heights above the optical axis are positive; all ray angles are positive where the optical axis must be rotated counter clockwise to coincide with the ray.

B. First-order Ray Traces

Marginal

$$Y_s = Y_{s-1} + \frac{t_{s-1}}{n_{s-1}}(nu)_{s-1}$$

$$(nu)_s = (nu)_{s-1} + (n_{s-1} - n_s)Y_s c_s$$

$$(ni)_s = (nu)_s + n_s Y_s c_s$$

Chief

$$\bar{Y}_s = \bar{Y}_{s-1} + \frac{t_{s-1}}{n_{s-1}}(\overline{nu})_{s-1}$$

$$(\overline{nu})_s = (\overline{nu})_{s-1} + (n_{s-1} - n_s)\bar{Y}_s c_s$$

$$(\overline{ni})_s = (\overline{nu})_s + n_s \bar{Y}_s c_s$$

where

c, t, n	are the constructional parameters — curvature, thickness, and index
Y_s	is the paraxial marginal ray height on surface S
$(nu)_s$	is the paraxial marginal ray angle times index in the medium after surface S
$(ni)_s$	is the paraxial marginal angle of refraction times the index in the medium after surface S. This is also equal to the angle of incidence times the index in the medium preceding surface S.
$\bar{Y}_s$	is the paraxial chief ray height on surface S
$(\overline{nu})_s$	is the paraxial chief ray angle times index in the medium after surface S
$(\overline{ni})_s$	is the paraxial chief ray angle of refraction times the index in the medium after surface S. This is also equal to the angle of incidence times the index in the medium preceding surface C.

The starting ray data is chosen so that the paraxial marginal ray corresponds to the marginal real ray in position while the paraxial chief ray is chosen to correspond to the real chief ray of the last field height. The values of $\bar{Y}$ and $\overline{nu}$ can then be scaled by the appropriate values to compare them to any actual chief ray. If the last field height is zero, the first-order chief ray is traced in this analysis to give an image height of 1.0.

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| C. Third-order Aberration Coefficients

$$Q = \frac{(nu)_s}{n_s^2} - \frac{(nu)_{s-1}}{n_{s-1}^2} \qquad \bar{Q} = \frac{(\overline{nu})_s}{n_s^2} - \frac{(\overline{nu})_{s-1}}{n_{s-1}^2}$$

$$SC = (ni)_s^2 \, Q \, Y_s$$

$$CC = (ni)_s (\overline{ni})_s Q \, Y_s$$

$$AC = (\overline{ni})_s^2 \, Q \, Y_s$$

$$PC = c_s \left(\frac{1}{n_s} - \frac{1}{n_{s-1}}\right) = (ni)_s \bar{Q} - (\overline{ni})_s Q$$

$$DC = (\overline{ni})_s^2 \, Q \, \bar{Y}_s + (\overline{ni}) \bar{Q}$$

Aspheric Third-order Aberration Coefficients

$$PA_s = (K c_s^3 + 8 A_s) \; (n_{s-1} - n_s)$$

$$SC_{as} = Y_s^4 \, PA_s$$

$$CC_{as} = \bar{Y}_s \, Y_s^3 \, PA_s$$

$$AC_{as} = \bar{Y}_s^2 \, Y_s^2 \, PA_s$$

$$DC_{as} = \bar{Y}_s^3 \, Y_s \, PA_s$$

D. First-order Chromatic Aberration Coefficients

$$AxC = -(ni)_s Y_s \Delta n_s$$

$$LatC = -(\overline{ni})_s Y_s \Delta n_s$$

$$\text{where} \quad \Delta n_s = \left(\frac{dn_s}{n_s} - \frac{dn_{s-1}}{n_{s-1}}\right) \quad \text{and} \quad dn = n_F - n_C$$

E. Transverse Aberrations

The seven aberration coefficients for each surface can be summed for all surfaces in the system to produce seven sums; the transverse aberrations can be easily obtained by multiplying by appropriate factors. These factors are dependent on the particular height in the aperture and the particular image height for which the third-order aberration is desired.

The same conversion factors (for the actual paraxial rays) are used in expressing both the surface contributions and sums in output for the **THI** command (and THO command in the LDM).

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Thus, assuming the paraxial chief ray lies in the Y-Z plane, the transverse dimensions in the image patches for each third-order aberration are:

Spherical Aberration:

$$SA = \frac{-R^3}{2(nu)_r} \sum_1^r SC = R^3 \text{ f/no}$$

Coma:

$$TCO = \frac{3}{2} Y_R R^2 \sum_1^r CC \quad \text{(tangential)}$$

$$SCO = \frac{1}{2} Y_R R^2 \sum_1^r CC = \frac{1}{3} TCO \quad \text{(sagittal)}$$

Astigmatism and Field Curvature:

$$TAS = \frac{Y_R^2 R}{4 \text{f/no}} \sum_1^r (3AC + PC \bullet I^2) \quad \text{(tangential)}$$

$$SAS = \frac{Y_R^2 R}{4 \text{ f/no}} \sum_1^r (AC + PC \bullet I^2) \quad \text{(sagittal)}$$

$$PTZ = \sum_1^r PC \quad \text{(petzval curvature - not transverse)}$$

$$PTB = \frac{Y_R^2 R}{4 \text{ f/no}} \sum_1^r PC \bullet I^2$$

Distortion:

$$DST = \frac{Y_R^3}{8(\text{f/no})^2} \sum_1^r DC$$

Axial Color:

$$AX = 2 \text{ f/no } R \sum_1^r AxC$$

Lateral Color:

$$LAT = 2 \text{ f/no } Y_R \sum_1^r LatC$$

where R is the ratio of the pupil height to the full pupil radius (i.e., the pupil fraction), Y_R is the ratio of height in the image plane to the height for the traced paraxial chief ray, f/no is a measure of the aperture in the image space

$$\left(\text{f/no} - \frac{-1}{2(nu)_r}\right),$$

the subscript r refers to the last system surface, and I is the Lagrange invariant, $I = Y(\overline{nu}) - \overline{Y}(nu)$. F and C refer to the shortest and longest wavelengths used. The symbols SA, TCO, TAS, SAS, PTZ, PTB, DST, AX, LAT are the mnemonics for both Macro-PLUS data base items and the corresponding specific constraints in AUTomatic Design, for partial or total sums.

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FIE - FIELD ABERRATIONS - ASTIGMATISM AND DISTORTION ANALYSIS

FIE computes and, on request, plots the distortion and astigmatic field curves of the lens as a function of the field; for rotationally asymmetric lenses, a field map of astigmatism is provided. A table of scan linearity is also available.

DEFAULT OPERATION

Tables are generated for distortion and astigmatic field curves for steps of 10% of the field. The astigmatic field curves are the values of X-focus and Y-focus as determined by close skew rays (equivalent to sagittal and tangential field curves for rotationally symmetric systems); separate columns give the results displaced by the axial defocusing value. One table is generated for each zoom position. Assumptions: The first field is the axis and the last field is the maximum field. If the lens is rotationally asymmetric, the calculation is changed to a field map of astigmatism. Note that FIE ignores CRA values.

SCREEN FLOW DIAGRAM

FIE1

Field Aberrations

```
FIE1                        Field Aberrations                         CODE V
                       (Astigmatism & Distortion)

    Select output mode:  1
      Longitudinal defocus___ 1
DIO   Diopters (afocal only)__ 2
PLO Plot (Y/N)?                      N
      (Default: automatic scaling)
AST   Maximum plotted astigmatism
         Chromatic (Y/N)?            N
DST   Maximum plotted distortion (%)
         Chromatic (Y/N)?            N
TIT   Temporary title                Double Gauss - U.S. Patent 2,532,751
ZFO   Shift field curves to zero
      focus (Y/N)?                   N
LSA   Longitudinal spher. aberration
      plot (Y/N/max. plotted value)? N

LIN List FX THETA linearity (Y/N)?   N
LIS List output (Y/N)?               Y
FFD Full field display (Y/N)?        N
G- Go (Execute) P- Prev Screen  T- Top Screen   O- Option      F- Files
K- Key Descr    M- Main Menu    C- Command Mode L- Lens Data   E- Exit CODE V
```


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FIE

COMMAND MNEMONICS (alphabetical)

AST	DIO	DST	FFD	LIN	LIS
LSA	PLO	TIT	ZFO		

DATA INPUT DESCRIPTION

Command Syntax		
Screen Prompt	Explanation	Default
DIO Yes | No		
Diopters (afocal only) (FIE1)	For afocal systems only. Use diopters in image space as measure of focal shift instead of longitudinal focal shift.	No.
PLO Yes | No....z		
Plot (Y/N)? (FIE1)	Plot distortion and field curves vs. field height - one single page plot per zoom position.	No.
AST [CHR] max_plotted_astigmatism....z		
Maximum plotted astigmatism (FIE1)	Use with PLO. Astigmatism scale limit; enter the maximum abscissa in focal shift. If DIO is used, enter in diopters. If CHR is entered, calculations are performed for all wavelengths; default is reference wavelength only.	Scaled to fit.
DST [CHR] max_plotted_distortion_%....z		
Maximum plotted distortion (%) (FIE1)	Use with PLO. Distortion scale limit; enter the maximum abscissa in %. **Ex:** 2.0 means 2%. If CHR is entered, calculations are performed for all wavelengths; default is reference wavelength only.	Scaled to fit.
TIT 'temporary_title'(40)....z		
Temporary title (FIE1)	Use with PLO. Up to 40 characters are plotted for the title of designated zoom position; if no zoom position is designated, the title is applied to all.	Uses the first 40 characters of the system title.
ZFO Yes | No		
Shift field curves to zero focus (Y/N)? (FIE1)	Use with PLO. Set origin of field curves at zero defocus instead of the axial defocus.	No. Set origin at axial defocus.

Continued....

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Special Functions

Command Syntax		
Screen Prompt	Explanation	Default
LSA [No | max_plotted_long_spherical_aber....z]		
Longitudinal spher. aberration.... (FIE1)	Include longitudinal spherical aberration calculation in listing; "No" turns off the LSA request for that zoom position. If PLO is used, enter the maximum abscissa in focal shift; if not supplied, it is scaled to fit.	Not included in listing or plot.
LIN Yes | No....z		
List fxTHETA linearity (Y/N)? (FIE1)	Replaces table, to show actual image height and f * Θ image height for 20 equally spaced points across the field;% difference of these is also listed. Useful measure of linearity in scanning systems.	No.

Listing Suppression

Command Syntax		
Screen Prompt	Explanation	Default
LIS Yes | No....z		
List output (Y/N)? (FIE1)	Include listings. No forces deletion of listings when only plots are wanted.	Yes.

Rotationally Non-symmetric Lenses

Command Syntax		
Screen Prompt	Explanation	Default
FFD Yes | No....z		
Full field display (Y/N)? (FIE1)	Change plotted and listed output to represent a rectangular (square) field to display astigmatism for non-rotationally symmetric systems. Dimensions of display are determined from X, Y field sizes.	No, for rotationally symmetric lenses. Yes, for asymmetric lenses.

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DISCUSSION OF INPUT AND COMPUTATIONS

When to Use the FIEld Option

Use the FIEld option if you need to analyze the system for a particular parameter as it changes with field angle. Specifically it provides:

- A combined plot and/or table of astigmatism (S and T curves) and distortion for half the field of a rotationally symmetric lens. (Uses **PLO**, **AST**, **DST**, **ZFO**, and **DIO** commands.)
- Adds a plot of longitudinal spherical aberration to the field plot; although this is not a function of field it is an addition desired by some for traditional reasons. (Uses **LSA** command.)
- A 2-D plot of astigmatism over the entire field; this is most often wanted for rotationally non-symmetric lenses. (Uses **FFD** command.)
- A table of linearity for a scanner lens vs. f*θ, where f is the calibrated focal length. (Uses **LIN** command.)

What to Include in the LDM Data

No added LDM data is required. Note that since FIE generates intermediate field points not defined by you, it ignores all CRA values entered for all fields.

Usage

The FIELD option (FIE) computes and plots distortion and astigmatic image focal curves across the field of the lens system. These curves are a traditional tool of the lens designer for characterizing lenses and determining if regions of the field are not being adequately represented in optimization or full analysis. A table for each axis for steps of 10% of the field is provided (Figure 1). The same data also can be plotted (**PLO**) (Figure 2). If only plots are desired, the table listings can be suppressed (**LIS** No).

Distortion is the change in magnification as a function of field (measured in percent relative to the paraxial image height), computed from tracing chief rays. Astigmatism is a measure (expressed in "longitudinal displacement" or "focus shift") of the difference in curvature of the two image surfaces formed by small (close skew ray) fans about the chief ray in the X and Y directions. These calculations are based on tracing real rays that are slightly displaced from the chief ray. Because real rays are used, the calculation can be done on any type of system, but care should be used in interpreting the data for tilted and decentered systems.

Astigmatism, by default, is represented in terms of longitudinal defocus. However, if the system being analyzed is afocal, **DIO** can be used to translate results into diopters of accommodation instead of longitudinal defocus.

Controlling the Plot

Plot scale factors for the abscissae of distortion and astigmatism are automatically determined so that the plots fit. This is most desirable for analysis of isolated lenses. However, for comparing lenses, or different versions of the same design, it is best to set the scale factors to the same value each time. The scale factors of field curve (**AST**) and distortion (**DST**) can be adjusted by entering the maximum desired abscissa for either. For example, entering DST 2.0 would set -2.0% and +2.0% as the scaling limits for the distortion plot. Entering AST 1.0 would set astigmatism scaling limits to -1 mm and +1 mm (assuming lens units are in millimeters); if **DIO** had been used, these would be -1 diopters and +1 diopters.

The origin of astigmatic field curves in the plotting function (**PLO**) defaults to the axial defocus determined by THI SI, which usually corresponds to the optimum focus if determined by AUTOMATIC DESIGN or the WAVEFRONT ANALYSIS option. This can be shifted so that the curves are plotted relative to the paraxial focus (zero defocus) by using **ZFO**, assuming a PIM solve (see the LDM) had been used to maintain paraxial image distance.

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Special Functions

While longitudinal spherical aberration (**LSA**) is not a field-dependent aberration, it is often desirable to include it on the same plot as part of the lens characterization. **LSA** is measured as displacement along the optical axis. As such, it can be usefully compared to the longitudinal displacement of the astigmatism curves. **LSA** always generates an extra table in the listing; if **PLO** is used, set the scale by entering the maximum desired abscissa value in the **LSA** command; the absence of a value will generate default scaling.

Scanning systems (lenses receiving the beam from a rotating mirror or prism) usually have a specification on scanning linearity – the uniformity between rotation angle and height on the image surface. If enough negative distortion has been designed into the lens, the image deflection will approach the function $f*\theta$ instead of the $f*\tan(\theta)$ of a distortionless lens; the $f*\theta$ form will give a scan speed that is constant with time. Use the **LIN** command to replace the table with one that analyzes scan linearity versus scan angle. The **LIN** calculation uses a calibrated focal length or magnification. Focal length is calculated if XAN, YAN input is used to specify the field positions; magnification is calculated if X,Y or XOB,YOB input is used to specify the field position. The calibrated focal length (or magnification) is that value which minimizes the squared-error between the actual image height and the predicted image height. (The predicted height is proportional to the input field angle or input object height.) Thus, the calibrated focal length (or magnification) is really the best estimate (in a least-squares sense) of the constant of proportionality between the input field angle (or object height) and the image height.

Chromatic Effects

The default is to compute longitudinal spherical aberration (if requested) at all system wavelengths, but to compute the astigmatism and distortion curves only in the reference wavelength. This can be altered with CHR on either the **AST** or **DST** commands. If either of these commands has the CHR qualifier, then separate field listings will be generated for all system wavelengths. If plots are requested (**PLO**) then multi-wavelength plots will be generated for astigmatism and/or distortion only if CHR was requested for that parameter.

Rotationally Non-Symmetric Lenses

The standard calculations, plots and listings are designed for use on rotationally symmetric lenses with field in the Y coordinate only. If the lens does not match this description (is rotationally non-symmetric or has X field), the standard forms are replaced by two dimensional (X and Y) listings and plots of the astigmatism alone. This form can also be requested by the **FFD** command for any kind of system.

The display grid for **FFD** is a 15 x 15 array of points. The extreme X and Y coordinates for this display are determined from the last field point. These values are used as both + and – extreme points for the symmetrical grid. For the last field point:

- No X field specified: Set X = Y, both relative fields = 1.0
- No Y field specified: Set Y = X, both relative fields = 1.0
- X, Y field specified: Use Y field (as 1.0) to define relative X field

Where X and Y fields are different, the format is still square but the labeling changes.

DESCRIPTION OF OUTPUT

A listing is given showing the distortion, x-focus and y-focus at the axis, and 10 steps across the field. Also the x-focus and y-focus are displaced by the axial defocusing value and the values are listed as separate columns (Table 1). If requested, (**PLO**) a plot like the ones shown will be generated (Figure 1). Longitudinal spherical aberration for the system can also be added to the plot (**LSA**) (Figure 2). The linear (**LIN**) request generates a table displaying ray trace image height, F-theta image height, and percent error from linearity at 20 steps across the field (Table 2).

Rotationally Non-Symmetric Lenses

The Full Field Display (**FFD**) command extends analysis to systems which are not rotationally symmetric. The conventional field curve plot illustrates (in longitudinal profile) the focal positions where rays with very small aperture values in X and Y (close skew rays) come to a focus. At these focal positions a spot diagram for a system with pure astigmatism would result in a line image. The length of the astigmatic line image is proportional to the distance between the two focal position curves. It is traditional to think of the two curves as sagittal (X-fan close skew rays) and tangential (Y-fan close skew rays); they often cross at some point in the field, as in Figures 1 and 2. This representation used for the field curve plot is appropriate only for rotationally symmetric systems.

It is wrong to use the concept of sagittal and tangential field curves for non-rotationally symmetric systems, because these curves do not exist. The logical extension to three dimensions would suggest that these curves represent the cross-section of rotationally symmetric continuous surfaces (for rotationally symmetric lenses). In reality, the only true continuous surfaces are the "forward" image surface (in the triplet, the sagittal surface out to the crossover and then the tangential surface to the edge of the field) and the "back" image surface (the tangential surface out to the crossover and then the sagittal surface to the edge), with a cusp at the crossover. Note that for the centered triplet, these continuous surfaces touch at the center of the field and in a ring at the crossover radius. When decentration is introduced, the "forward" and "back" surfaces remain continuous surfaces, whereas the sagittal and tangential surfaces do not; in general, the astigmatic lines in the "forward" and "back" surfaces are no longer parallel to the original radial and tangential directions, but are always orthogonal to each other; the "forward" and "back" surfaces no longer contact in a ring at the crossover radius, but can touch at a few points in the field. See Technical Notes for a fuller discussion.

For these reasons (above) do not use the standard field representation for systems that are rotationally non-symmetric. They do not represent any physically meaningful properties for such systems and wrongfully imply that continuous focal surfaces connecting the X-fan and Y-fan close skew ray foci individually exist. Because of this, the program automatically substitutes the Full Field Display as the default form for such systems.

The Full Field Display is a plot of the length and orientation of the astigmatic line images directly as a function of the X, Y field position. Conceptualize this as resulting from illuminating an optical system, whose only aberration residual is astigmatism, with an evenly spaced grid of point objects; record the images on a film whose surface is distorted to match one of the two ("forward" or "back") continuous three dimensional surfaces at which close skew rays focus. See Figure 3 for the centered triplet and Figure 4 for the decentered triplet; note the two zero points in the center column of Figure 4 - these were generated from the central zero for the centered case, where they coincide (there is a third one near the top of the column between displayed points). The scale for line length is given in the legend for the plot; it is exaggerated with respect to the grid scale for clarity. The Full Field Display representation is valid for both rotationally symmetric and nonsymmetric optical systems.

Listings are also provided with the Full Field Display (unless turned off by the **LIS** No command). Table 3 shows one table of the 15 generated, corresponding to one row (constant Y field points) of Figure 4.

The Full Field Displays are most effectively used in the design of nonsymmetric systems, single point perturbation studies where coma is removed by compensating parameters and in support of predictive realignment of optical systems at assembly. In nonsymmetric design, the coma field is often controlled in the definition of the tilts and decenters of the first-order configuration of the system. With the coma controlled, the aberration which limits system performance is often astigmatism. The Full Field Display will provide information on where in the design field of view the best performance will be obtained, and those areas that need improvement.

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Examples

Example 1. The minimum input possible for both listing (Table 1) and plotted output (Figure 1) for a Cooke triplet lens.

Table 1. FIE listed output.

POSITION 1 Cooke Triplet f/4.5

RELATIVE FIELD HEIGHT	ANGLE (DEG)	X-FOCUS AT THE IMAGE SURFACE	Y-FOCUS AT THE IMAGE SURFACE	X-FOCUS (DISPLACED BY 0.028933)	Y-FOCUS (DISPLACED BY 0.028933)	DISTORTION (PER CENT)
0.00	0.00	-0.028933	-0.028933	0.000000	0.000000	0.00000
0.10	2.08	-0.037182	-0.028489	-0.008249	0.000444	0.00914
0.20	4.16	-0.061447	-0.027326	-0.032513	0.001608	0.03691
0.30	6.23	-0.100284	-0.026219	-0.071351	0.002714	0.08432
0.40	8.28	-0.151294	-0.026989	-0.122361	0.001945	0.15316
0.50	10.31	-0.211129	-0.033366	-0.182196	-0.004433	0.24604
0.60	12.32	-0.275485	-0.052426	-0.246551	-0.023492	0.36657
0.70	14.29	-0.339076	-0.096828	-0.310142	-0.067894	0.51959
0.80	16.23	-0.395570	-0.188339	-0.366637	-0.159406	0.71153
0.90	18.14	-0.437458	-0.363387	-0.408525	-0.334454	0.95099
1.00	20.00	-0.455821	-0.681970	-0.426887	-0.653037	1.24964

Units of focus are MILLIMETERS

The minimum input possible for both listing (Table 1) and plotted output (Figure 1) for a Cooke triplet lens:

```
RES CV7_LENS:COOKE1   ! Restore a standard lens
FIE
PLO Y
GO
```

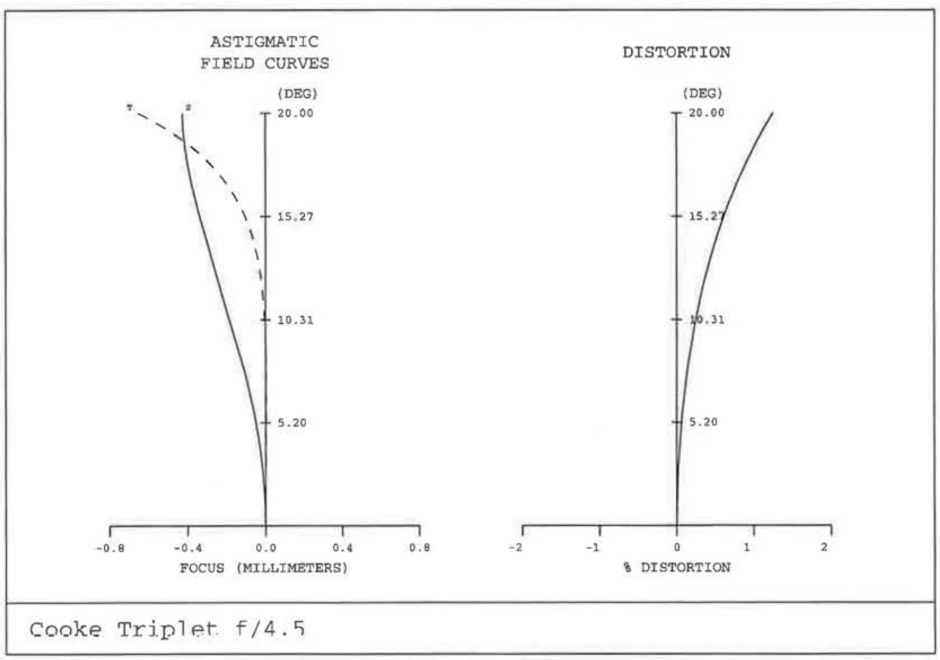

Figure 1. FIE plotted output.

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Example 2. Add **LSA** (longitudinal spherical aberration) to the plot and user-selected plot scales for the Cooke triplet (Figure 2).

Add **LSA** (longitudinal spherical aberration) to the plot and user-selected plot scales for the Cooke triplet (Figure 2):

```
FIELD
PLOT Y
DST CHR 1.0     ! ± 1.0% maximum plotted distortion, show chromatic effects
AST CHR 0.5     ! ± 0.5 mm maximum plotted astigmatism, show chromatic effects
LSA 0.5         ! ± 0.5 mm maximum plotted LSA
GO
```

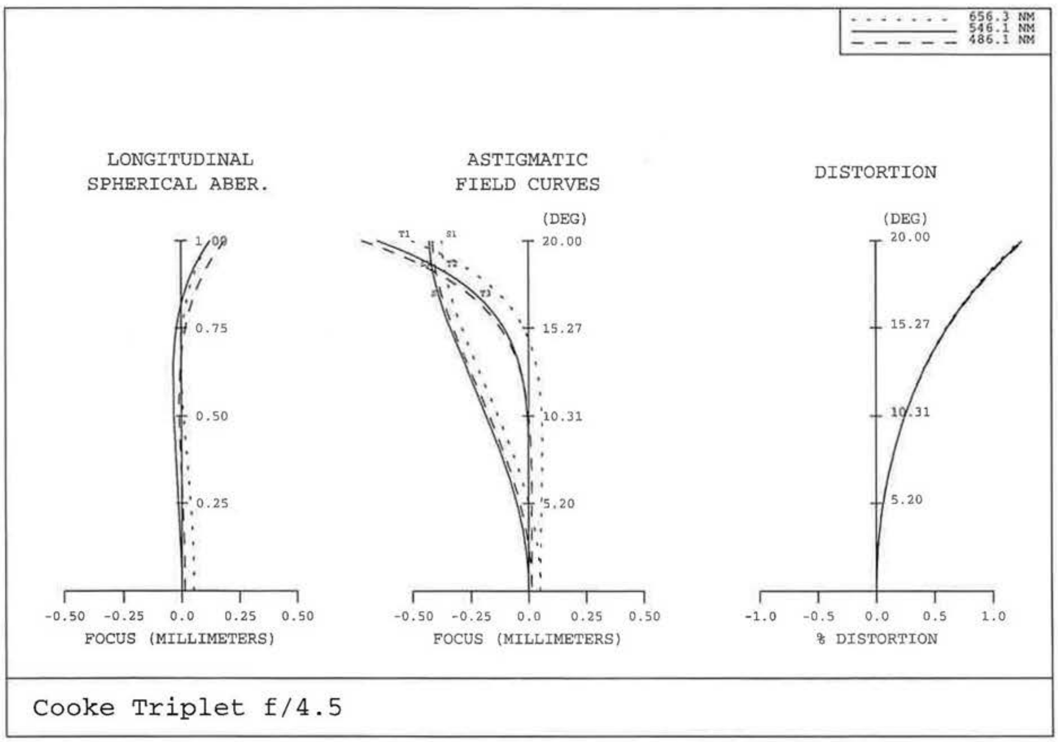

Figure 2. Enhanced FIE plotted output.

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Example 3. Use the **LIN** command, to obtain a listing of F-theta linearity (Table 2).

Table 2. FIE;LIN listed output.

```
Units of focus are MILLIMETERS

        ROTATIONALLY SYMMETRIC FIELD ABERRATIONS

POSITION 1          Cooke Triplet f/4.5
```

S C A N   L I N E A R I T Y

RELATIVE FIELD ANGLE	ANGLE (DEGREES)	IMAGE HEIGHT	REFERENCE IMAGE HEIGHT	ERROR (PERCENT)	LOCAL ERROR (PERCENT)
(A) 0.00	(B) 0.0000	(C) 0.000000	(D) 0.000000	(E) 0.0000	(F) -3.2843
0.05	1.0000	0.873238	0.902797	-3.2742	-3.2742
0.10	2.0000	1.747120	1.805595	-3.2386	-3.2029
0.15	3.0000	2.622293	2.708392	-3.1790	-3.0598
0.20	4.0000	3.499413	3.611190	-3.0953	-2.8442
0.25	5.0000	4.379146	4.513987	-2.9872	-2.5548
0.30	6.0000	5.262171	5.416784	-2.8543	-2.1901
0.35	7.0000	6.149190	6.319582	-2.6962	-1.7477
0.40	8.0000	7.040927	7.222379	-2.5124	-1.2251
0.45	9.0000	[illegible]	[illegible]	[illegible]	[illegible]
0.50	10.0000	[illegible]	[illegible]	[illegible]	[illegible]
0.55	11.0000	[illegible]	[illegible]	[illegible]	[illegible]
0.60	12.0000	[illegible]	[illegible]	[illegible]	[illegible]
0.65	13.0000	[illegible]	[illegible]	[illegible]	[illegible]
0.70	14.0000	[illegible]	[illegible]	[illegible]	[illegible]
0.75	15.0000	13.483997	13.541961	-0.4280	5.0549
0.80	16.0000	14.444676	14.444759	-0.0006	6.4114
0.85	17.0000	15.418935	15.347556	0.4651	7.9155
0.90	18.0000	16.408264	16.250353	0.9717	9.5849
0.95	19.0000	17.414349	17.153151	1.5227	11.4408
1.00	20.0000	18.439117	18.055948	2.1221	13.5104

Calibrated Focal Length = 51.7265

Use the **LIN** command, to obtain a listing of F-theta linearity (Table 2):

```
FIELD
LIN  Y
GO
```

(A) *Fraction of angle in object space*

(B) *Chief ray angle in object space in degrees*

(C) *Ray trace image height*

(D) *(Calibrated focal length)* $*$ *(B*$*\pi$*/180)*

(E) *100* $*$ *(C/D - 1)*

(F) *F(i) = 100* $*$ *{[C(i)-C(i-1)] / [C(2)-C(1)] - 1}*

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Example 4. Full-field display of centered triplet (Figure 3).

```
Full-field display of centered triplet. (Figure 3)

    RES  CV7_LENS:COOKE1
    FIE
    FFD    Y       ! Enable full-field display
    LIS    N       ! Suppress full-field listing
    AST    0.5     ! Maximum scale for astigmatic plot
    PLO    Y       ! Request plotted output
    GO
```

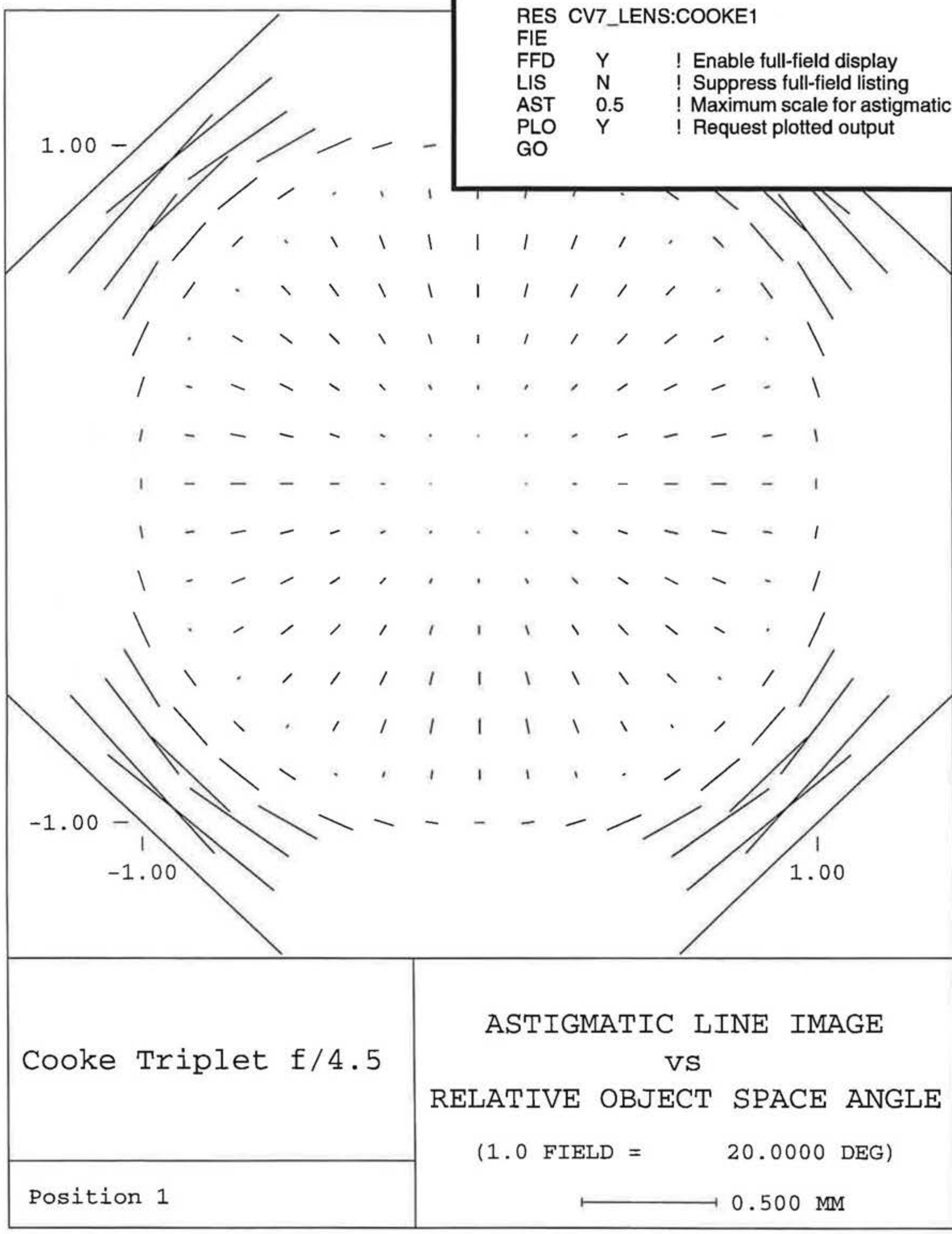

Figure 3. FIE;FFD plotted output.

Example 5. Full-field display of the decentered triplet (Figure 4). The decentered lens will trigger FFD automatically.

Full-field display of the decentered triplet (Figure 4). The decentered lens will trigger FFD automatically.

```
RES   CV7_LENS:COOKE1
DAR   S1          !
DAR   S2          ! LDM commands to make triplet decentered
YDE   S1    0.5   !
YDE   S2    0.5   !
FIE
AST   0.5         ! Maximum scale for astigmatic plot
PLO   Y
GO
```

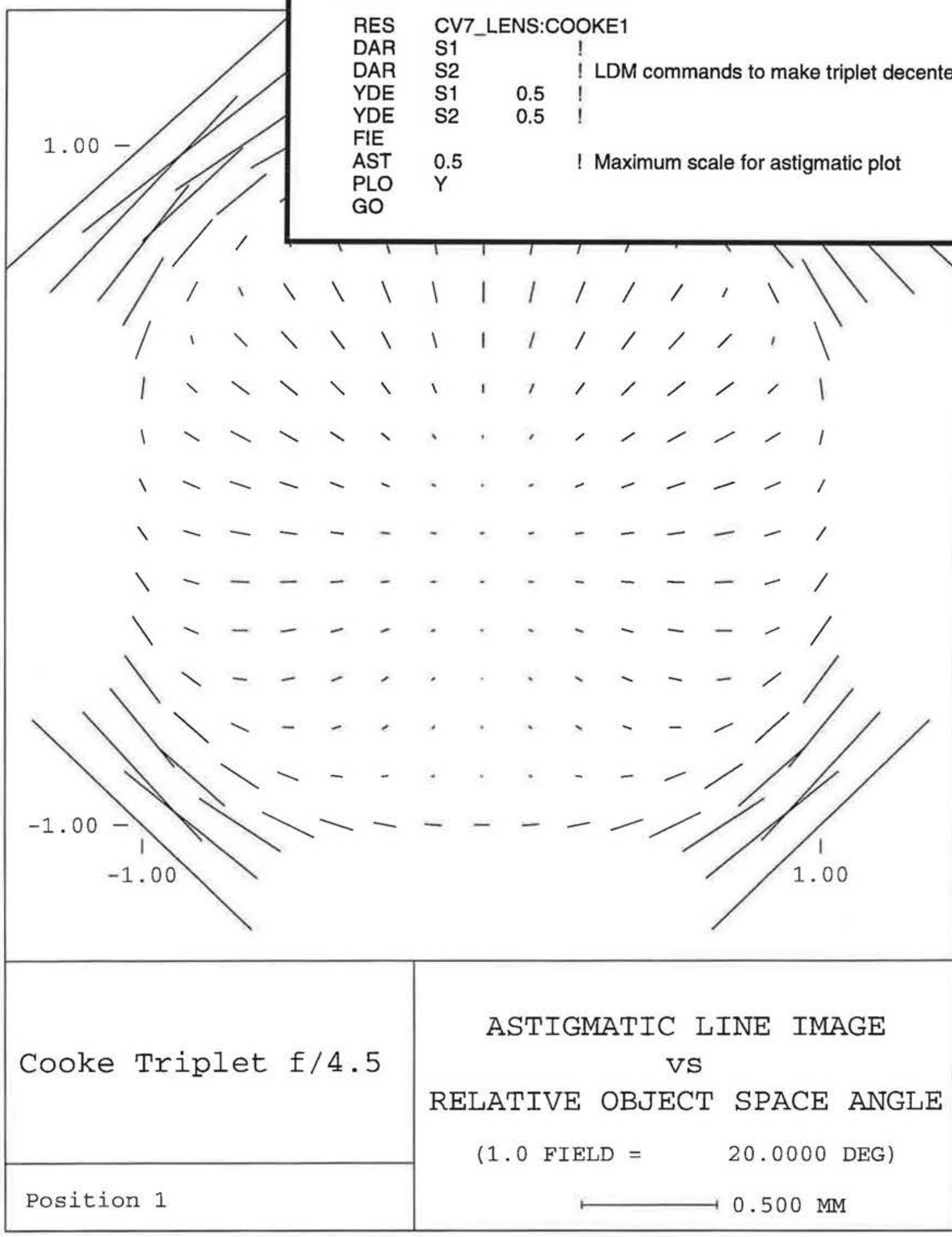

Figure 4. Decentered lenses default to FIE;FFD.

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Example 6. One table (of the 15 generated) corresponding to one row (constant Y field points) of the Figure 4 input (Table 3).

One table (of the 15 generated) corresponding to one row (constant Y field points) of the Figure 4 input. (Table 3)

```
RES   CV7_LENS:COOKE1
DAR   S1           !
DAR   S2           ! LDM commands to make triplet decentered
YDE   S1     0.5   !
YDE   S2     0.5   !
FIE
AST   0.5          ! Maximum scale for astigmatic plot
GO
```

Table 3. FIE;FFD listed output (partial).

FULL FIELD ASTIGMATIC LINE IMAGERY

POSITION 1 Cooke Triplet f/4.5

RELATIVE FIELD HEIGHT X	RELATIVE FIELD HEIGHT Y	LINE FOCAL SURFACES FROM THE IMAGE SURFACE A	LINE FOCAL SURFACES FROM THE IMAGE SURFACE B	ASTIGMATIC LINE IMAGE LENGTH	ASTIGMATIC LINE IMAGE ORIENTATION ON SURFACE A	ENT. PUPIL FROM 1ST SURF.
-1.0000	1.0000	-8.33112	0.29302	1.82211	47.831	-10.4385
-0.8571	1.0000	-5.05882	0.42737	1.02486	51.546	-10.0584
-0.7143	1.0000	-2.87405	0.20675	0.58264	55.820	-9.8074
-0.5714	1.0000	-1.63786	0.09083	0.33109	60.718	-9.6408
-0.4286	1.0000	-0.93570	0.03495	0.18793	66.330	-9.5336
-0.2857	1.0000	-0.54584	0.01156	0.10879	72.841	-9.4694
-0.1429	1.0000	-0.34994	0.00359	0.06933	80.667	-9.4362
0.0000	1.0000	-0.29033	0.00182	0.05738	89.994	-9.4261
0.1429	1.0000	-0.34992	0.00351	0.06931	99.321	-9.4362
0.2857	1.0000	-0.54580	0.01139	0.10873	107.148	-9.4694
0.4286	1.0000	-0.93561	0.03467	0.18783	113.661	-9.5336
0.5714	1.0000	-1.63767	0.09040	0.33090	119.273	-9.6408
0.7143	1.0000	-2.87364	0.20607	0.58230	124.171	-9.8074
0.8571	1.0000	-5.05797	0.42628	1.02424	128.445	-10.0584
1.0000	1.0000	-8.32745	0.29424	1.82093	132.160	-10.4385

UNITS OF FOCUS AND LENGTH ARE MILLIMETERS
1.0 Y-RELATIVE FIELD HEIGHT = 20.0000 DEG OBJECT SPACE

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TECHNICAL NOTES

Fundamental Aberration Characteristics of Rotationally Non-Symmetric Systems

The primary application for Full Field Displays is in the design of nonsymmetric optical systems. To make effective use of the information provided by the plot, recognize two fundamental properties of nonsymmetric optical systems:

1) There are no new aberrations in a nonsymmetric system with a circular entrance pupil.

2) The only new feature is the dependence of the primary aberrations on field of view. The new field dependence is entirely defined by the location of characteristic zeros of the aberration term in the field of view.

The basic rule for zeros is: the number of zeros any aberration term has is equal to the power of its field dependence in a symmetric system. For the primary aberrations then:

- Spherical aberration has no change, being independent of field.

- Coma, which is linearly dependent on field, has one zero; the appearance of axial coma in an optical system simply means the location of the zero about which the coma is linearly dependent has shifted away from the axis; there are no new features for coma other than this simple displacement.

- Astigmatism, which depends on field of view squared, develops two zeros in the field; the amount of astigmatism at any particular field point is proportional to the product of the distance to each individual zero; in a rotationally symmetric system, the two zeros coincide at the center of the field.

The fundamental concept from which the theoretical developments on zeros are derived is:

> In any optical system the third order aberrations at the image plane are the sum of the individual surface contributions. In a nonsymmetric system, the origin (in the field of view) for each surface contribution may be displaced to various locations in the image plane. To obtain the correct net aberration field, each surface contribution must be viewed as a vector field and added including both magnitude and orientation in a vector sense.

One new result, is that, for a nonsymmetric design, there may now be two points in the near axial field of view at which a system can be fully corrected for spherical aberration, coma and astigmatism. More generally, a summary measure of performance such as RMS wavefront quality will be influenced by contributors which will have multiple zeros scattered about in the field of view.

The Full Field Display is the primary tool required to characterize the performance of nonsymmetric systems; it is a tool which efficiently displays the locations of the dominant zeros which generate the performance degradation. With the zeros located and categorized an enlightened design approach may be developed to improve the system performance by review of the optimization run that generated the design; use re-weighting of existing field points, add other fields, or include some judiciously chosen constraints.

Astigmatism

In any optical system there are always two continuous three dimensional surfaces in space on which orthogonal close skew rays will come to a focus. On each surface the length of the line image is identical but the orientations are orthogonal. These two surfaces never cross. Where the two surfaces come into contact, the astigmatism contribution for that field point or set of field points is zero. Neither surface has image orientation as a defining property. This follows logically for systems with no inherent symmetry as there is no reference from which to define the orientation. Rather, the defining property is that the surfaces be continuous.

In nonsymmetric system design, primary astigmatism retains all the properties of a symmetric system except for the dependence on field. In a symmetric system, the third order astigmatism is zero at the center of the field and increases as the field of view squared; taking another view, for any point in the field, the length of the astigmatic line image is proportional to the distance to the location of zero

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astigmatism squared. On the other hand, for systems without symmetry, the length of the astigmatic line image is proportional to the product of the distance from each zero; this retains its second order character. Thus consider a rotationally symmetric system to be a special case where the two zeros for astigmatism are located in coincidence. When the symmetry of the system is broken, the degeneracy of the zero locations is also broken and in most cases the astigmatic fields will display two points in the field of view at which there is no astigmatism. As noted, the length of the line image is the product of the distance from each zero; the orientation of the line image will bisect the angle formed by the lines from the field point of interest to each of the zeros.

References

1. Thompson, K. P., "Astigmatic Focal Surfaces in General Optical Systems: A New Look for an Old Aberration," Abstract in *Opt. Soc. Am.*, Vol. 72, p. 1726, 1982.

2. Thompson, K. P., "Beyond Optical Design: Interaction between the Lens Designer and the Real World", *SPIE*, Vol. 541, p. 430, 1985.

3. Thompson, K. P., *Aberration Fields in Tilted and Decentered Optical Systems*, PHD Dissertation, University of Arizona, 1980.

4. Thompson, K. P., "A Graphic Approach to the Analysis of Perturbed Optical Systems," *SPIE*, Vol. 237, pp. 127-134, 1980.

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RIMRAY ABERRATION PLOT (**RIM**)

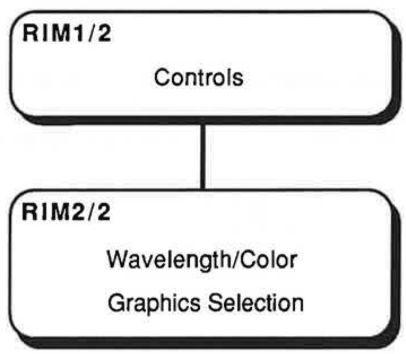
RIM plots ray or wave aberrations vs. ray position in the aperture for X and Y fans.

DEFAULT OPERATION

A bordered, titled, single page aberration plot is drawn for each zoom position (for up to five fields; more than five fields will generate multiple plots as necessary). Fans are traced and the ray aberration in the image surface is plotted at a default scale factor vs. the ray's intersection point with the aperture stop surface. At a general field angle, four fans are traced (+Y, -Y, +X, -X in the pupil); if the system is rotationally symmetric, the - X fan is dropped and on axis only the + X fan is traced. Only wavelengths with non-zero weights (WTW in the LDM) are plotted. In the plots, the Y ray aberration is plotted vs. the Y aperture stop coordinates for Y fans and similarly for X fans. The default scale factors are:

0.001	in for lens dimensions in inches
0.005	cm for lens dimensions in centimeters
0.05 mm	for lens dimensions in millimeters

SCREEN FLOW DIAGRAM



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RIM

```
RIM1/2            Ray Aberration Plot              CODE V
                         Controls

WFR Select aberration plot:            1
      Ray aberrations__________ 1
      Optical path difference_ 2
SSI Scale factor (aberration/inch)    .001

EP  Select coordinate type:            1
      Aperture stop____________ 1
      Entrance pupil___________ 2

NRD Number of rays across diameter    10

LAB Full plot labelling (Y/N/Color)? Y

TIT Temporary title                   Double Gauss - U.S. Patent 2,532,751

TYP Plot type in X-Y
    orientation (XX,XY,YY,YX)         XY
G- Go (Execute) P- Prev Screen T- Top Screen  O- Option     F- Files
K- Key Descr    M- Main Menu   C- Command Mode L- Lens Data E- Exit CODE V
```

```
RIM2/2            Ray Aberration Plot              CODE V
            Wavelength/Color Graphics Selection

WVL  Wavelengths (Y/N/Color)  1  BLA
                              2  BLA
                              3  BLA

G- Go (Execute) P- Prev Screen T- Top Screen  O- Option     F- Files
K- Key Descr    M- Main Menu   C- Command Mode L- Lens Data E- Exit CODE V
```


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COMMAND MNEMONICS (alphabetical)

EP	LAB	NRD	SF	SSI	TIT
TYP	WFR	WVL			

DATA INPUT DESCRIPTION

Command Syntax		
Screen Prompt	Explanation	Default
WFR Yes | No....z		
Select aberration plot: (RIM1/2)	Plot wave aberration (OPD - optical path difference), in waves, instead of ray aberration. Each wavefront is plotted as a fraction of its own wavelength.	No.
SSI aberration_for_plotted_inch....z		
Scale factor... (RIM1/2)	Scale size in aberration per plotted inch, in waves for OPD and lens units for ray aberrations.	For wave aberration: 1 For ray aberration: In inches: 0.001 In cm: 0.005 In mm: 0.05
EP Yes | No....z		
Select coordinate type: (RIM1/2)	Do plotting relative to entrance pupil instead of aperture stop. Plotting relative to stop (default) is best for most lenses, particularly for wide angle lenses with pupil expansion. But for telecentric lenses or ones with uncontrolled stop penetration points, use EP Yes.	No.
NRD num_rays_across_diameter		
Number of rays across diameter (RIM1/2)	Number of rays across diameter spline fitted for plot. **Range**: 20 to 200.	20
LAB Yes | No | color....z		
Full labeling (Y/N/Color)? (RIM1/2)	Label plots in standard manner. Use of No eliminates plotting of border, title and annotation for that zoom position - quick plot. Color for titling (BLA, RED, GRE, YEL, BLU, MAG, CYA, WHI) may be designated.	Yes. Labeling is included in default color.
TIT 'temporary_title' (20+20)....z		
Temporary plot title (RIM1/2)	Up to 40 characters are plotted in two 20 character lines for the title of the designated zoom position; if no zoom position is designated, the title is applied to all.	Uses the first 40 characters of the system title.

Continued...

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RIM

Command Syntax		
Screen Prompt	**Explanation**	**Default**
TYP XY | XX | YY | YX....z		
Plot type in X-Y orientation? (RIM1/2)	Select type of format: XY - plot X coordinate of X fans, Y coordinate of Y fans XX - plot X coordinate of X fans and Y fans YY - plot Y coordinate of X fans and Y fans YX - plot Y coordinate of X fans, X coordinate of Y fans	XY
WVL Yes | No | color....w		
Wavelengths (Y/N/Color?) (RIM2/2)	Draw curves in standard linestyles. Use of No eliminates plotting of that wavelength. Color for wavelengths (BLA, RED, GRE, BLU, YEL, MAG, CYA, WHI) may be designated.	Draw all wavelengths in default color.

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DISCUSSION OF INPUT AND COMPUTATIONS

When to Use the RIMray Option

RIM provides a graphic display of lens aberrations ("rimray," "ray-fan plot," "fans"). It can display two types of aberration:

- Transverse aberration (real-ray position measured from real chief-ray position on image surface vertex tangent plane in lens units - **WFR** No - Default)
- Wave aberrations (OPD, in waves at each wavelength - **WFR** - Yes)

What to Include in the LDM Data

No added LDM data is required.

Usage

Ray aberration curves are a traditional diagnostic tool for the lens designer. The shapes of these curves give information about the types and amounts of aberration present. For example, a parabolic shape is associated with coma. Of course, mixes of aberrations are typical in real systems. For information on the interpretation of curve shapes, see (for example) Smith, pp. 68 - 71.[1]

Any type of lens may be analyzed with this option, including all surface types, decentered systems, and zoom systems. A CODE V-supported graphics device (plotter or graphics CRT) is required to view the output from RIM.

Aberration is plotted vertically; the horizontal coordinate represents the position in the aperture of the entering ray, either in the aperture stop (default) or on the entrance pupil (**EP** Yes). Either the X or Y component of the aberration can be plotted for each fan direction (**TYP**); the default (**TYP** XY) is the usually desired case for centered systems. Both X and Y fans (sagittal and tangential for rotationally symmetric lenses) are plotted for each defined object point. See "Default Operation" for a discussion of which fans are traced as a function of lens symmetry.

The scaling and appearance of the plot can be controlled. The vertical scale (as shown at the top of each set of axes) can be set (**SSI**). Labeling information can be included or suppressed; if drawn, its color can be chosen (**LAB**). The individual wavelengths can be assigned colors in addition to the standard use of line types to differentiate plotted curves (**WVL**). The title placed on the plot can be temporarily changed from that of the lens (**TIT**). For some systems, you may need to change the number of rays traced to get a more accurate plot (e.g., systems with high-order aspheres; **NRD**).

Figure 1 (default input with transverse aberration) and Figure 2 (modified input with OPD) are typical RIM plots.

[1]W. J. Smith, *Modern Optical Engineering*, McGraw-Hill, New York (1966).

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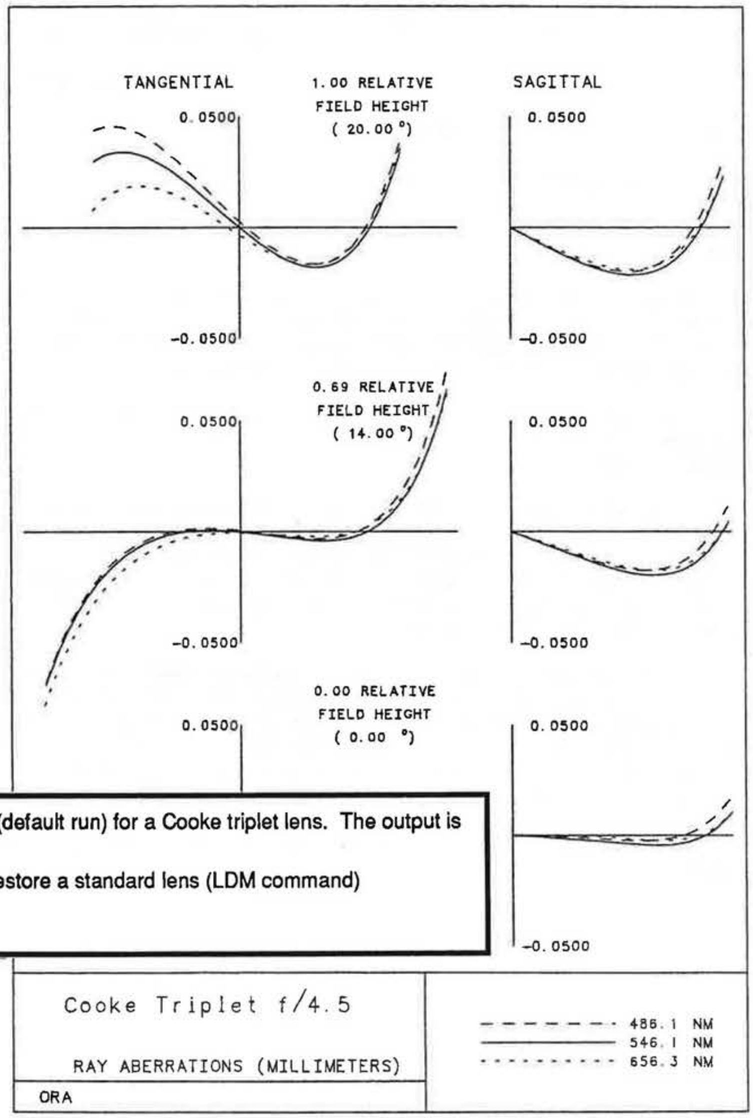
RIM

Examples

Example 1. This shows the minimum input possible (default run) for a Cooke triplet lens. The output is shown in Figure 1.

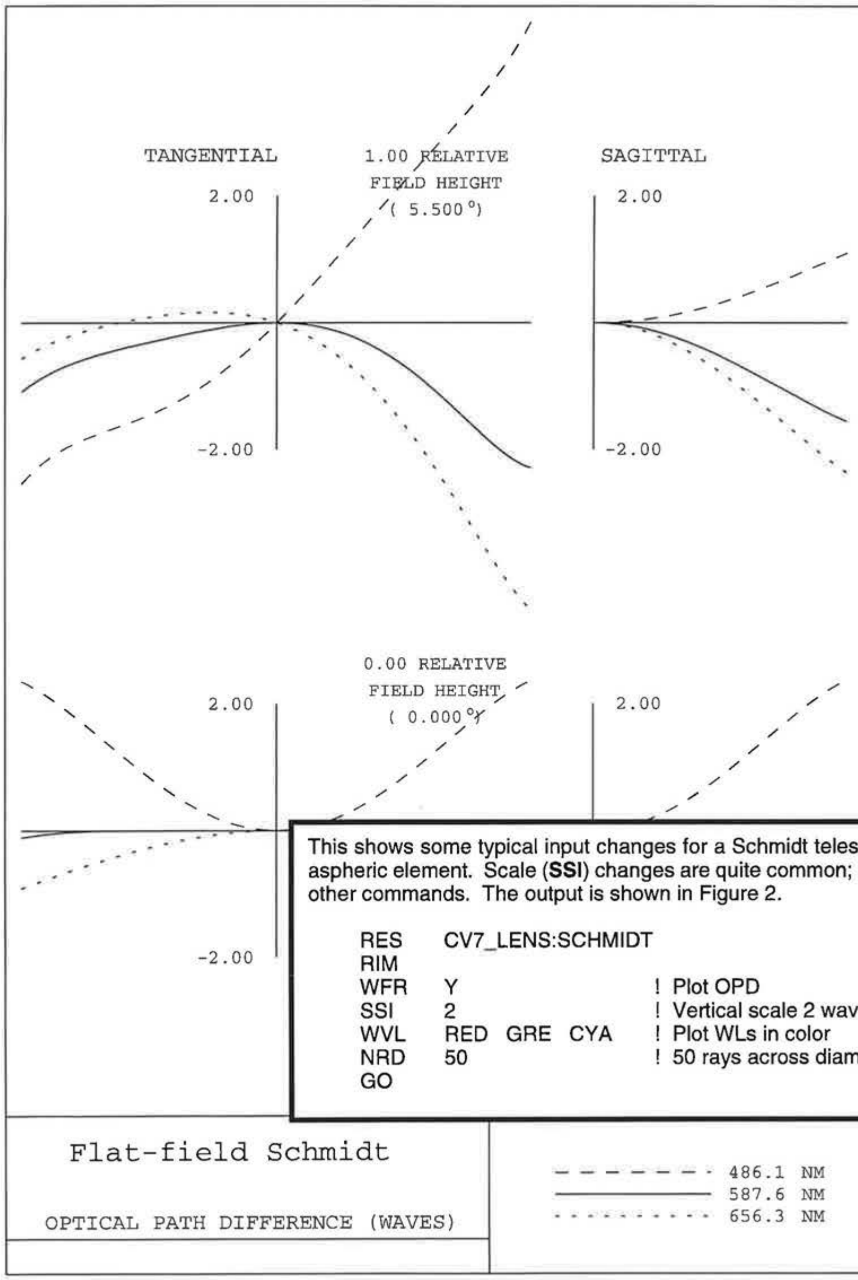


This shows the minimum input possible (default run) for a Cooke triplet lens. The output is shown in Figure 1.

```
res   cv7_lens:cooke1          ! Restore a standard lens (LDM command)
RIM
GO
```

Figure 1.

Example 2. This shows some typical input changes for a Schmidt telescope including an aspheric element. Scale (**SSI**) changes are quite common; see comments for other commands. The output is shown in Figure 2.



This shows some typical input changes for a Schmidt telescope including an aspheric element. Scale (**SSI**) changes are quite common; see comments for other commands. The output is shown in Figure 2.

```
RES    CV7_LENS:SCHMIDT
RIM
WFR    Y                   ! Plot OPD
SSI    2                   ! Vertical scale 2 waves
WVL    RED  GRE  CYA       ! Plot WLs in color
NRD    50                  ! 50 rays across diameter
GO
```

Figure 2. Enhanced RIM output.

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Example 3. This example shows some possible input changes for a zoom lens (the combination of commands is fairly arbitrary, but illustrates how commands can be changed by zoom position). The output is not shown.

```
RES    CV7_LENS:COOKE1
ZOO    3                        ! 3-position zoom
RIM                             ! Different scales for each position
SSI    .05  .10  1.0            ! Suppress labels for all zoom positions (Z1 fills across)
LAB    N
WFR    N  N  Y                  ! Plot OPD for Z3
NRD    30                       ! NRD applies to all zoom positions
TIT    Z1   'First position'
TIT    Z2   'Second position' ! Temporary titles for plots
TIT    Z3   'Third position - WFR'
GO
```

DESCRIPTION OF OUTPUT

The normal output of RIM is graphical only. Text output is used only for error and warning messages (the most common warning message is "Some points have been suppressed," indicating aberrations whose size exceeds the paper limits at the current scale size; the plot is done with the curves clipped at the borders).

For each active zoom position, a single page (or screen) plot is done (for up to five fields; more than five fields will generate multiple plots as necessary). Detailed labeling and a border are drawn unless suppressed (**LAB** N). For each defined field position, X and Y curves are drawn. In the absence of rotational symmetry, the curves are labeled "X-fan" and "Y-fan," and four fans are traced (+Y, -Y, +X, -X in the pupil). When rotational symmetry is present, the -X fans are dropped, and the curves are labeled "Tangential" (Y) and "Sagittal" (X). The Y ray aberration is plotted versus the Y aperture stop coordinates (similarly for X); you can change the plotted aberration (**TYP**) and the reference coordinates (**EP**).

Aberrations in all defined wavelengths are drawn for each field using a distinctive line type for each wavelength. The default color is used unless changed with **WVL**.

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Chapter 5

Image Evaluation

These options provide a variety of evaluation techniques, from which can be selected the form(s) most suited to predicting the performance of the lens to the specification.

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IMAGE EVALUATION

OPTION INDEX

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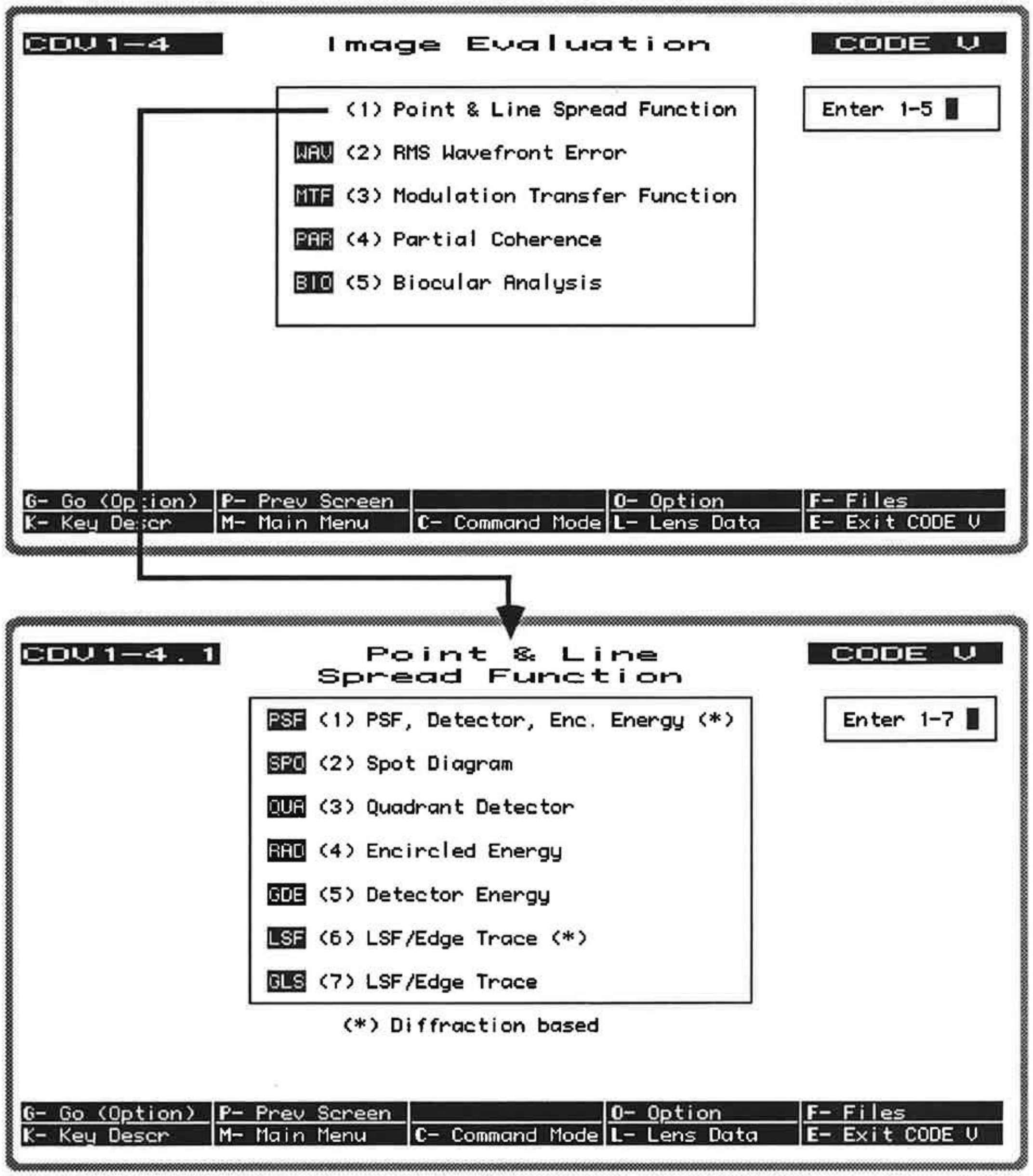
SCREENS


CDV1-4
Image Evaluation
CODE V
(1) Point & Line Spread Function
WAV (2) RMS Wavefront Error
MTF (3) Modulation Transfer Function
PAR (4) Partial Coherence
BIO (5) Biocular Analysis
Enter 1-5
G- Go (Option)
K- Key Descr
P- Prev Screen
M- Main Menu
C- Command Mode
O- Option
L- Lens Data
F- Files
E- Exit CODE V
CDV1-4.1
Point & Line
Spread Function
CODE V
PSF (1) PSF, Detector, Enc. Energy (*)
SPO (2) Spot Diagram
QUA (3) Quadrant Detector
RAD (4) Encircled Energy
GDE (5) Detector Energy
LSF (6) LSF/Edge Trace (*)
GLS (7) LSF/Edge Trace
(*) Diffraction based
Enter 1-7
G- Go (Option)
K- Key Descr
P- Prev Screen
M- Main Menu
C- Command Mode
O- Option
L- Lens Data
F- Files
E- Exit CODE V

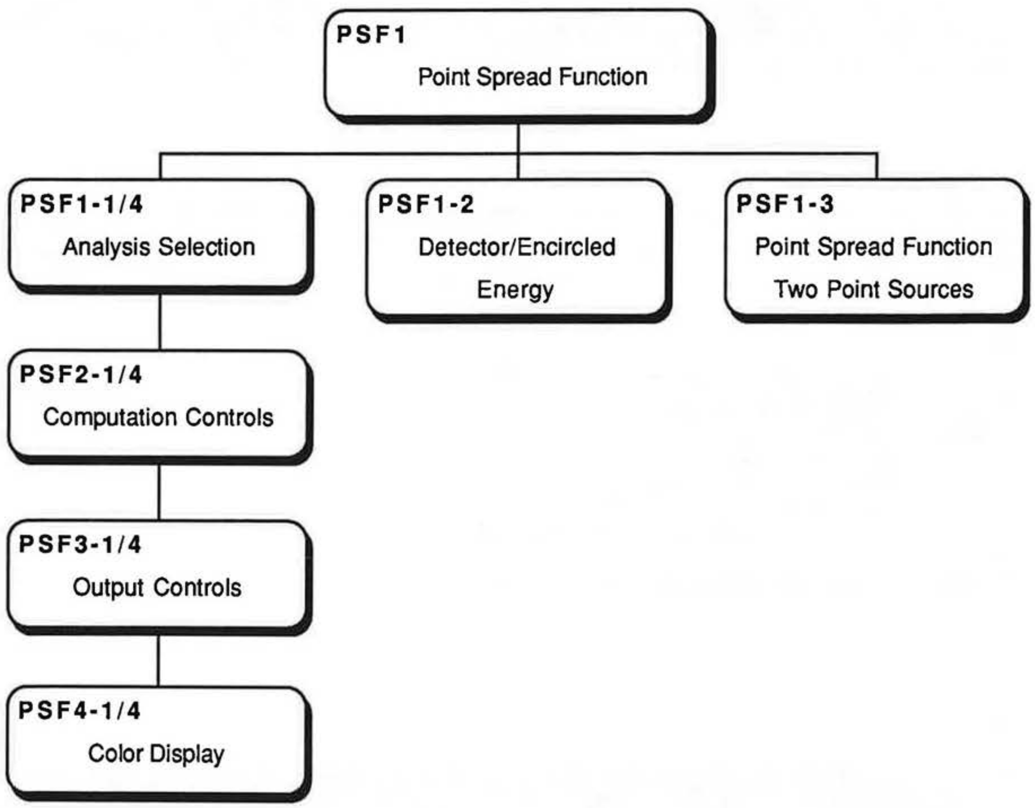
POINT SPREAD FUNCTION (**PSF**)

PSF computes the characteristics of the image of point objects, including the effects of diffraction.

DEFAULT OPERATION

For each field point and zoom position, and for the depth-of-focus values defined in the LDM (FFO, IFO, NFO), the point spread function is constructed by converting the pupil function into the diffraction image, weighted and integrated over all wavelengths. This image patch is represented as a listing of intensity values (normalized to 100) in a 64 x 64 grid with the chief ray or optical axis as the center point on the grid, which spans an area about 13 Airy disc diameters wide (for the shortest wavelength). PSF uses Gaussian and user-defined (.INT files) apodization, and polarization if present in the lens data.

SCREEN FLOW DIAGRAM



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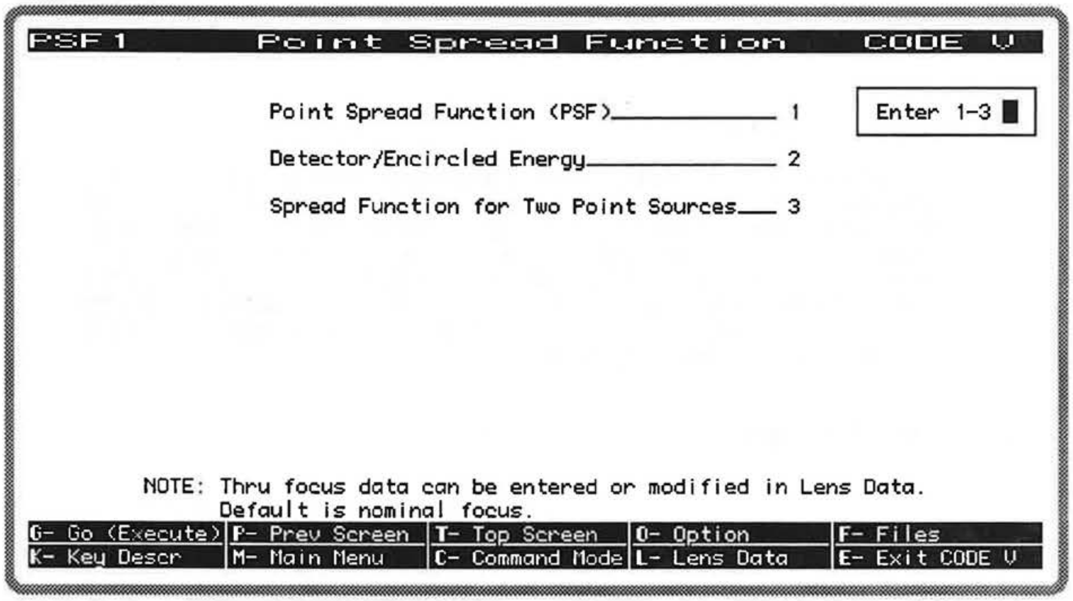
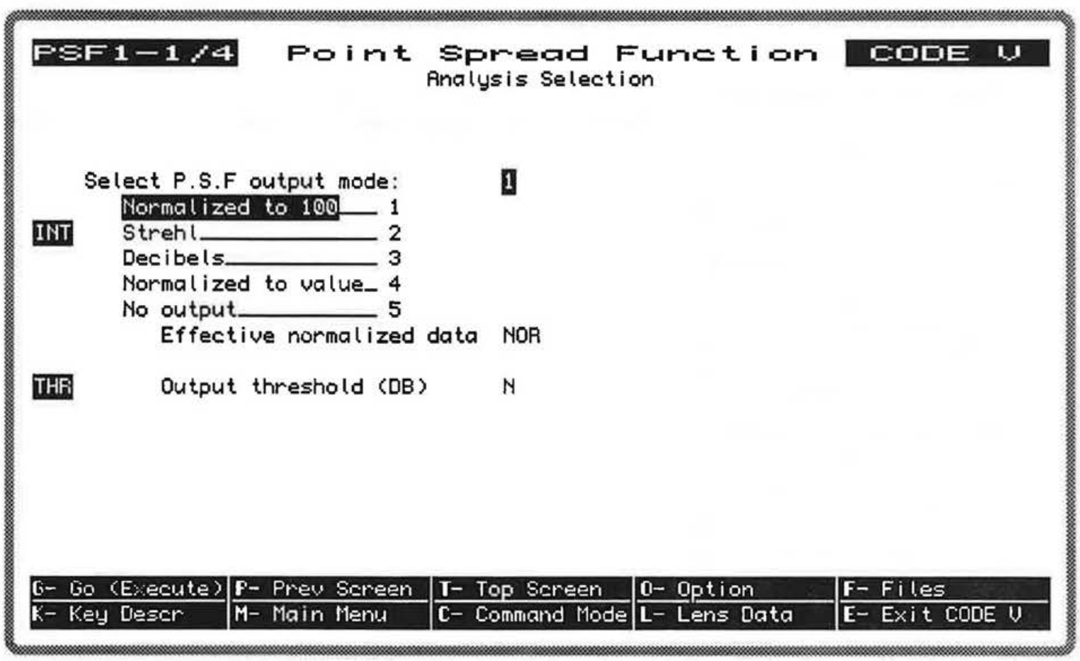
PSF


PSF1 Point Spread Function CODE V
Point Spread Function (PSF)_____ 1
Detector/Encircled Energy_____ 2
Spread Function for Two Point Sources___ 3
Enter 1-3
NOTE: Thru focus data can be entered or modified in Lens Data.
Default is nominal focus.
G- Go (Execute)
P- Prev Screen
T- Top Screen
O- Option
F- Files
K- Key Descr
M- Main Menu
C- Command Mode
L- Lens Data
E- Exit CODE V

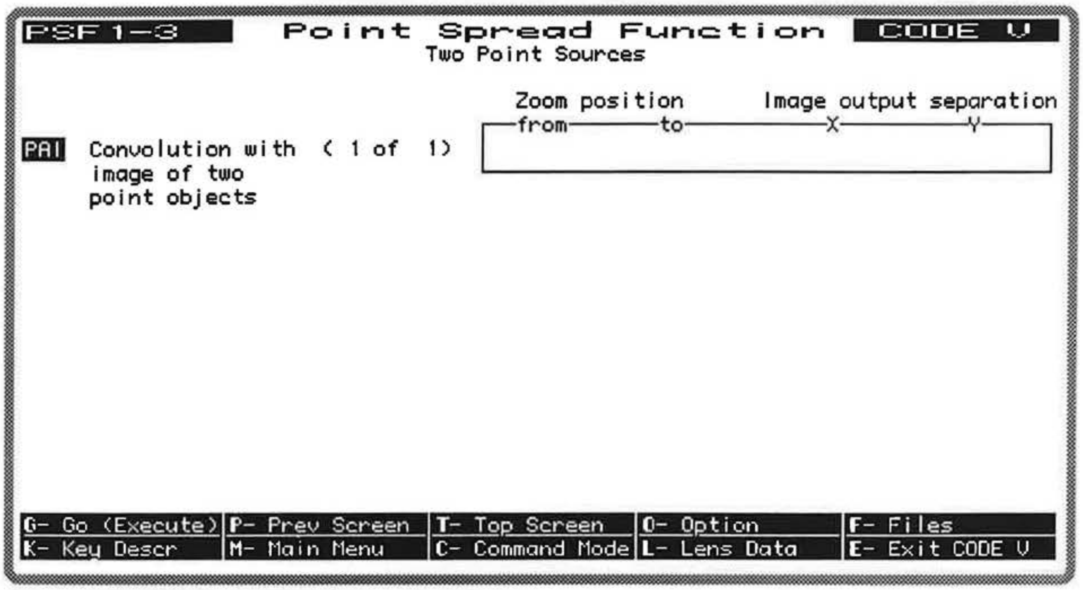

PSF1-1/4 Point Spread Function CODE V
Analysis Selection
Select P.S.F output mode: 1
Normalized to 100___ 1
INT
Strehl_____ 2
Decibels_____ 3
Normalized to value_ 4
No output_____ 5
Effective normalized data NOR
THR
Output threshold (DB) N
G- Go (Execute)
P- Prev Screen
T- Top Screen
O- Option
F- Files
K- Key Descr
M- Main Menu
C- Command Mode
L- Lens Data
E- Exit CODE V

```
PSF2-1/4          Point Spread Function           CODE V
                       Computation Controls

TGR FFT grid size                          64

PGR FFT integration grid size              63

NRD Number of rays across diameter         32

GRI Focal plane grid increment             0.0004876

PRO Near field propagation (Y/N)?          N

XSC Anamorphic scale factor                1.0

WIN File name for saving PSF
    grids in .INT format

G- Go (Execute)|P- Prev Screen |T- Top Screen  |O- Option      |F- Files
K- Key Descr   |M- Main Menu   |C- Command Mode|L- Lens Data   |E- Exit CODE V
```

```
PSF3-1/4          Point Spread Function           CODE V
                         Output Controls

COM Compact output (Y/N)?                  N
LIS List output (Y/N)?                     Y
PHA List phase (Y/N)?                      N

PLO PSF plot (Y/N)?                        N
ROT   Rotate X, Y coordinates (Y/N)?       N

CON Contour plot (Y/N)?                    N
      Suppress numbering (Y/N)?            N
LEV   Select ONE of the following:
        Number of contour levels           3
        Contour increment
        User-defined contour levels
                        ( 1 of  1)

TIT Temporary title                        Double Gauss - U.S. Patent 2,532,751
G- Go (Execute)|P- Prev Screen |T- Top Screen  |O- Option      |F- Files
K- Key Descr   |M- Main Menu   |C- Command Mode|L- Lens Data   |E- Exit CODE V
```

```
PSF4-1/4      Point Spread Function      CODE V
                  Color Display

DIS Color display (Y/N)?              N

RAN Color scale setup:
  SCA Set scale range:
      Number of color steps:          50
      Minimum data value:             0.0
      Maximum data value:             0.0
  COL Select color scale type:        1
    SPE Spectral color rainbow...1
    RGB Monochromatic ramp.......2    Ramp color:  Red     1.00
                                                   Green   1.00
                                                   Blue    0.00
SIZ Size of display area:             512

BAC Background color:           Red   0.30
                                Green 0.49
                                Blue  0.49
G- Go (Execute) P- Prev Screen T- Top Screen  O- Option     F- Files
K- Key Descr    M- Main Menu   C- Command Mode L- Lens Data E- Exit CODE V
```

```
PSF 1-2       Point Spread Function      CODE V
             Detector/Encircled Energy

    Select mode:
      Detector energy
DEX     Circular - X only       X-dir. N
        Rectangular -X and Y
DEY     (Full width value/N)    Y-dir. N
    OR:
ENC   Encircled energy type:  1
         Minimum diameter________ 1
         Centered at centroid___ 2
         Centered at chief ray__ 3
        Image diameter output (Y/N)? N
        Plot encircled energy (Y/N)? N
XMA     Horizontal axis maximum
XDE         "      "   increment
        (Def: automatic selection)
PER     Percentage of energy
        (Def:10,20,..90)  ( 1 of  1)
   NOTE: Detector energy and encircled energy are mutually exclusive operations
G- Go (Execute) P- Prev Screen T- Top Screen  O- Option     F- Files
K- Key Descr    M- Main Menu   C- Command Mode L- Lens Data E- Exit CODE V
```



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COMMAND MNEMONICS (alphabetical)

ADD	BAC	COM	CON	DEX	DEY
DIS	ENC	GRI	INT	LEV	LIS
NRD	PAI	PER	PGR	PHA	PLO
PRO	RAN COL	RAN SCA	ROT	SIZ	TGR
THR	TIT	WIN	XDE	XMA	XSC
Y	YC				

DATA INPUT DESCRIPTION

Analysis Selection

Command Syntax		
Screen Prompt	Explanation	Default
INT [NOR | STR | DB | listed_peak_intensity | No....z]		
Select PSF output... (PSF1-1/4)	Select form of intensity normalization: NOR - normalized to peak = 100 STR - (Strehl) normalized to perfect lens peak = 100 DB - db falloff from the peak = 0 listed_peak_intensity - normalized to peak = value No - skip computation and display for this zoom position. If STR is selected, and obscuration is present, the peak value is relative to a perfect lens of the same obscuration; if Gaussian apodization is present, the peak is relative to a perfect lens with uniform pupil intensity. **Note:** INT can be used with PAI <u>or</u> DEX, DEY, but not both; output will be provided for both the diffraction image and the convolved image. INT can also be used with ENC.	INT NOR, unless ENC or PAI or DEX, DEY are included.
THR output_noise_threshold_db....z		
Output threshold (DB) (PSF1-1/4)	Used only with INT DB. Suppress noise below output_noise_threshold_db; sets lower values to entered value for plots, deletes lower intensity values in listings. Helpful in smoothing plots.	-50

Computation Controls

Command Syntax		
Screen Prompt	**Explanation**	**Default**
TGR num_fft_grid_pow_of_two		
FFT grid size (PSF2-1/4)	Transform grid size. **Range**: 16 or more, must be a power of 2. Unless overridden by NRD or GRI, also determines the number of rays traced in proportion to TGR**2. Use to improve accuracy for systems with large or unusual obscurations, or to increase the size of the image area analyzed relative to the Airy disc.	64
PGR num_integration_grid_width		
FFT integration grid size (PSF2-1/4)	Integration grid size. **Range**: Any odd number less than TGR. Restricts the area used for display and for centroiding, moments, encircled energy, etc.; excluded data is assumed to have 0 energy in all of these operations.	= TGR-1.
NRD num_rays_across_diameter....z		
Number of rays across diameter (PSF2-1/4)	Number of rays traced across the pupil diameter for the shortest wavelength; other wavelengths are proportionately smaller to make image plane grids match. See GRI command, also. **Range**: Recommended - no more than 2 times up or down from the default; look out for artifacts of extreme choices. Use either NRD or GRI, if desired, not both.	= TGR/2 at short wavelength.
GRI image_grid_spacing....z		
Focal plane grid increment (PSF2-1/4)	Grid spacing measured on the image surface - alternative to NRD. Use to choose a more convenient number than the default. **Range**: Recommended - no more than 2 times up or down from the default; look out for artifacts of extreme choices. Use either NRD or GRI, if desired, not both.	Shortest wavelength * fnumber/2. (Airy disc diameter for shortest wavelength spans 4.88 grid increments regardless of TGR value.)

Continued...

Computation Controls (Continued)

Command Syntax		
Screen Prompt	**Explanation**	**Default**
PRO Yes | No		
Near field propagation (Y/N)? (PSF2-1/4)	Use near-field propagation, instead of far-field. Use when the image is out of focus and much larger than the Airy disc and occupies at least half of the output grid; the default GRI value will be set to this value. The lens should be in focus. Use non-zero FFO to defocus.	No.
XSC scale_x_psf_by_factor....z		
Anamorphic scale factor (PSF2-1/4)	Scale X dimension of image by this factor. Used to handle highly anamorphic exit pupils. The largest (X or Y) numerical aperture of the exit pupil is used in establishing default values for GRI/NRD; this may lead to insufficient sampling in either the X or Y dimension, depending on which was largest; check this with the PMA option. Use XSC to scale up the X dimension of the image, which correspondingly reduces the number of pupil sampling points in the X direction, and vice versa. **Ex**: XSC 2 scales the X dimension of the image by 2, the GRI or NRD by 0.5.	1.0
WIN int_filename		
Filename for saving PSF grids... (PSF2-1/4)	Generate a file, with the specified name, containing the PSF in the grid form of standard .INT type files (see LDM). File records produced are: Five comment records including grid spacing, defocus value, units, field/zoom positions, wavelengths and wavelength weights Title GRD x_size y_size FIL WVL wavelength SSZ scale_size NDA -32767 The file values following are the PSF values over the grid scaled to use a maximum dynamic range of 32767. The SSZ value, scale_size, and the dynamic range depend on the form of normalization specified: Normalization / Range of Values / scale_size INT NOR / 0 to 32767 at peak / 32767 INT STR / 0 to ≤ 32767 at peak / 32767 INT DB / -32766 for THR threshold to 0 at peak / -32766 Separate files are generated with ascending version numbers for each successive field.	No files generated.

Listing Controls

Command Syntax		
Screen Prompt	Explanation	Default
COM Yes | No....z		
Compact output (Y/N)? (PSF3-1/4)	Normal listed grid displays include two blank lines between grid rows to make vertical and horizontal scales equal. COM Yes cancels the blank lines.	No.
LIS Yes | No....z		
List output (Y/N)? (PSF3-1/4)	Use (with No) to turn off listed output when only plotting is wanted.	Yes.
PHA Yes | No....z		
List phase (Y/N)? (PSF3-1/4)	Changes output in grid to represent phase in the image, instead of intensity.	No.

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Plotting Controls

Command Syntax		
Screen Prompt	Explanation	Default
PLO Yes | No....z		
PSF plot (Y/N)? (PSF3-1/4)	Plot intensity (INT) and/or convolution using PAI or DEX,DEY as a single page oblique projection plot for each field point. Vertical scale of the peak: 4 inches corresponds to 100%.	No.
ROT Yes | No....z		
Rotate X, Y coordinates (Y/N)? (PSF3-1/4)	Use only with PLO. Rotate oblique projection plot 90° in X-Y plane, to reveal hidden features.	No.
CON [SUP] Yes | No....z		
Contour plot (Y/N)? Suppress numbering (Y/N)? (PSF3-1/4)	Plot intensity (INT) and/or convolution using PAI or DEX,DEY as a single page contour plot, with numbered contours, for each field point. SUP suppresses the numbering.	No.
LEV [contour_level_fraction....30] or **LEV INC** contour_increment_fraction or **LEV NUM** num_contour_levels		
Select one of the following .... (PSF3-1/4)	Use only with CON. Specify contours with one of: LEV - Up to 30 values for plotted contours. Omitting values returns to default. LEV INC - Specifies equal separation of contours between minimum and maximum levels. LEV NUM - Specifies the number of levels plotted between minimum and maximum values. The resulting increment is rounded to a reasonable value which may shift the count. For LEV and LEV INC, values are in fractions of the intensity. **Range**: 0 to 1.0.	LEV NUM 10.
TIT 'temporary_title'(20+20)....z		
Temporary title (PSF3-1/4)	Up to 40 characters are plotted in two 20 character lines for the title of the designated zoom position; if no zoom position is designated, the title is applied to all.	Uses the first 40 characters of the system title.

Color Display

Command Syntax		
Screen Prompt	**Explanation**	**Default**
DIS Yes | No....z		
Color display (Y/N)? (PSF4-1/4)	Display intensity (INT) and/or convolution using PAI or DEX,DEY as a color contour map for each field and zoom position. The displayed colors represent the different intensity levels in the image in two dimensions. This may only be displayed on devices that support color raster displays.	No.
RAN SCA num_steps [min_value max_value]		
Color scale setup: Set scale range: (PSF4-1/4)	Use only with DIS. Specifies the scaling of the data range as well as the number of color steps into which the range is divided. If the minimum and maximum values are omitted, the entire data range is shown.	RAN SCA 50
RAN COL SPE | RGB [r_value g_value b_value]		
Color scale setup: Select color scale type: (PSF4-1/4)	Use only with DIS. Specifies the type of color scale to be used to display the intensity data. SPE uses a spectral color rainbow (blue to green to red). RGB uses a monochromatic color ramp from black to the specified red, green and blue values. The default red, green and blue values are 1.0, 1.0 and 0.0 which creates a yellow ramp.	RAN COL SPE
SIZ max_pixels		
Size of display area: (PSF4-1/4)	Use only with DIS. Specifies the maximum dimension, in pixels, of the rectangular area into which the data is drawn.	512
BAC r_value g_value b_value		
Background color: (PSF4-1/4)	Use only with DIS. Specifies the background color for the region outside the data display area. Any text, titles and labels, are displayed over this color. The default color is dark slate gray.	0.30 0.49 0.49

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Detector/Encircled Energy

Command Syntax		
Screen Prompt	Explanation	Default
DEX No | x_dim_of_detector.....z		
Detector energy... X-direction (PSF1-2)	Replace output with a display to show the image convolved with detector. If DEX only is given, it is a circular detector with diameter equal to x_dim_ of_detector; if both DEX and DEY are given it is a rectangular detector of the specified X and Y dimensions. Each point in the display grid becomes the relative energy on the detector when it is centered at the grid point; or it is equivalent to the image formed by the lens of a circular or rectangular object of corresponding geometrical size. **Range**: Less than 1/2 the full grid X dimension. Can't be used with PAI; can be used with INT to include the INT output also.	No.
DEY No | y_dim_of_detector....z		
Detector energy... Y-direction (PSF1-2)	Use only with DEX. Designates the detector to be rectangular with the given y_dim_of_ detector. **Range**: Less than 1/2 the full grid Y dimension.	No.
ENC [CHI | CEN] [PLO] Yes | No....z		
Encircled energy (PSF1-2)	Replace output with a table of encircled energy (circle diameters that just enclosed fixed percentages of energy). The circles are minimized by scanning their centers along the Y axis running from the chief ray in the image; no scanning is done in the X direction. CHI or CEN eliminates scanning; CHI places each circle center at the chief ray; CEN places each circle center at the centroid. One table is generated for each field, focus, and zoom position. PLO generates a plot of encircled energy. Can be used with INT to include the INT output also.	No.
PER encircled_%....z		
Percentage of energy (of) (PSF1-2)	Use only with ENC. Cancel the default set and select the desired percentages for which circle diameters are to be calculated. Up to 10 PER commands can be given. **Range**: <100 - the diffraction spot goes to infinity. **Ex**: PER 15;PER 65 will give tables for 15% and 65% only.	10,20,..90

Continued...

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Detector/Encircled Energy (Continued)

Command Syntax		
Screen Prompt	Explanation	Default
XMA horiz_axis_max....z		
Horizontal axis maximum (PSF1-2)	Use only with ENC ... PLO for plot axis layout. The maximum\image radius value to be plotted along the horizontal (X) axis of the plot (7 inches, 178 mm long).	Radius needed to encircle 95% of the energy.
XDE incr_between_horiz_axis_ticks....z		
Horizontal axis increment (PSF1-2)	Use only with ENC ... PLO for plot axis layout. The increment in image radius between ticks plotted along the horizontal (X) axis of the plot. If XMA is not an even multiple of XDE, the excess lies at the right hand end of the X axis.	XMA/10

Two Point Sources

Command Syntax		
Screen Prompt	Explanation	Default
PAI [Zk | Zi..j] x_separation y_separation		
Convolution with image of two... (PSF1-3)	Replace output with a display to show the image convolved with the image of two point objects with the equivalent geometrical image surface X and Y separations. Each point in the display grid becomes the relative energy of the combined image. **Range**: Less than 1/2 the full grid dimension. Output is generated for each field and focus position, in all zoom positions, unless restricted with Zk|Zi..j. Can't be used with DEX, DEY; can be used with INT.	No, assumes single point source only.

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Perturbed Wavefront

Command Syntax		
Screen Prompt	Explanation	Default
ADD Fn [Wm] [B|Q]		
	Add a wave front perturbation, to be given in Y, YC commands, to the entrance pupil at Fn field, Wm wavelength; Wm defaults to the reference wavelength. Determine pupil grid rows and columns to be used by running the PMA option with the same TGR and NRD or GRI. Symmetry can be designated to reduce the number of Y, YC commands as follows: B - bi-lateral symmetry in X; give only the left half of the pupil grid, including the center column and row (TGR/2 + 1). Q - quadrant symmetry; give only the upper left quadrant of the pupil grid, including the center column and row (TGR/2 + 1). neither - no symmetry; give all columns and rows.	No perturbation.
Y num_row perturbation_waves_x100....TGR **YC** perturbation_waves_x100....TGR		
	Use only with ADD. Start each row with Y command; row is designated by num_row. Express perturbations in waves x 100 (waves of error), starting with the leftmost pupil grid point through which a ray passes and continue to the pupil grid point required by the symmetry qualifier on the ADD command; use zero values to span any obscurations. Put as many perturbations on one record as desired; continue the row with the YC (Y Continue) command.	No perturbation.

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DISCUSSION OF INPUT AND COMPUTATIONS

When to Use the PSF (Point Spread Function) Option

Use the PSF option for the following purposes:

- To generate and display the aberrated diffraction structure of the polychromatic image at all fields and at several adjacent focal surfaces, if desired. Displays include listings and/or plots (both oblique projection and contour); normalizations (**INT** command) include:
  - Peak intensity as 100%
  - Strehl - Perfect lens is 100%
  - dB normalization, with noise threshold elimination (**THR** command).

  Grids can be selected, if desired, for transform grids, pupil filling of transform grid, or grid spacing on the image.
- Analysis of significantly out-of-focus images can be done (**PRO** command).
- Anamorphosed scaling can be used to handle widely different X and Y image profile sizes (**XSC** command).
- Phase in the image, rather than intensity, can be displayed (**PHA** command).
- Output can be converted to detector energy for a given circular or rectangular detector placed at each image plane grid point - convolution of image and detector (**DEX**, **DEY** commands).
- Encircled energy tables and plots can be generated (**ENC** command).
- Output can be converted to the image of two point sources for given X, Y separations - convolution of image and sources (**PAI** command).
- Any of these combinations that generate grid tables also can be converted and output as .INT files (intensity type), for analysis by other programs.

Gaussian or user defined (.INT file) apodization, and polarization are all included in the analyses.

What to Include in the LDM Data

No additional LDM data is required. If you wish to do through-focus analyses, enter the LDM data for depth of focus (FFO, IFO, NFO).

Usage

PSF computes the wave aberration of the system, and by Fast Fourier Transform (FFT), the diffraction image shape in the designated focal plane integrated over the wavelengths according to the weights assigned to the system in the LDM. This image patch is represented in the computer by intensity values in a grid across the image with the chief ray or optical axis as the center point of the grid.

Due to the nature of the FFT process, if the pupil function is represented by many points, such as the default grid interval provides, the diffraction image (say, the Airy disc) will be represented by few points. Thus, asking for a smaller output grid spacing (**GRI**) to enlarge the image size will provide more detail in the output but will use less data to represent the lens. This trade-off should be understood when choosing grid sizes. The default grid size should usually be the largest value used, while the smallest should be one-half of it. Values outside this range should be recognized as introducing increasingly large errors.

Due to the fact that points on a square grid are used to represent the pupil function which is approximately circular in symmetry, artifacts[1] appear in the output when too small a grid interval is used. Thus, the default grid spacing, for a rotationally symmetric system, will produce a rather precise display of

[1] artifact: a structure not actually present in the system, but which appears to exist in plotted output, for example, due to an external agency such as mis-scaling.

the Airy disc. A grid spacing of one-half this amount will enlarge the image but use one-fourth as much data to represent the lens. The square grid representation of the pupil function now does not look so circular; it has flats and steps of twice the size on it. This produces slight distortions (a few percent) in energy in a four-fold symmetric pattern which may give an aesthetically unpleasant appearance to what should be a rotationally symmetric image.

Default Assumptions

1. All field angles and zoom positions will be included.
2. Wavelengths and their weights will be those of the system, determined by entries in the LDM.
3. The focal plane is determined by the combination of the last thickness (THI Si-1) and defocusing (THI Si).
4. The grid size is chosen to be:

$$\frac{\lambda s * f/no}{2}$$

   which results in the Airy disc diameter for the short wavelength (λs) being spread over 4.880 output grid elements. For curved image surfaces, the grid spacing is measured on the image surface.

5. Intensity across the pupil is assumed to be uniform.
6. Output is to be the relative intensity distribution in the image, on a scale of 100.
7. The size of the transform grid is 64 x 64.

Analysis Selection

The intensity display can be modified from the default by specifying a value other than 100 for any zoom position (**INT**). The presence of the word STREHL (or S) after the **INT** command gives output of the *intensity distribution in the image* (for that zoom position) relative to a perfect lens image whose peak would be 100. With obscuration the peak value is relative to a perfect lens of the same obscuration. If, instead,apodization (Gaussian or user-defined .INT files) has been used (in the LDM), the peak is relative to a perfect lens with uniform amplitude, where the uniform amplitude has the same value as the maximum of the apodized pupil amplitude. This is valid for both monochromatic and polychromatic images.

The use of the symbol DB (or D) for any position following the **INT** command gives output of the *relative intensity distribution in the image,* expressed as decibel fall off from the peak value. The values are:

$$dB = 10 * \log_{10}\left(\frac{I}{I\ peak}\right)$$

Used with **INT** DB only, the threshold command (**THR**) will set any intensity value which is lower than the value in the first field to equal the first field value. The entry must be a negative dB value (e.g., -50). This request is mainly for smoothing the lower limit on a DB plot, since noise tends to be magnified on a dB scale. The default value is -50.

Image Plane Interval

The default grid interval may not be a convenient size. It can be increased up to a factor of two to shrink the relative size of the image (**GRI** or **NRD**). The lens will be represented by more data which will take longer to calculate by the square of the scale change. The grid interval can also be decreased to expand the relative size of the image. It is unwise to do this beyond a factor of two because the lens will be represented by very few data points in the wavefront, especially in the long wavelengths. The artifacts mentioned previously will also become evident.

The default size of the transform grid used in the FFT is 64. This may be modified (**TGR**) but the value must be a power of 2 (minimum value is 16). If any other value is entered, it will be rounded up to the next

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allowable value. For example, **TGR** 45 will result in a 64 x 64 transform grid. The default physical spacing in the image plane is selected so that the pupil grid at the shortest wavelength fills up half the transform grid. Use **TGR** to improve accuracy for systems with large or unusual obscurations, or to increase the size of the image area analyzed relative to the Airy disc.

The integration grid, used to display the PSF and to do the auxiliary calculations such as centroiding, moments, encircled energy, etc., can also be modified (**PGR**). The default size is **TGR**-1. If the **PGR** value entered is larger than the **TGR** value, it will be reduced to **TGR**-1. Any odd number less than **TGR** is allowed. A lower **PGR** value restricts the area used for analysis, such as when noise is to be suppressed. Note, however, that when **PGR** is less than **TGR**-1, excluded data is assumed to have 0 energy.

The formulas relating each of the values are the following:

$$\mathbf{GRI} = \frac{\lambda s * f/no * \mathbf{NRD}}{\mathbf{TGR}}$$

$$\mathbf{PGR} < \mathbf{TGR}$$

The f/no is the f/number in the image space for the axial beam (or for 2X the largest half-beam at any field if larger than the axial beam.

Focus Considerations

Multiple (or modified) focus positions may be specified to display the through-focus (or shifted) characteristics of the image. These are requested in the LDM prior to invoking PSF. (See NFO, FFO, and IFO in Chapter 2A, "Specification Data - Depth of Focus").

When the image of the system is out of focus, is much larger than the Airy disc, and occupies at least half of the output grid, use near-field propagation (**PRO**) instead of the normal far-field diffraction calculation. If no grid interval (**GRI**) is specified in conjunction with **PRO**, it will be selected so that the geometrical spot will fill about half the output array. The lens should be in focus. Use non-zero FFO to defocus. (See Technical Notes for background on near field propagation.)

In general, the **GRI** value only applies to the first focal position. In normal use it is close enough so that other focal positions are accurate; if the systems are slow (high f/no), the user may have to run each focal position as a separate calculation to ensure that the scale chosen is used. If **PRO** (propagate) is used, the focal shift can be great (from pupil to near the image or beyond the image); for this, the printed value of the grid interval is re-calculated to show its true size for focal positions after the first.

Gaussian Apodization

To transform the uniformly illuminated pupil into one with a Gaussian intensity profile, use PUI, PUX, and PUY in the LDM (See Chapter 2A, "Specification Data - Aperture Specification").

Anamorphic Scale Factor

The largest (X or Y) numerical aperture of the exit pupil is used in establishing default values for **GRI/NRD**. With highly anamorphic exit pupils, this may lead to insufficient sampling in either the X or Y dimension, depending on which was larger. Check this with the PMA option. The X dimension of the image can be scaled up (**XSC**), which reduces the number of pupil sampling points in the X direction, and vice versa. Example: **XSC** 2 scales the X dimension of the image by 2, and the **GRI** or **NRD** by 0.5.

Generating Grid Files for Other Programs

Images sometimes need to be analyzed by other programs outside of CODE V. To facilitate this, the **WIN** command will cause any of the series of **PSF** grid-format analyses (**INT, PRO, PHA, DEX/DEY, PAI**) to be output to files in the .INT format described in the LDM; only encircled energy (**ENC**) of the major analysis forms in this option is not available this way.

The size of the grid that is written to the file is determined by the **PGR** value. The file will be in the standard CODE V interferogram file format, with the SUR/WFR/FIL indicator given as FIL, indicating intensity. A separate file will be written for each field, zoom and defocus position.

The leading comments and title record contain the information described with the command syntax so that the conditions of generation are retained with the file. Note that the range of values in the file (32767) is sufficient to retain all of the accuracy that can be contained in the calculation; the value following SSZ in the file can be used to normalize the data (typically by dividing by it). The value following NDA (-32767) is the value to scan for to identify data in the grid for which there are no values (outside of image, etc).

Listing Controls

The normal listed grid displays include two blank lines between grid rows to make the vertical and horizontal scales equal. The entire listed output can be suppressed (LIST N), or a more compact listing with blank lines suppressed can be selected (**COM**). The output in the grid listing can be changed to represent *phase in the image* (**PHA**) instead of intensity if desired.[2]

Plotting Controls

Two types of graphical output are available:

- A "three-dimensional" oblique projection plot (**PLO**)

  or

- A contour "map" of the intensity levels (**CON**).

3-D Projection Plots

There is automatic scaling for the oblique projection plots of intensity. The INTENSITY, INTENSITY DB, and INTENSITY STREHL plots are drawn so that 100% has a vertical deviation of 4 inches. For INTENSITY STREHL, the vertical height is less than 4 inches for a non-perfect lens; the vertical height, therefore, is a measure of absolute intensity. The Strehl ratio may be determined by taking the vertical height and dividing by 4.

Occasionally, the detailed structure of the image is hidden by the peaks of the oblique projection plot. The X and Y coordinates can be rotated 90° (**ROT**) to overcome this effect.

Contours

As an alternative to the projection plot, contour "mapping" of the intensity levels in the image in two dimensions can be requested (**CON**). The contour lines will be numbered unless suppressed (**CON** SUP). Three levels between minimum and maximum with reasonable rounding of the increment are the default. (For a normalized PSF plot, the levels will be .9, .8, .7 ...., .1). The user may specify up to 30 contour levels (**LEV** n..30), the contour increment (**LEV INC** n) and override the number of contour levels (**LEV NUM** n). Levels will be integral multiples of the contour increment. The number of levels plotted may change by one due to rounding.

A temporary title can be specified for either type of plot (**TIT**). Otherwise, the system title is used.

Color Display

Another alternative to either the projection plot or the line contour mapping is a color contour map of the intensity level of the image (**DIS**). In this type of display, different colors represent different intensity levels. The number of colors and the range of levels can be controlled with the **RAN SCA** command. The intensities may be colored either by a spectral color rainbow, blue to green to red (**RAN COL** SPE), or by a monochromatic color ramp, black to a specified color (**RAN COL** RGB). The maximum size of the rectangular display area is 512 pixels; this can be changed (**SIZ**). The background color value for the region outside the data display area can be specified (**BAC**). This type of display is only available on devices that support color raster displays. Output for this type of display is controlled by the RGR command.

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[2] See Born and Wolf, *Principles of Optics*, pp. 445-448 for discussion of phase behavior as a function of focus.

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Near Field Propagation

Use **PRO** to get the PSF of an out-of-focus image which is much larger than the Airy disc. The lens should be in focus. FFO, IFO, NFO are used to introduce the defocus. This mode uses near field propagation (see Technical Notes).

Analysis for Circular and Rectangular Detectors

The energy falling within a detector will be listed in a display grid showing intensity values which replaces the normal listed display. Specify the detector diameter in the X (skew) dimension only for a *circular* detector (**DEX** n). If the detector is *rectangular*, enter both the X and Y (meridional) dimensions (**DEX** n and **DEY** n). A convolution of the detector with the point spread function is done and an array is listed giving the relative values of the energy on the detector. The percent energy on the detector is given for the detector centered at the chief ray and for peak energy. This request is also equivalent to the image formed by the lens of a circular or rectangular object of corresponding geometrical size. The maximum detector dimension should be less than 1/2 the full grid X (or Y) dimension.

Analysis for Two Point Sources

The image of a pair of point sources may be requested (**PAI**). The listed output will display the image convolved with the image of two point objects with the equivalent geometrical image surface of the X and Y separations. Each point in the display grid becomes the relative energy of the combined image. Output is generated for each field and focus position, in all zoom positions, unless restricted with Zk|Zi..j. **Range:** less than 1/2 of the full grid dimension. Cannot be used with **DEX** or **DEY**; can be used with **INT**.

Encircled Energy of a Point Source

An alternate grid display available is one which displays circle diameters that enclose fixed percentages of light energy (**ENC**). The circles are minimized by scanning their centers along the Y axis running from the chief ray in the image. No scanning is done in the X direction. **ENC** can be used with **INT**. Scanning can be eliminated, with each circle center placed at the chief ray (**CHI**) or at the centroid (**CEN**). One listed table is generated for each field, focus, and zoom position. Up to 10 user-defined percentages for which the circle diameters are to be calculated may be specified (**PER**) in a range of <100. |

The **PLO** command causes a plot of encircled energy (percent energy as a function of spot diameter) to be generated. The default X axis maximum of this plot is the (95% encircled energy diameter for the particular system being evaluated. Sometimes, to facilitate comparisons of different designs, it is useful to plot the results for all of the designs at the same scale; this is done with the **XMA** command, in which the maximum spot diameter (X coordinate maximum) is entered. The **XDE** command can be used to change the increment used in the labeling of the X axis in the plot.

Perturbed Wavefront Analysis

A wave front perturbation can be added to the entrance pupil (**ADD**) at a selected field and wavelength. Determine the pupil grid rows and columns to be used by running the PMA option with the same **TGR** and **NRD** or **GRI**. Perturbations are expressed as 100 * (waves of error), in rows and quantities specified (**Y**), starting with the left most pupil grid point through which a ray passes and continuing to the pupil grid point required by the symmetry qualifier on the **ADD** command (B, Q). Use zero values to span any obscurations. Put as many perturbations on one record as desired by continuing the Y row with the Y CONTINUE command (**YC**). Note that in many cases, perturbed wavefronts can be modeled more easily with the interferogram feature of CODE V (see **INT** command, Chapter 2A, "Entering/Changing Data-BUILDING THE LENS - Interferometric Deformations"), but **ADD** allows discontinuities, different phase changes for each wavelength, and causes no ray direction changes.

Combination Runs

A single set of calculations (without re-tracing rays) can lead to several different forms of output:

- Multiple focal planes (NFO, FFO, IFO entered in the LDM)
- **INT**, **ENC**, **DEX**, **DEY** or **INT**, **ENC**, **PAI** can be used together to get all three types of output in one run; only **DEX**, **DEY** can not be used with **PAI**.
- **PLO**, **CON** and **LIS** control which combination of plots and listings are to be included.

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PSF

Examples

Example 1. Point spread function (oblique projection) of the Double Gauss lens, stopped down to f/4, in the 14° off-axis field. (Text output not shown) (Figure 1).

Point spread function (oblique projection) of the Double Gauss lens, stopped down to f/4, in the 14° off-axis field. (Text output not shown) (Figure 1).

```
res  cv7_lens:dbgauss
SCALE  EFY  50.0   ! Set effective focal length to 50.00 mm
FNO  4.0           ! Stop lens down to f/4
PSF
COM                ! Compact output; blank lines cancelled
NRD  40            ! Number of rays across pupil diameter
PLO                ! Plot intensity as single page oblique
                       projection plot for each field point
GO
```

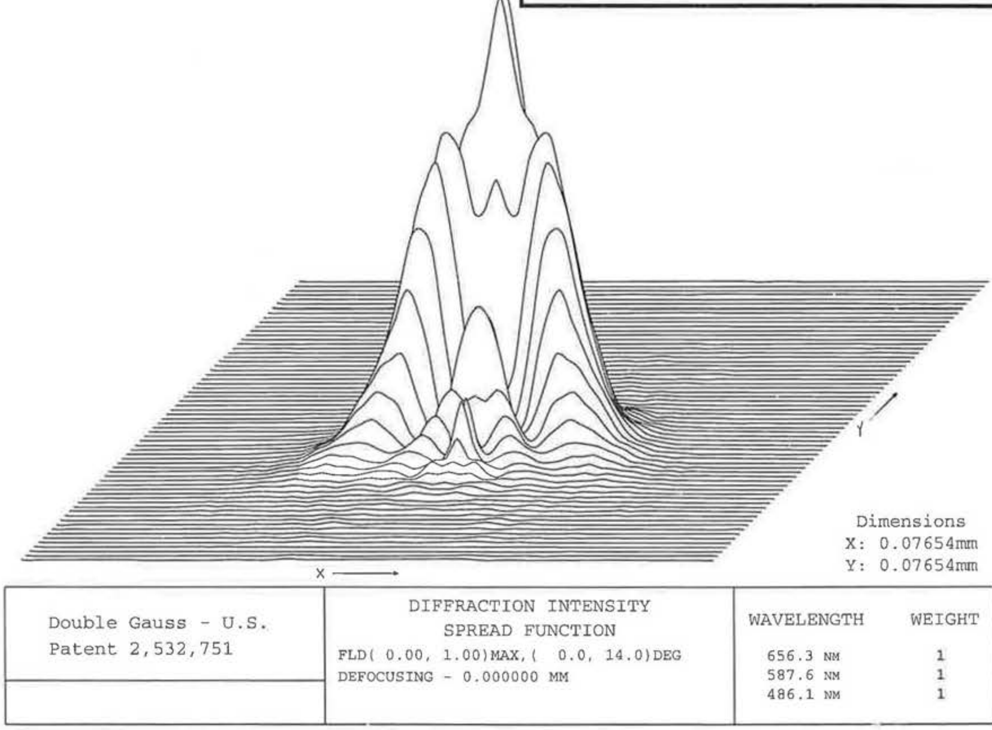

Figure 1. Perspective plot output from PSF.

Example 2. Point spread function (contour) of the same Double Gauss configuration shown in Figure 1. (Figure 2).

Point spread function (contour) of the same Double Gauss configuration shown in Figure 1. (Figure 2).

```
PSF
CON  SUP                     ! Draw contours, suppress line numbers
COM
LEV  .05 .15 .25 .35 .45 .65 .75     ! Specified contour levels
NRD  40
GO
```

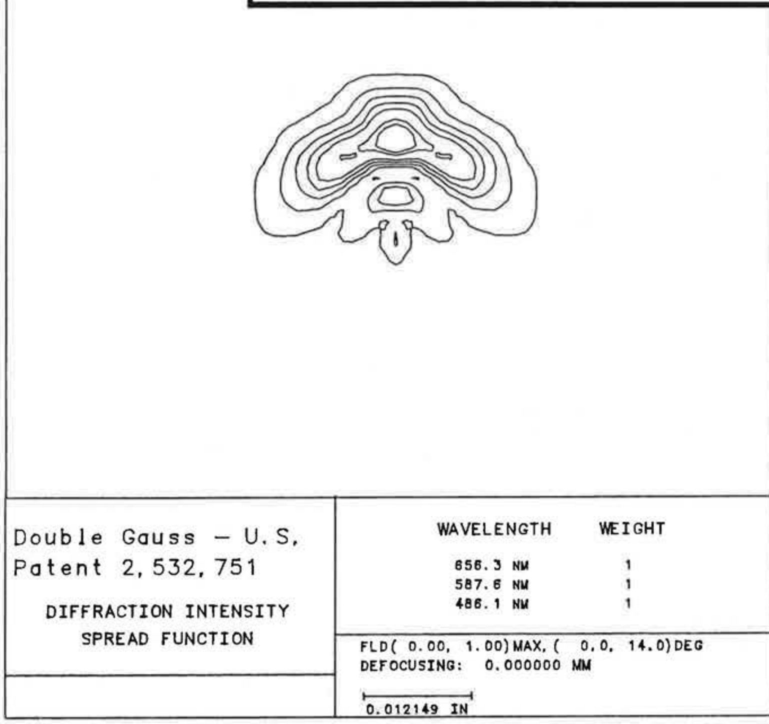

Figure 2.

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PSF

Example 3. Point spread function listed output for Cooke triplet (Figure 3).

```
RES  CV7_LENS:COOKE1
SET  APE
YAN  0.0   ! LDM Commands
PSF
COM        ! Compact listing
INT  STR   ! Normalize peak by Strehl Ratio
PLO
GO
```

Partial listed output of Example 3.

```
    POSITION 1          WAVE OPTICS POINT SPREAD FUNCTION              ORA

      Cooke Triplet f/4.5
                                                           WAVELENGTH   WEIGHT  NO. OF RAYS  PUPIL GRID
  FIELD (X,Y) = ( 0.00, 0.00)MAX, (  0.00,   0.00)DEG       656.3 NM      1        437        23 x  23
  DEFOCUS =    0.000000 MM.                                 546.1 NM      2        641        29 x  29
  SCALE- ONE INCREMENT= 0.00109365 MM.                      486.1 NM      1        797        33 x  33
  STREHL intensity values are on a scale where peak intensity of a perfect lens = 100
SUM OF VALUES =     652.
```

	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
27									1	1	1	1	1								
28							1	1	1				1	1	1						
29						1	1		1	2	3	2	1		1	1					
30						1		2	4	5	5	5	4	2		1					
31					1	1	1	4	5	6	8	6	5	4	1	1	1				
32					1		2	5	6	21	37	21	6	5	2		1				
33					1		3	5	8	37	63	37	8	5	3		1				
34					1		2	5	6	21	37	21	6	5	2		1				
35					1	1	1	4	5	6	8	6	5	4	1	1	1				
36						1		2	4	5	5	5	4	2		1					
37						1	1		1	2	3	2	1		1	1					
38							1	1	1				1	1	1						
39									1	1	1	1	1								

```
                                  X                    Y
  PSF centroid coordinates
  relative to chief ray       0.000000           0.000000   mm.


  Moment about
  the centroid:    Second     0.2102734E-04      0.2102734E-04
                   Third      0.1472407E-14      0.5304732E-14
                   Fourth     0.8848730E-08      0.8848730E-08
```

Figure 3.

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DESCRIPTION OF OUTPUT

Within the PSF option, the **PLO** or **CON** commands produce graphical output - either a "3-D" oblique projection (**PLO**) or a contour plot (**CON**). The remainder of the commands generate either a two dimensional grid representing the focal plane with the grid interval as specified (**INT**, **PHA**), or tables of values (**DEX, DEY, ENC PAI**). In two dimensional printed grids, there is a scale ("scale:one increment = xxx mm", etc.) for interpreting the grid. This grid value is the distance on the image surface between any two adjacent points (horizontal or vertical). The chief ray is always at the "center" grid point, i.e., for an N x N grid, the chief ray is at the point (N/2+1, N/2+1) for example, (33,33) in the default 64 x 64 FFT grid. See Figure 3.

Because Y coordinates are plotted up and X to the right (relative to format), the images appear as seen in the direction of the negative Z axis.

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TECHNICAL NOTES

Isoplanatism and OSC

Any calculation that deals with extended objects depends upon isoplanatism - constancy of the point image patch as the field changes over the width of the object, e.g. over enough cycles of the MTF target to integrate properly. Isoplanatism is connected with Offense Against Sine Condition (OSC) and is destroyed by significant OSC residuals. OSC can also lead to invalid distribution of rays over the exit pupil, if not properly compensated.

In all CODE V options that deal with diffraction or accurate intensity calculations (ALI, LSF, MTF, PAR, PMA, PSF, TOR, TRA, and WAV), special programming has been incorporated to represent the local intensity and magnification changes that occur with OSC, so that any wavefront and point image is correctly apodized and calculated, even in the presence of large OSC; for example, an f/0.3 parabola would have massive OSC. This special process is valid in all forms of calculation (convolution, FFT, etc.) and has little effect on compute time.

Even though the calculation is accurate, the lack of isoplanatism will still cast doubt on the usefulness of any option results dealing with extended objects, when the image is changing so rapidly across the target. In these options (LSF, MTF, PAR, PMA, PSF), a test is made to see if OSC is sufficient to affect results. If so, a warning is issued to alert you that the system is not isoplanatic at the field in question.

F-Numbers, Focal Lengths and Reduction Ratios

In some of the CODE V options that deal with diffraction calculations (LSF, MTF, PAR, PMA, and PSF), the listed output includes focal lengths (or reduction ratios if the object distance is finite) and f-numbers based on the references rays at each field. A value for both the X and Y directions is given. These numbers vary with field and are useful for relating image dimensions to object dimensions and for simple relative illumination calculations. Also included are the reference sphere radii for each field. Diffraction is assumed to take place at the reference sphere.

The f-numbers are based on a calculation of the image intensity. Thus, if the pupils are approximately elliptical, an estimate of the relative illumination can be obtained from the product of the X and Y numerical apertures (the numerical aperture is the reciprocal of the f-number). This calculation assumes a Lambertian object and a uniformly illuminated exit pupil and ignores transmission losses in the lens. It includes the effect of a non-flat image surface. Note that, for a perfect thin lens with stop in contact and the object at infinity, the X numerical aperture is proportional to the cosine of the field angle while the Y numerical aperture is proportional to the 3rd power of the cosine, thus giving the cosine 4th law.

The reduction ratio, which is listed for a system with a finite object distance, is the ratio of an incremental distance on the image to the corresponding distance on the object, measured in a coordinate system normal to the surface. In general, a square patch on the image can represent a parallelogram shaped patch on the object, with the X and Y reduction ratios used to calculate the sides. The angle of the parallelogram is not listed although it is included in the internal calculation.

The focal length, which is listed for a system with an infinite object distance, relates the image patch size to an angle in object space. It can be thought of as the product of the f-number and pupil diameter, similar to the paraxial definition. Consistent with the other calculations, it assumes a measurement normal to the object surface which is typically flat for an object at infinity. Thus, dividing the image patch size by the focal length gives the change in the sine of the field angle. To get the change in angle, divide this number by the cosine of the field angle.

The reference sphere radius is also listed for each field. It is used to calculate the wave aberrations and is also used in the calculation of the focal lengths and f-numbers although it normally has very little influence on these numbers. It can be used to identify potential problems when the radius is so short that the reference sphere is within the caustic of the image.

Near Field Propagation

The point spread function calculation in PSF is based on a Fourier Transform of the pupil function, where the pupil function contains the information describing the aberrations and the pupil shape. The Fourier Transform of the pupil function gives the complex distribution in the image and the complex square of this distribution gives the point spread function. For a description of the diffraction integral in terms of the

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pupil function, see, for example, H. H. Hopkins and M. J. Yzuel, *Optica Acta,* 1970, Vol. 17, No. 3, 157-182, Equation 29.

Near field propagation can be considered to be a case of an image which is far from focus. For example, if you want to see the distribution in the vicinity of the exit pupil, you would defocus by the distance of the exit pupil from the image. The distribution in the exit pupil is normally uniform. As you move away from the exit pupil, diffraction effects start to show up. The usual method, mentioned above, breaks down in this case because of the finite number of samples.

An alternate approach is to start with the Fourier Transform of the pupil function but, in this case, define it as the plane wave expansion of the pupil function. These plane wave components are then propagated a given distance from the exit pupil merely by modifying the phase. An inverse Fourier Transform then gives the complex distribution in the plane of interest and the complex square of this gives the intensity distribution. For converging and diverging beams, a scaling procedure is used to keep the size of the beam constant with respect to the size of the grid. This Fourier Transform approach to near field propagation is used in the **PRO** feature of PSF and is described in E. A. Sziklas and A. E. Siegman, *Appl. Opt.,* Vol. 14, No. 8, August, 1975, p. 1874.

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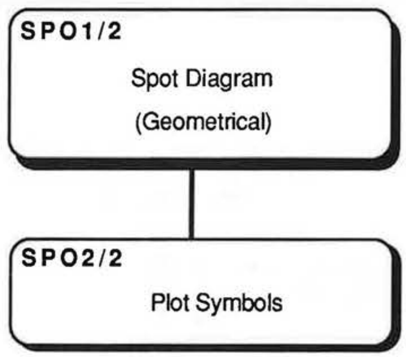
SPOT DIAGRAM (**SPO**)

SPO generates plots of ray intersections with the image surface(s) to represent image characteristics. Diffraction is ignored.

DEFAULT OPERATION

Spot diagrams are generated for all fields and focus positions designated by depth-of-focus values defined in the LDM (FFO,IFO,NFO), one plot per zoom position (up to five fields will be plotted per plot; more than five fields will generate multiple plots). If one focus position is used the plot fits a single page format; if more than one focus position is included, the format is extended with foldout pages. Images are scaled automatically to fit the available space with no overlap. The number of points attempted per wavelength is proportional to (approximately 1.5 times) the system wavelength weights; best appearance results when these weights total about 100; if weights total less than 15, the number is scaled up to give the effect of 100.

SCREEN FLOW DIAGRAM



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```
SPO1/2                        Spot Diagram                        CODE V
                              (Geometrical)

SSI Scale factor (aberr./scale bar)
    (Default: automatic scaling)
SSY    Independent scaling in Y
SSX          "        "    in X

PLO Plot (Y/N)?                         Y
LAB Full plot labelling (Y/N/Color)?    Y
TIT Temporary title                     DOUBLE GAUSS EXAMPLE
LIS List ray coordinates (Y/N)?         N
WVL Wavelength/Color (Y/N/Color)?  1    BLA
                                   2    BLA

NOTE: Use Lens Data to enter or modify thru focus.  Default is nominal focus.
G- Go (Execute) P- Prev Screen  T- Top Screen   O- Option    F- Files
K- Key Descr    M- Main Menu    C- Command Mode L- Lens Data E- Exit CODE V
```

```
SPO2/2                        Spot Diagram                        CODE V
                              Plot Symbols

DOT Plot symbols for wavelength no.   1  N
                  (N/Symbol)          2  N
                                      3  N

DSI Symbol size                          .025

G- Go (Execute) P- Prev Screen  T- Top Screen   O- Option    F- Files
K- Key Descr    M- Main Menu    C- Command Mode L- Lens Data E- Exit CODE V
```


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COMMAND MNEMONICS (alphabetical)

DOT	DSI	LAB	LIS	PLO	SSI
SSX	SSY	TIT	WVL		

DATA INPUT DESCRIPTION

Command Syntax		
Screen Prompt	Explanation	Default
PLO Yes | No....z		
PLOT? (Yes | No (SPO1/2)	Plot the spot diagram. If PLO NO is specified, then the plot will be suppressed, and the only output will be the centroid and RMS spotsize data in the listing.	Yes. (Plot is produced.)
SSI image_size_per_scale_bar....z		
Scale factor.... (SPO1/2)	For PLO Y, aberration scale size in X and Y per scale bar (on pen plotters, scale bar is 25 mm for M, C lens units, 1 inch for I lens units). Overrides automatic scaling which fits each spot into a square plot area small enough to allow all field points to fit into the long dimension of a single page plot.	Automatic scaling.
SSX image_size_per_scale_bar....z		
Independent scaling in X (SPO1/2)	For PLO Y, override SSI in X dimension so a highly distorted image can be fitted on the plot.	SSI
SSY image_size_per_scale_bar....z		
Independent scaling in Y (SPO1/2)	For PLO Y, override SSI in Y dimension so a highly distorted image can be fitted on the plot.	SSI
LAB Yes | No | color....z		
Full labeling (Y/N/Color)? (SPO1/2)	For PLO Y, label plot in standard manner. Use of No eliminates plotting of title, scale factor, and date for that zoom position - quick plot. Color for titling (BLA, RED, GRE, BLU, MAG, YEL, CYA, WHI) may be designated.	Yes. Labeling is included.
TIT 'temporary_title'(40)....z		
Temporary plot title (SPO1/2)	For PLO Y, up to 40 characters are plotted for the title of designated zoom position; if no zoom position is designated, the title is applied to all.	Uses the first 40 characters of the system title.
WVL Yes | No | color....w		
Wavelength/Color (Y/N/Color) (SPO1/2)	For PLO Y, draw or eliminate points for each wavelength. Use of No eliminates plotting of that wavelength. Color for wavelengths (BLA, RED, GRE, BLU, MAG, YEL, CYA, WHI) may be designated.	Draw all wavelengths in default color.

SPO

Command Syntax		
Screen Prompt	**Explanation**	**Default**
DOT No | num_dot_symbol....w		
Plot symbols for wave-length no. (N/Symbol) (SPO2/2)	For PLO Y, designate symbol to be drawn (0.025 of scale bar in size) for each wave-length:  No forces the use of the default for that wave-length.	Small 'el', 0.005 scale bars.
DSI dot_size_fraction_of_scale_bar		
Symbol size (SPO2/2)	Use only with DOT. Change symbol size.	0.025

Listing of Image Coordinates

Command Syntax		
Screen Prompt	**Explanation**	**Default**
LIS Yes | No....z		
List ray coordinates (Y/N)? (SPO1/2)	Generate listing of ray coordinates, for check-ing or for editing and input to another pro-gram.	No.

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DISCUSSION OF INPUT AND COMPUTATIONS

When to Use the SPOt Diagram Option

Use the SPO option for the following purposes:

- To plot the geometrical structure of the polychromatic image at all fields and at several adjacent focal surfaces, if desired.
- To list the image centroid coordinates and RMS spot size at each of the field points.
- To list the ray coordinates of the spot diagram for diagnostic purposes or processing by macros or by other programs.

Diffraction is ignored; only geometrical images are displayed. Use the PSF option if you wish to have point images that include diffraction.

What to Include in the LDM Data

No additional LDM data is required. If you wish to do through-focus analyses, enter the LDM data for depth of focus (FFO, IFO, NFO). The wavelength weights (WTW) control how many rays are traced in the spot diagram; if WTW are too low, SPO will temporarily increase them.

Usage

Spot diagrams show the geometrical structure of the image. They are particularly useful for non-diffraction-limited systems and are often helpful in reports and presentations.

Spot diagrams are generated by tracing a grid of rays evenly spaced on the entrance pupil from each wavelength for each object point. The resulting distribution on the real image surface (including any defocus value) is then plotted at a suitable scale. A diagram will be generated containing all field angles, defined focus positions, and zoom positions. Unless overridden, the scale factor is determined automatically from the size of the first field, first focus position spot.

Through-Focus Plots

By defining through-focus parameters in the LDM (FFO, IFO, NFO under Specification Data), you can run through-focus spot diagrams. The focal shifted distributions for all fields are plotted at the same scale for easy comparison (see Example 2). Up to 18 focal positions may be plotted in this manner. (**Note:** Your plotter must be able to plot over several pages in in order to display more than 2 or 3 focal positions).

Spot Density and Scaling

Wavelength weights determine the number of spots (rays) plotted; you can adjust the plot density factor with the Wavelength Weights selection of the LDM (WTW, under Specification Data). The spacing between rays in the entrance pupil for a given wavelength is (EPD/2)/SQRT(WTW); for a circular pupil (no vignetting) this will result in approximately $\pi \cdot$WTW rays traced for that wavelength. Best appearance is usually obtained when the wavelength weights total about 100. If the system's wavelength weights result in less than 15 rays, SPO will temporarily scale the system spectral weights (as set in the LDM) as necessary to provide a reasonable density of spots on the image surface.

The default program-determined scale size in X and Y can be altered (**SSI**), and independently scaled in the X (**SSX**) and Y (**SSY**) directions, so a highly distorted image can be fitted on the plot.

Plot Labels, Color and Dot Shape

A quick plot without labeling (**LAB** N) eliminates plotting of title, scale factor, and date for that zoom position. Color titles may be designated for the plot (**LAB** color - BLA, RED, GRE, BLU, MAG, YEL, CYA, WHI). Up to 40 characters are plotted for the title of designated zoom positions (**TIT**); if no zoom position is designated, the title is applied to all.

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If color plotting is available locally, each wavelength that has been defined for the system in the LDM may be plotted in a different color (**WVL** color). Alternatively, you can use **WVL** N for a specified wavelength to eliminate it from the plot.

The default plotting dot representing each ray-image intersection in the spot diagram is an "L" shaped character with a dimension of 0.005 inches or 0.125 mm. You can select different shapes (**DOT**) and sizes (**DSI**) for the dot as desired. Note that using **DOT** alone increases the default size so the different shapes are distinguishable.

The special dot shape symbols (see **DOT**) may not be supported on all graphics devices. Please check with ORA if you have questions about a specific device.

Other - RMS Spot Size, Centroid Data and Ray Listings

SPO will automatically list the centroid data (position of the centroid with respect to the chief ray) and the RMS spot size for each field point. Higher WTW values, to trace more rays, may be needed to increase the accuracy of the RMS spot size. In addition, the user may request (**LIS** command) a listing of the ray coordinates for diagnostic purposes or for input to macros or another program.

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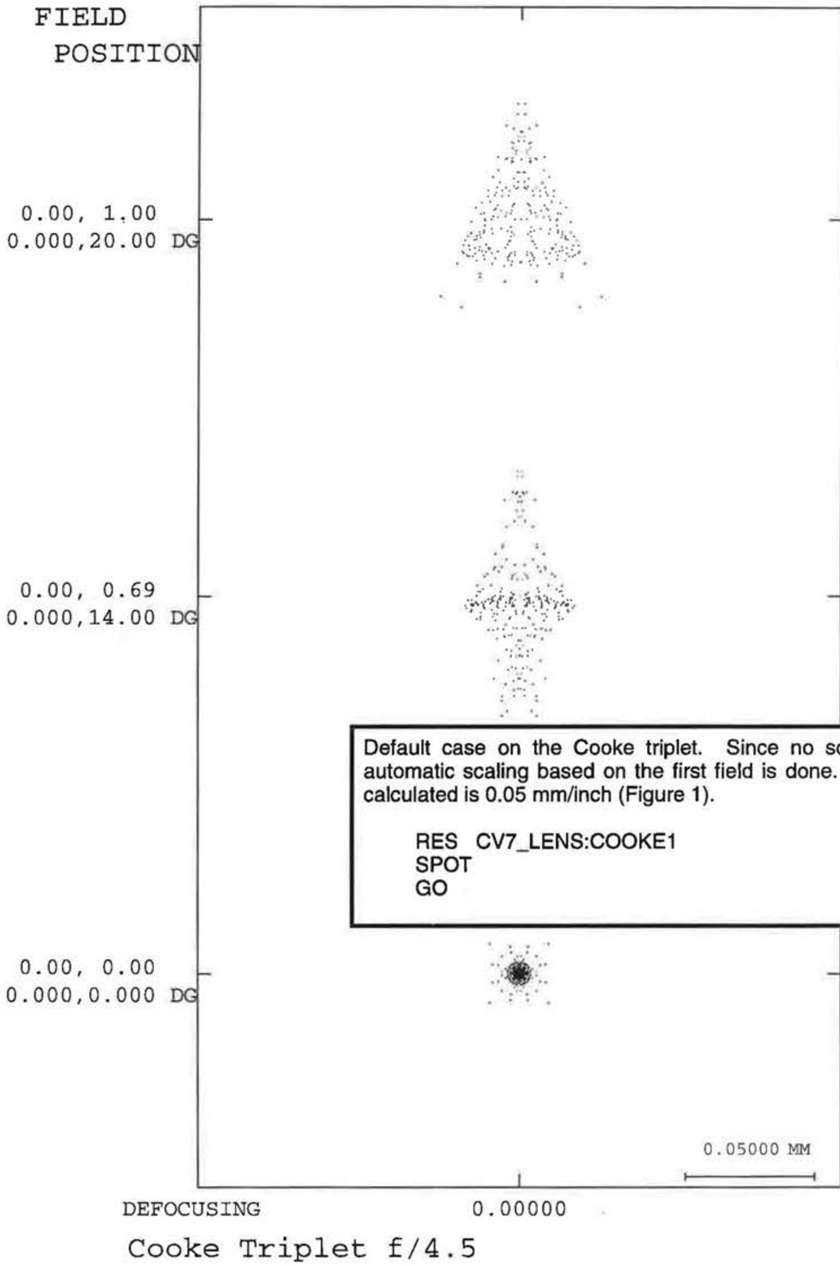
Examples

Example 1. Default case on the Cooke triplet. Since no scale size is given, automatic scaling based on the first field is done. The scale factor calculated is 0.05 mm/inch (Figure 1).



Default case on the Cooke triplet. Since no scale size is given, automatic scaling based on the first field is done. The scale factor calculated is 0.05 mm/inch (Figure 1).

```
RES  CV7_LENS:COOKE1
SPOT
GO
```

Figure 1. Default output from SPO.

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SPO

Example 2. Through-focus (defined in LDM) spot diagram with specified scale factor, separate plot colors and symbols for each wavelength, and temporary title (Figure 2).

Through-focus (defined in LDM) spot diagram with specified scale factor, separate plot colors and symbols for each wavelength, and temporary title (Figure 2).

```
RES  CV7_LENS:COOKE1
FFO  -.25                          ! mm, First focus
IFO  .25                           ! mm, Increment of focus
NFO  2                             ! Number of focus positions
SPOT
! Note:  SPOT uses focus data defined in LDM
SSI  .04                           ! Scale size, aberration per scale bar
WVL  RED  GRE  BLU                 ! Plot wavelengths in colors
DOT  1  2  3                       ! Plot wavelengths with unique symbols
DSI  .050                          ! Dot size in scale bars
TIT  'Triplet Through-Focus'       ! Temporary title
GO
```

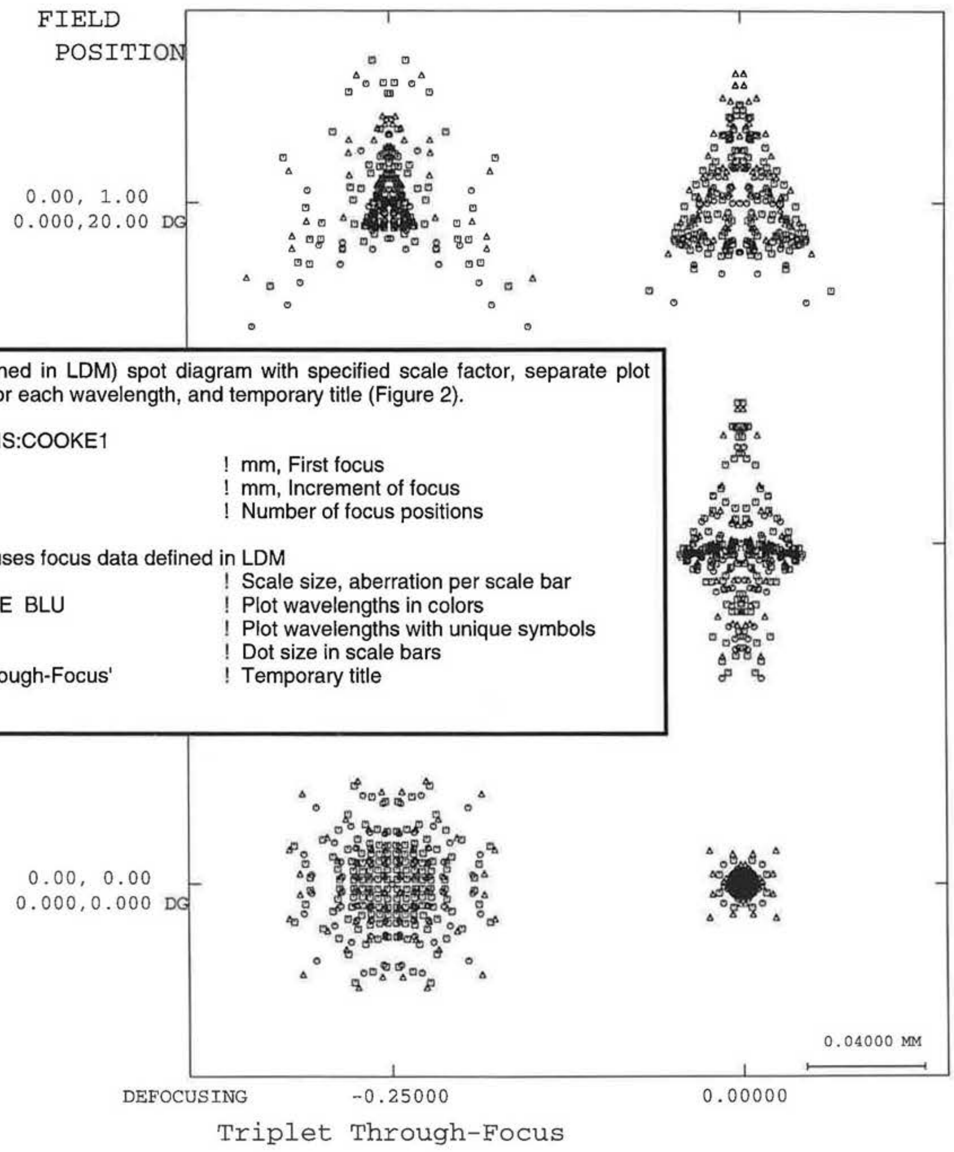

Figure 2. Enhanced SPO output.

DESCRIPTION OF OUTPUT

The spot diagrams, provided by the plotter and graphics-capable CRT, are the principal output; because Y coordinates are plotted up and X to the right (relative to format), the spots appear as seen from behind the image surface. A table comparing the number of rays traced to the number reaching the image surface is also produced, for diagnostic purposes. The difference between columns in that table indicates rays blocked by apertures. Any apertures (including obscurations) that have been defined in the LDM for the system are considered in determining rays passed, unless you set the Clear Aperture flag (CA) to "No" in the LDM (in Apertures/Obscurations/Edges).

Spot diagrams from neighboring fields or focus positions are not allowed to overlap. If any rays are too far from the center to be conveniently plotted, they are omitted and a message is printed.

A maximum of five fields can be plotted on a single plot. If there are more than five fields specified, multiple plots will be generated per zoom as needed to display spot diagrams for all fields.

In addition to the graphical output, SPO will also compute and list the position of the image centroid with respect to the chief ray. The RMS spot size is also automatically listed. See Example 3.

If requested (**LIS**), a printed listing of all rays is provided.

A related option (FOO), found in the Fabrication Support chapter, can produce outline or "spot diagram" "footprints" of ray bundles on any specified surface.

Example 3. Listing from SPO, showing the centroid and RMS spot size data that correspond to the spot diagram shown in Example 2.

```
The weights have been increased; too few points would have been plotted.
The new weights are   25   50   25

                                 POINTS     POINT
     WAVELENGTH       WEIGHT     TRACED    ATTEMPT

        656.3           25         40        51
        546.1           50         78        93
        486.1           25         40        51

     Field  1, (  0.00,   0.00) degrees.  Focus
   Displacement of centroid from chief ray
    X:    0.00000E+00      Y:    0.58804E-19

     Field  1, (  0.00,   0.00) degrees.  Focus  0.00000
   Displacement of centroid from chief ray                  RMS spot diameter
    X:    0.00000E+00      Y:    0.00000E+00                 0.81103E-02 MM

     Field  2, (  0.00,  14.00) degrees.  Focus -0.25000
   Displacement of centroid from chief ray                  RMS spot diameter
    X:    0.00000E+00      Y:   -0.52255E-02                 0.69117E-01 MM

     Field  2, (  0.00,  14.00) degrees.  Focus  0.00000
   Displacement of centroid from chief ray                  RMS spot diameter
    X:    0.00000E+00      Y:   -0.57359E-02                 0.45757E-01 MM

     Field  3, (  0.00,  20.00) degrees.  Focus -0.25000
   Displacement of centroid from chief ray                  RMS spot diameter
    X:    0.00000E+00      Y:    0.16725E-02                 0.43060E-01 MM

     Field  3, (  0.00,  20.00) degrees.  Focus  0.00000
   Displacement of centroid from chief ray                  RMS spot diameter
    X:    0.00000E+00      Y:    0.87652E-03                 0.39474E-01 MM
```

```
Input:
 RES CV7_LENS:COOKE1
 FFO -.25                  ! First focus (in mm)
 IFO .25                   ! Increment of focus (in mm)
 NFO 2                     ! Number of focus positions.
 !
 ! Generate the centroid and RMS spot size data only
 SPO
 PLO NO                    ! Suppress the graphical output
 GO
```


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