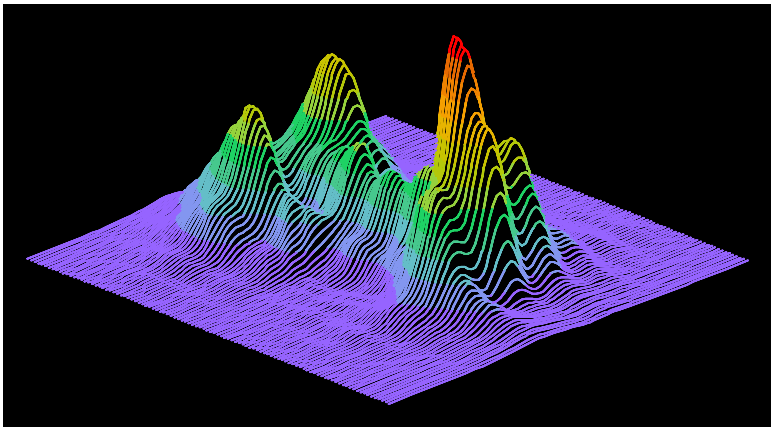
GLAD Commands Manual

Ver. 5.8



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1. Introduction

This document describes operation of the General Laser Analysis and Design (GLAD) program. GLAD may be used to analyze a large variety of optical and laser systems. GLAD performs a complete diffraction analysis of all aspects of a system. Optical beams are represented by complex amplitude distribution. This method gives a much more powerful capability for analysis than is possible with ray tracing programs. The physical optics methods used in GLAD are essential for analyzing and designing laser systems and form many non-laser systems where diffraction plays an important role. The physical optics description used in GLAD and the way GLAD is organized provide great generality and flexibility so that a great diversity of systems may be modeled. This is in contrast to some simple programs which only model idealized two-mirror bare-cavity resonators of provide only very limited and/or inefficient diffraction analysis capability.

GLAD includes most types of optical components including lenses, mirrors, apertures, binary optics, many types of gratings, beam splitters, beam combiners, Fresnel transmission and reflections losses, polarization effects, binary optics, etc. GLAD includes a great variety of nonlinear effects such as laser gain, Raman conversion, four-wave mixing, frequency doubling, thermal blooming, etc. GLAD can model almost any type of optical resonator, including any number of elements, gain, nonlinear elements, branching, etc.

1.1 Documentation

GLAD is documented in several volumes:

GLAD Users Guide (guide.pdf)

GLAD Command Descriptions (commands.pdf)

GLAD Theory Manual (theory.pdf)

GLAD Examples (examples.pdf)

1.1.1 Using the online documentation

Adobe Acrobat Reader^{TM} Ver. 7.0 (or higher) is required for viewing the *.pdf files—to be found on the GLAD CD or available free from www.adobe.com. The Acrobat Reader provides extensive capability to customize the view, search the document, jump to specified locations (hypertext features), and to launch another application. The user will benefit from being familiar with the methods of setting views and navigating in PDF documents as explained in the Acrobat Reader help documentation. Note that one can return to the previous view with Alt ← (hold down Alt and hit left arrow).

The GLAD online manuals make extensive use of hypertext links, including linking between the three major documents: GLAD Commands, Theory, and Examples Manuals. The three documents should be located in the same folder for proper functioning of hypertext links.

Hypertext links include:

- Jump between manuals using the blue highlighted items in the footnote on each page: “Jump to: Theory , Examples “.
- Table of contents lines highlighted in blue.
- Jump to selected page numbers. For example, you can jump to the index on page (339).
- Page numbers in the index (highlighted in blue) are linked to the respective items.
- Jump to commands (blue Courier text). Here is an example of a link to a command: `gain`.

- Jump to chapters and sections highlighted in blue text, for example GLAD Theory Manual, Sect. 9.4 or Example Ex95 .
- Launch GLAD to run an example file indicated by black text surrounded by a green box. All of the examples in the GLAD Examples Manual may be launched from the document. Here is an example that can be launched from this document if.inp .
- Equations numbers, figure numbers, and table numbers (in black text) are hypertext linked to the page displaying the item.

1.1.2 Printed versions of the manuals

Although many customers find the online manuals most convenient because of the hypertext linking, paper copies of the GLAD Theory and Commands manuals are provided with purchase of GLAD. The color images in the online manual are optimized to have the highest possible screen resolution and consequently do not print well, particularly the thousands of color images in the GLAD Examples Manual. AOR prints a special version of this document that has all illustrations in full color and is optimized to give excellent results on our color printers. This printed copy of the GLAD Examples Manual may be purchased from AOR as a separate item.

1.2 Installing GLAD

See the last page of this manual for instructions on installation and information about registration (344). See the second to last page for information about the security key (343).

1.3 Using GLAD

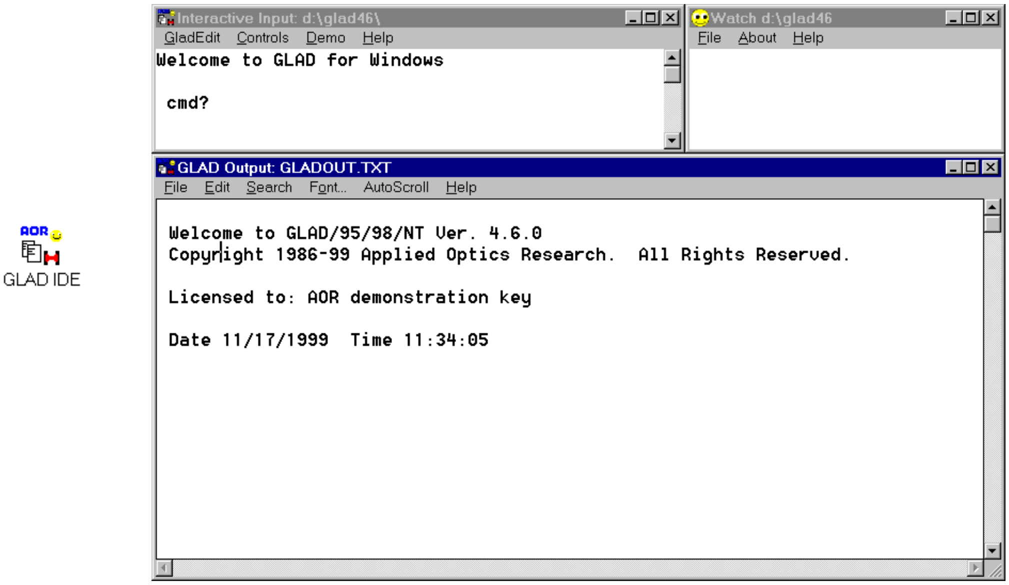
GLAD is designed with the objective of building a tool capable of modeling all physical optics and laser systems—no matter how complex. The command line format used in GLAD makes it possible to describe either simpler or quite complex systems. The hundreds of sample command files that are provided with GLAD (see the examples folder) make it easy to get started with GLAD. All examples are ready to run. You can use these examples as starting templates for your own applications. If you need technical support, it is easy and convenient to email your command file to AOR so that we can give you specific help with your questions.

1.3.1 The Integrated Design Environment (IDE)

The primary method of running GLAD is to run through the Integrated Design Environment (IDE). From the main MS Windows menu select, Start, Programs, GLAD 5.8, GLAD IDE. A typical arrangement of windows is shown in Fig. 1.1. When GLAD is first installed, Introduction to GLAD (intro.pdf) is also brought up to help first-time users. The three windows in Fig. 1.1. consist of the Interactive Input, GLAD Output, and Watch windows.

1.3.1.1 Interactive Input Window

The Interactive Input window is used for entering commands line-by-line. Command files may be run directly from the Interactive Input window (or from a command file). The GLAD editor is the preferred method of building command files, 1.3.1.2, GladEdit (17). The GLAD Output window gives line-by-line


GLAD IDE
Interactive Input: d:\glad46\
GladEdit Controls Demo Help
Watch d:\glad46
File About Help
GLAD Output: GLADOUT.TXT
File Edit Search Font... AutoScroll Help

```
Welcome to GLAD for Windows

 cmd?
```

```
Welcome to GLAD/95/98/NT Ver. 4.6.0
Copyright 1986-99 Applied Optics Research.  All Rights Reserved.

Licensed to: AOR demonstration key

Date 11/17/1999  Time 11:34:05
```

Fig. 1.1. Typical starting configuration after clicking on GLAD IDE. The interactive window is on the upper left. Enter interactive commands into this window. Text output appears in the GLAD Out window below. The Watch window displays and controls graphic files as they are created by GLAD.

text output. HTML output is also provided in a separate window as related below. The Watch window displays graphic files as they are generated by GLAD. You may position and resize these windows as you wish. The window position and size data are stored in glad.ini located in the GLAD installation directory.

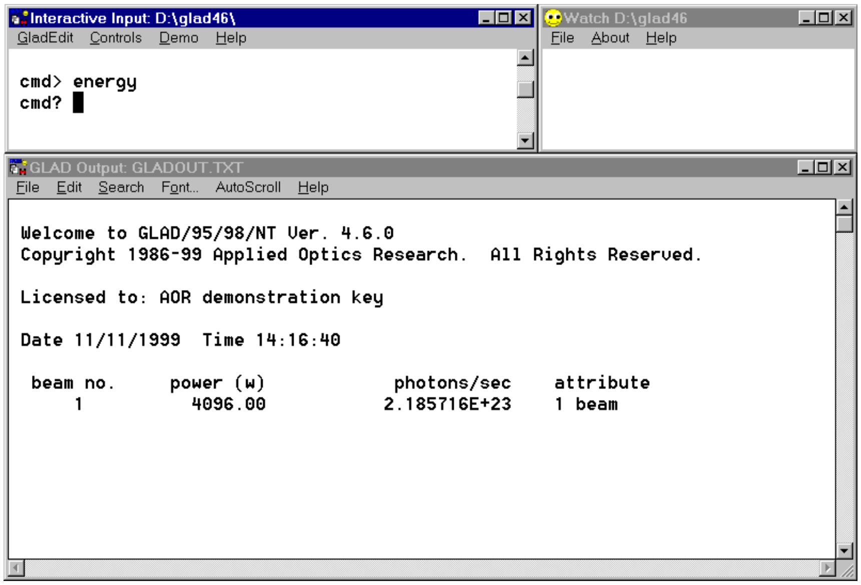
You may enter commands directly into the Interactive Input window, although for problems of any complexity you will find it easiest to build command files. Interactive Input is useful for diagnostics (such as energy) and graphical displays. Fig. 1.2 shows the result of entering the command `energy` into the Interactive Input window. The result of the command is given in GLAD Output window. The `energy` command gives the total power in the array. Fig. 1.3 shows the command `read/disk simple.inp` being entered into the Interactive input window. All GLAD commands can be abbreviated to the level of uniqueness. The command `rea/d simple.inp` will work as well as the fully expanded version.

The Interactive Input window has the menu items: GladEdit, Controls, Demo, and Help.

1.3.1.2 GladEdit

GladEdit is the center point of most GLAD activities. Select GladEdit from the Interactive Input window to start the Glad Editor. Fig. 1.4 illustrates the opened GladEdit window. Use File to open a command file. As shown in Fig. 1.4, the command file simple.inp has already been opened. Most GLAD command files have the “*.INP” file extension. The INP extension is registered in the Windows Registry. GLAD may be launched by clicking on any file with the INP extension from Windows Explorer.

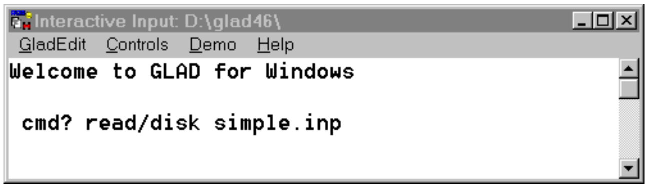
The file may be edited in the usual way. Selecting Init-Run, will save the edit file, reinitialize GLAD, and run the file (see Fig. 1.4). The Run menu item will save the edit file and run without reinitialization. Full details of the operation of GladEdit will be found under its own Help icon. The folder examples (C:\program files\aor\glad57\examples) contains the hundreds of examples that are distributed with GLAD. These pre-built examples may be used as a starting point for new projects.


Interactive Input: D:\glad46\
GladEdit Controls Demo Help
Watch D:\glad46
File About Help
GLAD Output: GLADOUT.TXT
File Edit Search Font... AutoScroll Help

```
cmd> energy
cmd?
```

```
Welcome to GLAD/95/98/NT Ver. 4.6.0
Copyright 1986-99 Applied Optics Research.  All Rights Reserved.

Licensed to: AOR demonstration key

Date 11/11/1999  Time 14:16:40

 beam no.        power (w)            photons/sec      attribute
     1            4096.00            2.185716E+23      1 beam
```

Fig. 1.2. Entering the command `energy` into the interactive window causes GLAD to list the current integral of irradiance over the array.



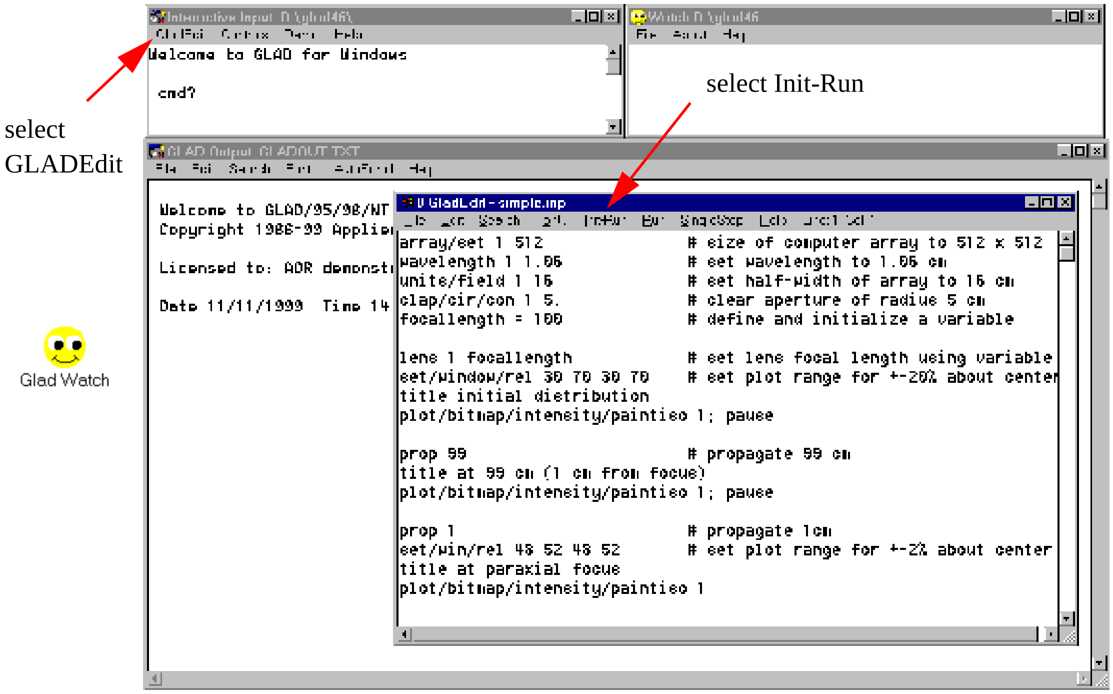
```
Welcome to GLAD for Windows

 cmd? read/disk simple.inp
```

Fig. 1.3. Command files may be entered directly in the Interactive Input window. `read/disk` will read simple.inp and execute the commands as they are read.

From Fig. 1.4, we see that executing simple.inp has created text output in GLAD Output window and a plot file in a new window. The plot name plot1.plt is listed the Watch window. See section, 1.3.2, Watch (23). Many styles of plot are available with the `plot` command. The plot size and position may be controlled by manipulating the window with the mouse, or preset when the plot is generated by GLAD (see the `plot`/watch command).

GladEdit may be run in text mode or rich text mode (RTF). Originally all GLAD command files were created in plain text. The new RTF mode allows the text to be formatted with color and different fonts. See Fig. 1.5. Figures (including equation figures drawn in MathType or similar program) and hypertext links to manual pages. The RTF features may be used to improve the readability of a GLAD command file. The RTF features do not affect operation of GLAD. They are stripped to simple text by making a text file with the same root name before processing. Text files and RTF files are indicated by “TXT” or “RTF in the lower left hand corner of the edit window. One can transfer from text to RTF by using SaveAs and selecting the file type as RTF. Reload the saved file to set the edit buffer. Similarly one can transfer from RTF to text by using Save As and selecting file type TXT and reloading the saved file to reset the edit buffer. See ex1b.inp for a simple example of an RTF command file.

Figure 1.6 shows some special features of the GladEdit window. Formatting is done similarly to the MS Wordpad editor. The three menu items: Init-Run, Run, and Controls are unique to GLAD. Init-Run is the primary method of running a GLAD command file. It saves, initializes and runs the file in the editor buffer.



```
Welcome to GLAD for Windows

 cmd?
```

```
Welcome to GLAD/95/98/NT
Copyright 1986-99 Applie

Licensed to: AOR demonst

Date 11/11/1999  Time 14
```

```
array/set 1 512              # size of computer array to 512 x 512
wavelength 1 1.06            # set wavelength to 1.06 cm
units/field 1 16             # set half-width of array to 16 cm
clap/cir/con 1 5.            # clear aperture of radius 5 cm
focallength = 100            # define and initialize a variable

lens 1 focallength           # set lens focal length using variable
set/window/rel 30 70 30 70   # set plot range for +-20% about center
title initial distribution
plot/bitmap/intensity/paintiso 1; pause

prop 99                      # propagate 99 cm
title at 99 cm (1 cm from focus)
plot/bitmap/intensity/paintiso 1; pause

prop 1                       # propagate 1cm
set/win/rel 48 52 48 52      # set plot range for +-2% about center
title at paraxial focus
plot/bitmap/intensity/paintiso 1
```

Fig. 1.4. To create a command file or open an existing file, select GladEdit from the menu bar of the Interactive Input window. A version of GladEdit will be selected. Use File to open an existing command file. In this case, simple.inp was opened. This file may be edited. Use Init-Run to reinitialize and run GLAD.

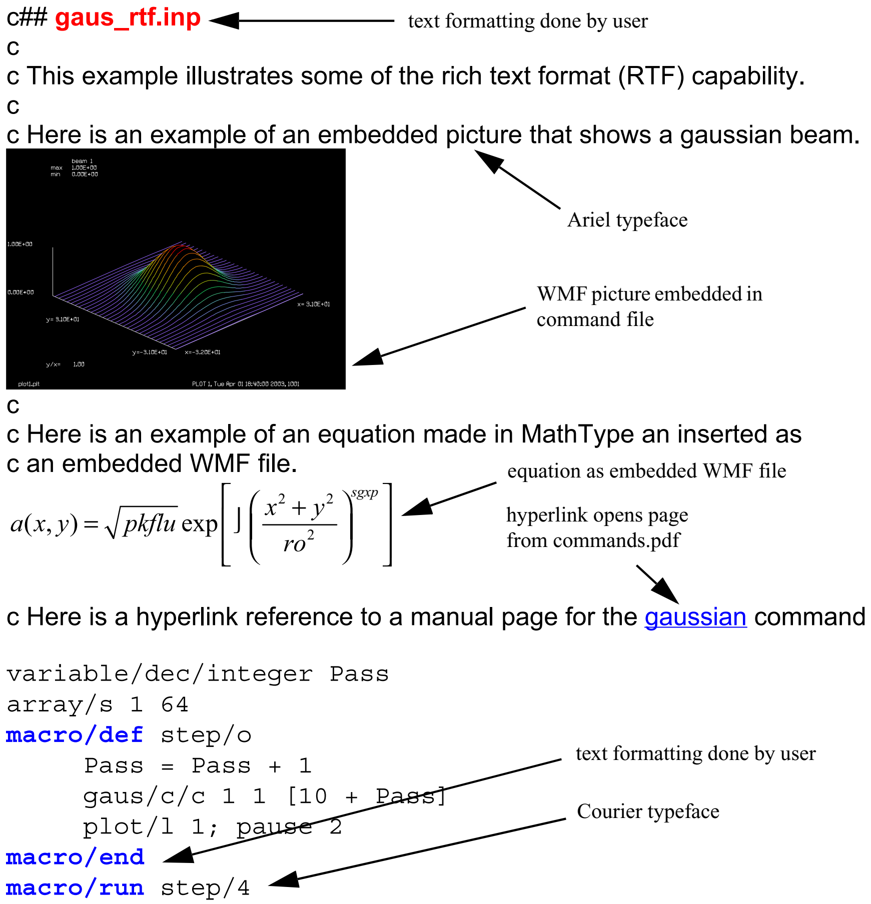
Run saves and runs the command file but does not reinitialize. This can be useful if part of the command sequence is contained in a secondary file to be run after the primary file that is run by Init-Run. The Controls menu item gives access to the break controls and single step operation. Command files can be either in plain text (TXT) or rich text format (RTF) — both under the file extension INP. The current file type in the editor buffer is indicated by TXT or RTF as shown in Fig. 1.6. The line and column of the caret position (often incorrectly called the cursor) are also indicated on the bottom of the editor window. GLAD displays the line number with the report of execution error.

Hyperlinks may be created from “Insert” on the GladEdit menu. Any GLAD command may be included in a hyperlink. The command is executed when the hyperlink is double clicked. A hyperlink is created from the menu of GladEdit from Insert, Hyperlink. Among the most useful commands are `manual` that can launch and control Adobe PDF documents and `system` that can run other applications and launch documents.

PDF documents may be opened to a named destination or page number using the `manual` command. Examples of hyperlinks include:

```
manual/destination 'commands.pdf energy'
manual/page 'commands.pdf 252'
manual/dest 'd:\\temp\\temp.pdf'
system/launch 'd:\\temp\\temp.doc'
```

In the first example, “energy” is the named destination in the PDF document for the `energy` command. In the second example, “252” indicates the page number of the PDF document to be displayed. Single quotes are required if the string contains blanks. Hyperlinks require the use of double back slashes to represent the



c## **gaus_rtf.inp**

text formatting done by user

c

c This example illustrates some of the rich text format (RTF) capability.

c

c Here is an example of an embedded picture that shows a gaussian beam.

Ariel typeface

WMF picture embedded in command file

c

c Here is an example of an equation made in MathType an inserted as

c an embedded WMF file.

$$a(x,y) = \sqrt{pkflu}\,\exp\left[\,J\left(\frac{x^2+y^2}{ro^2}\right)^{sgxp}\right]$$

equation as embedded WMF file

hyperlink opens page from commands.pdf

c Here is a hyperlink reference to a manual page for the gaussian command

```
variable/dec/integer Pass
array/s 1 64
macro/def step/o
     Pass = Pass + 1
     gaus/c/c 1 1 [10 + Pass]
     plot/l 1; pause 2
macro/end
macro/run step/4
```

text formatting done by user

Courier typeface

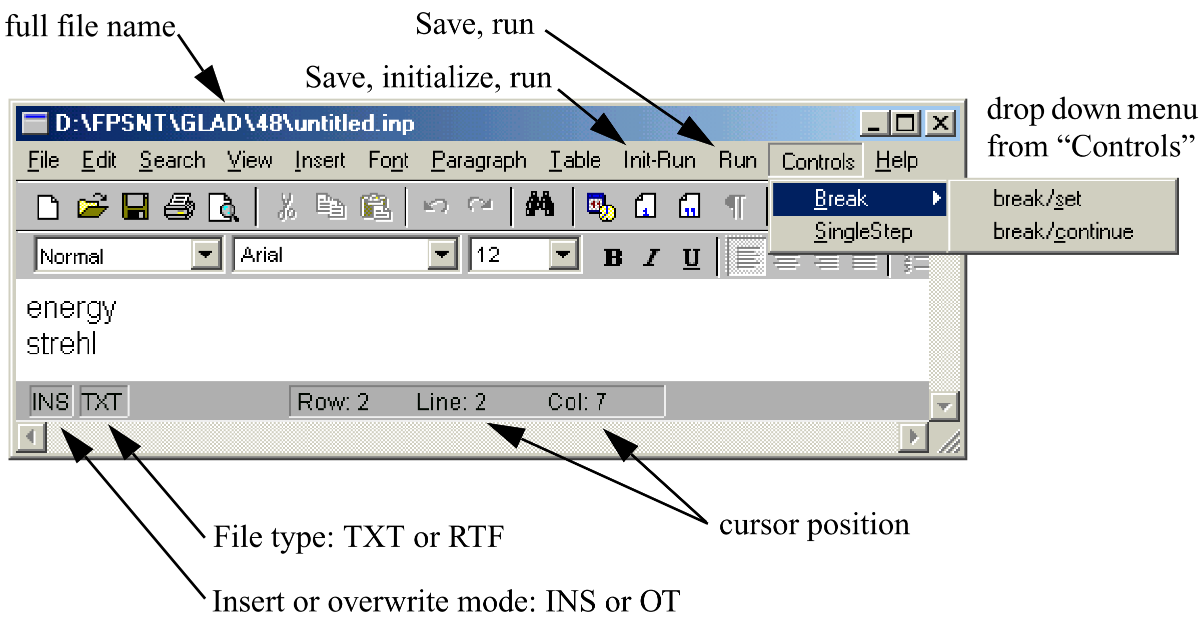
Fig. 1.5. Example of rich text (RTF) format command file. The user may select font, color, and other text formatting. Pictures may be embedded. Here we have a WMF file generated by GLAD and an equation generated by MathType 5® as a WMF file. A hyperlink command is shown that calls the command `manual/destination commands.pdf gaussian`. Double clicking the hyperlink will start the Adobe Acrobat Reader on the page describing the gaussian command. GLAD creates a text “shadow” file with file extension “txt” and reads commands from the shadow file. Dynamic highlighting under the control of the TraceBack window indicates the executing line.

back slashes character used in file paths. See the `manual` commands for a complete description of the named destinations that may be used in GLAD documents and the `system` command for information on executing applications and launching documents. Hyperlinks can not be edited. To change a hyperlink, delete it and recreate it.

The default type face for the Glad editor is “FixedSys” and the default point size is 12 points. These defaults may be changed by modifying the file glad.ini to be found in the installation folder. In glad.ini, change GladEditFontName and GladEditFontHeight to the desired default values for typeface name and font size.

1.3.1.3 Command Composer

The Command Composer is used for both parsing and composing GLAD command lines. It is accessible from GladEdit by either clicking with the right mouse button (“right clicking”) or selecting “Controls”, “Command Composer” from the menu of the GladEdit window. Once activated, the Command Composer will dynamically parse command lines in GladEdit as the cursor is moved up or down to select


full file name
Save, run
Save, initialize, run
drop down menu from “Controls”
D:\FPSNT\GLAD\48\untitled.inp
File Edit Search View Insert Font Paragraph Table Init-Run Run Controls Help
Break
SingleStep
break/set
break/continue
Normal
Arial
12
B I U
INS TXT
Row: 2 Line: 2 Col: 7
File type: TXT or RTF
Insert or overwrite mode: INS or OT
cursor position

```
energy
strehl
```

Fig. 1.6. The title of the GladEdit window shows the full file name. “Init-Run” is the primary method of starting execution of a command file. “Run” starts without reinitializing GLAD. The “Controls” menu item gives access to the “break” controls and single step operation. “TXT” indicates the command file is in plain text format. “RTF” indicates rich text format is being used. The line and column number of the position of the cursor (more correctly called the caret). Formatting is very similar to MS WordPad and is described in the associated help file.

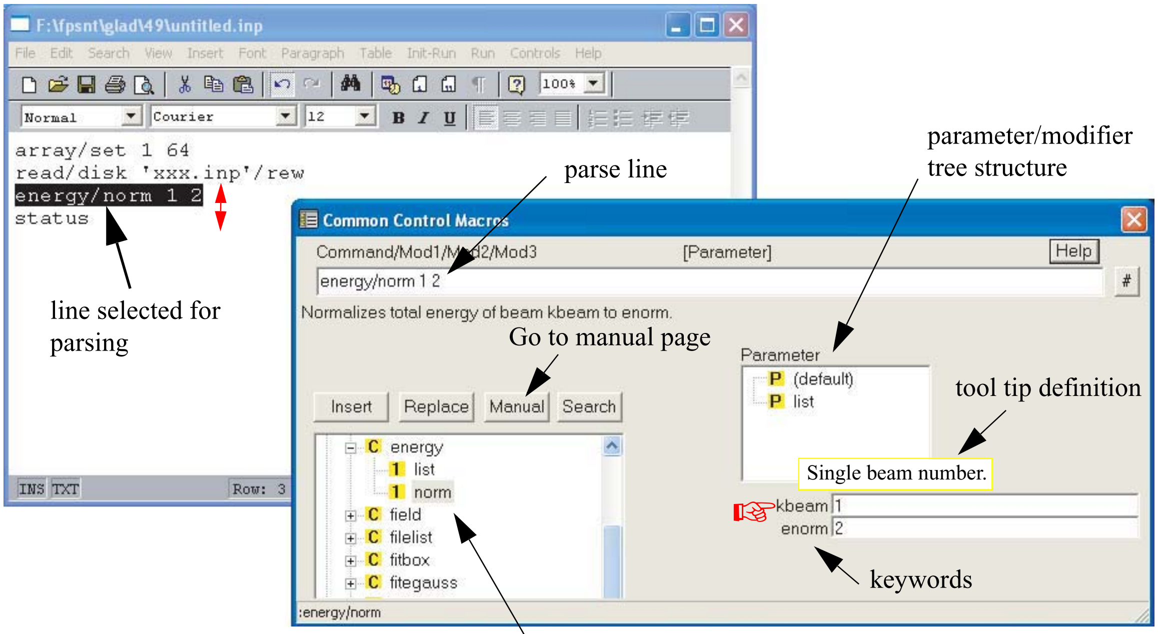
different lines in the GladEdit window. Only a single command per line can be parsed: line continuations and multiple commands per line can not be parsed.

Fig. 1.7 illustrates a representative command file and Composer window. The red up-down arrow indicates that commands are automatically parsed in real-time as different lines are selected. The commands and modifiers are parsed into a tree structure, keywords are parsed into individual edit boxes. Strings and parameters are parsed into edit boxes with modifier trees (where appropriate). Each element has a tool tip giving the definition in an immediate and convenient manner. As shown, the red hand indicates the cursor position and is portrayed in Fig. 1.7 as pointing to “kbeam”. The associated tool tip pops up with the definition. In this case, “Single beam number”. All parsed elements including the command/modifier and parameter/modifier tree elements are equipped with tool tips. The “Manual” button opens the GLAD Commands Manual to the specific page for the selected command.

The commands are organized into groups (as indicated at the top right hand position on each page of the GLAD Commands Manual) to make selection between commands easier. The “Search” button allows commands to be searched by name allowing abbreviated entries and wild cards.

The Composer may be used to modify a command line or create a new line. The line may be built using the tree structure controls and edit windows. The parse line is automatically updated to follow the edit control selections and entries. The Composer helps greatly by providing the correct syntactical structure for each command/modifier selection. The tool tip definitions provide immediate and convenient hints for all commands, modifiers, keywords, strings, and parameters.

The command line may also be modified by directly typing into GladEdit line or the parse line window. When typing into the parse line window, use [enter] to activate reparsing.



```
array/set 1 64
read/disk 'xxx.inp'/rew
energy/norm 1 2
status
```

energy/norm 1 2

Normalizes total energy of beam kbeam to enorm.

Single beam number.

kbeam 1

enorm 2

:energy/norm

parse line

parameter/modifier tree structure

line selected for parsing

Go to manual page

tool tip definition

keywords

command/modifier tree structure

Fig. 1.7. The Command Composer provides automatic and real-time parsing of command lines from a GladEdit window. It also may be used to edit and create command lines using the convenient “control” elements: command/modifier tree structure, keyword edit boxes, parameter/modifier structures, etc. The red up-down arrow indicates that one may scan through the command file with the Composer automatically responding in real-time. Definition of all elements are provided by “tool tips” which are activated when the cursor (shown as a red hand) is placed over an element (in this case “kbeam”). The Manual button brings up the Commands Manual at the particular page. One may create new lines by using the various controls. Alternately, one may also type new or modified lines directly into the parse line at the top of the Compose screen. Use [enter] to cause the line to be reparsed. One may also type changes into the GladEdit window with automatic reparsing if the line. “Insert” places the parse line data into a new line above the current selection. “Replace” replaces the selected editor line with the parse line. The hash symbol “#” is used for hash-style comments.

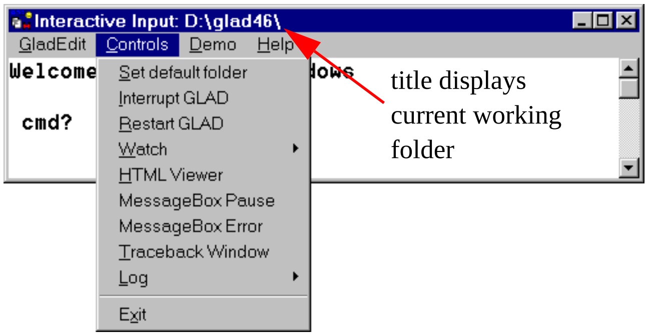
Use “Insert” to enter the parse line in a new line above the current selection. Use “Replace” to replace the currently selected line with the contents of the parse line.

1.3.1.4 Controls

Controls is the second menu item on Interactive Input. Fig. 1.8. You may set the default folder that GLAD works from as well as a number of other operations including starting the HTML viewer. Note that the current working folder is displayed in the title of Interactive Input window. These controls are explained in the Help icon for the Interactive Input window.

1.3.1.5 IDE Demo

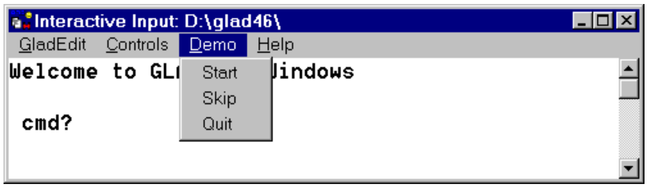
Demo is the third menu item. The associated drop down menu is shown in Fig. 1.9. You can play the nine prearranged demo programs to get a quick look at some of the types of calculations that GLAD does. A special manual is included to describe these demo examples: demo.pdf.



```
Welcome              dows

 cmd?
```

title displays current working folder

Fig. 1.8. The Controls menu item allows selection of a number of operations. See section, Help (41), for a detailed explanation. Use “Set default folder” to select the folder for GLAD to work from. The current working folder is displayed in the title of this window.

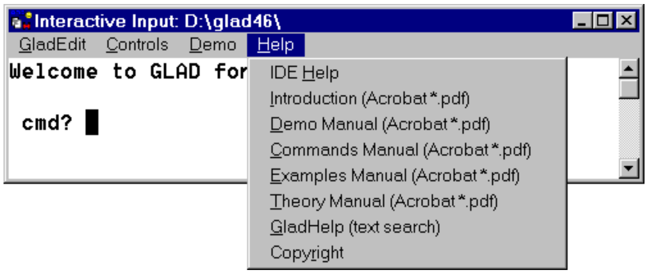


```
Welcome to GL     Windows

 cmd?
```

Fig. 1.9. The Demo menu item runs preselected examples. Select Start to begin the demo, Skip to skip to the next example, and Quit to end the demonstration. See Demo.pdf in the installation folder for a description of the examples.

1.3.1.6 IDE Help

Help is the fourth menu item of Interactive Input. Fig. 1.10 shows the corresponding drop down m menu. IDE.HLP is the Windows help file for the IDE. The various PDF file give detailed information about the commands, theory, examples, and introductory materials. Up-to-date versions of the PDF version of the manuals are maintained on the AOR web site www.aor.com.

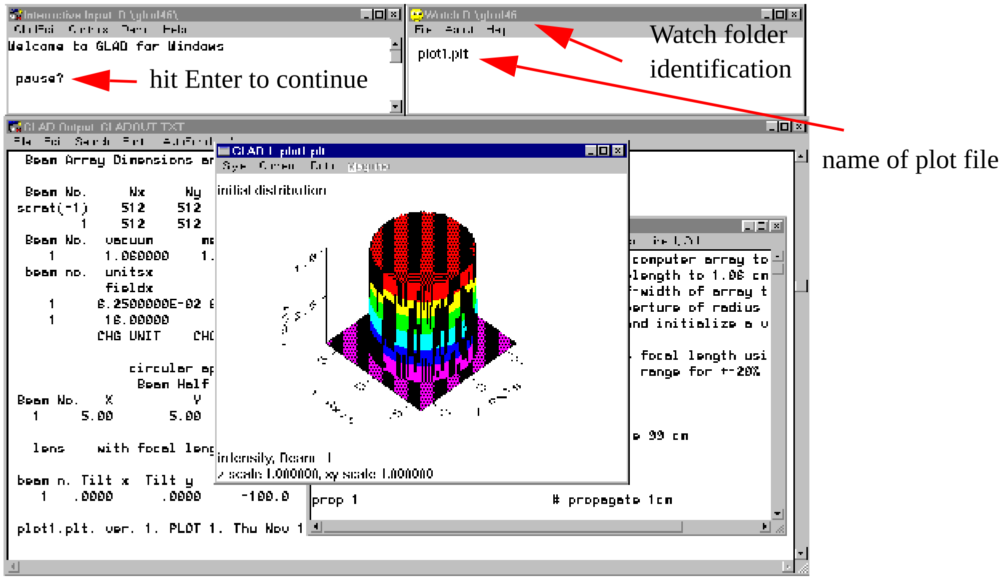

Interactive Input: D:\glad46\
GladEdit
Controls
Demo
Help
IDE Help
Introduction (Acrobat*.pdf)
Demo Manual (Acrobat*.pdf)
Commands Manual (Acrobat*.pdf)
Examples Manual (Acrobat*.pdf)
Theory Manual (Acrobat*.pdf)
GladHelp (text search)
Copyright

```
Welcome to GLAD for

 cmd? █
```

Fig. 1.10. IDE Help gives specific information about operating GLAD IDE. Details about the commands, examples, and theory are in the respective PDF files, viewed with the Adobe Acrobat Reader.

1.3.2 Watch

Watch is an independent program that runs in parallel with GLAD. Watch performs the work of displaying files as they are created by GLAD, so that GLAD does not have to wait for the graphic tasks to be completed. You may run Watch independently of GLAD to recreate the last display. Click on the Watch icon: yellow smile face.Watch may also be used to view other plot files (*.PLT) that have previously been created. Refer to the Help icon from the Watch menu.



```
Welcome to GLAD for Windows

pause?
```

hit Enter to continue

```
plot1.plt
```

Watch folder identification

name of plot file

```
 Beam Array Dimensions ar

 Beam No.      Nx      Ny
scrat(-1)     512     512
        1     512     512
 Beam No.   vacuum       mi
    1       1.060000     1.
 beam no.   unitsx
            fieldx
    1      6.2500000E-02 6
    1       16.00000
           CHG UNIT     CHC

                circular ap
                 Beam Half
Beam No.    X          Y
  1      5.00       5.00

  lens      with focal leng

beam n.  Tilt x   Tilt y
   1    .0000      .0000      -100.0

plot1.plt. ver. 1. PLOT 1. Thu Nov 1
```

```
initial distribution

intensity, Beam  1
z scale 1.000000, xy scale 1.000000
```

```
computer array to
length to 1.06 cm
-width of array t
erture of radius
nd initialize a u

 focal length usi
 range for +-20%

 e 99 cm

prop 1                      # propagate 1cm
```

Fig. 1.11. After running simple.inp by selecting Init-Run, a graphic file is displayed and “pause?” in the interactive input window. This `pause` command was written into simple.inp to require a response from the user before proceeding. Put the cursor into the Interactive Input window hit Enter to continue. Note the plot name plot1.plt in the Watch window.

GLAD passes the plot names and other necessary information through the file watch.dat. When running Watch separately, it is sometimes useful to edit watch.dat directly to set up a collection of files to view. Whenever watch.dat is saved, Watch will update the display accordingly. The PLT file extension is defined in the Windows Registry. Clicking on a PLT file will cause Watch to start and display the file. Note that the current working folder of Watch is displayed in the title of the Watch window. The folder used by Watch may be changed from its menu controls via File, Set Folder.

The plot size and position may be controlled by manipulating the window with the mouse, or preset when the plot is generated by GLAD (see the `plot`/watch command).

1.3.3 Traceback Window

GLAD includes a traceback window that displays the line number of the various input command files and macros as well as the macro iteration number. The tracking window may be turned on or off from IDE, Controls. See Fig. 1.5.

1.3.4 Highlighting source text lines

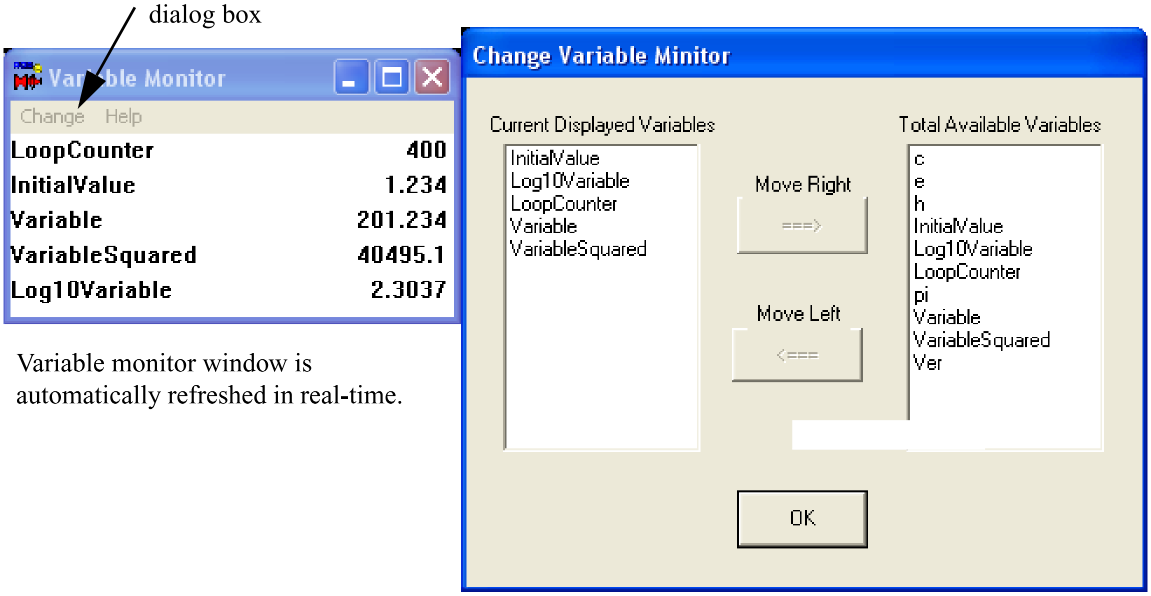
This feature was deleted at Ver. 5.2 and other measures have been implemented for source code line tracking that require less computational overhead. Improved line number tracking has been made in the Traceback window, the `line` command has been added to record the current line number during execution, and the `echo` command now provides the source line number in the output window as commands are executed.

1.3.5 Variable monitor window

The variable monitor window provides a real-time display of specified variables and their values, making it easier to see critical information than with the streaming text output displayed in the GLAD Ouptut window (Fig. 1.12). The variables to be displayed are set with `variable/monitor/add`. Variables must be declared before they can be added to the displayed list. During command file execution or at the end of execution variables may be added or deleted from the display list. See Fig. 1.12 for more details. Also, see the `variables` command and monitor.inp. The Variable Monitor window may be shown or hidden through “Controls” on the menu of the Interactive Input Window.

activate Change dialog box

Change dialog box active



LoopCounter	400
InitialValue	1.234
Variable	201.234
VariableSquared	40495.1
Log10Variable	2.3037

Current Displayed Variables

InitialValue
Log10Variable
LoopCounter
Variable
VariableSquared

Total Available Variables

c
e
h
InitialValue
Log10Variable
LoopCounter
pi
Variable
VariableSquared
Ver

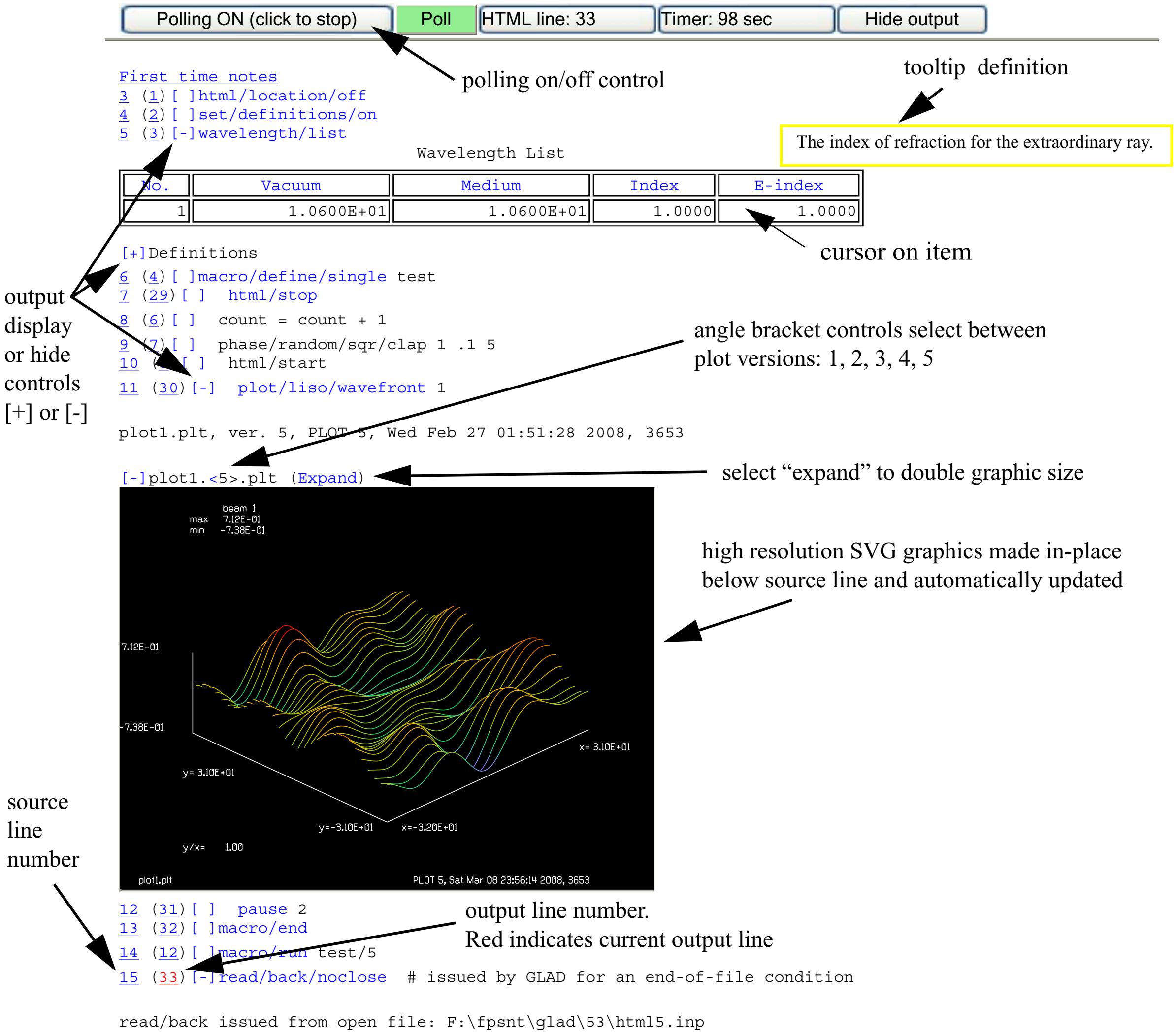
Variable monitor window is automatically refreshed in real-time.

Fig. 1.12. The variable monitor provides a display of selected variables in real time making it easy to observe key aspects of the calculation. The variables to be displayed are selected in the command file with the `variable/monitor/add` and is reset each time the command file is run with “Init/Run”. With Ver. 4.9, the user may add to delete variables from the displayed list using the “Change” dialog box — shown in its expanded mode. To add a variable to the displayed list, select form the list of all defined variables in “Total Available Variables” and use “MoveLeft”. To delete a variable, select one of the variables from “Current Displayed Variables” and use “MoveRight”. See the `variable` command for details. Also see the help file on the menu of the Variable Monitor window.

1.3.6 HTML output

Output may be written in HTML format. See the command `html` . The HTMLfile will be started automatically in the user’s default browser. This has been tested with Internet Explorer, Firefox, and Corel. Output is in the form of text, tables, and plots. Fig. 1.13 shows a simple HTML file.

Table items have tooltips (popup definitions) that provide definitions when the mouse is placed over the item. This action is called a mouse-over. The output line information is placed below the source line and dynamically and automatically updated, so that the user may easily see the program progress through a macro. Output information may optionally be hidden or displayed with the “[-]” and “[+]” controls. Graphics are displayed at the output information at the point they are generated. The new scalable vector



```
Polling ON (click to stop)   Poll   HTML line: 33   Timer: 98 sec   Hide output

First time notes
3  (1)[ ]html/location/off
4  (2)[ ]set/definitions/on
5  (3)[-]wavelength/list
                              Wavelength List
 No. |        Vacuum |        Medium |    Index |  E-index
   1 |    1.0600E+01 |    1.0600E+01 |   1.0000 |   1.0000

[+]Definitions
6  (4)[ ]macro/define/single test
7  (29)[ ]  html/stop
8  (6)[ ]  count = count + 1
9  (7)[ ]  phase/random/sqr/clap 1 .1 5
10 ([illegible])[ ]  html/start
11 (30)[-]  plot/liso/wavefront 1

plot1.plt, ver. 5, PLOT 5, Wed Feb 27 01:51:28 2008, 3653

[-]plot1.<5>.plt (Expand)
```

```
12 (31)[ ]  pause 2
13 (32)[ ]macro/end
14 (12)[ ]macro/run test/5
15 (33)[-]read/back/noclose   # issued by GLAD for an end-of-file condition

read/back issued from open file: F:\fpsnt\glad\53\html5.inp
```

polling on/off control

tooltip definition

The index of refraction for the extraordinary ray.

cursor on item

output display or hide controls [+] or [-]

angle bracket controls select between plot versions: 1, 2, 3, 4, 5

select “expand” to double graphic size

high resolution SVG graphics made in-place below source line and automatically updated

source line number

output line number. Red indicates current output line

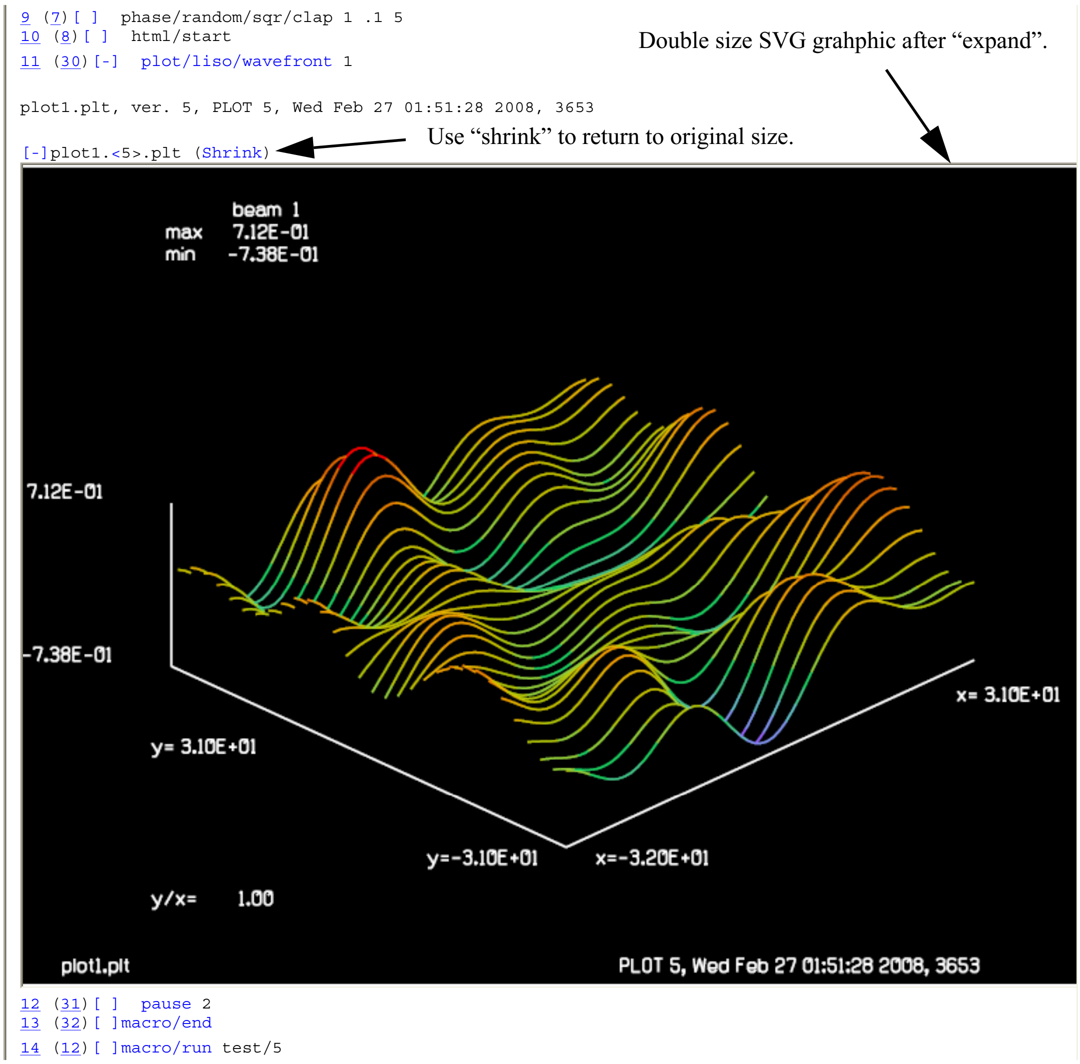
Fig. 1.13. An HTML page is shown. Both source and output lines appear in proper sequence. In macros, new output lines from the same source line are automatically and dynamically replaced. The souce line 15 is shown with output line 33, highlighted red because it is current. Tooltips are provided to provide a popup definition when the mouse cursor is placed over the item. See “E-index” at the upper right. Output information may be hidden by selecting “[-]” (less) or displayed by “[+]” (more). Multiple versions of plots having the same name are retained. Earlier version may be displayed with the angle bracket controls “<“ and “>” when shown in blue.

graphics (SVG) are the default plot format for HTML graphics. The SVG graphics may be scaled to double size or hidden. See Fig. 1.14 for an illustration of an SVG file that has been expanded to double size.

Most tables now have definitions of all terms that may be activated by `set/definitions/on`. See Fig. 1.15

When the same plot name is used multiple times each version is saved. By default the most recent vers. ion is displayed but the user may select any version using the “<“ and “>” controls in the HTML plot name. See Fig. 1.16. Note that the graphic in Fig. 1.13 with version 5 is slightly different from Fig. 1.16 with version 3.

A display/hide control is provided for the output for all commands. See Fig. 1.17. Hiding all output makes it easier to concentrate on the source line structure.



```
9  (7) [ ]  phase/random/sqr/clap 1 .1 5
10  (8) [ ]  html/start
11  (30) [-]  plot/liso/wavefront 1

plot1.plt, ver. 5, PLOT 5, Wed Feb 27 01:51:28 2008, 3653

[-]plot1.<5>.plt (Shrink)
```

Double size SVG grahphic after “expand”.

Use “shrink” to return to original size.

```
12  (31) [ ]  pause 2
13  (32) [ ]macro/end
14  (12) [ ]macro/run test/5
```

Fig. 1.14. The SVG graphics may be expanded by clicking on “expand” in the plot name. The graphic doubles in size and “expand” is changed to “shrink”. Click on “shrink” to return the graphic to the original size. The graphic may be hidden with “[-]” or redisplayed with “[+]”. Multiple versions of plots having the same name are retained. Earlier version may be displayed with the angle bracket controls “<“ and “>” when shown in blue. In this case the left angle bracket is blue and the version is 5 indicating version 4 may be selected with “<“.

Optionally the user may use `/location` to cause the browser to keep the current line (along with other choice) in view as the output lines are generated. The browser view may be “refreshed” but the “back” control of the browser does not work on this type of dynamically generated HTML files.)

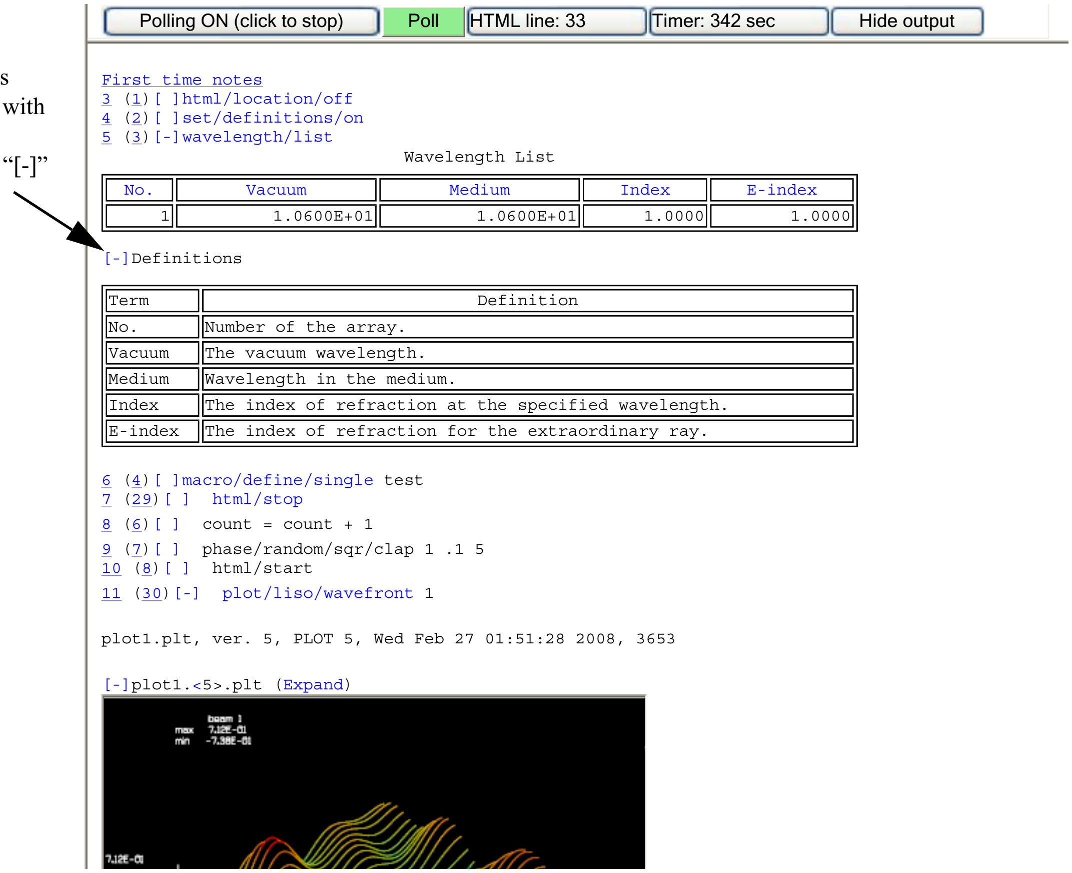
1.3.7 Running GLAD as a console program

You may run GLAD as a console program separately from the IDE. This is quite useful where GLAD is to be called from another program to process a command file. The console version of GLAD is named GLAD.EXE. This program is actually a true windows program based on the WIN32 protocol but has an input-output window that has the simple appearance of an old DOS program, see Fig. 1.18.

GLADE.EXE may be started in three ways:

- Select “Console style GLAD” from the GLAD 5.8 group.

- definitions displayed with “[+]”
- hide with “[-]”



```
First time notes
3 (1)[ ]html/location/off
4 (2)[ ]set/definitions/on
5 (3)[-]wavelength/list
```

Wavelength List

No.	Vacuum	Medium	Index	E-index
1	1.0600E+01	1.0600E+01	1.0000	1.0000

[-]Definitions

Term	Definition
No.	Number of the array.
Vacuum	The vacuum wavelength.
Medium	Wavelength in the medium.
Index	The index of refraction at the specified wavelength.
E-index	The index of refraction for the extraordinary ray.

```
6 (4)[ ]macro/define/single test
7 (29)[ ]  html/stop
8 (6)[ ]  count = count + 1
9 (7)[ ]  phase/random/sqr/clap 1 .1 5
10 (8)[ ]  html/start
11 (30)[-]  plot/liso/wavefront 1

plot1.plt, ver. 5, PLOT 5, Wed Feb 27 01:51:28 2008, 3653

[-]plot1.<5>.plt (Expand)
```

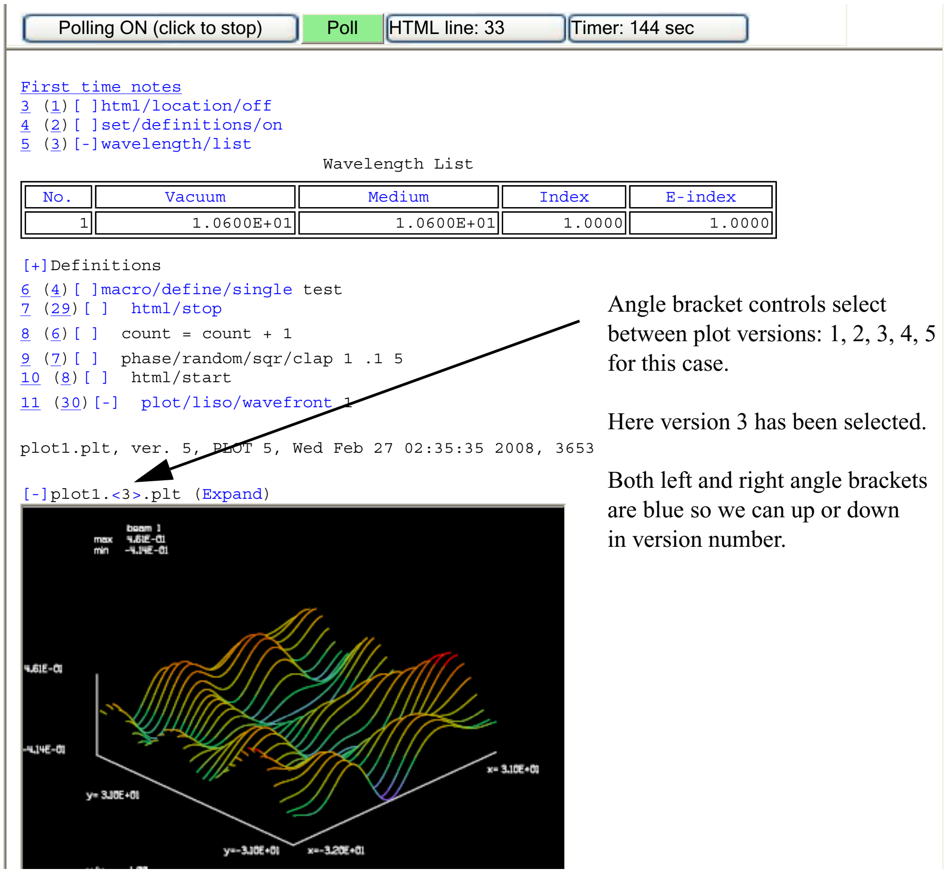
Fig. 1.15. `set/definitions/on` will cause definitions to be output. In HTML the definitions are output in hidden form but may be displayed with “[+]” (more) and compressed with “[-]” (less).

- From the MS Windows menu select, Start, Run and enter C:\program files\aor\glad57\glad.exe. You may add a file name as a command line argument, e.g., “C:\program files\aor\glad57\glad.exe simple.inp”. GLAD will begin running the indicated command file.
- From a DOS Command window enter “cd C:\program files\aor\glad57” to select the GLAD distribution directory. Enter “`glad`” to start GLAD. You may also specify a command file as a command line argument, e.g. “`glad simple.inp`”.

The console form of GLAD uses a single screen for input and output commands. This mode is slightly faster because no interprocess connections are required. When you run GLAD separately, Watch will start automatically as indicated in Fig. 1.18. Almost all GLAD and Watch features are accessible from the GLAD command line. Some of the Controls from the IDE are not available. Use Ctl-C typed into the dialog window to interrupt GLAD if necessary. The command `set/folder` will change the working folder.

1.3.8 Making a video

Use commonly available commercial screen capture software to capture a series of plots in one of the Watch.exe windows to form a *.AVI or *.WMVfile. See Fig. 1.19 for an example of 200 instances of time-evolving atmospheric aberration.



```
First time notes
3  (1) [ ]html/location/off
4  (2) [ ]set/definitions/on
5  (3) [-]wavelength/list
                                Wavelength List
```

No.	Vacuum	Medium	Index	E-index
1	1.0600E+01	1.0600E+01	1.0000	1.0000

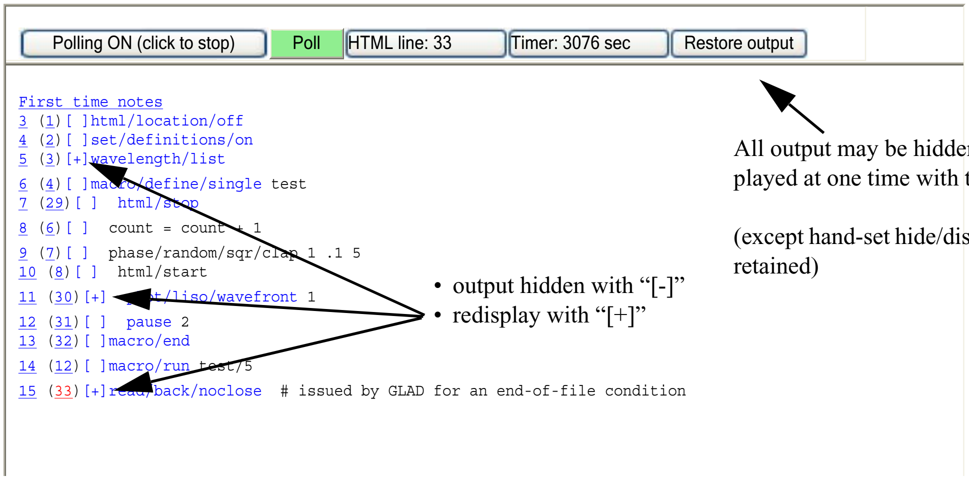
```
[+]Definitions
6  (4) [ ]macro/define/single test
7  (29) [ ]  html/stop
8  (6) [ ]  count = count + 1
9  (7) [ ]  phase/random/sqr/clap 1 .1 5
10  (8) [ ]  html/start
11  (30) [-]  plot/liso/wavefront 1

plot1.plt, ver. 5, PLOT 5, Wed Feb 27 02:35:35 2008, 3653

[-]plot1.<3>.plt (Expand)
```

Angle bracket controls select between plot versions: 1, 2, 3, 4, 5 for this case.

Here version 3 has been selected.

Both left and right angle brackets are blue so we can up or down in version number.

Fig. 1.16. A control in the plot name allows the user to display earlier versions. In this figure the final version is 5 but the display is showing version 3 which will be seen to be slightly different (Fig. 1.13). The blue angle brackets indicate a lower or higher version exists and may be used to shift lower or higher.



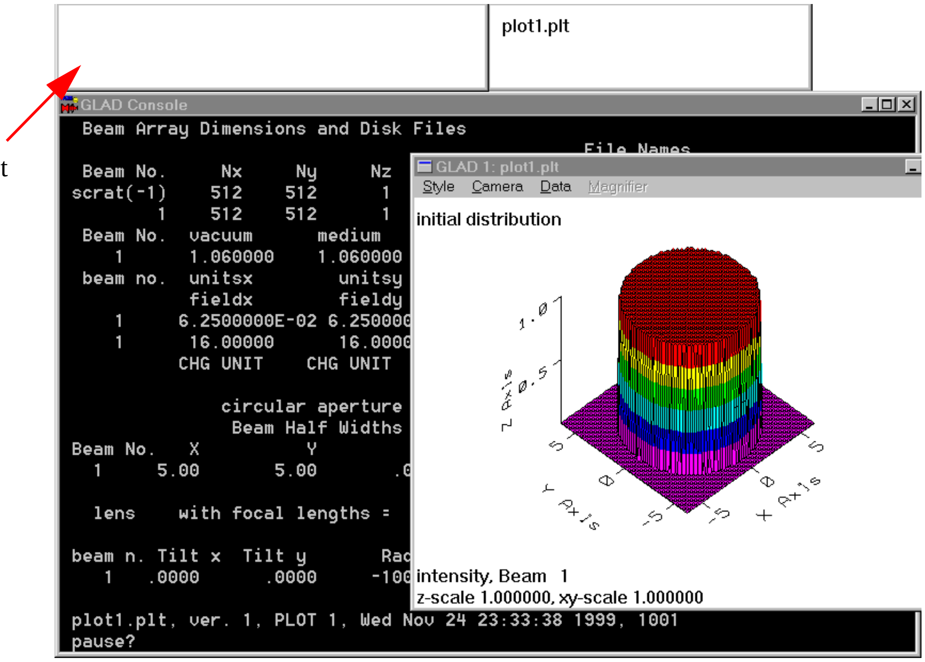
```
First time notes
3  (1) [ ]html/location/off
4  (2) [ ]set/definitions/on
5  (3) [+]wavelength/list
6  (4) [ ]macro/define/single test
7  (29) [ ]  html/stop
8  (6) [ ]  count = count + 1
9  (7) [ ]  phase/random/sqr/clap 1 .1 5
10  (8) [ ]  html/start
11  (30) [+]  plot/liso/wavefront 1
12  (31) [ ]  pause 2
13  (32) [ ]macro/end
14  (12) [ ]macro/run test/5
15  (33) [+]read/back/noclose   # issued by GLAD for an end-of-file condition
```

All output may be hidden or redisplayed at one time with this control.

(except hand-set hide/display status is retained)

- output hidden with “[-]”
- redisplay with “[+]”

Fig. 1.17. Hiding the command output may makes a “top level” view of commands possible. The output from all commands may be hidden with “[-]” and redisplayed with displayed with “[+]”. All output may be compressed with the special hide/restore control (hand settings are not changed).



select GLADEdit

```
 Beam Array Dimensions and Disk Files
                                           File Names
 Beam No.     Nx      Ny      Nz
scrat(-1)    512     512       1
        1    512     512       1
 Beam No.  vacuum       medium
    1      1.060000     1.060000
 beam no.  unitsx         unitsy
           fieldx         fieldy
    1     6.2500000E-02 6.250000
    1      16.00000       16.0000
          CHG UNIT     CHG UNIT

              circular aperture
               Beam Half Widths
Beam No.   X           Y
  1     5.00        5.00        .0

  lens     with focal lengths =

beam n. Tilt x  Tilt y       Rad
   1    .0000       .0000     -100
plot1.plt, ver. 1, PLOT 1, Wed Nov 24 23:33:38 1999, 1001
pause?
```

Fig. 1.18. Console form of GLAD. As shown, the main dialog window has white letters on black background. It has both input and out commands interspersed. GladEdit may be started from the main GLAD window as indicated above.

ex122a.avi

Fig. 1.19. A movie consisting of 200 images showing progression of atmospheric turbulence without a cross wind. The images were displayed in a Watch window and captured using commercial screen capture software. The file ex122a.avi should be present in the installation folder. Click on the phrase “ex122a.avi” in the picture above.

1.4 Command Language

The command language incorporates a powerful macro capability, similar to user-defined subroutines or functions. The macro capability allows almost any type of optical resonator to be defined Å no matter how complex. The macro capability also is the basis for GLAD's system optimization capability with which and combination of system features may be optimized to achieve user-defined performance targets. The command language includes a powerful capability to define variables and use mathematical expressions that greatly facilitates use of the program.

An on-line help capability is included to provide quick look-up of command descriptions. The HELP program may be used to look up commands by category, by name, or by for a specific command by including the work help on the input line. GLAD will also prompt interactively for user input.

1.4.1 Data Input Lines

Input consists of a series of command lines. Input lines may be entered as discrete physical lines separated by a carriage return ([CR]) or data lines may be entered together in a single physical line by separating the lines with a semicolon and ending the input stream with a carriage return. macro and `read` commands can not be followed by a semicolon

```
    (line1) [CR]
    (line2) [CR]
    (line3) [CR]
```

or

```
line1; line2; line3 [CR]
```

Input lines may be written on more than one physical line by using the ampersand as a continuation mark at the end of the input line.

```
    (first part of line) &[CR]
    (second part of line) &[CR]
    (third part of line) [CR]
```

1.4.2 Command Parsing

The GLAD input line is one of four types:

Table. 1.1. The four types of lines.

Input line type	Example
command line	`units/set 1 1`
conditional line	`if [x==y] status` or `if x=y status`
assignment	`x = x + 3` or `x = x + 3 list`
comment	`c some comment`

Conditional lines may contain mathematical expressions in brackets. If the math expression evaluates to zero, the logical value is false. Evaluation to any non-zero value yields the logical value of true. A limited number of rational expressions may be written in the non-bracket form, but the mathematical expressions are more powerful and the recommended approach.

Assignment lines may take the parameter `list` to cause a display of the result.

The command line is of the form:

```
command/mod1/mod2/mod3 string values parameters
```

Commands and their modifiers must be on the left, followed by strings, values, and parameters in that order, if required. Fields are separated by one or more blanks.

Table. 1.2. Elements of the command line.

Command line component	**Description**
command	Defines function to be used.
mod1, mod2, mod3	Modifiers of the command line to direct operations of the function.
string	A string of characters to define a title, filename, macro name, lens name, system commands, etc. Strings have no preassigned values. File names should be enclosed in single quotes if they contain slashes, "/", or other special characters. Some strings have modifiers as do commands. Variables may be included in strings if preceded by the "@" symbol.
values	Variables, numbers, mathematical expressions, or numerical assignments.
parameters	Parameters are similar to commands but are on the right end of the command line, after values. Parameters are checked against the list of preassigned values. Variables and expressions may be included in parameters names and their modifier names. Optional parameters are listed in brackets in the command descriptions. Literal parameter names are listed in typewrite font (Courier). Reference to the first or second parameter are shown in parentheses and in a proportional font (Times Roman). Neither the brackets nor the parentheses shown in the listing of parameters should not be entered.

1.4.2.1 Command lines and assignment lines

The command line and modifiers establish the operation to be performed. Command line parsing proceeds as follows:

- read command and modifiers from the left and transfer control to the appropriate routine
- look for parameters on the right that match the parameter list for that command.
- evaluate mathematical expressions in square brackets, right to left
- Alias and variable substitution
- string extraction.
- numbers in order of occurrence
- command assignment with an equal sign (lvalue = rvalue)

Numerical values take the form of numbers, variables, mathematical expressions (which are evaluated to numbers and numerical assignments.

Table. 1.3. Various forms of numerical values.

Numerical Values	**Description**	**Examples**
numbers	Integers, real numbers, and complex numbers may be entered in simple decimal form or using scientific notations entered in order. Use “e” to designate an exponent and “i” to designate the imaginary part of a complex constant. “1i” is square root of -1. Units of length are in centimeters. Numbers corresponding to length may have “mm” (millimeters), “in” (inches), “ft” (feet), “mi” (microns), “nm” (nanometers), “km” (kilometers), or “m” (meters) appended to cause appropriate scaling to centimeters. For example “1.3mm” is converted to 0.13 cm.	`1.23456, 1.23e+10, 1+3i, 1.3mm`
variables	Names consisting of no more than 20 characters which may be used in mathematical expressions. Allowed characters include A-Z, a-z, _, and $.	`x, y, Peak, Pass_Counter, energy$2`
command value assignments	lvalue = rvalue form, where lvalue is one of the list of names of the for the numerical values of the specific command.	`units ibeams=1 xunit=2.5`

mathematical expressions	Expressions containing spaces must be enclosed in square brackets, [ ], except in assignment lines. IF statements require brackets for mathematical expressions. A mathematical expressions used in command lines with postional assignment must also be enclosed in brackets.	`x = 2.*sin(2.*pi*y/period)`
		`pass = pass+1`
		`min(3.4, x, z)`
		`x==12.3+2.5e3`
		`units 1 xunit=z=z+1`
		`units 1 [z=z+1]`
		`units 1 xunit=[z = z + 1]`
		`if [z==x] status`

Numbers may be written as integers (no decimal point), floating point numbers (with a decimal point), or in scientific notation using “e”. For example, 12,300 may be expressed as 1.23e4. pi, e, h, c, and Ver (version number, e.g., 58.0) are predefined constants that may be used in any expression.

Variables may be used wherever a number may be used. Variables and mathematical expressions are a great convenience and adds to the reliability and readability of GLAD command decks. Variables may be of either real (default) or integer (see variables/declare type. A new variable name will be recognized, and automatically declared as a real variable, the first time it appears on the left side of an equal sign (an lvalue). Variables will also be automatically declared by the variables/parameter and table commands, unless set/strict/on has been invoked.

Use `variables/declare/integer` prior to the first use of variable to establish it as an integer. If a variable appears on the right side of an equal sign (rvalue) before it has been declared, GLAD will report an error condition. Variable names may include the characters A-Z, a-z, _ and $. The variable names must be written in exact form. “`pi`” has a preassigned value. Other preassigned constants are “`c`” speed of light, “`e`” natural logarithm constant, “`h`” Plank's constant, and “`Ver`” for version number (for example 58.1 is version 5.8.1. These constants may be reassigned in the command file, so it is best to use caution. Real-time display of selected variables may be done with the variable monitor window, Sect. 1.3.5.

Mathematical expressions may be used as rvalues in command line assignments, in parameters and their modifiers, in strings, and in assignments. Mathematical expressions may always be enclosed in square brackets “ `[]` ”. Math expressions are not required in assignment lines. Assignment lines are equations, that appear on a line with no commands. Math expression in command lines do not need to be enclosed in brackets if there are no internal spaces. The exceptions are: 1) math expressions in IF statements must be enclosed in brackets; and 2) in command lines using assignment by position variable assignments in math expressions must be enclosed in brackets.

`if [z==0] energy/norm 1 1`	(brackets are required in IF statement)
`units 1 [a=a+1]`	(brackets are required for math assignment with postional assignment of command values)

The last sample code line is specifying the command value by position. Without brackets the expression `h=h+1` would be interpreted as an lvalue-rvalue assignment and would fail as `h` is not a valid lvalue for this command. A math assignment without internal spaces may be used without brackets in an lvalue-rvalue form:

`units 1 xunit=a=a+1`	(no brackets required if no spaces and lvalue-rvalue form of command assignment)

Mathematical expressions may use any of the functions defined in Table 1.4 or the operators in Table 1.5.

Table. 1.4. Functions which may be used in GLAD expressions.

Function	**Description**
`abs(a)`	Absolute value.
`acos(a)`	Arc cosine in radians.
`acosd(a)`	Arc cosine in degrees.
`asin(a)`	Arc sine in radians.
`asind(a)`	Arc sine in degrees.
`atan(a)`	Arc tangent in radians.
`atand(a)`	Arc tangent in degrees.
`atan2(a,b)`	Arc tangent of `a/b` in radians.
`atan2d(a,b)`	Arc tangent of `a/b` in degrees.

Table. 1.4. Functions which may be used in GLAD expressions. (Continued)

Function	**Description (Continued)**
`ceil(a)`	Round upward to nearest integer.
`cmul_r(ar,ai,br,bi)`	Return real component of complex multiplication of “a” times “b”.
`cmul_i(ar,ai,br,bi)`	Return imaginary component of complex multiplication of “a” times “b”.
`cdiv_r(ar,ai,br,bi)`	Return real component of complex division of “a” divided by “b”.
`cdiv_i(ar,ai,br,bi)`	Return imaginary component of complex division of “a” divided by “b”.
`cexp_r(ar,ai)`	Return real component of complex exponent of “a”.
`cexp_i(ar,ai)`	Return imaginary component of complex exponent of “a”.
`cos(a)`	Cosine of the argument in radians.
`cosd(a)`	Cosine of the argument in degrees.
`cosh(a)`	Hyperbolic cosine of the argument in radians
`exp(a)`	e^{a}, same as `e^a`
`exp10(a)`	power of 10, same as 10^{a}, same as `10^a`
`floor(a)`	Round downward to nearest integer.
`gauss(a,b,c,d)`	supergaussian function, $\exp\left\{-[(a-b)/c]^{2d}\right\}$
`line()`	Returns the number of the source code line.
`log(a)`	Natural logarithm.
`log10(a)`	Logarithm base 10.
`max(a,b,...)`	Maximum of any number of comma-delimited numbers.
`min(a,b,...)`	Minimum of any number of comma-delimited numbers.
`mod(a,b)`	`a` modulo `b`.
`pi`	Inserts the value of π.
`power(a,b)`	a^{b}, same as `a^b`.
`rand()`	Returns a random number. Takes no argument. See `srand()`.
`ramp(a,b,c)`	Ramp function.
`sin(a)`	Sine of the argument in radians.
`sind(a)`	Sine of the argument in degrees.
`sinh(a)`	Hyperbolic sine of the argument in radians.

Table. 1.4. Functions which may be used in GLAD expressions. (Continued)

Function	**Description (Continued)**
`srand(a)`	Set random number with integer value a. Returns 0. See `rand()`. Returns value of previous seed.
`sqrt(a)`	Square root.
`step(a,b)`	Step function: 1 if $a \geq b$, 0 otherwise.
`tan(a)`	Tangent of the argument in radians.
`tand(a)`	Tangent of the argument in degrees.
`tanh(a)`	Hyperbolic tangent if the argument in radians.
`time()`	Number of seconds since January 1, 1970 GMT.
`udata(a,b)`	Udata value for row = `a` and column = `b` (`a` = 0 gives x-values).

Table. 1.5. Operators which may be used in GLAD expressions, in descending order of precedence.

Function	**Description**
`()`	Parentheses.
`+`, `-`	Unary positive and negative sign. Examples: `+3.2`, `-x`.
`^`	Exponent (raise to power).
`*`, `/`, `%`	Multiply, divide, remainder.
`!`, `>`, `<`, `>=`, `<=`, `||`, `&&`, `==`, `!=`	Not operator (negation), greater, lesser, greater or equal, less or equal, or, and, equal, not equal.
`=`	Assignment.

Command line assignments are similar in form to variable assignments: both have the form lvalue = rvalue. However, for command line assignments the lvalues have specific names for each command. The names of the lvalues for numerical assignments may be truncated, provided the truncated form is unique among the list of numerical assignment names for the particular command-modifier sequence. Lvalues may contain variables or aliases preceded by @).

Examples:

Consider the `units` command that gives the pixel-to-pixel spacing:

```
units ibeams xunit yunit
```

The following command lines are valid:

```
x = sin(pi/2)list                1, (assignment line needs no brackets)
units 1 [y^2] [y=x+1.5]          (2, command assignment by position with math expressions
units 1 xunit=y^2 yunit=y=x+1.5  (3, command line assignments)
units 1 x=y^2 y=y=x+1.5          (4, abbreviated lvalues)
units 1 [x = y^2] y = [y = x+1.5]  (5, spaces require brackets)
units 1 x = y^2 y = y=x+1.5      (6, expressions without spaces, no brackets required)
```

In the first line, *x* is recognized as a variable name and is assigned the value 1.0.

In the second line, math expressions are used to assign `xunit` values and `yunit` values by position. Since processing proceeds from right to left, `y=x+1.5` is processed first. `y` is recognized as a new variable name and assigned the value 2.5. `set/strict/off` may be used to prevent such on-the-fly definitions of new variables. The second mathematical expression `y^2` uses the variable `y`, as just established on the same line to the right, and the expression takes the value 6.25 for the `xunit` assignment.

In the third line, the predefined values `xunit` and `yunit` are used in the lvalue-rvalue form of assignment (left value equals right value). If the lvalue-rvalue form is used, the assignments may be made in any order on the line. In general, math expressions used in command lines should be enclosed in brackets, but brackets may be dropped if there are no spaces in the math expression. See brackets.inp included with the example files.

In the fourth line, the full name of the lvalues are abbreviated from `xunit` to `x` and from `yunit` to `y`. The numerical assignment `x=y^2` is recognized as an abbreviated form of `xunit=y^2`. The lvalue `y` on the far left of `y=y=x+1.5` is recognized as an abbreviated form of the numerical assignment name `yunit` and the value 2.5 is assigned to it.

In the fifth line spaces are included in the math expressions, so brackets are required.

Notice in the sixth line that the spaces may be placed in the lvalue-rvalue expression on either side of the equal sign. The mathematical expression "`y=x+1.5`" has no spaces and therefore does not need brackets. The lines above are equivalent to the command lines:

```
x=1
y=6.25
units 1 6.25 2.5
```

Or

```
units ibeams=1 xunit=6.25 yunit=2.5
```

The variables `x` and `y` are available for use elsewhere in the program. Assuming the variables `x` and `y` are defined, other equivalent forms are:

```
units 1 y x
units 1 x=y y=x
units 1 x=[y] y=[x]
```

Variables may be used in strings or parameters and their modifiers by preceding them with the “@” symbol. For example consider the use of integer variables in the example below,

```
variable/declare/int i
i=1
plot/watch plot@i.plt
i=i+1
plot/watch plot@i.plt
```

These code lines establish plot names plot1.plt and plot2.plt successively. If variables are included in titles, the title is updated to include the current value of the variable.

A similar approach may be used to build a vector. Assume that we have some data which is to be called in sequence:

```
x1 = 3.35
x2 = 4.73
```

```
x3 = 3.001
x4 = 2.73
variable/dec/int i
macro/def system/o
   i = i + 1
   prop x@i                          # a simple form of vector for x values
   title Position @i
   plot/l 1
macro/end
i = 0
macro/run system/4
```

Parameters and their modifiers are used by many commands to control program execution. The special parameter “?” causes GLAD to prompt for commands, modifiers, and values. For example,

```
   clap/?/? ?
```

will prompt for the first and second modifiers and the numeric assignments. Also, see the fitzern command.

1.4.2.2 Conditional line or `if` command

The IF and BLOCKIF may be written in terms of a mathematical expression enclosed by brackets or without brackets if the expression has no internal spaces:

```
   if arg1 [Expression] arg2 (input line)
   if arg1 [Expression] arg2 then
     .
     .
   else
     .
   endif
```

where “Expression” is any mathematical expression created from the elements of Table 1.5. “input line” is any command line (except another `if`). It can no be an assignment statement. Note that `[0]` is taken as false and any non-zero value is taken as true. Also, “`if 1 then`” or “`if 0 then`” may be used with no brackets required. It may be useful at times to temporarily place a block of lines inside a BLOCKIF, so that the block may be easily switched out with a “`0`” value or switched back in with a “`1`” value.

The IF command may also be written in an older form:

```
   if arg1 (Relop) arg2 (input line)
```

where `arg1` and `arg2` are numbers, variables, or mathematical expressions enclosed in brackets. Relop should be one of the relational operators <, >, =, <=, =>, != or <>. A number or mathematical expression is judged false if zero, true otherwise. If the condition is true, the input line is processed. See the `if` command description for details. The `if` command may also be used in the form of a BLOCKIF,

```
   if arg1 (Relop) arg2 then
     .
     .
   else
   .
   endif
```

The commands in the BLOCKIF are processed only if the expression is true. IF blocks may be nested to any number of levels.

1.4.2.3 Comments

Comment lines are identified by the pattern "`c `" in columns 1 and 2 (lower case "c" followed by a space), "`$ `", or "`//`". These comments are not processed by GLAD. The c-style or $-style comment is terminated by a semicolon and other commands may be placed on the same entry line. The double slash comment is treated as a $-style comment. In-line comments are identified by "#" or "//". Nothing on the entry line is processed after # or // including semicolons.

```
c this is a comment up to the semicolon; energy/norm 1 2.0 # more comment
```

Processing of the c-style command jumps to the semicolon. The `energy` command will be processed.

A comment may also be started by a numeric digit (0-9) as the first character. For example

```
131;energy/norm 1 1
```

treats "131" as a comment. This feature may be used to number commands or to create line numbers.

A comment beginning with "`C `" (upper case C) or `comment` will make a comment that is displayed. See the `comment` command. Variables and aliases will be expanded. For example:

```
   x = 3
   C x = @x
```

will print

```
   C x = 3.000
```

to the output device. The format of the variables may be defined with `C/format` or `comment/format` similarly to `title/format`.

1.4.3 Aliases

Character string substitutions may be used to create aliases for any string of up to 20 non-blank characters. The alias name may consist of the characters A-Z, a-z, 0-9, _ and $. The leading character should not be a number. The aliased pattern many contain any non-blank characters. GLAD will substitute blanks for comas when the alias name is replaced, so that blanks may be introduced into the alias string. For example

```
   alias xxx units,1,2
   @xxx
```

has the same effect as `units 1 2`.

1.4.4 Breaks

GLAD may be interrupted form command file by the Break menu item. `break/set` activates the interrupt menu when the command file is running. The user may then elect to continue, stop immediately, or create a break point. If a break point is placed, the user may issue `break/continue`, either from the Interactive Input window or from GladEdit, to cause GLAD to continue execution. GLAD may also be interrupted from the Interactive Input window under the Controls menu item.

1.4.5 File Names and Folders

File names are entered for the `read/disk`, `write/disk`, `plot/disk`, `infile` , and `outfile` commands. GLAD allows the file names to be specified as string variables in the form `'filename'`, where the single quotes are used to delimit the string variable. Single quotes are not needed if he string contains no spaces or forward slashes. The case is not altered and any characters may be included in the string variable. Consider an example,

```
write/disk '../outputdata/out.dat'/overwrite
```

This example will cause the output to be directed to the file "`out.dat`" with the path name consisting of a subdirectory of the current directory called "`outputdata`".

The current working directory may be set through GLAD IDE, Controls, Set default folder. The current working directory may also be changed through the GLAD command `set/folder`. For example:

```
set/folder 'd:\myfiles'
```

A popup dialog box for folder selection may also be generated from GLAD with the command:

```
set/folder/popupmenu
```

See details under the `set` command.

For compatibility with earlier versions the `set/path` command is retained. The specified path will be placed in front of all input and output files. Also for compatibility with earlier versions, pathnames and filenames for beam arrays may be set with the `array/path` and `array /name` commands.

1.4.6 Registry settings

GLAD sets the name of the installation folder into the MS Windows operating system registry. The installation directory and other registry information is set at the time of installation from the distribution CD.

The utility setup_58.exe (requires administritative privileges) will reset the all registry information to the default values, and the system folder will be set to the folder in which setup_58.exe is located when it is run. It performs the same registry operations as installation from the CD and, indeed, is called by "setup.exe" or "setup_32.exe" from the CD installation. The utility reg_r58.exe will display current values (does not require administrative privileges).

If one is knowledgeable in working with the registry, the settings may be explicitly changed. It is wise to back up the registry before making any changes. Run "regedit.exe". Locate

```
HKEY_CLASSES_ROOT\AppliedOpticsResearch\Shell\Open\Command
```

You will find a data value giving the folder name. For example “C:\AOR\GLAD58\ide.exe %1”. `HKEY_CLASSES_ROOT\AppliedOpticsResearch\DefaultIcon` should be set to the same value of folder name.

`HKEY_CLASSES_ROOT\AppliedOpticsResearchWatch\Shell\Open\Command`

You will find a data value giving the folder name. For example: C:\AOR\GLAD58\watch.exe %1. `HKEY_CLASSES_ROOT\AppliedOpticsResearchWatch\DefaultIcon` should be set to the same value.

One should also have `HKEY_CLASSES_ROOT\.inp` with `REG_SZ` set to AppliedOpticsResearch and ContentType set to application/inp and `HKEY_CLASSES_ROOT\.plt` with `REG_SZ` set to “AppliedOpticsResearch.Watch” and Content Type set to “application/plt”.

Data definiting window locations and various operational data is located in

`HKEY_CURRENT_USER\Software\AppliedOptics Research\5.8`

1.4.7 Command Line Description Conventions

In describing command lines, we will identify the following types of entities

Explicit parameters or commands—Courier font (evenly spaced typewriter letters)

```
clap/(Modifier1)/(Modifier2) ibeams
```

`clap` is an explicit command word, “`Modifier1`” and “`Modifier2`” are names of character strings to be entered, “`ibeams`” is the name of a numeric value.

Modifiers may be character strings or numbers. For example,

```
macro/run (Filename)/icount
```

“Filename” is the name of the filename to be used. `icount` is the name of the number to be used as the filename modifier. In the list of modifiers, the default modifier is always listed first.

1.4.8 Help

Online help is available in three forms. Both IDE.EXE, WATCH.EXE, GLAD Output, and GladEdit have MS Windows Help files available from the associated menu to describe operation of these windows programs. You can also access the full set of GLAD manuals in online form from the IDE Help item on the IDE.EXE menu bar. These online documents use the Adobe Acrobat Reader and provide high quality online viewing and support printing of selected pages with high resolution.

1.4.9 Batch mode

GLAD may be run by other programs that are capable of issuing a system command of the form:

```
glad filename noconsole
```

The optional “`noconsole`” parameter causes GLAD to run without console window, top level window, or Watch. The traceback window may also be turned off by setting “`tracebackwindow=0`” in glad.ini located in the GLAD system directory.

The file “startup” may also be used. GLAD first looks for a file called startup (no file extension). If the file is found, it is read before any other commands are read. This feature provides a convenient means of initializing GLAD without display to the terminal. It also provides a means to run the program in batch mode, since all commands may be put into the startup file.

A customers application may be called in the middle of a GLAD run by using the system/execute command. For example:

```
outfile/beam file1.dat/no/binary 1
system/execute/wait customer.exe file1.dat file2.dat
infile/beam file2.dat/no/binary 1
```

The modifier wait is used to cause GLAD to stop until customer.exe completes.

GLAD may also be run in a batch file (*.BAT) so that a customer’s programs may be interspersed with GLAD operations. For example the file batch.bat might take the form:

```
start /wait glad start.inp noconsole
start /wait customer.exe file1.dat file2.dat
start /wait glad end.inp noconsole
```

where GLAD generates file1.dat using outfile from the command file start.inp. Customers program customer.exe inputs file1.data and outputs file2.dat. GLAD then continues the calculation by using infile to read file2.dat. The file batch.bat may be run in the same way as an executable file.

1.5 Good Programing Practice, Solving Problems, and Technical Support

GLAD may be considered a programming language for physical optics. As such, some of the principles of good programing practice and debugging will prove helpful. A well organized approach will make it much easier to obtain technical support should that be necessary.

1.5.1 Organizing a problem for solution

A complex problem is best solved in stages, beginning with a very simple representation and adding complexity in stages. In many cases, one can start from one of the examples from the GLAD Examples Manual and modify it to suit the new requirements. Generally one makes a new sub-example to test a new feature, ultimately one would have versions “a”, “b”, “c”, etc. One should verify the reasonableness of the result for each stage before going to the next. It is wise to save the various stages in case it is necessary to reverify certain performance features. This provides an excellent way of validating the model in easily understood stages.

Consider the example of designing a stable laser. If you have not modeled a stable cavity laser before, you might begin by familiarizing yourself with Example 33, adapting the example to suit the new configuration, and add new features. One do this in the following steps:

- Become familiar with Ex 33, a bare cavity, stable resonator
- Make a copy into a new name. For example MyLaser1.inp
- Change the length and mirror curvatures. Examine output of resonator/test to verify that the laser is stable.

- Verify that the resonator is indeed stable and that the surrogate gaussian is indeed an eigenfunction. Do this by checking the values of the surrogate gaussian by running `geodata` and noting the parameters. Then run `resonator /run 1` followed by `geodata` and check that the surrogate gaussian is unchanged. Repeat this test again just to be sure. If this test fails, look for some complex logic that may cause the resonator to change from one pass to another.
- Now try using random noise as a starting point. You will want to use one of the functions that does not alter the surrogate gaussian. For example “clear 1 0” followed by “noise 1 1” would initialize beam 1 to uncorrelated random noise. One could also construct a desired starting distribution in another array (use attribute “data”) and copy it to the array propagating in the cavity using “copy/con”.
- One can then make a new sub-example and add laser gain.

1.5.2 Debugging

If a command file fails to give the expected result, endeavor to isolate the specific command that separates the region of expected behavior from unexpected behavior. This is the principle of “divide and conquer”. One can use `break /set` or `read /screen` to interrupt the program at a certain point. If a problem only occurs after a certain number of passes in a resonator, one may use IF logic so that the break only occurs at the desired pass.

Once the specific command that causes the problem is identified, check the description of the command carefully to be sure of the use of parameters. Graphic plots just be fore and just after the command may be helpful as well as energy checks and other diagnostic commands. For example if an aperture is defined with global positioning in a very complex folded and decentered system, one might interrupt the code just before and just after the aperture in question to check the vertex position and rotation and the global beam position and direction.

For a complex command, one may also wish to check its use from the examples supplied with GLAD. One may also wish to construct a simple test case to become familiar the use of the command in question.

In some cases it is not clear which command is causing the problem. Our usual approach is to make a copy of the troublesome file and try to simplify the copy as much as possible while still observing the error. For example one may delete plots and comments and still have the problem. Perhaps the problem will still exist if a simple plane wave input is used. If so, use the simplest solution. Quite often this process of simplification, will reveal the source of the problem.

It is our observation over many years, that those who do not intent macro definitions and logic branches, have much more trouble than those who do. When we receive a command file as part of a technical support request, the first thing we do is indent macros and logic branches if this has not been done by the customer.

1.5.3 Technical Support

AOR provides one year of technical support from the date of invoice. The technical support period is renewed with the purchase of an upgrade. Here are some suggestions to make the best use of technical support.

Most questions may be divided into either general questions about the concepts and principles or specific questions regarding a particular command file.

At any time that an errors is fixed the changes are posted to the web. To obtain the latest code, download glad58.zip from the demo/download section of www.aor.com. Copy glad58.zip to your installation folder and unzip into the installation folder.

1.5.4 General questions about concepts

The GLAD Theory Manual is the first and most important resource for understanding the numerical modeling concepts. If you have a question about concepts or methods, locate the section of the Theory Manual. You will find an answer to virtually all questions of concepts and theories in the GLAD Theory Manual.

If you email to AOR, “Please explain sampling.”, you will likely get the reply, “Please take a look at Chapter 5, GLAD Theory Manual.”, as we have already made our best effort to explain this important subject in the manual. If you have questions after reading the appropriate sections, we will be happy to help by phone or email.

1.5.5 Specific questions about particular command files

If you have problem with a specific command file. You will find the fastest way to a solution is to go through the debugging process, particularly with regard to attempting to reduce the command file to the shortest and simplest form that still exhibits the problem.

You will need to send us the specific command file manifesting the file. Please do not send a file that works and suggest that we will find a problem if the file is changed. Send the file in “broken” form so that it demonstrates the problem. It is best to send command files as email attachments. On occasion email processing software may change characters, tabs, etc. This seems to be less of a problem with email attachments.

Please provide some notes as to what you are attempting to do. We can not infer your desired configuration from the command file alone. Nor can we infer your intentions from the command file alone.

We can not accept proprietary designs. We look at hundreds of customer command files each year. There is no way that we can keep track of which concept is proprietary to which customer. It is our experience that a command file of a proprietary design that manifests a problem can always be modified into a non-proprietary form that still exhibits the same problem.

1.6 New features

1.6.1 Enhancements from Ver. 5.7 to 5.8

- The command `point/record` saves the same system variables as `point/list`, but does not display the values when the command is called.
- The command `plot/plot log/load` now adds file names from an external file to the list of files generated in the current command file execution.
- There are new predefined variables: “Ver” the GLAD version number as a real value such as 5.8 and “Bits” the number of bits of the running version of GLAD either 32 or 64.

- The command language now accepts complex numbers in calculations. It is necessary to declare the variable by the command variables /declare/complex. The imaginary part of a constant may be indicated by a following "i". For exampe 1+2i. The square root of minus one is "1i".
- mult /mode/correlation will set the complex correlation to a complex variable. The system variable corra may be assigned to a complex variable such as "variable/set x corra" where "x" has been defined as a complex variable.
- point/list/ij/sa or /xy/sa and point/list/ij/pa or /xy/pa will display the complex amplitude for s- or p-polarization respectively. The system variable point/sa or point/pa will assign the complex amplitude for s- or p-polarization to a complex variable.
- plot/plot_log/top will place the designated plotfile name on the top of the Watch plot displays.
- plot/liso accepts an array number pattern. For example 1,3,6:8 displays arrays 1, 3, 6, 7, and 8.
- The system variable resonator /status returns values giving the state of resonator processing. A variable value of 1 indicates normal processing after the two resonator test passes.
- Example Ex33f revised to allow backward input (parity = -1) to a globally defined resonator.
- Example Ex92i has been added to demonstrate how a thermal window would impact a laser mode from heating due to continual end pumping. Figure 1.20 shows the wavefront distortion of a window after 40 seconds of end-pumping. Figure 1.21 shows the wavefront distortion after 320 seconds. Figure 1.22 portrays the drop in Strehl Ratio over the 320 seconds and illustrates the temperature distribution is approaching the steady state condition.

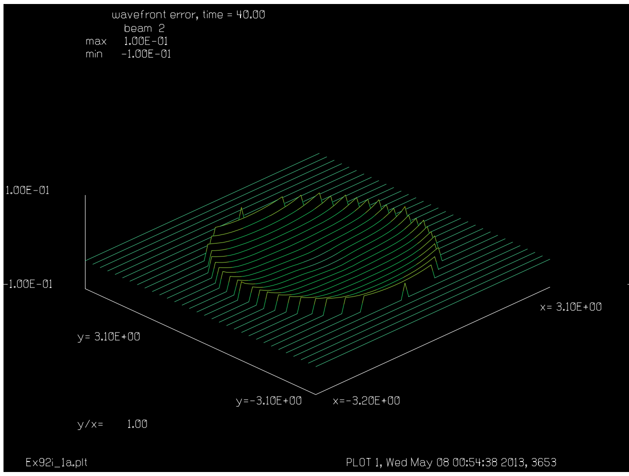


Fig. 1.20. Wavefront distortion after 40 seconds of end pumping for Ex92i.

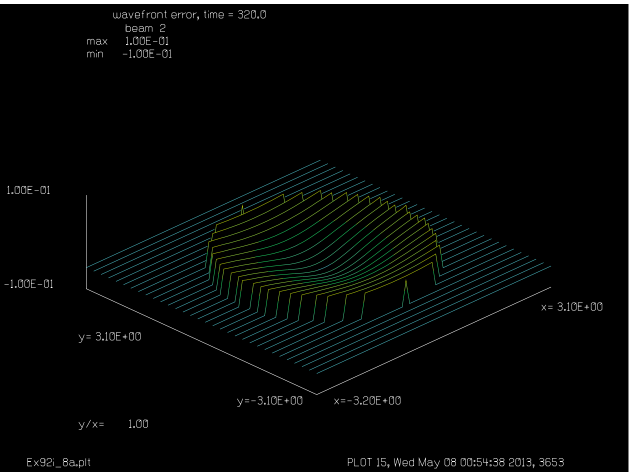


Fig. 1.21. Wavefront distortion after 320 second of end pumping. Distribution is approaching steady state for Ex92i.

- Example Ex11g illustrates a confocal, negative branch 1-D resonator.
- Example Ex33n illustrates a bowtie resonator using global positioning. See the configuration Fig. 1.23, converged mode Fig. 1.24, and correlation with the ideal mode Fig. 1.25.
- Example Ex86o illustrates a pencil of light making four bounces in a dielectric waveguide at near-TIR incident angle.

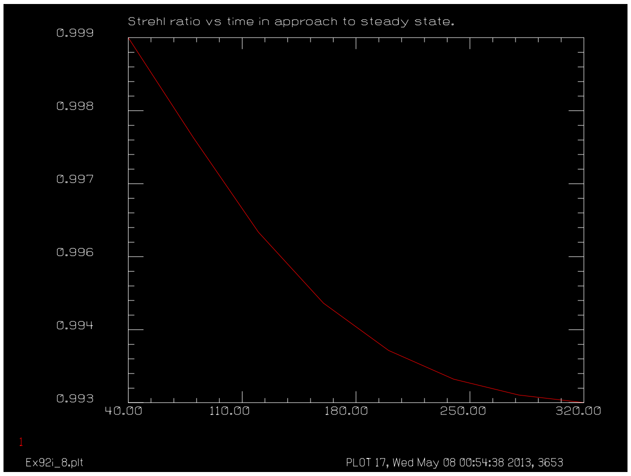


Fig. 1.22. Strehl Ratio over 320 seconds of end pumping. The Strehl Ratio is approaching a steady state condition as the thermal distortion stabalizes for Ex92i.

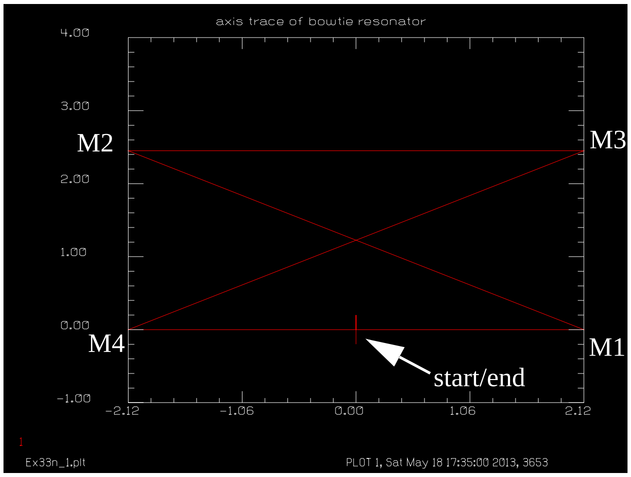


Fig. 1.23. Path of center ray for bowtie resonator. The calculation emanates from “start” and proceeds to M1, M2, M3, and M4 and finally returs to “end”.

- Example Ex86p compares a straight waveguide with a tapered waveguide for a pencil of light injected at an angle that is near the TIR condition. Because of the tapered reflecting walls the angle of the light increases with each bounce and the transmission losses correspondingly increase with each bounce.
- Example Ex117d shows complex pumping used in a stable resonator. Figure 1.32 shows a complex pumping distribution from Ex117c . Figure 1.33 shows the optical distribution early in the laser startup at pass = 100 with the complex pumping distribution printing into the optical intensity. Figures 1.34 and 1.35 show the staturated population inversion and the corresponding optical mode at pass = 5,000. Details of the pump distribution are not evident near steady state.

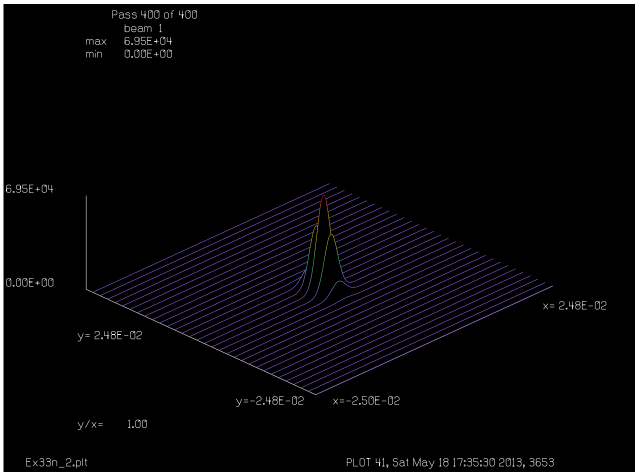


Fig. 1.24. Converged mode for bowtie resonator after 400 passes.

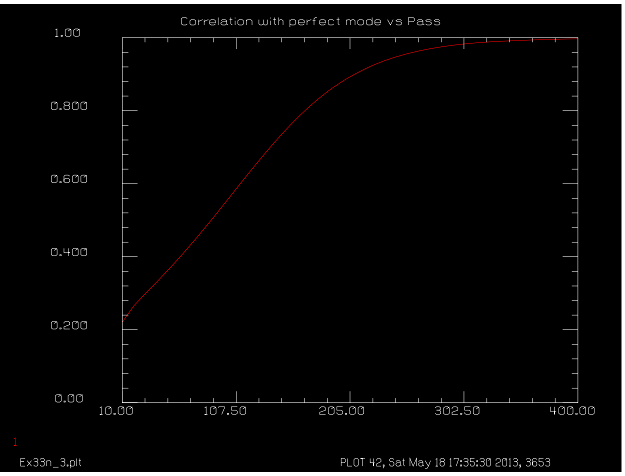


Fig. 1.25. Correlation of cavity mode for bowtie resonator with ideal mode versus pass number, showing a high degree of convergence to the ideal mode.

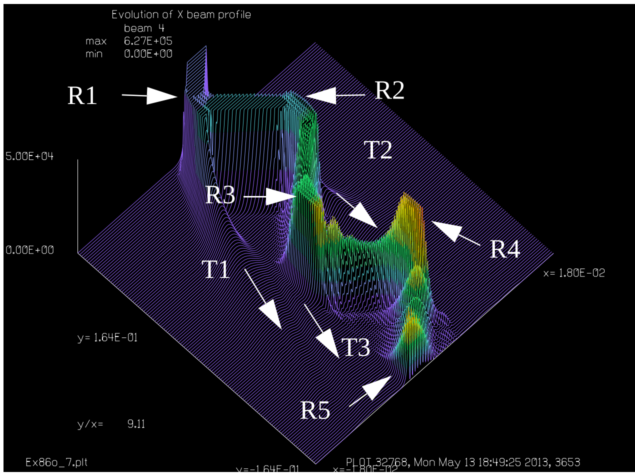


Fig. 1.26. A pencil of light is injected into a dielectric waveguide for Ex86o, initially headed to the left and making bounces at points R1 through R5. Reflection R3 appers to be distorted by the presence of the strong transmitted beam T1. The intermal mode follows a zigzag path. Light transmitted through the boundaries is strongly refracted in accord with near-TIR condition.

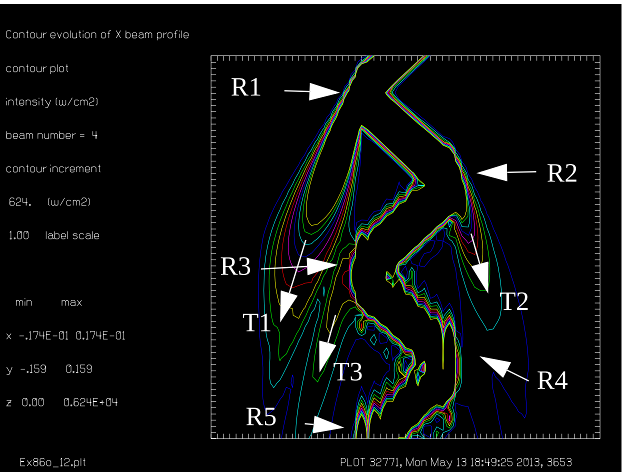


Fig. 1.27. A countour plot of the same situation as displayed in Fig. 1.26 for Ex86o with staturation to show only values below 1% of peak. It appears that the strong transmiited beam from R1 is affecting the reflection behaviour at R3.

1.6.2 Enhancements from Ver. 5.6 to 5.7

- A new, advanced coherent gain model, `gain/coherent`, treats both short pulse and coherent medium behavior. Ex125a shows transient, short pulse behavior. Ex125b shows a calculation of the atomic line width for a range of short pulses. See Ex125.

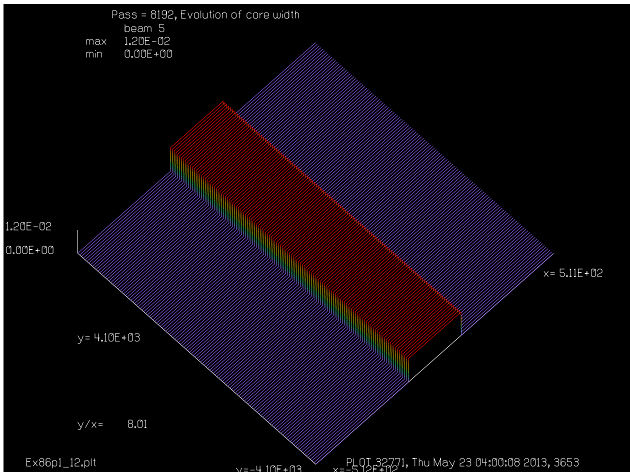


Fig. 1.28. For SWITCH=1, the index profile from start to finsish at the length of 0.328 cm is a constant 0.0040 cm half width.

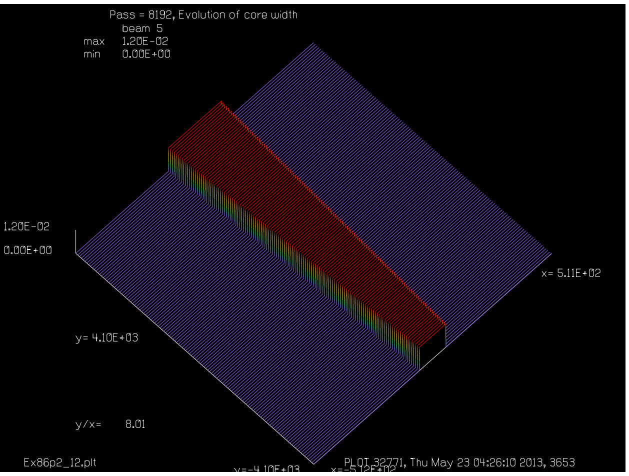


Fig. 1.29. For SWITCH=2, the index profile starts at 0.0040 half widht and finishes at 0.0020 cm half width over the length 0.328 cm.

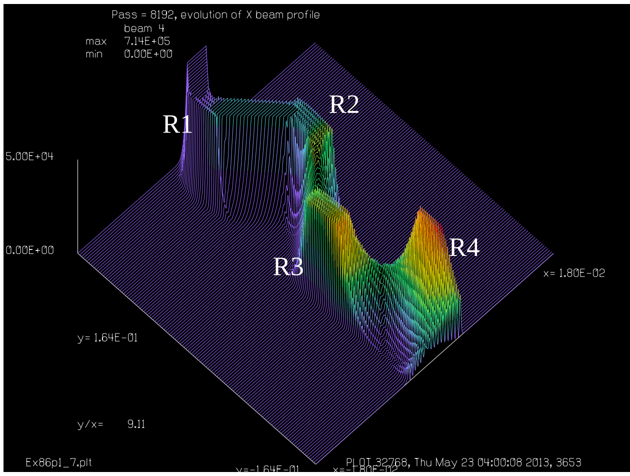


Fig. 1.30. For SWITCH=1 the core has constant width as shown in Fig. 1.28. A pencil of light is injected at an angle toward the left wall. The angle is set to be slightly less than the TIR angle. Leakage is very low through all reflections from R1 to R4. The primary change is due to the expansion of the gaussian beam.

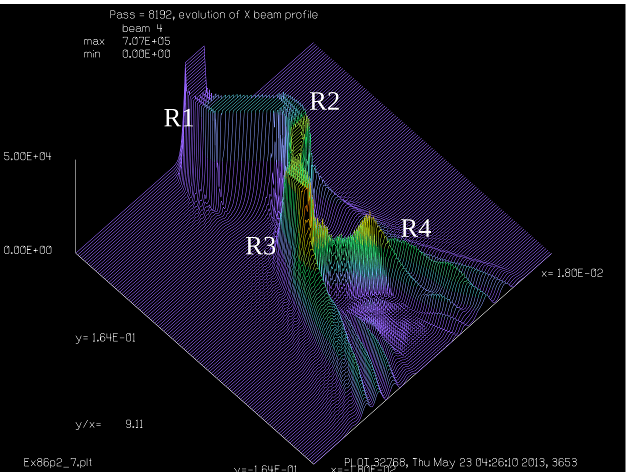


Fig. 1.31. For SWITCH=2 the core tapers from 0.0040 half width to 0.0020 half width as shown in Fig. 1.29. A pencil of light is injected at the same angle as Fig. 1.30 with an angle slightly less than the TIR angle for the tapered wall. There is almost no leakage at the first reflection R1, but with each reflection from R2 to R4 the angle increases and leakage increases correspondingly.

- GLAD 64 now can use up to 16 CPU’s for the `gain rate`, `zigzag` gain, and `energy/list` commands. All multi-threaded commands, including diffraction propagation, allow any number of CPU’s up to 16—not just powers of two. See `set/cpu`. Due to thread overhead, the best performance is often found with four to six CPU’s. GLAD 32 continues to allow two CPU’s.
- Arrays may now be used as optimization variables. Ex60b.inp through Ex60e.inp. See Ex60.
- A routine to model a saturable absorber has been developed for Q-switched lasers. Both ground and excited state absorption are included. See `gain/absorber`. It is illustrated in Ex80g and Ex80h. See Ex80 .

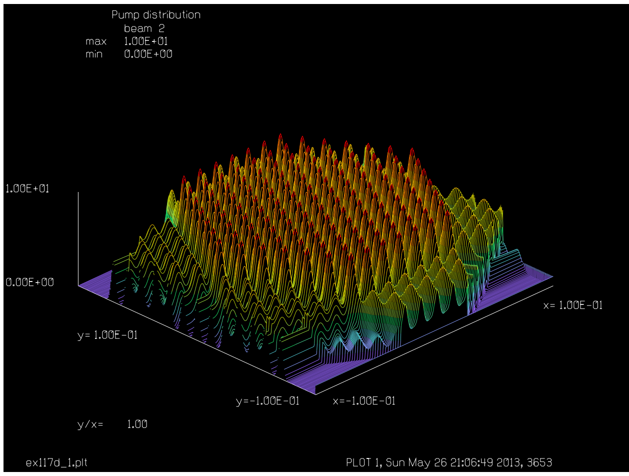


Fig. 1.32. A complex pump distribution from Ex117c that was formed by three banks of laser diodes at relative angles of 120 degrees.

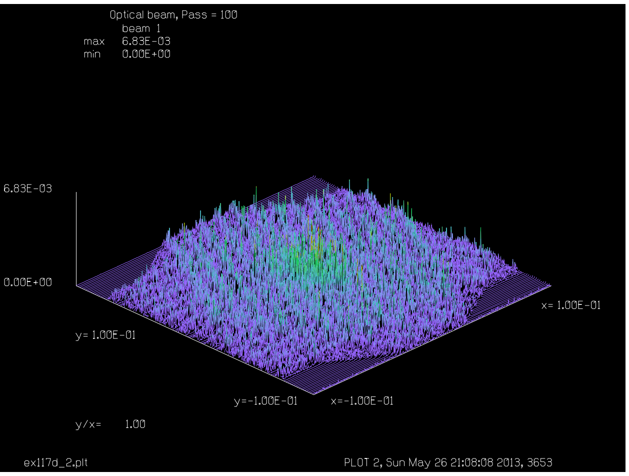


Fig. 1.33. Optical field at pass 100. The field has grown from spontaneous emission noise at pass 100 showing imprint of complex pumping.

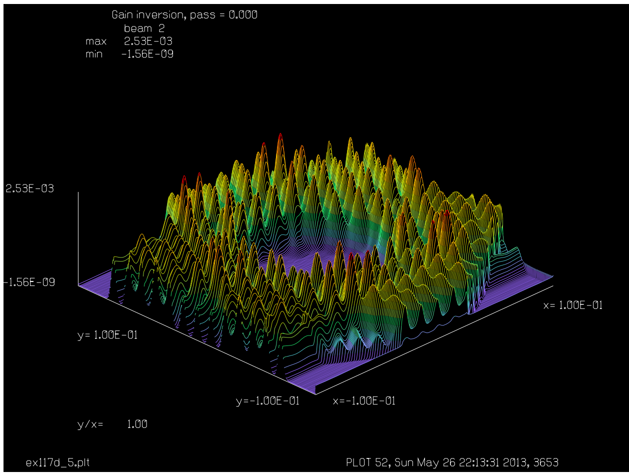


Fig. 1.34. Population inversion after 5,000 shows a high degree of saturation in the center. Compare with the complex pumping distribution shown in Fig. 1.32.

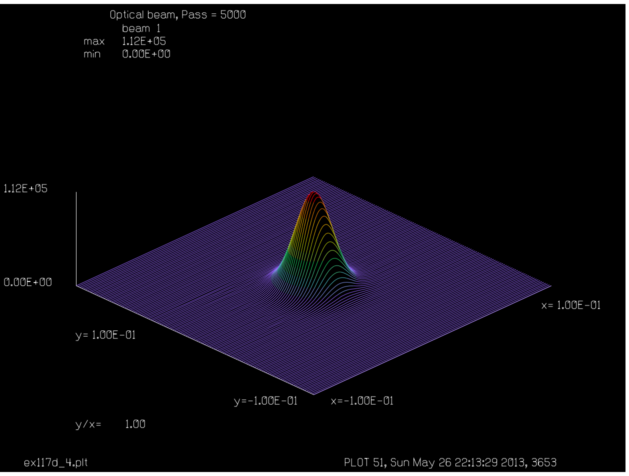


Fig. 1.35. Optical field at pass 5,000. The optical field near steady-state no longer shows any print through of the complex pumping field. Compare with Fig. 1.33.

- Ex32b shows how to implement a conjugate mirror or correction plate in either the near- or far-field. See Ex32 .
- Example psd_two.inp (in the examples folder) shows how to set a random distribution to a specified power distribution. Example psd_two_wavefront.inp shows how to set a random wavefront distribution to a specified power distribution. In both examples, the frequency units are controlled by setting the focal length to the wavelength.
- Ex11f.inp illustrates an unstable resonator with gain. In an unstable resonator the beam size in the forward direction is usually different than the backward direction. Of course the size of the gain region is fixed, so an iterpolation step is required to match the units of optical beam and gain region. Ex11f.inp illustrates the best way to do this. The See Ex11f .

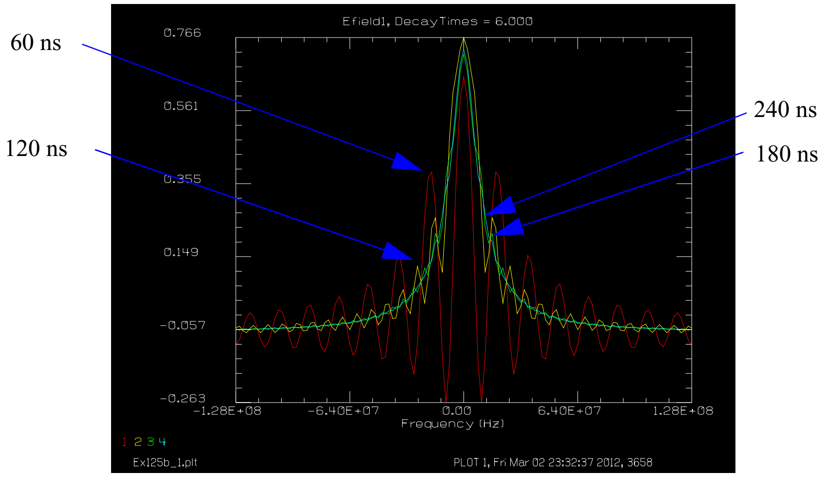


Fig. 1.36. Illustration of the variation of the transient atomic line width with pulse length. The curves were calculated by taking scans through a range of frequencies for various pulse length times of 60ns (red), 120ns (yellow), 180ns (green), and 240ns (cyan). At the longest time of 240ns, the curve approaches the stead-state atomic line width shape.

- The keynumber is now a predefined integer variable “Key”—useful form marking text and plot titles with the key identifier.
- The `pause` command now allows “Terminate GLAD”. The new modifier `pause /label` prints an identifying label in the popup message to identify the position of the `pause` command.
- Plotting activities may be turned off or on with `plot/off` and `plot/on`. Its use is comparable to `write/off` and `write/on` to limit output display.

1.6.3 Enhancements from Ver. 5.5 to 5.6

- GLAD 64 bit is now available with Ver. 5.6 and higher versions. It requires 64 bit Windows and can access all the memory available on the syste—no longer limited by 2GB per application. GLAD 64 will also automatically multi-thread the diffraction propogation to use from 1 to 16 processors as available as physical cores or hyperthreading. GLAD 64 also has an upgraded editor.
- The system variable `uniformity` now has modifier `sum`, to set a variable to the sum of all irradiance values or the sum of irradiance differences for `/two`.
- Commands `opo` and `sfg` now use a polarization definition pattern based on “o” and “e” for ordinary and extraordinary rays. For example: “oeo”. The old “x” and “y” description is still accepted, but “x” is interpreted as “o” and “y” is interpreted as “e”.
- GLAD now calculates the OPL, PPL, round trip time, and Gouy shift for stable resonators. These are displayed by `resonator /eigen/list` and available as system variables.
- The `resonator/run` command now trims additional geometric data at each pass for more stable performance over very long convergence runs. Trimed parameters include units, waist size and location, and the index of refraction. These parameters are maintained at the original valuse when `resonator /eigen/test` was performed.
- An example of finding higher order modes in a stable resonator by successive orthogonalization against the modes already found is given in Ex33m.

- Finding the first six modes of an unstable resonator using successive orthogonalization against the modes already found. See Ex11e .
- An array may be initialized to the first analytical mode of a cylindrical step index fiber. See `fiber`.

1.6.4 Enhancements from Ver. 5.4 to 5.5

- With Version 5.5.2, GLAD runs approximately 18 percent faster due to a change to new Intel compilers.
- Notice of expiration of technical support and version upgrade period has been added to the banner displayed at the start of the program for convenient reference.
- GLAD 5.5 supports running from a non-administrative account. Installation still requires administrative privliges.
- Trigonometric functions that accept degrees as arguments or return values in degree have been added. Each function is identified by a trailing “d” in the name. Functions include: `sind`, `cosd`, `tand`, `tan2d`, `asind`, `acosd`, `atand`, and `atan2d`.
- The function `time()` has been added to give the time in seconds since January 1, 1970 GMT. It can be used to generate a unique random seed in the expression `i = srand(time()).`
- The command `energy/ginversion` will integrate over *z* for 3D arrays if the section number is set to zero and yield a value with units of [j]. Similarly the variable produced by energy/ginversion will yield the same value for 3D arrays if the section number is set to zero.
- `intensity /zslice` now prints field data for a z-slice through a 3D array.
- `infile/real`, `infile/aimaginary`, `outfile/real`, and `outfile/aimaginary` have been added.
- The title of the security key may be changed at the time of upgrade following the instructions included with the upgrade password.
- Keyread.exe provides a user interface when called by means of the short cut. This the same as executing “keyread.exe menu”. The interactive menu may be called from GLAD by `privileges /keyread`. A log file named keyread58.log is generated and contains information about keyread activity.
- A closed-form solution for steady-state solution for the upper and lower levels based on the pumping rate and the incident irradiance. This is implemented in `gain/rate /steady`. A numerical check is illustrated in Ex69j .
- `gain/rate/steady` and `gain/rate/step` now have a “`list`” parameter to provide a list of overall properties and properties of the center step. Ex69f illustrates the use of this feature to gain insight into the numerical calculations of gain.
- `gain/three/step` now have a “list” parameter to list overall properties and properties of the center step. Ex69g illustrates the use of this feature to gain insight into the numerical calculations of gain.
- Section 9.6 provides more detail about the pump rate for three-layer gain with a single upper state.
- The Watch refresh time may now be set under the File, Preferences. The default is 1.5. This may be changed within the range 0.1 to 10 seconds.

- The offset values of graphic files may be specified in pixel coordinates relative to the lower, left corner of Watch.exe. See `plot`/`watch` and `plot/plot log`.
- The Watch program has a new menu item “Restore to Watch.dat” to restore the position and size of all graphic files to the original condition specified by GLAD through watch.dat. This removes the effect of user resizing or repositioning.
- The Watch program will now correctly set only the size if `xsize` or `ysize` is specified without the need to specify `xoff` or `yoff`.
- Column labels on the `udata` listing may be set with `udata`/`clabel`.
- Any variable may be locked to prevent inadvertend change. See `variables`.
- Labels may be added to variables with the command `variables`/`label`. The labels will be displayed in the variables listings.
- Variables may be assigned, locked, and labeled to arrays with `array`/`variable`. Many commands will display the variable name rather than the array number.
- `variables`/`value` will declare and set a single variable allowing “real” or “integer” specification. Any text after the value will become a variable label.
- The variable for `opl` and `oply` may be set to waves or length (in cm).
- `lensgroup` can now access the pre-built library names. For example if a lens called “mylens” has previously been defined and built for Beam 1 by `lensgroup/build` or a previous call to `lensgroup/run`, the physical optical equillavent system may be accessed by `lensgroup/run _mylens_001`.
- `set`/`prescan` turns “on” or “off” prescan—a search for macro definitions so that macros may be defined at any point in the command file. GLAD will look in external files accessed by `read`/`disk` only if the file name has no embedded variables or alias names as such names must be computed in real-time during command file execution.
- mult /`mode`/`reflector` enables a simple and efficient calculation of the feedback into a laser of light reflecting from external optics based on the curvature of a surface at that point.
- Ex124 illustrates the use of mult /mode/reflector for evaluating feedback coupling of an external surface into a laser cavity.
- Ex117c illustrates side pumping from three azimuthal angles spaced 120 degrees apart.
- Ex11d illustrates injection of the collapsing mode into an unstable resonator.
- Ex123 illustrates encoding a complex pattern into a hologram using a random noise key. The pattern can be reconstructed with the same random noise key, but not with a different random noise key.
- Ex69k illustrates the numerical procedures for single layer, three level rate equation model with multiple steps.
- Etalon1.inp demonstrates an iterative solution for the transmission through a thin film as an alternative to the closed form solution using `jsurf`/`single`.
- All main windows for IDE, Watch, GladOut, TraceBack, VariableMonitor, and the first edit window can be restored to the initialization values from the Interactive Input Window, Controls, “Reset Main Window Positions.”

- Six functions for calculating complex values have been added: `cmul_r`, `cmul_i`, `cdiv_r`, `cdiv_i`, `cexp_r`, and `cexp_i` for complex multiplication, division and exponenetiation returning either the real or imaginary component 1.4.2.1.
- `glass /index` has been added to set the index of the parameter "glass" in several commands. It performs the same function as "`glass/set 5 a0`".
- An example of a movie is included in this PDF file in Sect. 1.3.8 .
- `read /disk` may be included within a macro or another `read /disk` to one level.
- mult `/mode/correlation/intensity` calculates the correlation of the intensity distributions of two beams.
- `resonator /list` now displays the round trip time and `variables /set` (variable) `resonator/roundtriptime` sets a variable to the round trip time. The round trip time may be used for the gain pumping time. The frequency separation of longitudinal modes is the inverse of the round trip time.
- `pause /label` allows the user to add an identifying label for the pause. Variables may be included by preceeding them by the "@" symbol.

1.6.5 Enhancements from Ver. 5.3 to 5.4

- The family of plots displayed by Watch may be moved as a group by moving the main Watch window. This makes it easy to drag all Watch windows across the screen or onto a second monitor for a dual-monitor setup.
- GLAD now pre-scans the entire command file and identifies and saves all macros. Locating the macros at the bottom of the command file after `end` can improve readibility.
- The position and size of the first editor window is saved and used as the default for the next execution of GLAD.
- Enhanced metafile (EMF) graphics may be generated from Watch or from `plot /meta/emf`.
- The GladOut display may be cleared from the command line `write /screen/clear`.
- The pattern "//" may be used as an in-line, non-displayed comment similar to "#".
- The command `energy /ginversion` displays the integrated population inversion in j/cm.
- A variable may be set to the population inversion at a point with `point/ginversion` or the integrated population inversion with `energy/ginversion` in j/cm.
- The modifier `ginversion` has been added to most plots to show the population inversion distribution.
- `plot /udata/set` with no column identifiers lists current identifiers.
- Prism ends with variable angles on the input and output faces are now incorporated into the command `zigzag` to model a zigzag amplifier. See Example Ex121b .
- `plot/zigzag` displays the configuration of the zigzag amplifier in gain or beam coordinates.
- The `line` command displays the current source line in the output. The function `line()` returns the current source code line.

1.6.6 Enhancements from Ver. 5.2 to 5.3

- The html command has been completely rewritten to provide dynamic generation of HTML output with automatic update by sourceline, tables with tooktip definitions, and scalable vector graphic (SVG) graphics that may be expanded and the range of plot versions viewed. See Sect. 1.3.6. The old GLAD HTML viewer is no longer used after Ver. 5.2.
- The resonator command has been enhanced. This command now tests the system macro, issues an internal resonator/set command, and makes a second test to verify stable behavior. The resonator/set command is no longer needed explicitly and the double tests catch many errors causing instability of the round trip ABCD matrix that a single test would not.
- The internal testing by the resonator now, by default, ignores gain, plot, thermal, and udata commands.
- resonator/reset resets various parameters to initial conditions without changing the complex amplitude distribution. Useful to prevent drift of parameters during very long resonator settling or multi-pulse problems.
- Comment “CC” is the same as the printing comment “C”, except that “CC” always prints, even if writing is turned off.
- For HTML output tooktips have been added. Tooltips are a small window that gives the definition of the term in a table when the mouse is placed over the word. Only works when the HTML file is viewed from a regular browser. The old GLAD HTML viewer is no longer used after Ver. 5.2.
- phase2real and waves2real have been added to transform phase or wavefront into a real distribution.
- Example Ex120 illustrates efficient gain interactions in a five-pass, zigzag amplifier; laser diode cross pumping, and associated thermal distortion.
- Magnification factors are now calculated for lensgroup . Variables xmag, ymag, and oblique give the respective x-, y-, and 45 degree components of magnification due to refraction at tilted surfaces.
- Scalable vector graphics (SVG) plot files can now be output from Watch and may be used in HTML output with the capability to expand or hide the plot.
- pack /reference specifies which beam being packed is to provide the reference units to which all other beams are interpolated.
- plot/xslice and plot/yslice now use keyword ibeams instead of kbeam. The command will now accept 0 for all beams and patterns such a 1,2,3:5.
- abcd /operator can now build up a sysem of lenses and spacings (with no intervening apertures) into a single ABCD operator that may be applied with a single step.
- The user may now cut and copy from the GLAD Output window to the system ClipBoard.
- The GladOut display may be cleared from the menu with Edit, Clear.
- Init-Run now writes a better heading with a time and date stamp for easier reading of GLAD Output to distinguish among multiple command file executions.
- pause now includes the choice of “Cancel” to call up the termination/break option menu and has the source line number in the title of the message box.
- pause now accepts a decimal value for a timed pause.

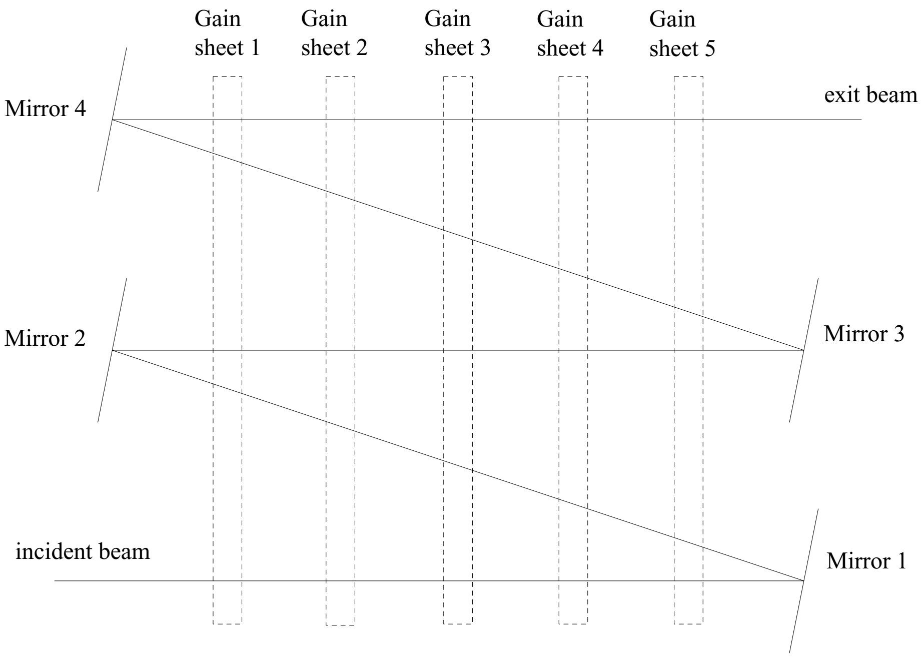


Fig. 1.37. A beam makes five passes through an amplifier region. In the two expanding paths, the optical beam will interact with each of the gain sheets at different points. For this configuration, if the rise in pixels is a multiple of six pixels, then the rise at the gain sheets will be successively multiples of 1, 2, 3, 4, and 5 pixels.

- `mult /complex` now has four keywords to allow separate multiplication factors for s- and p-polarization states. Keywords have changed.
- `add /coherent/factors` and `add /incoherent/factors` have been revised to peform similarly to the other `add` commands.
- Error traceback has been improved including better line number identification.
- Ex88 g.inp illustrates an example of a high Fresnel number diffraction pattern formed with a partially coherent LED having an M^2 = 60 illuminating a square aperture and propagating a short distance. This partial coherence removes much of the edge diffraction ringing.
- The data type `ginverse` has been added to most plots to display the population inversion of a gain sheet. Note that `gain /rate/inversion` will extract the population inversion into another array.
- `copy /section` now copys a single input section to all output sections if the section number is set to zero so that a all sections of a 3D array can be easily set to be identical.
- `clear`/complex will now set the 2nd polarization state.
- `time/halt` and `time/resume` have been added to allow the accumulation of time to be halted and then resumed without resetting to zero. Allows the times of several operations to be summed.
- The command `zigzag` models a zigzag amplifier. See Example Ex121a .
- The `plot` commands now have the option to display the population inversion with `/ginversion`.
- `add/coherent/con` and `add /incoherent/con` accept decentration keywords and allow allow the arrays to be of different size.

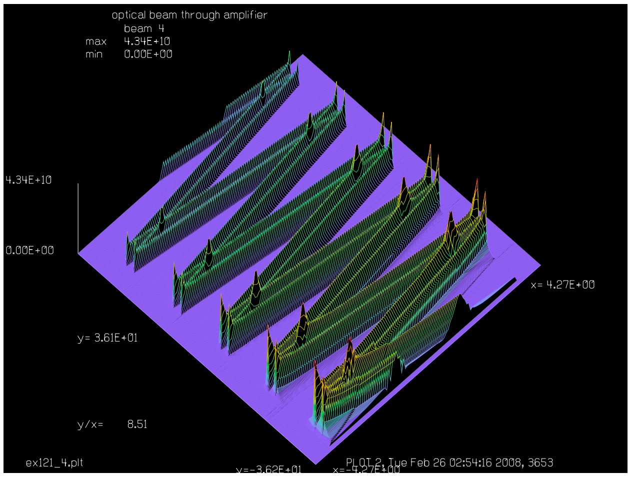


Fig. 1.38. Optical beam passing through a zigzag amplifier, as illustrated in Ex121, by entering from the top and heading first to the right mirror. The beam makes ten reflections and five full cycles. Note the high intensity in the overlap region that leads to higher inversion depletion. Gain is calculated at approximately 10,000,000 points. Approximately 70,000,000 differential equations are solved in about six seconds on an ordianry PC.

1.6.7 Enhancements from Ver. 5.1 to 5.2

- `mult/beam` /`jones` allows implementation of a 2D array where each element of the array is a Jones matrix. This allows the Jones matrix operations to vary across the aperture. See example jones1.inp and jones2.inp.
- `gain/three` implements three level gain where both upper and lower levels may consist of multiple levels forming a manifold.
- Example Ex119 illustrates how to implement sub-sampling of the round-trip time of a resonator.
- For macros, the Traceback window now gives the absolute line position in the file for easier reference.
- The command `line` gives the source line position and source file name. The system variable `line` gives the source line position. The `echo` command now gives the source line position.
- The `clear` command now takes a beam number range.

1.6.8 Enhancements from Ver. 5.0 to 5.1

- A model of three-level gain has been added. See `gain/three`. Also see Ex69e .
- A detailed numerical check of the four-level, rate equation gain equations. See Ex69f .
- A procedure was developed for doing through-focus diffraction calculations projected onto a tilted surface. See tilt.inp.
- Memory will now be automatically expanded as required up to the maximum physical memory available `memory`.
- `functions` /exp added.

- Several accelerator keys have been revised to conform with MS Wordpad®, MS Word®, and many other text editing programs. Ctrl S (hold down Ctrl, then strike S key) “Save” to save the file. Shift Ctrl S invokes “Save As”. Ctrl F invokes the search dialog box. F3 does a forward search with the same search string. Shift F3 does a backward search with the same string. Ctrl P invokes the print operation. Shift Ctrl P invokes the print setup dialog box.
- Numbers corresponding to length may have “mm” (millimeters), “in” (inches), “ft” (feet), “mi” (microns), “nm” (nanometers), “km” (kilometers), or “m” (meters) appended to cause appropriate scaling to centimeters. For example `1.3mm` will be read as 0.13 cm.
- The command `adapt` can now either correct directly or create a phase plate.
- The elements `roof` and `cornercube` now have either `\global` or `\nonglobal` forms.
- The maximum number of variables has been increased from 400 to 999, with five predefined constants (and 994 available for use in command files. The predefined constants are π, e, h, c, and the version number Ver.
- The macro library is now held in memory for faster execution. This library may be displayed by the `set/maclib/show` command. Highlighting of lines and commands is now done in the macro library as well as in the source files. The library is rebuilt each time Init-Run is executed.
- Line numbers may be added, updated, or removed by Controls on the GladEdit menu.
- Command files may be reformatted automatically with indents for different levels of macros, IF-ELSE-THEN constructs, and `pack/in` and `pack/out` blocks. Indenting the source text greatly improves readability. See Controls, Indent on the GladEdit menu.
- The Traceback window now identifies multiple commands on the same line.
- Highlighting now displays lines dynamically in both the source and macro library and identifies command position for multiple commands on one line. Highlighting may be turned on or off from Controls from either the Interactive Input Window or any GladEdit window.
- The GladEdit windows may be controlled from a GLAD command file or the Interactive Input Window by the command `edit`. Files may be opened. Windows may be hidden or shown.
- Command `time` now provides microsecond accuracy and the system variable `time` gives the value from the most recent call to `time/show`.
- `jsurf/fresnel/refl` allows for general complex index of refractions to accommodate reflection from metal surfaces or TIR with absorbing material on the low index side.
- `rms` and `variance` now may now be applied to irradiance as well as wavefront.
- A model of semiconductor gain has been added. See `gain/semiconductor`. Also see example Ex69d.
- The keyword `ibeams` now accepts beam number ranges and sequences in addition to “0” for all beams and a single beam number. For example “:2,6:8,11,13,19:” processes beams 2 and below, 6 to 8, 11, 13, and 19 and higher.
- Definitions of terms used in output tables will be displayed or hidden with the `set/definitions` command. For example using `set/definitions/on` before `geodata` will cause the definitions to be printed at the end.
- `fitgeo/msquared` has been added to calculate M-squared by second moment.

1.7 Incompatibilities with earlier versions

1.7.1 Incompatibilities of Ver. 5.8 with 5.7

- The variable parity used in `global` `/def` no longer reverses the paraxial direction indicator.
- Commands `connect` and `disconnect` are obsolete and have been deleted. Use the equivalent commands `infile` and `outfile` with string modifiers `noheader` and `binary`.

1.7.2 Incompatibilities of Ver. 5.7 with 5.6

None.

1.7.3 Incompatibilities of Ver. 5.6 with 5.5

- In optimization tables `/cha` and `/del` have been deleted. Use `/clear` to remove all table entries. Tables may be rebuilt after being cleared.
- `times` has been droped in `optimize/run` which will now run only once.

1.7.4 Incompatibilities of Ver. 5.5 with 5.4

- The keyword `nstep` has been deleted from `gain/step` for three-level and four-level gain. Only one step is required or appropriae for Frantz-Nodvik gain.
- `add` `/opl` now leaves the phase of the beam receiving the sum unchanged.

1.7.5 Incompatibilities of Ver. 5.4 with 5.3

None.

1.7.6 Incompatibilities of Ver. 5.3 with 5.2

- Line highlighting in GladEdit has been reactivated with improvements and is active with error traceback. Switching highlighting on causes highlighting of the current line in the edit window.
- `co2gain` `/dist` is obsolete use `co2gain` `/prop`.
- `plot/xslice` and `plot/yslice` now use keyword `ibeams` instead of `kbeam`. The command will now accept 0 for all beams and patterns such a 1,2,3:5.
- mult `/complex` has different keywords to allow for different multiplication of p-polarization.
- `add` /coherent/factors and `add` /incoherent/factors have been revised.
- `flip` no longer alters the global coordinate system for the beam respective.
- The menu item “Run” on the GladEdit menu has been renamed to “NoInit-Run”.
- `time/init/coarse` and `time` `/show/coarse` have been deleted. All timer functions use the high precision clock.

1.8 License levels

There are three license levels: GLAD, GLAD Pro and GLAD 64.

1.8.1 GLAD (58G) features:

- Intended for laser and physical optics engineering modeling.
- Native 32 bit code. Runs on both 32 and 64 bit operating systems.
- Limited to 2GB system memory.
- Laser resonators: stable, unstable, ring lasers.
- Detailed four-level laser gain, steady-state gain, gain sheets.
- Complex physical optics systems.
- Finite element thermal modeling.
- Propagation in 3D geometry.
- Astigmatism of tilted and decentered mirrors.
- Idealized refractive elements.
- Dielectric waveguide modeling.

1.8.2 GLAD Pro (58P) has all GLAD (58G) features and adds:

- Intended for both engineering modeling and advanced research.
- Native 32 bit code. Runs on both 32 and 64 bit operating systems.
- Limited to 2GB system memory.
- Diffration propagation multi-threading supports two CPU’s.
- Detailed ray tracing calculations of tilted and decentered mirrors.
- Detailed ray tracing calculations of complex lens groups with tilts and decenters.
- Damped least squares optimization of all system parameters.
- In addition to detailed four-level gain, includes three-level gain, and semiconductor gain.
- Nonlinear optics: Raman, frequency doubling, four-wave mixing, optical limiting, sum frequency generation.
- Zigzag amplifier.
- Atmospheric effects: turbulence and thermal blooming.
- High NA vector diffraction calculations.
- Lens array features.

1.8.3 GLAD 64 (58P64) has all features of GLAD (58P) and adds:

- Performance enhancement and coherent gain model.
- Requires 64 bit operating system.
- Native 64 bit code is faster than 32 bit code.
- Security dongle supports both GLAD Pro (32 bit) and GLAD 64 (64 bit). Customer has access to both GLAD Pro (32bit) as well as GLAD 64 bit.
- Can access all available memory on the computer.
- Multi-threading of four-level gain and diffraction propagation up to 16 CPU’s.
- Coherent gain for short pulse effects

2. Command Descriptions

ABCD General ABCD paraxial operator. Operator

Command Forms(s): **ABCD**

```
abcd/set                 kbeam
abcd/list                kbeam
abcd/last
abcd/operator/direct     kbeam ax bx cx dx ay by cy dy
abcd/operator/set        ax bx cx dx ay by cy dy
abcd/operator/multiply   ax bx cx dx ay by cy dy
abcd/operator/lens       xfl yfl
abcd/operator/prop       zstep
abcd/operator/list
abcd/operator/apply      kbeam
```

Description: ABCD

This command models general systems and gradient index media in terms of the ABCD matrix. `/set`, `/list`, and `/last` control the ABCD operator for the specified beam.

The ABCD operator using `/direct` may be used to represent an arbitrary optical system. applied to any of the beams and will implement propagation, change of index, magnification change, and optical power.

$$\begin{bmatrix} A_x & B_x \\ C_x & D_x \end{bmatrix} \qquad \begin{bmatrix} A_y & B_y \\ C_y & D_y \end{bmatrix} \tag{1}$$

One can represent a simple system of lenses and spacings that has no intervening apertures by a single ABCD operator. This can save calculation time as only one diffraction propagation is required and is particularly effective for an imaging system. One can either specify the entire system with `/direct` or build up the ABCD operator in steps.

Using `/direct` explicitly specifies an arbitrary ABCD matrix and applies it to the specified beam. Only a single propagation step is required in combination with appropriate magnification, index of refraction, and beam curvature changes. The determinant of the matrix is the index of refraction and must be identical for both x- and y-directions.

Instead of specifying the total ABCD matrix by means of `/direct`, the ABCD matrix may be built-up by initializing a separate ABCD matrix with `/set` and then specifying the components of a simple lens system with spaces by `/lens` and `/prop`. The total length will be determined from the sum of all `/prop` specifications. Alternately any system element may be specified in general ABCD form with `/multiply`. The built-up ABCD system is implemented with the `/apply` command.

Modifier 1	Description
/set	Sets the ABCD operator to the unity matrix.
/list	Lists the current ABCD matrix (default).
/last	Lists the last change ABCD matrix.
/operator/direct	Iimplements the ABCD operator directly (default).
/operator/set	Sets ABCD operator without applying it. By default the ABCD matrix is set to the unit matrix.
/operator/multiply	Multiplies the specified ABCD operator without applying it.
/operator/lens	ABCD of idealized lens multiplies the currnt ABCD operator without applying it.
/operator/prop	ABCD multiplies the currnt ABCD operator without applying it.
/operator/list	Lists the stored ABCD operator.
abcd/operator/apply	Applies the current ABCD operator.

Numerical Values	Description	Defaults
kbeam	Unique beam number.	
ax, bx, cx, dx	Matrix elements for x-direction.	1,0,0,1
ay, by, cy, dy	Matrix elements for y-direction.	ax, bx, cx, dx

System Variable Data	Description
abcd/(mod) mod = ax, bx, cx, dx, ay, by, cy, dy	Current ABCD properties of kbeam.

Example of abcd/operator

System with three lenses and three spacings (requiring three propagation steps)

```
lens/sph 1 F1
prop T1 1
lens/sph 1 F2
prop T2 1
lens/sph 1 F3
prop T3 1

ABCD operation implementing the entire system with a single step: /apply
abcd/oper/set                       # reset local ABCD matrix
abcd/oper/lens F1                   # build up ABCD operator
abcd/oper/prop T1
abcd/oper/lens F2
abcd/oper/prop T2
abcd/oper/lens F3
abcd/oper/prop T3                   # total length is now T1 + T2 + T3
abcd/oper/apply 1                   # apply ABCD operator with a single step
```

ABR or ABERRATION Aberrations. Aberration

Command Forms(s): **ABERRATION**

aberration/ripple	Phase gratings.
aberration/seidel	Seidel aberration.

Command Forms(s): **ABERRATION (Continued)**

`aberration/zernike`	Zernike aberration.
`aberration/radial`	Radial mode aberration.
`aberration/grin`	Gradient index aberration.

Description: ABR

Various types of aberration. Random aberrations of gaussian distribution and Kolmogorov atmospheric aberration are implemented with the `phase/kolmogorov` command. Also see `phase`.

ABERRATION/GRIN Gradient index aberration. Aberration

Command Forms(s): **ABERRATION/GRIN**

```
aberration/grin  ibeams deltan exp zstep rnorm xdec ydec
```

Description: ABERRATION/GRIN

This command implements a gradient index lens (GRIN):

$$W(x, y) = \frac{\mathtt{Deltan}\bullet\mathtt{Zstep}}{\lambda_0}\left(\frac{(x-\mathtt{Xdec})^2+(x-\mathtt{Ydec})^2}{\mathtt{Rnorm}^2}\right)^{\frac{\mathtt{Exp}}{2}} \tag{2}$$

where $W(x, y)$ is the wavefront error per step, (x, y) are the coordinates, and λ_0 is the wavelength. The aberration is added but diffraction propagation is not performed. Use `prop zstep` to add diffraction effects.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams). Accepts pattern.	`1` to `nbeam`
`deltan`	Range of index of refraction that is modulated for abr/grin.	`0`
`exp`	Coefficient for exponent for abr/grin.	`0`
`zstep`	Step length.	`0.`
`rnorm`	Normalization radius (cm).	largest of x- or y-beam size
`xdec`, `ydec`	Decenter of aberration.	`(0.,0.)`

ABERRATION/RADIAL Special radial aberrations for axicons. Aberration

Command Forms(s): **ABERRATION/RADIAL**

```
aberration/radial/decenter  ibeams ewav azdeg irefbeam
abertation/radial/tilt      ibeams ewav azdeg rnorm irefbeam
```

Description: ABERRATION/RADIAL

These commands add tilt (Fig. 1) and decenter (Fig. 2) error to a beam in radial mode, after an axicon.

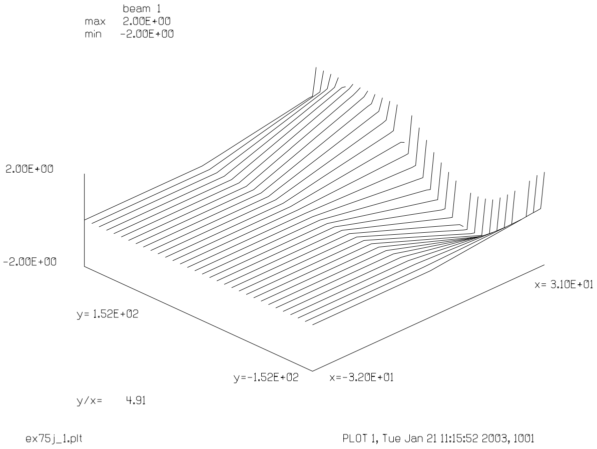


Fig. 1. Phase plot of tilt aberration on a radial beam. The vertical direction corresponds to the azimuthal direction.

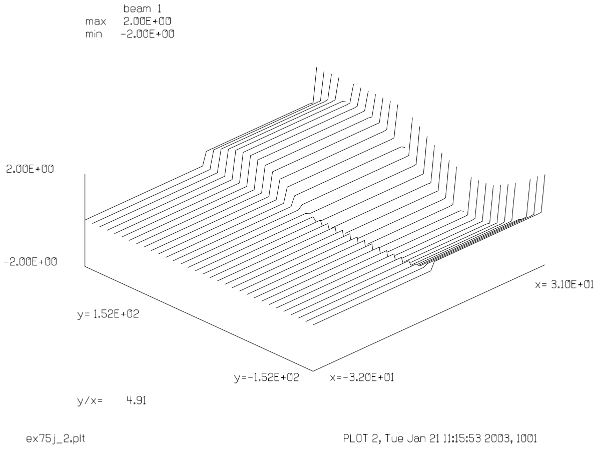


Fig. 2. Phase plot of decenter aberration on a radial beam.

Modifier 1	Description
`/decenter`	Radial piston error. $W(\theta) = \texttt{ewav} \bullet \cos(\theta - \texttt{azdeg})$
`/tilt`	Radial tilt error. $W(x, y) = \texttt{ewav}\dfrac{r}{\texttt{rnorm}}\cos(\theta - \texttt{azdeg})$

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams). Accepts pattern.	`1` to `nbeam`
`ewav`	Aberration coefficient (waves).	0.
`azdeg`	Azimuth angle clockwise from top of beam (degrees).	0.
`rnorm`	Normalization radius (cm).	Largest beam size (X or Y)
`irefbeam`	Reference beam number for wavelength.	`ibeams`

ABERRATION/(ripple) Adds phase grating. Aberration

Command Forms(s): **ABERRATION(ripple)**

```
aberration/crip    ibeams ewav wnbr pcent rnorm xdec ydec irefbeam
aberration/hrip    ibeams ewav wnbr pcent rnorm xdec ydec irefbeam
aberration/lrip/   ibeams ewav wnbr azdeg phi rnorm xdec ydec irefbeam
cosine
aberration/lrip/   ibeams ewav wnbr duty azdeg phi rnorm xdec ydec
square             irefbeam
aberration/lrip/   ibeams blazeangle wnbr azdeg phi rnorm xdec ydec
blazed             irefbeam
```

Description: ABERRATION/(ripple)

These commands put a phase ripple (grating) into the beam distribution. Also, see `grating` .

Modifier 1	Description
`/crip`	Circular ripple. $W(r) = \mathtt{ewav} \bullet \sin\left(\frac{2\pi r \bullet \mathtt{wnbr}}{\mathtt{rnorm}}\right), r = \sqrt{x^2 + y^2}$
`/hrip`	Hexagonal ripple. $W(x, y) = \mathtt{ewav} \bullet \sin\left(\frac{2\pi r \bullet \mathtt{wnbr}}{\mathtt{Rnorm}}\right), \begin{cases} \frac{\lvert y\rvert}{\lvert x\rvert} > \frac{1}{\sqrt{3}}, r = \frac{\sqrt{3}}{2}\lvert y\rvert + \frac{\lvert x\rvert}{2} \\ \frac{\lvert y\rvert}{\lvert x\rvert} \le \frac{1}{\sqrt{3}}, r = \lvert x\rvert \end{cases}$
`/lrip`	Linear ripple. $W(x, y) = \mathtt{ewav} \bullet \sin\left\{[y\cos(\mathtt{Azdeg}) + x\sin(\mathtt{Azdeg})]\frac{2\pi \bullet \mathtt{wnbr}}{\mathtt{rnorm}} + \mathtt{Phi}\right\}$

Modifier 2	Description
`/cosine`	Cosine phase linear ripple.
`/square`	Square profile phase linear ripple.
`/blazed`	Blazed phase grating.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`ewav`	Aberration coefficient (waves).	`0.`
`blazeangle`	Angle of blazing. Refracted/reflected angle should match diffracted angle for best efficiency.	
`duty`	Duty cycle (ratio of raised region to line width).	`0.5`
`azdeg`	Azimuth angle clockwise from top of beam (degrees).	`0.`
`wnbr`	Number of cycles from center to `rnorm`.	
`pcent`	`pcent` = 0 or 1. 0 for null at center, 1 for peak at center.	`0.`
`phi`	Phase at center (degrees).	`0.`
`rnorm`	Normalization radius (cm) for `/crip` or half width for `/hrip`.	largest beam size (X or Y)
`xdec`, `ydec`	Coordinates of aberration center.	`0.`, `0.`
`irefbeam`	Reference beam number for wavelength.	`ibeams`

ABERRATION/(Seidel) Adds Seidel aberration. Aberration

Command Forms(s): **ABERRATION/SEIDEL**

```
aberration/ast/   ibeams ewav azdeg rnorm xdec ydec irefbeam
polar
```

Command Forms(s): **ABERRATION/SEIDEL (Continued)**

```
aberration/ast/   ibeams ewavx ewavy rnorm xdec ydec irefbeam
cartesian
aberration/coma   ibeams ewav azdeg rnorm xdec ydec irefbeam
aberration/focus  ibeams ewav rnorm xdec ydec irefbeam
aberration/sph    ibeams ewav rnorm xdec ydec irefbeam
aberration/tilt/  ibeams ewav azdeg rnorm xdec ydec irefbeam
runout
aberration/tilt/  ibeams thetarad azdeg xdec ydec irefbeam
angle
aberration/cone   ibeams ewav rnorm xdec ydec irefbeam
```

Description: ABERRATION/(Seidel)

These commands put Seidel and similar aberrations into the beam distribution.

Modifier 1	Description	Mathematical form
`/ast/polar`	Astigmatism.	$W(r, \theta) = \mathtt{ewav}\left(\frac{r}{\mathtt{rnorm}}\right)^2 \cos^2(\theta - \mathtt{azdeg})$
`/ast/cartesian`	Astigmatism.	$W(x, y) = \mathtt{ewavx}\left(\frac{x}{\mathtt{rnorm}}\right)^2 + \mathtt{ewavy}\left(\frac{y}{\mathtt{rnorm}}\right)^2$
`/coma`	Coma.	$W(x, y) = \mathtt{ewavx}\left(\frac{r}{\mathtt{rnorm}}\right)^3 \cos(\theta - \mathtt{azdeg})$
`/focus`	Focus.	$W(x, y) = \mathtt{ewav}\left(\frac{r}{\mathtt{rnorm}}\right)^2$
`/sph`	Spherical.	$W(x, y) = \mathtt{ewav}\left(\frac{r}{\mathtt{rnorm}}\right)^4$
`/tilt`	Tilt.	$W(x, y) = \mathtt{ewav}\left(\frac{r}{\mathtt{rnorm}}\right) \cos(\theta - \mathtt{azdeg})$
`/fold`	Folding.	$W(x, y) = \mathtt{ewav}\left\lvert\left(\frac{r}{\mathtt{rnorm}}\right) \cos(\theta - \mathtt{azdeg})\right\rvert$
`/cone`	Cone.	$W(x, y) = \mathtt{ewav}\left\lvert\frac{r}{\mathtt{rnorm}}\right\rvert$
`/grin`	GRIN.	$W(x, y) = \mathtt{deltan}\frac{2\pi}{\lambda_0} r^{\mathtt{exp}}$

Modifier 2	Description
`ast/polar`	Astigmatism in polar coordinates (default).
`ast/cartesian`	Astigmatism in x- and y-coordinates.
`tilt/runout`	Define the angle by the height of the tilt of the angle at radius `rnorm`.
`tilt/angle`	Define the tilt angle in radians.

Modifier 2	Description (Continued)
fold/runout	Define the angle by the height of the folding error at radius rnorm. Similar to tilt except the absolute value of radius is used.
fold/runout	Define the fold angle in radians. Similar to tilt except the absolute value of radius is used.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
ewav	Aberration coefficient (waves).	0.
ewavx, ewavy	X- and y-components of aberration (\coefficient (waves).	
thetarad	Tilt angle in radians.	
azdeg	Azimuth angle clockwise from top of beam (degrees).	0.
rnorm	Normalization radius (cm).	largest beam size (X or Y)
xdec, ydec	Coordinates of aberration center.	0., 0.
irefbeam	Reference beam number for wavelength.	ibeams

ABERRATION/ZERNIKE Adds Zernike aberration. Aberration

Command Forms(s): **ABERRATION/ZERNIKE**

```
/rad/rotational       ibeams nrad coef rnorm rignore xdec ydec irefbeam
                      [(parameter)]
/sin/rotational       ibeams nrad mazi coef rnorm rignore xdec ydec
                      irefbeam [(parameter)]
/cos/rotational       ibeams nrad mazi coef rnorm rignore xdec ydec
                      irefbeam [(parameter)]
/rad/anamorphic       ibeams nrad mazi coef xnorm ynorm xignore yignore
                      xdec ydec irefbeam [(parameter)]
/sin/anamorphic       ibeams nrad mazi coef xnorm ynorm xignore yignore
                      xdec ydec irefbeam [(parameter)]
/cos/anamorphic       ibeams nrad mazi coef xnorm ynorm xignore yignore
                      xdec ydec irefbeam [(parameter)]
/number/(Modifer 3)   ibeams rnorm rignore xdec ydec irefbeam
```

Description: ABERRATION/ZERNIKE

These commands put Zernike aberrations into the beam distribution.

Modifier 2	Description
/rad	Radial Zernike. $W(r, \theta) = R_n(r)$
/sin	Sine Zernike. $W(x, y) = R_{nm}(r)\sin(m\theta)$
/cos	Cosine Zernike. $W(x, y) = R_{nm}(r)\cos(m\theta)$

Modifier 2	Description (Continued)
/number	Coefficients input by polynomial number. See fitzern Tables 1 and 2. Form: Number Coef Number Coef . noop

Modifier 3	Description
rot	Rotational form of Zernike polynomials (default).
ana	Anamorphic form of Zernike polynomials and $\tilde{x} = \frac{x}{\mathtt{xnorm}}$, $\tilde{y} = \frac{y}{\mathtt{ynorm}}$, and $\left(\frac{x}{\mathtt{xignore}}\right)^2 + \left(\frac{y}{\mathtt{yignore}}\right)^2 \le 1$.

Parameter	Description
standard	Set of polynomials organized by radial order. All azimuthal terms are included (default). See fitzern , Table 1.
fringe	Set of 37 polynomials organized by polynomial order based on the sum of radial and azimuthal orders. Used in many interferometric reduction programs. fringe has more radial terms and fewer azimuthal terms. See fitzern, Table 2.
radial	Set of radial polynomials to 20th order. See fitzern , Table 3.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
nrad	Radial Zernike order, *n*.	0.
mazi	Azimuthal Zernike order, *m*. (*n*-*m*) must be even and greater or equal to 0.	0.
coef	Zernike coefficient (waves).	
rnorm	Normalization radius (cm).	Beam size
rignore	Operation cutoff radius (cm).	rnorm
xnorm,ynorm	Normalization coefficients for x- and y-coordinates (cm) for anamorphic mode.	Beam size
xignore, yignore	Operation cutoff coordinates (cm) for anamorphic mode.	xnorm, ynorm
xdec, ydec	Coordinates of aberration center.	0., 0.
irefbeam	Reference beam number for wavelength.	ibeams

Example of abr/zern/number

```
clap/c/c 1 20
abr/zern/number/standard 1 rnorm=20
11 1.2
22 -.5
noop
```

Add Zernike terms 11 and 22 (4th and 6th order spherical aberration from the standard set). The input of Zernike terms is terminated when any GLAD command is entered. In this case, `noop` (no operation), terminates data input.

ADAPT Adaptive mirror model. Component

Command Forms(s): **ADAPT**

```
adapt/apply        kbeam xspace yspace
adapt/phaseplate   kbeam1 kbeam2 xspace yspace
```

Description: ADAPT

This command models an adaptive optic mirror using a bandpass model (see GLAD Theory Manual, Chap. 15, theory.pdf). It is assumed that the actuators are evenly spaced in a rectangular array. `Xspace` and `yspace` define the separation of the actuator influence function. Spatial frequencies below $1/(2\times \texttt{Xspace})$ and $1/(2\times \texttt{Yspace})$ are removed.

The modifier `/phaseplate` creates a compensating phase plate in `kbeam2` and leaves the incident beam unchanged. Use an aperture in front of the adaptive optic to establish the shape of the phase plate.

Modifier 1	**Description**
`/apply`	Apply adaptive optic correction (default).
`/phaseplate`	Create a phase plate in kbeam2 and leave kbeam1 unchanged.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`kbeam1`, `kbeam2`	`Kbeam1` is incident and `kbeam2` is phase plate. `Kbeam2` must be of attribute data.	
`xspace`	Actuator spacing in the x-direction.	
`yspace`	Actuator spacing in the y-direction.	`xspace`

Example

```
nbeam 2 data
clap/c 1 20
phase/random 1 .1 3 iseed=11; str 1
plot/w plot1.plt
title starting plot
plot/x 1  pmin=-1.2 pmax=1.2
if 0 then
  adapt/apply 1 3 3
  plot/w plot3.plt
  title after correction
  plot/x 1 pmin=-1.2 pmax=1.2
else
  adapt/phaseplate 1 2 3 3
  plot/w plot2.plt
  title original (yellow) and phaseplate (green)
  plot/x fi=1 la=2 pmin=-1.2 pmax=1.2
  mult/beam 1 2
  plot/w plot3.plt
  title corrected (yellow)
  plot/x 1 pmin=-1.2 pmax=1.2
endif
str 1
```

ADD Adds beams coherently or incoherently. Operator

Command Forms(s): **ADD**

add/coherent/con	k1beam k2beam...k10beam icent jcent
add/coherent/res	k1beam k2beam...k10beam
add/incoherent/con	k1beam k2beam...k10beam icent jcent
add/incoherent/res	k1beam k2beam...k10beam
add/coherent/factors	k1beam k2beam r1 i1 r2 i2
add/incoherent/factors	k1beam k2beam fac
add/opl	k1beam k2beam...k10beam
add/vector	k1beam k2beam...k10beam

Description: ADD

Adds the contents of beams with numbers kbeam2...k10beam to the contents of kbeam1. Under the default scale method, /res, the units for beam k1beam are determined such that the field array encloses the field arrays from all the beams being added. Data from the beam k1beam is included in the summation. All field data is interpolated into beam k1beam. When the /con modifier is selected, the units and beam center of beam k1beam is conserved (no rescaling).

Example of add/incoherent/factors to make a gaussian dimple of irradiance

```
nbeam 2
gaussian/cir 1 1 20
gaussian/cir 2 .5 10
add/inc/factors 1 2 -1                # subtract irradiance of 2 from 1
plot/x/i 1
```

Modifier 1	Description
/coherent	Adds beams coherently into beam k1beam.
/incoherent	Adds beams incoherently into beam kbeama.
/opl	Adds beams coherently with absolute phase factor $\exp(jkz)$ into beam kbeama.
/vector	Adds beams according to vector diffraction and allows high angle interference. The rotation of the global coordinate commands is considered, but not the translation. The x- and y-components of the sum are placed in K1beam. The z-component is placed in k2beam. Beams 3 to 10 are summed.

Modifier 2	Description
/con	Conserves current units (default). Arrays to be summed need not match the dimensions of the summing array. Decenter is allowed.
/res	Permits rescaling when needed (not used for \vector).
/factor	Add k2beam to k1beam with multiplication factor(s).

Numerical Values	Description	Defaults
`k1beam`	Beam array to which data is added. For `/vector` the x- and y-components are summed into `k1beam` and the z-components are summed into `k2beam`.	
`k2beam-k10beam`	Beams being added. For `/vector` beams `k3beam-k10beam` are added. for `/factor` only k2beam should be specified.	
`fac_mult`	Multiplication factors for `add/inc/factors` (pixel-to-pixel): i(1) = i(1) + fac*i(3)	`1.`
`r1`, `i1`,`r2`, `i2`	Multiplication coefficients for `add/coh/factors` (pixel-to-pixel): s(1) = s(1) + (r1,i1)*s(2), p(1) = p(1) + (r2,i2)*p(2) where “s” and “p” represent the complex amplitudes of the respective polarization states.	`(1.,0.)`,`(1.,0.)`
`icent`, `jcent`	Offset of center for `add/./con`, `jcent` is measured positive downward (pixels).	0, 0

ALIAS Builds a table of alias names. Language

Command Forms(s): **ALIAS**

`alias/add`	(Alias string) (Source string)
`alias/delete`	(Alias string)
`alias/change`	(Alias string) (Source string)
`alias/list`	
`alias/reset`	

Description: ALIAS

This command controls a table of aliased character strings. See the `declare` command which is especially designed for using variables. Any character string consisting of non-blank characters and not exceeding 20 characters may be given an alias. The alias must also have no blanks and is limited to 20 characters. Commas may be substituted for blanks in the source string. The commas will be converted to blanks during the command parsing which follows the alias substitution. The leading character should not be a number. All variables are aliases of internal registers. See the `variables` command. π, e, Plank's constant h, the speed of light c, and the version number `Ver` are predefined aliases.

One of the uses of this capability is to provide mnemonic names for register variables. For example,

```
alias/add x_y_z Radius
```

sets `x_y_z` to be an alias for `Radius`. The alias must be prefixed by “@”. For example,

```
clap 1 @x_y_z
```

is equivalent to

```
clap 1 Radius
```

using the definition above. `Alias` preserves the case of both character strings, so that for

```
alias Valx 1
alias ValX 2
```

the values `Valx` and `ValX` are different.

Modifier 1	Description
`/add`	Adds an alias to the table. A maximum of 99 aliases are allowed.
`/del`	Deletes the aliased value from the table.
`/list`	Lists the aliases and names (default).
`/change`	Change the string assigned to the specified alias name.
`/reset`	Deletes all aliases from the table.

AMPLITUDE Takes square root or real part of distribution. Operator

Command Forms(s): **AMPLITUDE**

```
amplitude/abs      kbeam
amplitude/sqrt     kbeam
```

Description: AMPLITUDE

This command takes the square root of the real part of the distribution in `kbeam`. This function will convert an irradiance distribution into amplitude form so that the existing plotting routines (the plotting routines square the distribution before plotting) will give correct representation of the irradiance pattern.

The mathematical operation is

`/abs`

$$a(x,y) \to \{\mathrm{Real}[a(x,y)a^*(x,y)]\}^{1/2}$$

`/sqrt`

$$a(x,y) \to \{\mathrm{Real}[a(x,y)a^*(x,y)]\}^{1/4}$$

where $a(x,y)$ is the complex amplitude distribution and Real[] is the operator which takes the real part of the distribution.

Modifier 1	Description
`/abs`	Takes absolute value of complex amplitude.
`/sqrt`	Takes square root of absolute value of complex amplitude.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1

ARRAY Defines beam array size and polarization state. Begin-end

Command Forms(s): **ARRAY**

```
array/list                   ibeams
array/set/2d                 ibeams nlinx nliny ipol [(Attribute)]
array/set/3d                 ibeams nlinx nliny nlinz ipol [(Attribute)]
array/path                   (path name)
array/name                   (generic beam name)
array/attribute              kbeam attribute [(Attribute)]
array/convert/polarize       kbeam
array/convert/unpolarize     kbeam
array/convert/2d             kbeam
array/convert/3d             kbeam nlinz
array/reset                  ibeams
array/variable/declare       (name) kbeam # (label)
array/variable/list
array/variable/free          (name)
```

Description: ARRAY

Initializes the beam(s) array, array dimensions, and polarization status, and prints disk unit numbers used to store beam arrays and array dimensions. This command will destroy the existing disk file for the beams specified and create a new file. Calling `array` with an existing beam will erase all field data. At program startup, all beam arrays are dimensioned 64 × 64 with one polarization state. Usually, `nbeam` and array should be among the first commands called. The user may increase the number of data points on an existing array by using `nbeam` and `array` to create a new beam file and copy to interpolate data into the new beam array.

If the command `noinit` is entered into the STARTUP (no file extension) file, GLAD will suppress file initialization, allowing the user to define the directory path name and the generic file name. This can be used to put the beam files on a different directory or even a different disk. The generic beam name may be used to avoid overwriting existing beam files which are being saved. The array must be initialized using the `array/set` command if `noinit` is used. See `noinit`.

The array is considered to be a beam array by default (attrib = 1). By specifying the attribute of the array to be data (attrib = 2), the array is rendered nonpropagating. The `axicon/radial` command generates a radial beam (attrib = 3). The `axicon/annular` command has attribute, attrib = 4. An annular beam with area weighted intensity is attrib = 5.

The `array` command reinitializes all beam data except for wavelength and refractive index. These may be explicitly set by the `wavelength` command.

Modifier 1	Description
`/list`	Prints local file names used to store beam arrays and the array dimensions.
`/set`	Initializes the beam(s) array disk unit, array dimensions, and polarization status.
`/path`	Establishes path name for beam files if they are not to be in the local directory. Enclose name in single quotes to allow "/" or other special characters.

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Modifier 1	Description (Continued)
/name	Defines generic beam file name. By default this is beam. Enclose name in single quotes for long paths and special characters. The total length of path and beam names must not exceed 80 characters.
/attribute	Specify attribute. Array has attribute beam by default. (attrib = 1).
/convert	Toggles between $N \times M \times 1$, 2D polarized array and $N \times M \times 2$ for non-polarized beam. Allows the use of sections to address the polarization states separately.
/reset	Reset geodata , zreff, global data without changing beam size. Useful in macros to reinitialize the beam.
/variable	Declares, lists, or frees variable assignments to arrays. Many commands will display any variable assignments rather than arrray numbers.

Modifier 2	Description
set/2d	Two-dimensional array with transverse dimensions x and y.
set/3d	Three-dimensional array.
convert/2d	Convert from $N \times M \times L$ to $N \times ML$, where L represents the number of z-sections.
convert/3d	Convert from $N \times M$ to $N \times M/L \times L$, where L represents the number of z-sections.
convert/polarize	Convert from $N \times M \times 2$, unpolarized, $N \times M \times 1$ polarized.
convert/unpolarize	Convert from $N \times M \times 1$, polarized to $N \times M \times 2$, unpolarized.
variable/declare	Declare a variable assignment for an array number.
variable/list	List variable assignments for array numbers.
variable/free	Free the variable assignement to the array.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
kbeam	Single beam number.	1
nlinx	Array dimension in x-direction, must be of form 2^N.	Required
nliny	Array dimension in y-direction, must be of form 2^N.	nlinx
nlinz	Array dimension in z-direction, must be of form 2^N.	1
ipol	Determines polarization state, 0, one polarization state 1, two polarization states	0
attribute	Attribute number. Can also be specified by attribute name.	

Parameters	Description
(name)	Name of the variable.
(label)	A comment after “#” to be used as a label for the array variable.

Attribute	Description
beam	Array represents the complex amplitude of an optical beam and may propagated. This state is listed as attrib = 1 in status /p listing. (attrib = 1).

Attribute	Description (Continued)
data	Array represents non-beam data and can not be propagated by either prop or dist. This state is listed as attrib = 2 in status /p listing. (attrib = 2).
radial	Radial beam for axicon commands. (attrib = 3).
annular	Annular beam with normal intensity. (attrib = 4).
annular2	Annular beam with area weighted intensity. (attrib = 5).
circular	One-dimensional array representing rotationally symmetrical beam. (attrib = 7).

Three dimensional arrays may be defined with the modifier /3d. The three dimensional arrays consists of nlinz X-Y sections. The ordinary two dimensional array operations may be used on three dimensional arrays with the specific section defined by set/section section. The copy /res, and copy/con will copy all sections. Use copy /section to copy a specific section of one beam to a different section of another without presetting the section numbers. clear will set only the current section. If clear is zero, all sections will be set. Here is an example of some simple 3D beam operations:

```
array/s/3d 1 32 32 2 # define 3d array
set/section 1 0 # define 0 section for clear command
clear 0 2 # clears entire 3d array to 2
set/section 1 1 # set section to 1
clap/c/c 1 10 # apply clear aperture
intmap 1
set/section 1 2 # set section to 2
clap/c/c 1 5 # apply different clear aperture
intmap 1
array/convert # convert to polarized array
plot/ell # show array as elliptical polarization
```

AUTOCORRELATION Calculates autocorrelation. Operator

Command Forms(s): **AUTOCORRELATION**

autocorrelation kbeam

Description: AUTOCORRELATION

Calculates the autocorrelation of the array. Note that the irradiance value of the autocorrelation function is not meaningful. Use real and imaginary displays to display the autocorrelation function. For example, plot/liso /real.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1

AXICON Axicon elements. Component

Command Forms(s): **AXICON**

axicon/radial/left/focal	kbeam radius [(Parameter)]
axicon/radial/right/focal	kbeam radius [(Parameter)]
axicon/radial/left/afocal	kbeam radius zshift [(Parameter)]

Command Forms(s): **AXICON (Continued)**

```
axicon/radial/right/afocal                kbeam radius zshift [(Parameter)]
axicon/annular/(left or right)            kbeam
axicon/annular/(weight or unweight)       kbeam
axicon/axial/left                         kbeam radius zshift
axicon/axial/right                        kbeam radius zshift
```

Description: AXICON

The axicon command controls a number of operations associated with axicons. The axial beam maybe treated in unfolded form as illustrated in Fig. 3.

Normally beams propagate as “pencils” of light with a well defined optical axis. This condition is referred to as axial mode. Axicon mirrors can transform axial beams into radially (or nearly radially) propagating beams. A radius is specified for the exiting radius of the radial beam. GLAD propagates the distance past the cone tip and then does a geometric transformation. to the radial mode. After an axial beam hits an axicon, the optical axis is split into a plane perpendicular to the original axis. This condition is referred to as radial mode. See Fig. 4.

See Fig. 5. In the general case, an axicon will operate on a beam in radial mode to produce a beam with the optical axis transformed into a cylinder. This is referred to as annular mode. See Fig. 6. An important special case is when the radius of the cylindrical axis of the annular beam degenerates into the optical axis. This case constitutes a return to axial mode.

Axicons may be designated as left or right axicons depending on whether the tip points left or right respectively (see Fig 7). There are two general types of axicon calculations focal and afocal, selected by the parameter. In afocal operations, it is assumed that the beam is collimated and there is no fundamental difference between annular propagation and axial propagation. The choice of left or right axicons for return from radial mode is arbitrary and the axicons may be shifted along the axis.

In afocal operation, the radial mode is always returned to axial mode, with the complex amplitude calculated correctly but without maintaining the cylindrical axis. In afocal operation the geometric radius of curvature is not necessarily correctly propagated through an axicon system. Not only may axicons be selected arbitrarily with left or right orientation but the axicons may be shifted forward or backward along the axis. See Fig. 8.

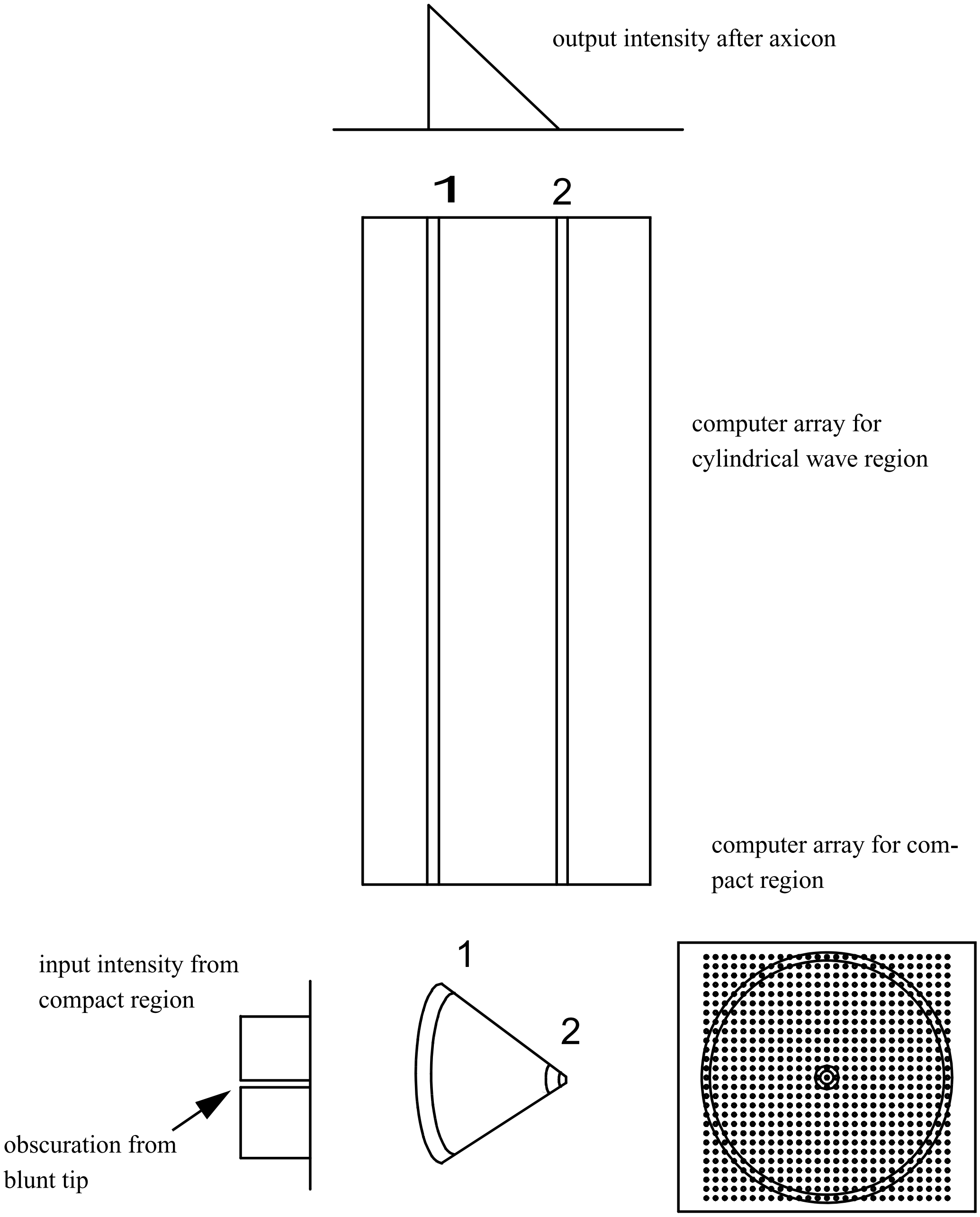


Fig. 3. The axicon /radial command maps zones in the compact beam path into the cylindrical wave representation of radial mode and vice versa. The compact beam may be represented by a conventional square array. The inner zone 2 must be greatly stretched, reducing the intensity substantially. The tip of the zone can not be treated.

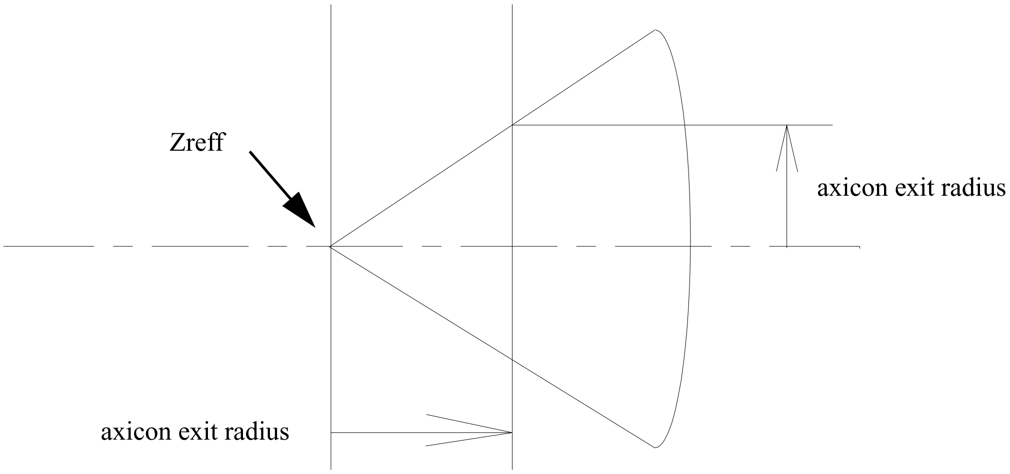
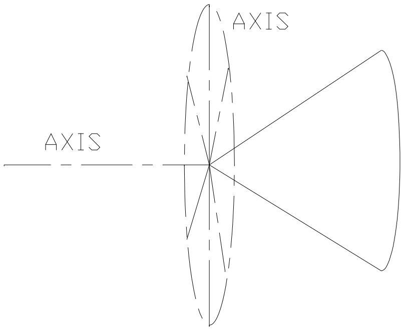


Fig. 4. A radius is specified for the exiting radius of the radial beam. GLAD propagates the distance past the cone tip and then does a geometric transformation. to the radial mode.



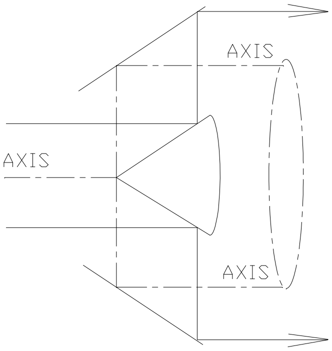


Fig. 5. An axicon mirror splits the optical axis of an axial beam into a plane perpendicular to the axis in forming a radial beam.

Fig. 6. A second axicon can generate an annular beam from a radial beam with the axis taking the form of a cylinder. In `afocal` operation the beam be propagated as an axial beam.

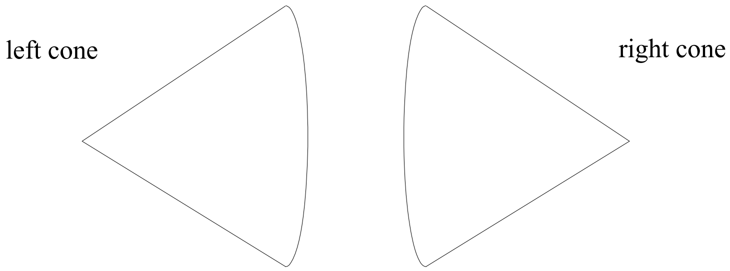


Fig. 7. Axicon mirrors are divided into left and right forms depending on which way the apex points. GLAD locates the axicon at with the apex at the current `Zreff` position.

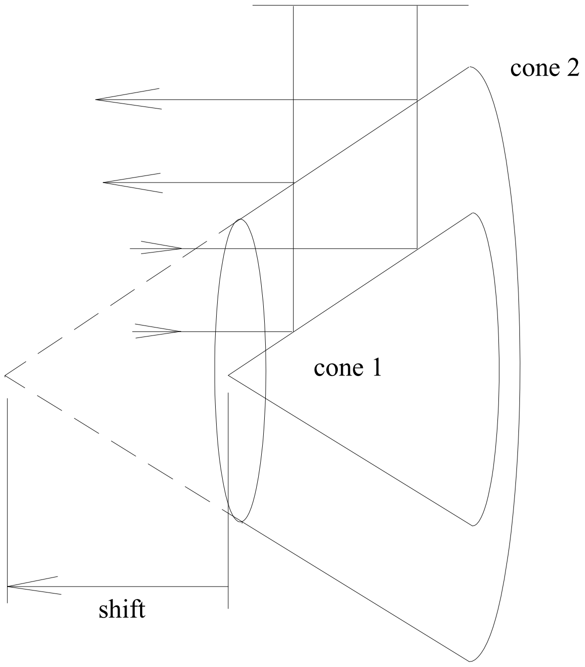


Fig. 8. The position of the optical axis in radial mode is established at the apex of Cone 1 (unless `zshift` is specified). Cone 2, to return from radial mode, may also be shifted. `Zshift` applies only to `afocal` operation.

In focal operation, beams may be converging or diverging and the geometric radius of curvature is correctly propagated, as shown in Fig. 9. focal operation is the default condition for axicons. For a beam in radial mode, the command `axicon/axial` will calculate the location and left or right orientation necessary to return the radial beam to an axial beam. GLAD keeps track of the parity change at each mirror in order to determine the correct axicon orientation. In radial mode, `Zreff` is measured with respect to the optical axis, as shown in Fig 10.

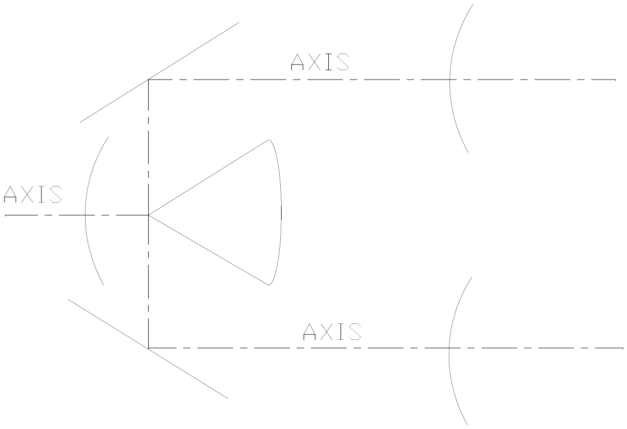


Fig. 9. A noncollimated beam may be propagated correctly in `focal` operation. The divergence of the beam is propagated through the system and leads to a toroidal wavefront in annular mode.

A special command `axicon/annular` is provided to generate annular beams. In annular mode, beams may have optical power which causes the beam to converge or diverge with respect to the cylindrical optical axis. A beam in annular mode may be returned to radial mode by `axicon.eps/radial`. In annular mode, the intensity of the beam may be weighted by the area by the `/weight` modifier and unweighted by the `/unweight` modifier. Noncollimated beams in annular mode should be weighted before and unweighted after propagation through a ring focus to properly maintain energy conservation. In annular mode, `zreff` is measured parallel to the original optical axis but offset by the radius of the annular optical axis, as shown in Fig. 10.

Axicons require special consideration of nonuniform irradiance and polarization disruption. The axicon remaps the irradiance in nonuniform fashion. See Fig. 3. From geometrical theory, intensity in each zone is changed by the ratio of the radius of that zone before and after the axicon. In propagating from an axial beam to a radially expanding beam, all axial zones are converted to zones in the radial beam with identical radii. This causes inner zones in the axial beam to have greatly reduced intensity in the radial beam. The process is reversed in converting radial beams to axial beams. Zones in the radial beam which are converging to the axicon tip have high intensity in the axial beam. In principle the intensity of the axial beam goes to infinity at the axicon tip after conversion from a radial beam. In reality, diffraction will cause the “hot tip” effect to spread. In converting from axial to radial mode or vice versa, GLAD requests specification of a finite radius of the radial beam. For axial-to-radial conversion the final state in radial mode is set at the specified radius. For radial-to-axial conversion, the beam is propagated in radial mode to the specified radius and then converted.

In `axial` mode, the variable `Zreff` represents the position along the axis. This may be displayed by the `zreff` command. In radial mode, `Zreff` represents the radial distance from the optical axis. In annular mode, `Zreff` represents the position along the axis.

The aberrations associated with decenter or tilt of axicons and toroidal mirrors in radial mode may be treated by using the `aberration/radial/decenter` and `aberration/radial/tilt` commands.

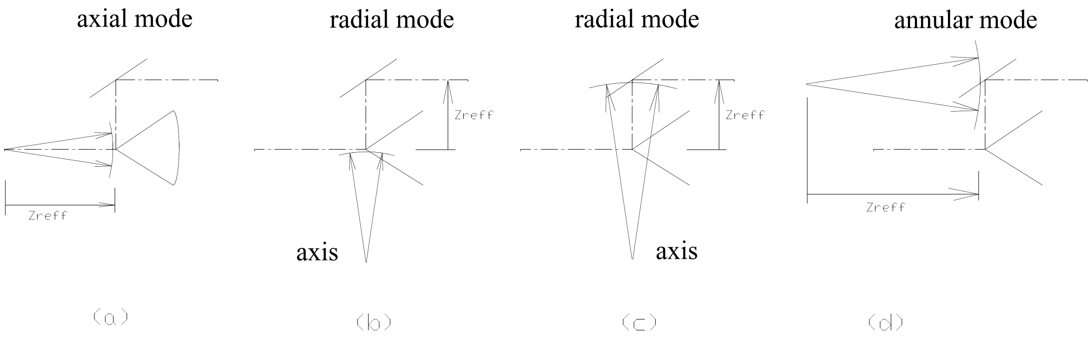


Fig. 10. In `focal` operation the reference position is measured radially with respect to the optical axis in radail mode. Fig. (a) shows the axial mode with `zreff` = 0 to the left. In Fig. (b) `zreff` is measured with respect to the optical axis. The center of curvature is shifted negatively. In Fig. (c) the beam has expanded to the next axicon mirror. In Fig. (d), `zreff` is measured along the optical axis. The position `zreff` = 0 is has been displaced by the radius of the annular axis with respect to the optical axis.

In radial mode, the cylindrical wavefront is represented on a square array by cutting the cylindrical wavefront at the top, flattening it, and pasting it onto the square array. The complex amplitude distribution is represented by a square array similar to the representation of the usual axial mode except the positive x-direction now represents positive projection along the axis and the y-direction represents the azimuthal direction with the center of the y-direction corresponding to the top of the cylindrical wavefront and the positive y-direction corresponding to clockwise rotation. The cylindrical wavefront is made to completely fill the square array in the vertical array so that the wrapping behavior of discrete Fourier transforms correctly treats the problem of cylindrical wave propagation. In annular mode, the same form of numerical representation is used although, unlike the cylindrical wave, some error in diffraction propagation exists in the azimuthal direction.

Modifier 1	**Description**
`/radial`	Converts from axial or annular mode to radial mode. (attrib = 3).
`/axial`	Converts from radial mode to axial mode, selecting the appropriate axicon to matches the radial axis to a conventional axis. (attrib = 1).
`/annular`	Converts radial mode to annular mode. The radius of axicon which converts radial to annular mode is determined by the current distance of the radial beam from the axis. This is `Zreff` and may be displayed by the `zreff` command. (attrib = 4).

Modifier 2	**Description**
`/left`	Select axicon with tip pointing to negative axial direction.
`/right`	Select axicon with tip pointing to positive axial direction.

Modifier 2	**Description (Continued)**
/weight	Weight the intensity in annular mode by the area of the annular zone. (attrib = 5).
/unweight	Restore unweighted intensity. (attrib = 4).

Modifier 3	**Description**
focal	Beam may be noncollimated and geometric radii are preserved (default). Beam may be returned to axial mode only by using axicon /axial and letting GLAD select the correct axicon orientation and position to properly convert the radial axis to a simple line axis.
afocal	Assumes beam is collimated and does not preserve geometric radii. Beam may be restored to axial mode by any second axicon.

Numerical Values	**Description**	**Defaults**
ibeam	Beam number (0 to select all beams).	1 to nbeam
radius	The exit radius in radial mode to end axicon conversion for axicon /radial or to begin axicon conversion for axicon /axial.	
zshift	Translation of the axicon along the axis for afocal operation.	

Parameter	**Description**
mirror	Implements the axicon including the effects of a mirror (default).
nomirror	Implements the axicon except that the mirror reflection is not included.

BEAMS — Turns on/off beams for global commands. — Propagation

Command Forms(s): **BEAMS**

```
beams/list       ibeams
beams/all/on
beams/all/off
beams/on         k1 . . . kn
beams/off        k1 . . . kn
```

Description: BEAMS

This command controls which beams are to be propagated with the global commands. If a beam is set on, it will be propagated. If it is set off, it will not be propagated. Beams may be set to attribute “data” so that they will never be propagated and the beams control is not needed. See the array command.

Modifier 1	**Description**
/list	Lists operational status.
/all	Sets all beams on or off depending on second modifier.
/off	Sets the beams whose numbers are listed off.
/on	Sets the beams whose numbers are listed on.

Modifier 2	Description
/on	Used with beams/all. Sets all beams on.
/off	Used with beams/all. Sets all beams off. Useful to turn on only one beam. For example: beams/all/off beams/on 7 # turns on beam 7

BEER Beer's Law saturated gain. Laser gain

Command Forms(s): **BEER**

```
beer/prop            ibeams z nstep
beer/noprop          ibeams z
beer/dist            ibeams z nstep
beer/nodist          ibeams z
beer/set/gauss       g0 es q nx ny xrad yrad xdec ydec rp
beer/set/invgauss    ig0 inx iny ixrad iyrad ixdec iydec
beer/set/cosh        g0 es q ny xrad yrad xdec ydec
beer/list
```

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
k1 . . . kn	List of up to 8 beam numbers to be turned on or off.	

Description: BEER

Applies Beer's Law to beams ibeams and propagates a distance of z cm in nstep steps. (See also gain. Use beer/set to define the necessary coefficients, beer/list to list the coefficients, and beer/prop to carry out the propagation. The gain may be limited in the transverse dimensions by a supergaussian roll-off or an inverse supergaussian roll-up. Alternatively the apodization of the small signal gain may have a “cosh” form in the x-direction and exponential form in the y-direction. The saturation parameter requires the solution of a differential equation for each point in the array. If no apodization functions are specified, GLAD recognizes that all points in the array have the same behavior and builds an interpolation table that speeds calculation times.

The supergaussian roll-off allows representation of a finite gain region. The inverse supergaussian roll-up may be used with the supergaussian roll-off to model the case of lower gain in the center of the beam. The /cosh function gives roll-up in the x-direction and roll-off in the y-direction.

Also see gain/sheet for additional Beer's Law capabilities.

Modifier 1	Description
/prop	Execute Beer's Law kinetics and propagation (using prop algorithms).
/noprop	Beer's Law without diffraction propagation.
/dist	Execute Beer's Law kinetics and propagation (using dist algorithms).
/nodist	Beer's Law without diffraction propagation (same as /noprop).
/set	Sets parameters for Beer's Law.

Modifier 1	Description (Continued)
`/list`	List the Beer's law parameters which are stored.

Modifier 2	Description
`/gauss`	Supergaussian roll-off of small signal gain.
`/invgauss`	Inverse supergaussian roll-up of small signal gain.

Small signal gain for `/gauss` and `/invgauss`

For $\mathtt{ny} > 0$ and $\mathtt{iny} > 0$ the rectangular supergaussian form is used

$$g(x, y) \ = \qquad (3)$$

$$g_0 \exp\left[-\left(\frac{x-\mathtt{xdec}}{\mathtt{xrad}}\right)^{2\mathtt{nx}} - \left(\frac{y-\mathtt{ydec}}{\mathtt{yrad}}\right)^{2\mathtt{ny}}\right]\left\{1 - \mathtt{igo}\exp\left[-\left(\frac{x-\mathtt{ixdec}}{\mathtt{ixrad}}\right)^{2\mathtt{inx}} - \left(\frac{y-\mathtt{iydec}}{\mathtt{iyrad}}\right)^{2\mathtt{iny}}\right]\right\}$$

If $\mathtt{ny} < 0$ and $\mathtt{iny} < 0$ the elliptical supergaussian form is used

$$g(x, y) \ = \qquad (4)$$

$$g_0 \exp\left\{\left[-\left(\frac{x-\mathtt{xdec}}{\mathtt{xrad}}\right)^{2} - \left(\frac{y-\mathtt{ydec}}{\mathtt{yrad}}\right)^{2}\right]^{\mathtt{nx}}\right\}\left(1 - \mathtt{ig0}\exp\left\{\left[-\left(\frac{x-\mathtt{ixdec}}{\mathtt{ixrad}}\right)^{2} - \left(\frac{y-\mathtt{iydec}}{\mathtt{iyrad}}\right)^{2}\right]^{\mathtt{inx}}\right\}\right)$$

Small signal gain for `/cosh`

$$g(x, y) \ = \ g_0 \cosh\left(\frac{x-\mathtt{xdec}}{\mathtt{xrad}}\right)\exp\left\{-\left(\frac{y-\mathtt{ydec}}{\mathtt{yrad}}\right)^{2\mathtt{ny}}\right\} \qquad (5)$$

Saturated gain for all operations

$$gsat(x, y) \ = \ \frac{g(x, y)}{\left[1 + \frac{I(x, y)}{E_s}\right]^{Q}}, \ t(x, y) \ = \ \exp[gsat(x, y)Z] \qquad (6)$$

where $g(x, y)$ is the local small signal gain, $gsat(x, y)$ is the local saturated gain, $t(x, y)$ is the local transmission, Q is the saturation exponent (Q = 1 for homogeneous and Q = 0.5 for inhomogeneous), and $I(x, y)$ is the fluence or power at (x, y). The other parameters are defined in the table of numerical values. The factor `rp` allows the gain for the two polarizations to be different:

$$gsat_s(x, y) = \frac{g_0(x, y)}{1 + \frac{1}{I_{sat}(x, y)}[I_s(x, y) + rI_p(x, y)]} \tag{7}$$

$$gsat_p(x, y) = \frac{rg_0(x, y)}{1 + \frac{1}{I_{sat}(x, y)}[I_s(x, y) + rI_p(x, y)]} \tag{8}$$

where $gsat(x, y)_s$ and $gsat(x, y)_p$ are the gain coefficients for the s- and p-polarizations, r is the relative significance of the p-state (nominally), and $I_s(x, y)$ and $I_p(x, y)$ are the intensities of the respective polarizations.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`z`	Total propagation distance (cm).	`0.`
`nstep`	Number of steps.	`1`
`g0`	Small signal gain.	`0.`
`es`	Saturation fluence.	`1000.`
`q`	Saturation exponent: 1 for homogeneous, 1/2 for inhomogeneous.	`1.`
`nx`, `ny`	Supergaussian exponents. Elliptical form of `ny` < 0 .	`20`
`xrad`, `yrad`	Supergaussian radii.	`1e20`, `1e20`
`xdec`, `ydec`	Coordinates of supergaussian gain center.	`0.,0`
`ig0`	Relative inverse small signal gain factor.	`1.`
`inx`, `iny`	Inverse supergaussian exponent. Elliptical form of `iny` < 0 .	`20`
`ixrad`, `iyrad`	Inverse supergaussian radii.	`1e20`, `1e20`
`ixdec`, `iydec`	Coordinates of inverse supergaussian gain center.	`0.`, `0.`
`rp`	Polarization discrimination factor.	`1.`

BELL Rings bell. Language

Command Forms(s): **BELL**

```
bell                times
```

Description: BELL

Rings bell on computer specified number of times.

Numerical Values	**Description**	**Defaults**
`times`	Number of times to ring bell.	`1`

BINARY Binary optics. Component

Command Forms(s): **BINARY**

```
binary/grating/surface      kbeam period level nlevels azdeg phase
binary/grating/phasescreen  ibeams rindex period level nlevels azdeg
                            phase
binary/lens/surface         kbeam xrad yrad level nlevels
binary/lens/phasescreen     ibeams rindex xrad yrad level nlevels
binary/lens/residual        ibeams rindex xrad yrad level nlevels
binary/surface              kbeam level nlevels
```

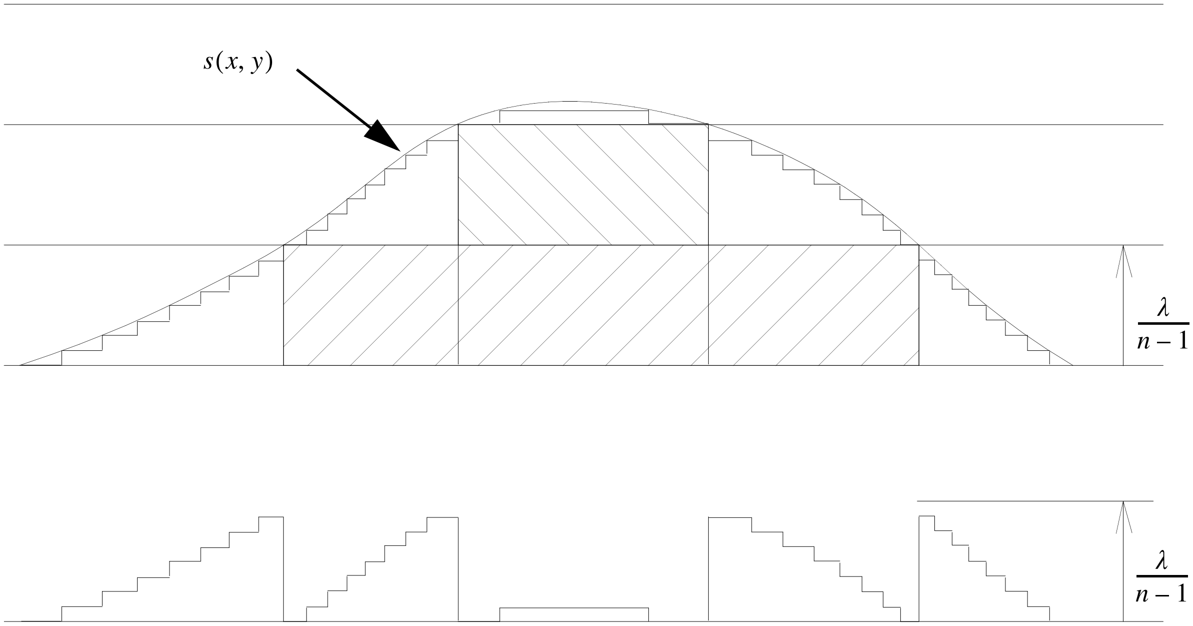
Description: BINARY

This command implements binary gratings and lenses. The binary surface may be constructed with the /surface modifier or implemented directly as a phase screen. The binary surface may be implemented later as a phase screen with the int2phase, int2waves, or sfocus command. The binary surface may be plotted as irradiance.

Modifier 1	**Description**
/grating	Binary linear grating.
/lens	Binary lens.
/surface	Form binary optic from current irradiance distribution. See Fig. 11.

Modifier 2	**Description**
/surface	Creates a surface array containing the surface profile. Use int2phase to implement the surface function as a phase screen.
/phasescreen	Implements the binary optic directly into the array(s) (default for grating).
/residual	Implements a binary lens with the basic phase radius of curvature treated as a standard lens plus residuals. This enables the binary optic to be incorporated with the standard propagation control algorithms (default for lens).

Numerical Values	**Description**	**Defaults**
ibeams	Beam number (0 to select all beams).	1 to nbeam
kbeam	Single beam number.	1
rindex	Index of refraction for /phasescreen or /residual.	1
period	Period of the grating.	
xrad, yrad	Radii of curvature for lens.	1e20, xrad
level	Height of the surface profile (asymptotic).	
nlevels	Number of sublevels per major level.	
azdeg	Azimuth angle in degrees, counter-clockwise from vertical.	90
phase	Phase shift (degrees) of grating per period.	0.



binary optics equivalent

Fig. 11. A surface divided into major levels of thickness $(\lambda/(n-1))$ and into 8 sublevels to create a binary optic. The major levels, of height L, may be subtracted without optical effect at wavelength λ, i.e., by removing the hatched areas. The sublevels produce some diffractive loss into high angle scattering. Note that the maximum height of the binary optic is $[(N-1)/N][\lambda/(n-1)]$, where N is the number of sublevels. The mathematical description of the binary optic surface is $S'(x, y) = (L/N)\mathrm{mod}\{\lfloor((Ns(x, y))/L) - N[(1/N)\lfloor((Ns(x, y))/L)], N\}$, optical phase induced $= ((2\pi)/\lambda)(n-1)S'(x, y)$ where $\lfloor$ is the least integer function (rounds down to next integer value).

BLOOM Atmospheric thermal blooming. Aberration

Command Forms(s): **BLOOM**

bloom/set

bloom/list

bloom/altitude

bloom/prop

Description: BLOOM

Bloom is the general thermal blooming command. Parameters may be set by bloom/set and listed by bloom/list. The GLAD feature set is required. The propagation including blooming phase errors, fitting of tilt and focus errors, and diffraction propagation is accomplished by bloom/set. Target parameters are set by the target command.

To set the parameter, call bloom/set before calling any other bloom commands.

Modifier 1	Description
`/set`	Set `boom` parameters.
`/list`	List `bloom` parameters.
`/altitude`	Define altitude.
`/prop`	Implement propagation with thermal blooming.

BLOOM/ALTITUDE Sets altitude information for BLOOM. Aberration

Command Forms(s): **BLOOM/ALTITUDE**

```
bloom/altitude/set    height
bloom/altitude/list
```

Description: BLOOM/ALTITIDE

This routine establishes values for the atmosphere based on the U.S. Standard Atmosphere and on absorption values based on published data by Woods, et. al. Values set are temperature, relative pressure, relative temperature, density, heat conductivity, and absorption of CO_2, H_2O and aerosols.

References

1. Frank J. Regan, An Atmosphere Model, ACCESS Vol. 6, No. 6, p33 (1987), author may be reached at Naval Surface Weapons Center, White Oak Laboratory, Silver Spring, Maryland 20903-5000.
2. U.S. Standard Atmosphere 1976, National Oceanographic and Atmospheric Administration, Washington D.C. (1976).
3. A.D. Woods, M. Camac and E.T. Gerry, Appl. Opt., Vol 10 p1877 (1971).

Modifier 1	Description
`/set`	Define and store Beer's law parameters.
`/list`	List parameters.

Numerical Values	Description	Defaults
`height`	Height in the atmosphere (km).	`1.`

BLOOM/PROP Propagate with thermal blooming. Aberration

Command Forms(s): **BLOOM/PROP**

```
bloom/prop/xy/(modifier 3)        ibeams z nstep relwind
bloom/prop/xonly/(modifier 3)     ibeams z nstep
bloom/prop/fft/(modifier 3        ibeams z nstep
```

Description: BLOOM/PROP

This routine propagates a beam under conditions of thermal blooming. The routine calculates the temperature rise and the phase perturbations as described in the GLAD Theory Manual, Chap. 13, (theory.pdf). The computation of the temperature rise is the most difficult part of the problem. The equation to be solved is

$$\Delta T(x, y) = -\frac{\alpha}{\rho C_{\mathrm{p}}} \int_{-\infty}^{0} \left(1 - \sigma \mathrm{e}^{-\frac{\tau}{\tau_{N_2}}}\right) I(x - v_{c_x}\tau, y - v_{c_y}\tau)\mathrm{d}\tau, \tag{9}$$

α	total atmospheric coefficient = $\alpha_{\mathrm{H_2O}} + \alpha_{\mathrm{CO_2}}$,
ρ	density of air 1.226 $\text{kg/m}^{3,}$
C_{p}	specific heat 1017 J/kgK,
τ	time variable,
τ_{N_2}	time constant of nitrogen for kinetic cooling,
v_{c_x}, v_{c_y}	crossing velocity (see `target` command),
σ	kinetic cooling factor, from GLAD Theory Manual, Chap. 13, Eq. (13.10) (theory.pdf).

The phase is calculated from the equation below

$$\phi = -\frac{2\pi}{\lambda}(n_0 - 1)\frac{P_{\mathrm{rel}}}{T_{\mathrm{rel}}}\frac{\Delta T}{T}\Delta z, \tag{10}$$

n_0	n_0 is the index of refraction air at STP,
P_{rel}	Relative pressure,
T_{rel}	Relative temperature with respect to 288°K,
ΔT	Temperature rise due to absorption,
T	Temperature of the atmosphere,
Δz	Propagation step length,
λ	Wavelength.

There are three basic forms in which the calculation may be performed. We shall use two constants in each case:

$$C = -\frac{2\pi}{\lambda}(n_0 - 1)\frac{\alpha}{\rho C T}\Delta z \tag{11}$$

$$\sigma = 2.441(n_0 - 1)\frac{\alpha_{\mathrm{CO_2}}}{\alpha}. \tag{12}$$

Command: `bloom/prop/xy`

1) Convert from complex amplitude to intensity and phase

$$A(x, y) \rightarrow I(x, y)e^{\mathrm{i}W(x, y)} \tag{13}$$

2) Calculate wavefront change

$$W(x, y) = \sum_{T=0}^{T_{\min}} C\left(1 - e^{-\frac{\tau}{\tau_{N_2}}}\right) I(x - v_{x_c}\tau, y - v_{y_c}\tau)\Delta\tau \tag{14}$$

3) Convert from intensity and phase to complex amplitude

$$I(x, y)e^{iW(x, y)} \rightarrow A(x, y) \tag{15}$$

This is the default method and is considered the most reliable. Use the `relwind` value to limit the integration to the center rectangle of the beam to reduce the calculation time if the beam is significantly underfilling the array.

Command: `bloom/prop/xonly`
If the crossing velocity is strictly along the x-direction considerable speed improvements are possible. The thermal blooming and kinetic cooling are based on two sums taken over the array. The code scans in the x-direction than the y-direction because data is stored contiguously along the rows. The intermediate sums are:

Intensity sum

$$\text{Sum1} = \sum_{k=-\infty}^{0} I(x - k\Delta x) \tag{16}$$

Kinetic cooling sum with temporal decay

$$\text{Sum2} = \sum_{k=-\infty}^{0} e^{-\frac{k\Delta\tau}{\tau_{N_2}}} I(x - k\Delta x) \tag{17}$$

Represented as a series

$$\text{Sum2} = e^{-\frac{\Delta\tau}{\tau_{N_2}}}\left[I(\Delta x) + e^{-\frac{\Delta\tau}{\tau_{N_2}}}\left[I(x - \Delta x) + e^{-\frac{\Delta\tau}{\tau_{N_2}}}\left[I(x - 2\Delta x) + \ldots\right]\right]\right] \tag{18}$$

The exponentials may be eliminated by using an intermediate value

$$\text{Sum2} = r_{fac}\left[I(\Delta x) + r_{fac}\left[I(x - \Delta x) + r_{fac}\left[I(x - 2\Delta x) + \ldots\right]\right]\right], \text{ where } r_{fac} = e^{-\frac{\Delta\tau}{\tau_{N_2}}} \tag{19}$$

The computer coding takes the form

$$\mathrm{Sum2} \;=\; r_{fac}[I(x) + \mathrm{Sum2}] \tag{20}$$

$$\phi \;=\; C\Delta\tau(\mathrm{Sum1} - \sigma\mathrm{Sum2}) \tag{21}$$

Command: `bloom/prop/fft`

The temporal integration may be performed in the frequency domain. This method avoids the spatial domain shifting which is rather time consuming. The Fourier method is derived below:

$$\int_{\tau_{\min}}^{0} \left(1 - \sigma \mathrm{e}^{-\frac{\tau}{\tau_{N_2}}}\right) I(x - v_x\tau, y - v_y\tau)\,\mathrm{d}\tau, \tag{22}$$

$$= \mathrm{FF}^{-1}\left[\int_{\tau_{\min}}^{0} \left(1 - \sigma \mathrm{e}^{-\frac{\tau}{\tau_{N_2}}}\right) \mathrm{FF}[I(x, y)]\mathrm{e}^{\mathrm{j}2\pi(\xi v_x\tau + \eta v_y\tau)}\,\mathrm{d}\tau\right], \tag{23}$$

$$= \mathrm{FF}^{-1}\left[\int_{\tau_{\min}}^{0} \left(1 - \sigma \mathrm{e}^{-\frac{\tau}{\tau_{N_2}}}\right) I(\xi, \eta)e^{\mathrm{j}2\pi(\xi v_x\tau + \eta v_y\tau)}\,\mathrm{d}\tau\right], \tag{24}$$

$$= \mathrm{FF}^{-1}\left[\int_{\tau_{\min}}^{0} \left[I(\xi, \eta)e^{\mathrm{j}2\pi(\xi v_x\tau + \eta v_y\tau)} - \sigma I(\xi, \eta)\mathrm{e}^{-\frac{\tau}{\tau_{N_2}} + \mathrm{j}2\pi(\xi v_x\tau + \eta v_y\tau)}\right]\mathrm{d}\tau\right], \tag{25}$$

$$= \mathrm{FF}^{-1}\left[\mathrm{FF}[I(x, y)]\left[\frac{1 - \mathrm{e}^{\mathrm{j}2\pi(\xi v_x + \eta v_y)\tau_{\min}}}{\mathrm{j}2\pi(\xi v_x + \eta v_y)\tau_{\min}} - \frac{\sigma\left(1 - \mathrm{e}^{-\frac{\tau}{\tau_{N_2}} + \mathrm{j}2\pi(\xi v_x + \eta v_y)\tau_{\min}}\right)}{-\frac{\tau}{\tau_{N_2}} + \mathrm{j}2\pi(\xi v_x + \eta v_y)\tau_{\min}}\right]\right]. \tag{26}$$

We choose $\tau_{\min}$ to be the time that results in the beam being 1/4 of the array width from the center. Choosing a larger value will result in "wrapping" of the intensity distribution. There is still some slight wrapping with the current algorithm. Wrapping effects are minimized by windowing the intensity distribution to the inner one-half rectangle. Some slight wrapping is still evident. Upon completion of the blooming step, the scratch array contains the heating profile. This may be observed by using `intmap` `/abs -1`. The scratch array may also be examined by `copy -1 kbeam`, where `Kbeam` is another array, however the other diagnostic routines will square the array before displaying it which is inappropriate for the heating profile.

The phase calculations are followed by an internal call to `fitphase` to remove tilt and focus error and to invoke a diffraction propagation. If `Nstep` is specified then successive steps of kinetics and diffraction will be used—each of length `Z/Nstep`.

Modifier 3	**Description**
`/fitphase`	Fit and remove defocus and tilt to phase at each propagation step. Tilt and decenter terms are included in paraxial values accessible from `defocus` and `tilt` commands. Defocus correction is incorporated into `geodata` values (default).
`/nofitphase`	Turns off phase fitting. Useful if the beam has become so broken up that there is no clear value for overall tilt or defocus.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`z`	Propagation distance.	`0.`
`nstep`	Number of steps to use in propagation.	`1`
`relwind`	Relative window `bloom/prop/xy`.	`1.`

BLOOM/SET Set atmospheric blooming parameters. Aberration

Command Forms(s): **BLOOM/SET**

```
bloom/set        xvelocity yvelocity height ah2o temp aco2 tn2 rind dens
                 conduc spcheat aaer prel trel
```

Description: BLOOM/SET

Meaning of parameters are defined with `bloom/prop` command.

Numerical Values	**Description**	**Defaults**

`xvelocity,`
`yvelocity`
	Velocity components of wind (m/sec).	`0., 0.`

`height`	Height in the atmosphere (km).	`1.`
`ah2o`	Water absorption coefficient (1/km).	`0.001`
`temp`	Air temperature (Kelvin).	`281`
`aco2`	CO_2 absorption coefficient (1/km).	`0.03`
`tn2`	Time constant for N_2 (sec) (affects kinetic cooling).	`0.002`
`rind`	(n-1) where n is the index of air.	2.74×10^{-4}
`dens`	Density of air (kg/m^3).	`1.226`
`conduc`	Conductivity of air (w/mK).	`0.02525`
`spcheat`	Specific heat (J/kgK).	`1017`
`aaer`	Aerosol absorption coefficient (1/km).	4.365×10^{-3}
`prel`	Relative air pressure.	`0.887`
`trel`	Relative temperature.	`0.981`

BREAK Implements a break point for debugging. Language

Command Forms(s): **BREAK**

```
break/set
break/continue
break/info
beak/clear
```

Description: BREAK

Implements a break point in a macro or batch file. When GLAD reads `break/set`, it switches to terminal input. Entering `break/continue` will cause GLAD to continue processing commands after the break point. This is useful for interrupting command processing to determine the status of the calculation. Calling a macro or reading from another file will cause the break point to be lost.

Modifier 1	**Description**
`/set`	Sets a break point for subsequent return.
`/continue`	Returns to the last set point.
`/info`	Shows current real levels. The same as `read/info`.
`/clear`	Clear the break point.

Input file: break1.inp

```
#
# Test break from input deck
#
echo/on
color
read/info
pause
# enter 'break/cont' to return
break/set # break 1
units
read/d break2.inp
```

Input file: break2.inp

```
status
read/info
# enter 'break/cont' to return
break/set # break 2
wavelength
macro/def step/o
 count = count + 1
 if count=3 then
# macro inside break2.inp
read/info
 pause
# enter 'break/cont' to return
 break/set # break 3
 endif
macro/end
macro/run step/4
```

C, CC, or COMMENT Line comment (displayed in output Language

Command Forms(s): **C**

`C/define`	(comment string)
`C/format`	(Type) `iwidth idec`
`C/write`	
`CC/define`	(comment string)
`CC/format`	(Type) `iwidth idec`
`CC/write`	

Description: C or CC

The command `C` (upper case "`C`") or `comment` define a comment that is displayed during execution. Note that `c` (some string) (lower case "`c`" or "`$`" followed by at least one space) defines a non-displayed comment (see Sect. 1.4.2.3). "`//`" acts the same as "`c` ". Both "#" and "//" may be used to define the start of a non-displayed comment and the remainder of the line will be ignored. Comments "`c{`" and "`c}`" define comments that start and end indent blocks respectively.

Variables may be used in displayed comments. Preceed the variable by "`@`". For example:

```
comment distance = @z
```

or

```
C distance = @z
```

will display the current value of `z` in the comment. The variables values are automatically updated.

`CC` is the same as `C` except that it prints even if writing is turned off.

Modifier 1	Description
(no modifier)	Defines (`/define`) and writes (`/write`) a comment.
`/define`	Defines a comment without writing.
`/format`	Establishes the format of real displayed values. The formats are based on Fortran conventions: F(iwidth).(idec), fixed floating point number of Width total characters and Dec numbers to the right of the decimal point; 1PE(Width).(Dec) creates a number with an exponent; 1PG(Width).(Dec) writes in fixed floating point format if the numbers will fit the width or numbers with exponent otherwise. If no format is specified, the current format is printed.
`/write`	Updates and displays the most recently defined displayed comment.

Character String	Description
comment string	Character string to be used as in comment.
Type	Real data format type. "f", "g", or "e".

Numerical Values	Description	Defaults
`iwidth`	Total width of the real format.	12
`idec`	Number of digits to the right of the decimal point.	4

```
C/format e 12 6
C pi = @pi, h = @h
```

Result: `C pi = 3.1416E+00, h = 6.6260E-34`

CLAP Implements a clear aperture. Component

Command Forms(s): **CLAP**

```
clap/cir          ibeams rad xdec ydec azdeg [(parameter)]
clap/sqr          ibeams rad xdec ydec azdeg [(parameter)]
clap/ell          ibeams xrad yrad xdec ydec azdeg [(parameter)]
clap/rec          ibeams xrad yrad xdec ydec azdeg [(parameter)]
clap/hex          ibeams rad xdec ydec azdeg [(parameter)]
clap/pentagon     ibeams rad xdec ydec azdeg [(parameter)]
clap/gen
```

Description: CLAP

Sets a clear aperture of radius or half-width `xrad` and `yrad` (cm) for beam(s). The aperture is centered at (`xdec`, `ydec`)[cm]. When the aperture radius is inside the beam radius, GLAD will compute a new waist position and size for the beam. Also, see `obs` for obscurations.

Modifier 1	Description
`/cir`	Circular aperture.
`/ell`	Elliptical aperture.
`/sqr`	Square aperture.
`/rec`	Rectangular aperture.
`/hex`	Hexagonal aperture, pointed ends are in the vertical direction.
`/pentagon`	Pentagonal aperture. Upper face is horizontal.
`/gen`	General aperture.

Modifier 2	Description
`/con`	Conserves current units, surrogate gaussian may reset (default except in resonator mode).
`/noadjust`	Conserve current units, do not reset surrogate gaussian. Always selected in resonator mode.
`/res`	Permits rescaling when needed.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams). Accepts pattern.	`1` to `nbeam`
`rad`	Radius of aperture. Half-width for square, rectangular, or hexagonal. Center to corner distance for pentagonal.	
`xrad,yrad`	Radius or half-width x, y (cm). Half-width for square or rectangular.	
`xdec,ydec`	Coordinates of aperture center relative to the beam.	`0.,0.`

Jump to: Theory , Examples

Numerical Values	Description (Continued)	Defaults
azdeg	Azimuthal rotation of aperture. Implemented by an internal call to rotation and involves an interpolation step. The rotation angle is measured clockwise from vertical. The rotation is performed after any decenters.	

Parameters	Description
beam_clap	Aperture is defined in beam coordinates (default).
vertex	Aperture is defined in vertex coordinates. Beam is propagated to the vertex before applying aperture (if beam attribute allows propagation: attribute beam or axicon The projected size of the aperture on the beam transverse plane is applied to the beam. Note that vertex rotations obey the right hand rule, but that azdeg is measured clockwise as defined above.

CLAP/GEN Implements a clear aperture of general shape. Component

Command Forms(s): **CLAP/GEN**

```
clap/gen/screen    ibeams xdec ydec xscale yscale theta [verify]
clap/gen/disk      (Filename) ibeams xdec ydec xscale yscale theta
                   [verify]
```

Description: CLAP/GEN

The general aperture is defined by specifying a series of points that generate a polygon. The command parameters can be used to offset, rescale, and rotate the polygon to fit the required size and position of the current beam. The x-coordinate of point is Xo(i) = Xdec + X(i) * Xscale. If a rotation angle is specified, the rotation is counterclockwise about the centroid of the data points.

The general aperture data has the format

```
npts
x(1),y(1)
 .
 .
 .
x(npts),y(npts)
```

where: npts = number of data points.

Modifier 2	Description
/screen	Reads from screen.
/tty	Same as /screen. Obsolete.
/disk	Reads from file.

Character String	Description
Filename	Local file containing data to define general aperture.
null	No local file. Used to allow specification of verify as the second parameter when no file name is specified.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
xrad, yrad	Radius of aperture (cm).	Required
xdec, ydec	Decentering parameters.	0., 0.
xscale, yscale	Scale factors.	1., 1.
theta	Rotation angle (deg).	0.0

Parameters	Description	Defaults
verify	Enables viewing aperture with orthographic plot. Does not apply aperture to beam.	Not selected. Aperture is applied.

CLEAR Reset all points in array. Begin-end

Command Forms(s): **CLEAR**

```
clear/intensity    ibeams value
clear/complex      ibeams real imaginary preal pimaginary
```

Description: CLEAR

Sets all points in the beam array with an intensity defined by value. Other beam parameters such as units and geometric factors are not changed. For 3D beams, setting the section number to zero in advance will cause clear to set all sections.

Modifier 1	Description
/intensity	Set intensity to indicated value (default).
/complex	Set complex amplitude to indicated values.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
value	Intensity to be set.	0.0
real	Real part of complex word for /complex.	0.0
imaginary	Imaginary part of complex word for /complex.	0.0
preal	Real part of complex word of 2nd polarization state.	0.
pimaginary	Imaginary part of complex word of 2nd polarization state.	0.

CO2GAIN Frantz-Nodvik CO_2 gain for pulsed systems. Laser gain

Command Forms(s): **CO2GAIN**

```
co2gain/prop       ibeams z nstep
co2gain/set        g0 es nx ny xrad yrad xdec ydec
co2gain/list
```

Description: CO2GAIN

Applies Frantz-Nodvik kinetics for CO_2 pulsed lasers. Use `co2gain/set` to define the necessary coefficients, `co2gain/list` to list the coefficients, and `co2gain/prop` to carry out the propagation. The gain may be limited in the transverse dimensions by a supergaussian roll-off.

$$g(x, y) = \mathtt{g0}\exp\left[-\left(\frac{x - \mathtt{xdec}}{\mathtt{xrad}}\right)^{\mathtt{2nx}} - \left(\frac{y - \mathtt{ydec}}{\mathtt{yrad}}\right)^{\mathtt{2ny}}\right] \qquad (27)$$

$$t(x, y) = \frac{\mathtt{es}}{I(x, y))}\ln\left(1 + \exp\left\{g(x, y)\mathtt{z}\left[\frac{I(x, y)}{\mathtt{es}} - 1\right]\right\}\right) \qquad (28)$$

where $g(x,y)$ is the local small signal gain, $gsat(x,y)$ is the local saturated gain, $t(x,y)$ is the local transmission, and $I(x,y)$ is the fluence or power at (x,y) and the other parameters are defined below.

Reference

1. L. M. Frantz and J. S. Nodvik, “Theory of pulse propagation in a laser amplifier”, J. Appl. Phys., **34**, No. 8, 2346–2349, Aug. 1963.

Modifier 1	Description
`/prop`	Execute propagation.
`/list`	List the `co2gain` stored parameters.
`/set`	Define and store `co2gain` parameters.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`z`	Total propagation distance (cm).	Required
`nstep`	Number of steps.	`1`
`g0`	Small signal gain.	
`es`	Saturation fluence.	`1000`
`nx`, `ny`	Supergaussian exponents.	`100`, `100`
`xrad`, `yrad`	Supergaussian radii.	`1e20`
`Xdec`, `ydec`	Coordinates of beam center.	`0.`, `0.`

CONJUGATE Conjugates the beam. Operator

Command Forms(s): **CONJUGATE**

```
conjugate/beam        kbeam
conjugate/amplitude   kbeam
```

Description: CONJUGATE

Models a phase conjugate mirror (`/beam`). The GLAD is required. The phase in the array is conjugated, the direction of the beam is reversed, and the k-vector is reversed in the global data and the wavefront error is flipped in sign as shown below in Fig. 12.

The form `/amplitude` conjugates the complex amplitude field without changing the beam direction.

Modifier 1	**Description**
`/beam`	Conjugates the beam as a real phase conjugator would do.
`/amplitude`	Conjugates the complex amplitude without changing the beam direction.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1

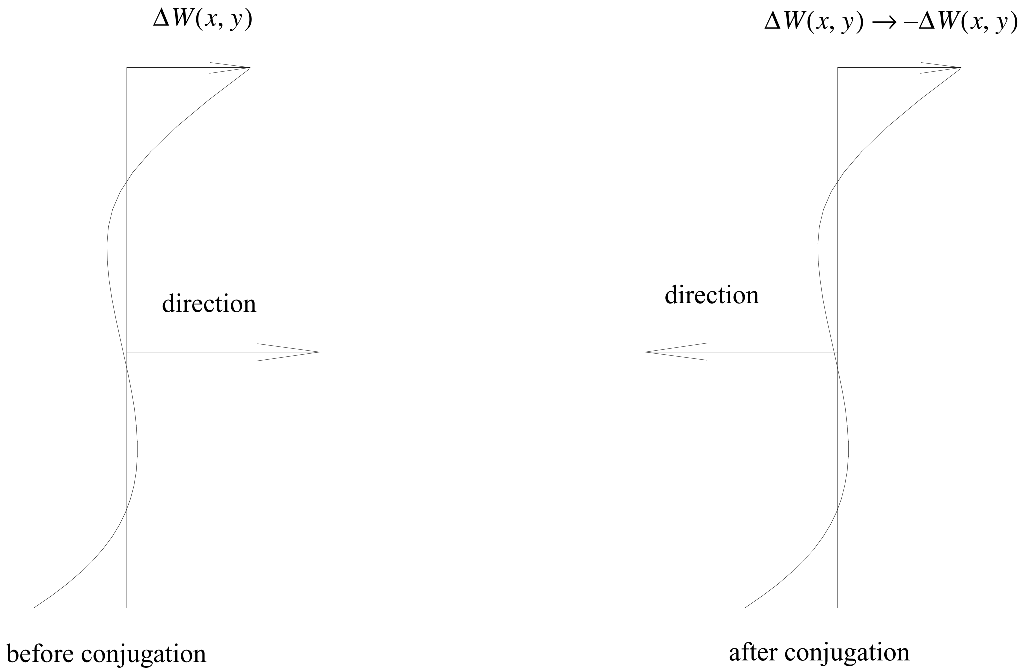


Fig. 12. In wavefront conjugation the direction beam is reversed and the sign of the wavefront is flipped.

CONVOLVE Convolves beam with a smoothing function. Operator

Command Forms(s): **CONVOLVE**

```
convolve/gaussian          kbeam xomega yomega
convolve/rect              kbeam xwidth ywidth
convolve/inverser          kbeam coefficient
convolve/beam/fft          kbeam mbeam
convolve/beam/nofft        kbeam mbeam
```

Command Forms(s): **CONVOLVE (Continued)**

```
convolve/xderivative       kbeam order
convolve/yderivative       kbeam order
convolve/front/both or x   kbeam
convolve/back/both or x    kbeam
convolve/deconvolve/fft    kbeam mbeam
convolve/deconvolve/nofft  kbeam mbeam
```

Description: CONVOLVE

This command convolves the distribution in the beam identified by `kbeam` by a gaussian function defined by the coefficients `xomega` and `yomega`. The gaussian convolution is implemented in the Fourier domain by

$$A(\xi, \eta) \to A(\xi, \eta)e^{-\pi^2(\omega_x^2\xi^2 + \omega_y^2\eta^2)} \tag{29}$$

where ω_x and ω_y correspond to `xomega` and `yomega` and $A(\xi, \eta)$ is the Fourier transform of the complex amplitude distribution. The convolution with the rect function takes the form

$$A(\xi, \eta) \to A(\xi, \eta)\frac{\sin(\pi\xi L_x)}{\pi\xi L_x}\frac{\sin(\pi\eta L_y)}{\pi\xi\eta L_y} \tag{30}$$

where L_x and L_y are the widths of the rect function. Either operation results in smoothing of the distribution.

The `/beam` modifier allows convolution of `kbeam` by `mbeam`. `mbeam` is left unchanged. Both beams are Fourier transformed, multiplied and `kbeam` is inverse Fourier transformed. `Mbeam` is left unchanged. If the `/nofft` modifier is selected, `mbeam` is not Fourier transformed before multiplication. See Example Ex65 for an illustration of the use of this command.

`/front` and `/back` compute the forward and inverse Fourier transform respectively. The units are left unchanged.

Modifier 1	**Description**
`/gaussian`	Convolve with a gaussian.
`/rect`	Convolve with a rect function.
`/inverser`	Convolve with $1/r$.
`/beam`	Convolve `kbeam` by `mbeam`.
`/xderivative`	Computes x-derivative by convolving with $-j\xi/2\pi$.
`/yderivative`	Computes x-derivative by convolving with $-j\eta/2\pi$.
`/front`	Computes forward Fourier transform.
`/back`	Computes inverse Fourier transform.

Modifier 1	**Description (Continued)**
`/deconvolve`	Computes the deconvolution of `kbeam` by `mbeam`. Deconvolution is performed in the Fourier domain by dividing the spectrum of `kbeam` by the spectrum of `mbeam`. The process is extremely sensitive to noise and may fail if there are exact zeros in the spectrum at any pixel location.

Modifier 2	**Description**
`/fft`	Take FFT of `mbeam` to form convolution (default).
`/nofft`	Assume `mbeam` is already transformed such as an OTF distribution. See `otf` command.
`/both`	Perform FFT for both x- and y-directions.
`/x`	Perform FFT for x-direction only.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`xomega`	X-radius of gaussian.	
`yomega`	X-radius of gaussian.	`xomega`
`xwidth`	Total x-width of rectangle function.	
`ywidth`	Total y-width of rectangle function.	`ywidth`
`mbeam`	Beam used to convolve `kbeam`.	
`coefficient`	Multiplier for `/inverser`.	
`order`	Order of the derivative to be taken.	1

COPY Copies one beam to another. Operator

Command Forms(s): **COPY**

```
copy/res          kbeami kbeamo fout xfhwid yfhwid xdec ydec xnline
                  ynline
copy/con          kbeami kbeamo icent jcent
copy/row          kbeami kbeamo rowi rowo
copy/column       kbeami kbeamo coli colo icent jcent
copy/section      kbeami kbeamo secti secto secte icent jcent
copy/border       kbeami kbeamo ishift jshift iskip1 jskip1 iskip2
                  jskip2
copy/reorder      kbeami kbeamo (Pattern)
copy/geodata      kbeami kbeamo
```

Description: COPY

Copies array number `kbeami` into array number `kbeamo`. When any of the geometric data is entered, `kbeami` is interpolated into the scratch array and then copied into beam `kbeamo`. If `xnline` or `ynlin` do not match the dimensions of `kbeamo`, the array is automatically reset to `xnline` or `ynline`. When an entry is made for the geometric data, `kbeamo` may be the same as `kbeami`.

`/reorder` allows reordering, adding, and subtracting the elements of `kbeami` in creating `kbeamo`. Any or all of the parameters of the form `rxxxx`, `axxxx`, `sxxxx` may be specified.

Modifier 1	**Description**
`/res`	Rescale distribution (default).
`/con`	Copy distribution without rescale and without copying geometric parameters. In the case of 3D arrays, `copy/con` will copy between sections as previously defined by a call to `set/section`. If the output section is set to 0, the input section will be copied to all output sections. See `copy/section`.
`/row`	Copies `rowi` from the input beam to `rowo` for the output beam. Very useful for making summary plots of through-focus calculations. See Example Ex.
`/column`	Copies column `coli` from the input beam to column `colo` for the output beam. Very useful for making summary plots of through-focus calculations.
`/section`	Copies of one section of `kbeami` to `kbeamo`.
`copy/border`	Does a point-to-point copy of arrays which may be of different size. `/border` does not change the size of the receiving array. The arrays are matched at the upper left point, unless shifted by `ishift` and `jshift`. A shift of $N/2$ for both directions will align the centers. i1 = (s-1)*`jskip1` + 1, i2 = (s-1)*jskip2 + `ishift` + 1, where s is the counter for points copied P(i1) => P(i2).
`/reorder`	Allows replacing, adding, and/or subtracting the real and imaginary parts of either polarization state of `kbeami`.
`copy/geodata`	Copy only the geometric information between beams. Useful to set the surrogate gaussian beam to match without changing the complex amplitude distribution.

Numerical Values	**Description**	**Defaults**
`kbeami`	Input beam number.	`1`
`kbeamo`	Output beam number.	`2`
`fout`	Intensity multiplier for output beam.	`1.`
`xfhwid`, `yfhwid`	Output field halfwidths (cm).	
`xdec`, `ydec`	Output field center.	`0.0`, `0.0`
`xnline`, `ynline`	Output array dimensions.	`0.0`, `0.0`
`icent`, `jcent`	Offset of center for `copy/con`, `jcent` is measured positive downward (pixels).	`0`, `0`
`rowi`, `rowo`	Input and output rows for `copy/row`. If `rowo` = 0, all rows of `kbeamo` are set to row `rowi`.	
`coli, colo`	Input and output columns for `copy/column`. If `colo` = 0, all rows of `kbeamo` are set to column `coli`.	
`secti`, `secto`, `secte`	Input and output sections for `copy/section`. Setting `secto` to zero causes `secti` to be copied to all sections of the output beam. This helps in initializing all sections of a 3D array to the same value. `Secto` and `secte` form a range of output sections for the input section `secti`.	`1`, `1`
`ishift`, `jshift`	Shift from upper left corner for `/border` (pixels).	`0`, `0`
`iskip1`, `jskip1`	Skip points in Beam 1 (pixels) for `/border`.	1, 1
`iskip2`, `jskip2`	Skip points in Beam 2 (pixels) for `/border`.	1, 1

Pattern	**Description**
`rabcd`	Replaces real and/or imaginary components of `kbeamo` with elements of `kbeami`. Positions a, b, c, and d correspond to the (real, imaginary) (real, imaginary) values of `kbeamo` considering both polarization states. The values of a, b, c, and d may take the values 0, 1, 2, 3, and 4 having the following meaning. 0, take no action 1, replace with real part of polarization state 1 2, replace with imaginary part of polarization state 1 3, replace with real part of polarization state 2 4, replace with imaginary part of polarization state 2 For example `r0300` replaces the imaginary value of `kbeamo` with the real part of polarization state 2. If multiple operations are specified by using more than one parameter, then the order of implementation is “replace”, “add”, and “subtract”.
`aabcd`	Similar to `rabcd` except the values of `kbeami` are added to `kbeamo` instead of replacing them. The coding pattern is the same. For example `a0103` adds the real part of the first polarization state of `kbeami` to the imaginary part of polarization state 1 of `kbeamo` and the real part of the second polarization state of `kbeamo` to the imaginary part of polarization state 2 of `kbeamo`.
`sabcd`	Similar to `aabcd` except the values of `kbeami` are subtracted from `kbeamo` instead of replacing them. The coding pattern is the same.

CORNERCUBE Corner cube reflector. Component

Command Forms(s): CORNERCUBE

```
cornercube/global     kbeam
cornercube/nonglobal  kbeam
```

Description: CORNERCUBE

Applies a cube corner reflector to the beam. Given an initial coordinate system of

$$\text{initial system} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \tag{31}$$

$$\text{after reflection from corner cube} \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix}. \tag{32}$$

The coordinate system is transformed as illustrated in Fig. 13.

Modifier 1	Description
`/global`	Acts as global mirror and must be used with other `mirror/global` and `lensgroup` (default).
`/nonglobal`	Acts as paraxial mirror and should be combined with `mirror` and `lens` commands—not with global commands.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1

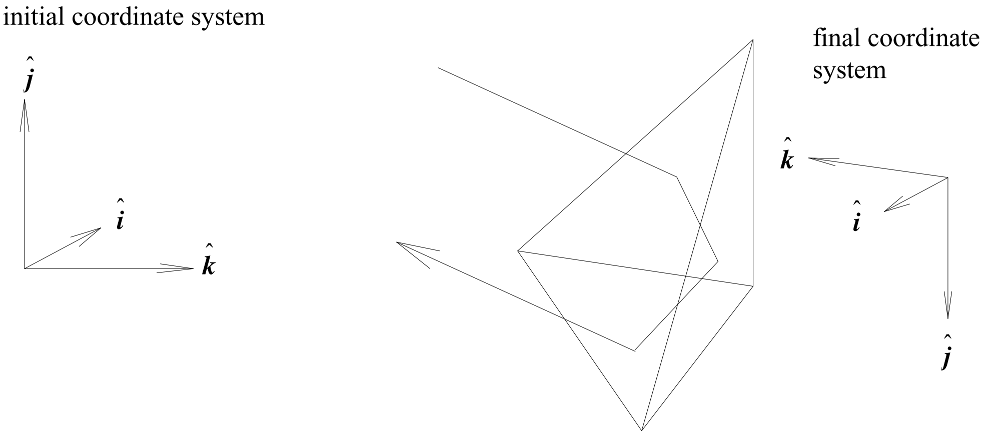


Fig. 13. Transformation of coordinate system by corner cube.

COSINE Single cycle of cosine irradiance. Begin-end

Command Forms(s): **COSINE**

```
cosine                     kbeam period offset xdec ydec
```

Description: COSINE

Makes cosine shaped distribution of irradiance. The functional form is

$$I(r) = \frac{1}{1+\mathtt{offset}}\left[\cos\left(\frac{2\pi r}{\mathtt{period}}\right)+\mathtt{offset}\right] \qquad (33)$$

`Offset` may very between -1 and 1. GLAD calculates this function out to the first nonzero value at radius,

$$Radius = \frac{\mathtt{period}}{2\pi}\cos^{-1}(-\mathtt{offset}) \qquad (34)$$

The distribution is set to zero outside this radius. See Fig. 14.

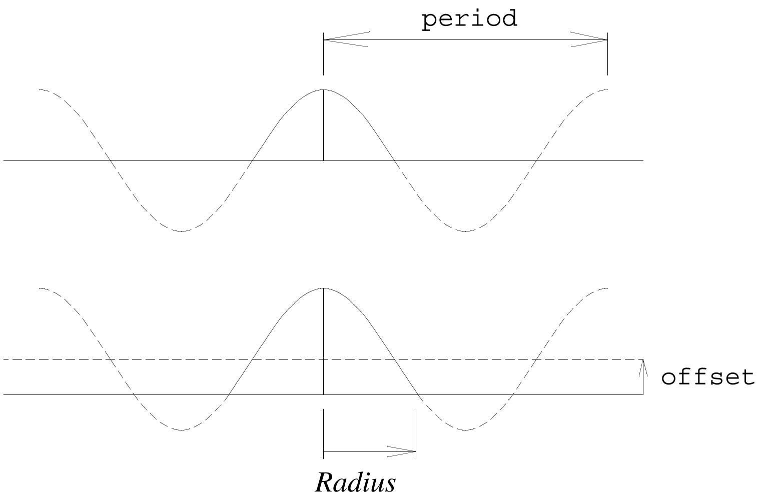


Fig. 14. Cosine function. The solid line indicates the part of the cosine function which defines the irradiance pattern.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`period`	Period of the cosine function.	
`offset`	Offset of the cosine function.	`0.0`
`xdec`, `ydec`	Coordinates of distribution center.	`0.`, `0.`

CRYSTAL — Anisotropic medium for propagation. — Component

Command Forms(s): **CRYSTAL**

```
crystal/uniaxial/set     polar azimuthal
crystal/uniaxial/list
crystal/uniaxial/clear
```

Description: CRYSTAL

Defines crystal properties. At present only a uniaxial crystal may be modeled. This command defines the polar angle with respect to the z-axis and the azimuthal angle with respect to the y-axis. The azimuthal angle can be either 0 or 90 degrees. If the azimuthal angle is 0, then the y-polarization state is the eccentric beam. For an azimuthal angle of 90 degrees, the x-polarization state is the eccentric beam. The indices of refraction n_o and n_e must be defined by the `wavelength` command. n_o and n_e are then assigned to the x- or y-polarization state according to whether the azimuthal angle is 0, 90, 180, or 270 degrees.

The eccentric state (e-ray) will propagate with a different medium wavelength and will see walk-off effects as well. Beam walk-off is due to the gradient of index with respect to propagation angle. This causes the beam to shear with distance resulting in propagation at angle with respect to the normal to the wavefront.

Modifier 1	Description
`/uniaxial`	Uniaxial crystal (default).

Modifier 2	Description
`/set`	Sets the crystal properties.
`/list`	List crystal properties.
`/clear`	Clear crystal properties and return to ordinary isotropic propagation.

Numerical Values	Description	Defaults
`polar`	Polar angle of crystal axis with respect to z-axis.	0.
`azimuthal`	Azimuthal angle with respect to y-axis measured clockwise. Angle must be 0, 90, 180, and 270 degrees.	`0.`

DATE Displays date and time. Language

Command Forms(s): **DATE**

```
date
```

Description: DATE

Writes date and time to output file.

DEBUG Controls diagnostic information for internal AOR use. Language

Command Forms(s): **DEBUG**

```
debug/add           (keyword1) . . . (keyword10)
debug/delete        (keyword1) . . . (keyword10)
debug/list
debug/reset
```

Description: DEBUG

This command controls the debug function for diagnostic information. It is primarily for AOR use. An example of `rdwr` is illustrated in Ex73 and Ex74.

Modifier 1	Description
`/add`	Adds a debug name.
`/delete`	Deletes a name.
`/list`	Lists all current debug names.
`/reset`	Clears all debug names.

Parameters	Description	Defaults
keyword	Keyword selected from the source code listing.	

DECLARE Assigns names to variables (also see variables command). Language

Command Forms(s): **DECLARE**

```
declare/real        (Variable 1) (Variable 2) . . .
```

Command Forms(s): DECLARE (Continued)

```
declare/integer      (Variable 1) (Variable 2) . . .
declare/list
declare/export
```

Description: DECLARE

`Declare` assigns variable names to either real or integer register addresses. See the `variables` command for a more convenient method of defining variables. This command is the same as `variables /declare`. The variable name may consist of the characters a-z, A-Z, 0-9, and _. The leading character should not be a number. The `declare` command is case sensitive: "`x`" is a different variable from "`X`". Declare assigns the variables to register values beginning at 200 and decrementing with each new variable declared.

For example,

```
declare/real X_rad Y_rad
X_rad = 13.25
Y_rad = 23.6
clap 1 X_rad Y_rad.
```

Modifier 1	Description
`/real`	Declare real variable.
`/integer`	Declare integer variable.
`/list`	Lists the variables and the associated register addresses.
`/export`	Simpler form of list suitable for exporting with `write/disk` (filename), followed by `variables/export`. Can be read in by `read/disk` (filename).

DERIVATIVE Take spatial derivatives. Operator

Command Forms(s): DERIVATIVE

```
derivative/x/linear   kbeam
derivative/y/linear   kbeam
derivative/x/spline   kbeam
derivative/y/spline   kbeam
```

Description: DERIVATIVE

Takes derivative of real and imaginary components of field. Also see `convolve /xderivative` and `convolve /yderivative` for Fourier method of calculating derivatives.

Modifier 1	Description
`x`	Calculate x-derivatives (default).
`y`	Calculate y-derivatives.

Modifier 2	Description
`linear`	Calculate derivatives by finite-difference using nearest neighbors (default).
`spline`	Fit splines to function and differentiate splines analytically.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1

DIST Propagate assuming simple optical axis (see prop). Propagation

Command Forms(s): **DIST**

```
dist/spectp           z kbeam1...kbeam9 [xonly] [list]
dist/finitdif         z kbeam1...kbeam9
dist/avgkern          z kbeam1...kbeam9
```

Description: DIST

Applies diffraction propagation. Also see the prop command. The angular spectrum propagator is the only one fully integrated into the propagation control algorithms. We recommend that the users not use the other propagation algorithms except in special circumstances. By default all beams are propagated.

GLAD will automatically select an appropriate propagator and units for the specified distance. The default propagator and default units will produce accurate results and, while always accurate, may not be optimum for a given problem. The knowledgeable user may make the sampling more efficient by changing the units and/or using an alternate propagator. Overriding the default conditions will increase the risk of introducing such errors as aliasing, energy loss, inadequate resolution, and accumulated numerical errors. Users are advised to read the theory section and have a basic knowledge of the propagators and unit selection before attempting to override the automatic unit or propagator control.

Only propagations which result in a gain of physical path length are physically meaningful. The dist command does not protect the user from making nonphysical propagations. The dist command is designed to move forward or backward along a principal optical axis. The direction of the beam is reversed each time the beam strikes a mirror. The dist command should use positive or negative values of z to correspond to the beam direction. The status command gives the direction of the beam as a positive or negative movement along the z-axis. GLAD tracks the axial position with the parameter, zreff. Small angle tilts and decenters are allowed, but the optical path lengths are not correctly calculated.

The prop command is a more powerful propagation command which allows movement in a general three-dimensional space when used with the global, vertex, and mirror/global commands.

Propagation of a beam against the forward direction of a beam can produce errors when a lens is encountered. The proper way to go through a lens in the negative z-direction is to use a mirror to reverse the propagation direction of the beam. For a beam initially moving in the plus z-direction, the commands below show incorrect and correct commands to go through a lens in the negative z-direction..

Incorrect	Correct
dist -100	mirror/flat 1
lens 1 100	dist -100
	lens 1 100

Modifier 1	Description
/spectp	Spectrum of plane waves propagator (default). (recommended for all applications).

Modifier 1	Description (Continued)
`/finitdif`	Finite difference propagator (recommended for short steps only).
`/avgkern`	Average kernel propagator (moderate length steps only).

Numerical Values	Description	Defaults
`z`	Propagation distance (cm).	Required
`kbeam1-kbeam9`	List of beams to be propagated if “on” by the `beams` command. `kbeam1` = 0, propagates all “on” beams. Beams with attribute “data”, set with the `array` command, are never propagated.	

Parameters	Description	Defaults
`xonly`	Does diffraction on the x-direction only. This is not physically realizable but is useful for processing a large number of one dimensional arrays formed into one large array for convenience.	
`list`	List output. Default is to not list.	

System Variable Data	Description
`xray`, `yray`, `zray`	Global position of beam along chief ray for `kbeam`.
`opl`, `ppl`	Optical path and physical path lengths for `kbeam`.
`zreff`	Current z-position of beam.

DOUBLE Frequency doubling. Component

Command Forms(s): **DOUBLE**

```
double/full                 zstep ipump istokes g deltak nstep zstart kappa
double/simple/pump          kbeam zstep g deltak kappa
double/simple/harmonic      kbeam zstep g deltak kappa
```

Description: DOUBLE

This command implements frequency doubling. The command is changed from Ver. 5.8 so that `kappa` is the preferred coupling coefficient. See original photon flux formulation below. The GLAD feature set is required. `double/full` implements the full second harmonic coupled differential equations[1],

$$\frac{\partial A_\omega}{\partial z} = \mathrm{j}\tilde{\kappa}^* A_\omega^* A_{2\omega} e^{-\mathrm{j}\Delta kz} \tag{35}$$

$$\frac{\partial A_{2\omega}}{\partial z} = \mathrm{i}\tilde{\kappa} A_\omega^2 e^{\mathrm{j}\Delta kz} \tag{36}$$

where A_ω and $A_{2\omega}$ are the complex amplitudes of the electrical fields for the pump and second harmonic beam respectively (in GLAD $AA^* = I$).

Type I and Type II crystals

In this routine exact crystal orientation is not considered explicitly. The incident amplitude is assumed to be x-polarization and the output is also in the x-polarization. For Type I crystals, input on the ordinary ray will create a doubled beam on the extraordinary ray, so the output should be roated ±90° according to the roatation of the extraordinary ray relative to x-polarization. For Type II crystals, input on the ordinary ray will create a doubled beam on the extraordinary ray, so the output should be roated ±45° according to the roatation of the extraordinary ray relative to x-polarization. Rotation by an azimuthal angle (positive clockwise) may be done by the command `jones/optact`.

If the harmonic array is polarized the harmonic response is placed in the y-polarization.

The total intensity is

$$I = I_1 + I_2 = |A_\omega|^2 + |A_{2\omega}|^2 \tag{37}$$

is a constant that is independent of z (known as Manley-Rowe relation) indicating conservation of energy.

The coupling constant is

$$\tilde{\kappa} = \frac{1}{\sqrt{2}}\omega\left(\frac{\mu_0}{\varepsilon_0}\right)^{3/4}\frac{1}{\sqrt{n_\omega^2 n_{2\omega}}}\chi^{(2)} \tag{38}$$

where $\mu_0 = 4\pi\times10^{-7}$ H/m and $\varepsilon_0 = 8.85\times10^{-12}$ F/m and $\left(\frac{\mu_0}{\varepsilon_0}\right)^{1/2}$ = 377 Ω. For $I_\omega(0) = 5\times10^6$ w/cm^2,

$\lambda_\omega = 1.06\times10^{-4}$ cm, $\chi_{MKSA}^{(2)} = 5\times10^{-23}$, $n_\omega \approx n_{2\omega}$ = 2.2, and L = 1 cm. The coupling coefficient is

$$\tilde{\kappa} = \frac{1}{\sqrt{2}}\omega\left(\frac{\mu_0}{\varepsilon_0}\right)^{3/4}\frac{1}{\sqrt{n_\omega^2 n_{2\omega}}}\chi^{(2)} = 1.4939018\times10^{-4}\ \text{w}^{-1/2} \tag{39}$$

The gain coefficient for $I_\omega(0) = 5\times10^6$ w/cm^2 is $g' = 2\tilde{\kappa}A(0)$ = 0.66809318 cm^{-1}.

For $A_{2\omega} = 0$ and no detuning, the solution is

$$\frac{I_{2\omega}(z)}{I_\omega(z=0)} = \frac{A_{2\omega}(z)A_{2\omega}{*}(z)}{A_\omega(0)A_\omega{*}(0)} = \tanh^2[\tilde{\kappa}A_\omega(0)z] = \tanh^2\left(\frac{g'}{2}z\right) \tag{40}$$

Detuning is treated by reducing the coupling coefficient according to Δk. For the simple model implemented with the command `double/simple`, detuning is treated by reducing the coupling coefficient according to Δk.

The detuning factor reduces the coupling coefficient by a factor of

$$\frac{\sin^2\left(\frac{1}{2}\Delta kz\right)}{\left(\frac{1}{2}\Delta kz\right)^2} \tag{41}$$

where z is the total distance from the start of the crystal.

When the frequency doubling is broken up into several intervals using separate calls to `double`, the cumulative effect of detuning may be accomplished by setting `zstart` to the length of previous passes through the doubler.

The command `double/simple` implements the equations:

$$\texttt{double/simple/harmonic}\ A_{2\omega}(z) = iA_\omega(0)\tanh[\tilde{\kappa}A_\omega(0)z] = iA_\omega(0)\tanh\left(\frac{g'}{2}z\right), \tag{42}$$

$$\texttt{double/simple/pump}\ A_\omega(z) = A_\omega(0)\operatorname{sech}[\tilde{\kappa}A_\omega(0)z] = A_\omega(0)\operatorname{sech}\left(\frac{g'}{2}z\right), \tag{43}$$

$$\text{where } g' = 2\tilde{\kappa}A_\omega(0) = \sqrt{2}\,\omega\left(\frac{\mu_0}{\varepsilon_0}\right)^{3/4}\frac{1}{\sqrt{n_\omega^2 n_{2\omega}}}\chi^{(2)}A_\omega(0). \tag{44}$$

Photon flux representation

This command implements frequency doubling. The GLAD feature set is required. `double/full` implements the full second harmonic coupled differential equations,

$$\frac{\mathrm{d}p_2}{\mathrm{dz}} = -\mathrm{j}\frac{g}{2\sqrt{2}}p_1^2 e^{\mathrm{j}\Delta kz}, \tag{45}$$

$$\frac{\mathrm{d}p_1}{\mathrm{dz}} = -\mathrm{j}\frac{g^*}{\sqrt{2}}p_2 p_1{}^* e^{-\mathrm{j}\Delta kz}, \tag{46}$$

where p_1 and p_2 are the photon flux complex amplitudes of the pump and second harmonic beams, such that $|p|^2$ has units of photons/cm/sec. For this command g takes only real values. The energy per photon is

$$\text{energy per photon} = \frac{hc}{\lambda} = \frac{19.8762\times10^{-24}[\text{jules per cm}]}{\lambda[\text{cm}]} \tag{47}$$

$$p_1 = A_1\sqrt{\frac{\lambda_1}{hc}},\ p_1 = A_1\sqrt{\frac{\lambda_1}{hc}} \tag{48}$$

where A_1 and A_2 are the usual amplitude quantities used in GLAD with dimensions of $\sqrt{\mathrm{w}}/\mathrm{cm}$.

The gain g has the units $\mathrm{cm}\sqrt{\mathrm{sec}/\mathrm{photon}}$. g is related to the second order susceptibility constant $\chi^{(2)}_{\mathrm{MKSA}}$.

$$g = 2\tilde{\kappa}\sqrt{\frac{hc}{\lambda_1}} = \sqrt{\frac{hc}{\lambda_2}}\omega\left(\frac{\mu_0}{\varepsilon_0}\right)^{3/4}\frac{1}{\sqrt{n^2_\omega n_{2\omega}}}\chi^{(2)}_{\mathrm{MKSA}} \tag{49}$$

Numerical Example:

For $I_\omega(0) = 5\times10^6$, $\lambda_\omega = 1.0\times10^{-4}$ cm, $\chi^{(2)}_{\mathrm{MKSA}} = 5\times10^{-23}$, $n_\omega \approx n_{2\omega} = 2.2$, and $\Delta z = 0.01$ cm, $\tilde{\kappa} = \frac{1}{\sqrt{2}}\omega\left(\frac{\mu_0}{\varepsilon_0}\right)^{3/4}\frac{1}{\sqrt{n^2_\omega n_{2\omega}}}\chi^{(2)} = 1.4939018\times10^{-4}$ $\mathrm{w}^{-1/2,}$ $g = 2\tilde{\kappa}\sqrt{\frac{hc}{\lambda_1}} = 1.2938\times10^{-13}$

$$\text{Note that } \frac{\mu_0}{\varepsilon_0} = \frac{4\pi\times10^{-7}}{8.85\times10^{-12}}. \tag{50}$$

When the frequency doubling is broken up into several intervals using separate calls to `double`, the cumulative effect of detuning may be accomplished by setting `zstart` to the length of previous passes through the doubler. The gain length for the power conversion is

$$\text{gain length} = \frac{g}{2}\sqrt{\frac{I_1\lambda_1}{hc}} = \frac{g}{2}\sqrt{\frac{I_1\lambda_1}{19.8762\times10^{-24}}} \tag{51}$$

where the wavelength is expressed in centimeter and I_1 is the incident intensity in watts/cm^2 of the pump. For I_1 = 10Mw/cm^2, and $\lambda_1 = 1.06\times10^{-4}$, the gain length is 1.83 cm. For $A_2(0) = 0$ and no detuning the solution is

$$I_2(z) = \frac{I_1(0)}{2}\tanh^2\left[\frac{g}{2}\sqrt{\frac{I_1(0)\lambda_1}{hc}}z\right] \tag{52}$$

The detuning factor reduces the coupling coefficient. `double/simple` implements the equations

double/simple/harmonic

$$p_2(z) = -\mathrm{j}p_1(0)\tanh\left[\frac{g_e}{2}\sqrt{\frac{I_1(0)\lambda_1}{hc}}z\right] \tag{53}$$

`double/simple/pump`

$$p_1(z) = p_1(0)\mathrm{sech}\left[\frac{g_e}{2}\sqrt{\frac{I_1(0)\lambda_1}{hc}}z\right] \tag{54}$$

which are a good approximation to the exact solution of the differential equations. g_e is the effective gain coefficient

$$g_e = g\frac{\sin^2\left(\frac{1}{2}\Delta kz\right)}{\left(\frac{1}{2}\Delta kz\right)^2} \tag{55}$$

Modifier 1	**Description**
`/full`	Implements full differential equation solution.
`/simple`	Implements second harmonic closed-form solution for pump or harmonic (see below).

Modifier 2	**Description**
`/pump`	Implements pump closed-form solution.
`/harmonic`	Implements second harmonic closed-form solution.

Numerical Values	**Description**	**Defaults**
`zstep`	Z-step distance (cm).	0.
`ipump`	Number of pump beam.	`1`
`istokes`	Number of second harmonic beam.	`2`
`kbeam`	Number of beam for simple set.	
`g`	Coupling coefficient (units of cm-sec$^{1/2}$ /photon$^{1/2}$). (See `kappa` below for alternate form).	
`deltak`	Wavenumber detuning (radians/cm).	`0.`
`nstep`	Number of steps for phase integration (set at about 10 or more), higher numbers give higher sampling of phase matching).	`10`
`zstart`	Starting value for detuning distance.	
`kappa`	Coupling coefficient (units of cm-w$^{-1/2}$). See `g` above for alternate form. (Note this kappa is just a keyword name and not identical to the kappa used in Chap. 9, GLAD Theroy Manual.	`0.`

elative temperature, density, heat conductivity, and absorption of CO_2, H_2O and aerosols.

References

1. Y. R. Shen, Chap. 7, *The Principles of Nonlinear Optics*, John Wiley & Sons, New York (1984).

EXAMPLE

This example illustrates the use of `double/full` with `kappa`.

```
wavelength 1 1.06 2.2
wavelength 2 .53 2.2
gaus/c/c 1 5e6 1
clear 2 0
pack/set 1 2 # initializes z-position for phase matching
```

```
pack/in
 double/steps ipump=1 istokes=2 zstep=1 kappa=1.4939e-4
pack/out
prop 1
```

Step size parameters for `double/full`

doubling characteristic length $$\text{zgain} = \frac{1}{g|P_1|} \qquad (56)$$

dispersion characteristic length $$\text{zdisp} = \frac{1}{\Delta k}$$

zmin = min(zgain,zdisp) (57)

number of steps per zstep $$\text{nstep} = 10\frac{\text{zstep}}{\text{zmin}} + 1 \qquad (58)$$

integration step length $$\frac{\text{zstep}}{\text{nstep}} \qquad (59)$$

EXAMPLE

This example illustrates the use of `double/full` with *g*. It yields a peak intensity 5.4×10^{-4} of w/cm for the second harmonic for the 1 cm step.

```
nbeam 2
wavelength 1 1.06
wavelength 2 .53
gaus/c/c 1 1e7 1
pack/set 1 2 # initializes z-position for phase matching
pack/in
 double zstep=1 g=1.2938e-13
pack/out
dist 1
```

ECHO Controls echo of input commands to the output. Language

Command Forms(s): **ECHO**

```
echo/list
echo/on
echo/off
echo/values/on
echo/values/off
echo/log/on          [nooverwrite or overwrite]
echo/log/off
echo/log/list
```

Description: ECHO

Input lines may be echoed to the output file with the `echo` command. `/on` is the default condition. `/off` turns off the specified function.

Echo lines are preceded by "C:" for commands from the screen and "M:" for `macro` commands when GLAD is writing to the screen. When writing to the disk file, GLAD precedes the echo with the line number of the input deck, macro level, macro name, macro pass counter, and macro line number to facilitate analysis of complex runs.

`/log` copies the echoed command, in the form determined by initial condition, `/values`, or `/lines`, to a file called log.out. This file can be used as input to repeat the sequence of commands used in an interactive session. log.out is a simple ASCII file and may be examined or edited with any text editor.

Modifier 1	Description
`/list`	List current echo state as `on` or `off`. `Off` is default.
`/on`	Turns on echo of line as is. Comments are not echoed.
`/lines/on`	Turns on echo of command line after breaking the line into separate command lines at ";" line breaks and after register assignments. s are echoed.
`/values/on`	Turns on echo of the values from numeric assignments and IF logical values.
`/log/on`	Turns on logging of input lines in log.out. Parameter overwrite (default) overwrites the file. Parameter `nooverwrite` adds the new lines to the existing file. `/log/on` initiates `echo/on`.
`/log/list`	Lists the echoed lines.

Parameters	Description
`nooverwrite`	Write log information at the end of log.out (default).
`overwrite`	Rewind log.out and begin writing at the start.

EDIT Control GladEdit windows from command lines. Language

Command Forms(s): **ECHO**

```
edit/open                    (filename)
edit/close/name              (filename)
edit/close/window_number     window_number
edit/show/name               (filename)
edit/show/window_number      window_number
edit/hide/name               (filename)
edit/hide/window_number      window_number
edit/info
```

Description: EDIT

Control the GladEdit windows from command lines.

Modifier 1	Description
`/open`	Open specified file into GladEdit. Default folder is defined by `set` `/folder`.

Modifier 1	Description (Continued)
/close	Close GladEdit window by name or window number.
/show	Show and bring to top a GladEdit window by file name or window number.
/hide	Hide (without closing) GladEdit window by file name or window number.
/info	List whether windows are visible or hidden.

Modifier 2	Description
/name	Window identified by file name.
/window_number	Window defined by window number as shown in window title.

Numerical Values	Description	Defaults
window_number	Number of the GladEdit window in order of creation.	1

ENCIRCLED Calculates encircled energy. Diagnostics

Command Forms(s): **ENCIRCLED**

```
encircled/calculate/(energy or profile)   kbeam
encircled/level                           kbeam level
encircled/list/screen                     min max nskip
encircled/list/disk                       (filename) min max nskip
encircled/udata                           column
encircled/plot                            radius
```

Description: ENCIRCLED

Encricled calculates either the encircled energy (/energy) or average radial profile (/profile). This command is intended to replace the pib command. It provides more features and is easier to use. encircled/calculate generates a data base for the beam. The data may be displayed in subsequent calls to /list, /udata, or /plot. The tabulated values of the encircled energy can be displayed by to the terminal or to a disk file. The modifier /udata will copy the data to the udata data base in the specified column (1 to 12). The x-coordinate values are reset. /udata facilitates display of several sets of encircled energy calculated for different conditions. Encircled/plot displays the data base out to the specified value of radius.

Encircled/level calculates the radius of the circular region containing the specified relative energy—similar to pib /level. /level does not use the same data base as /calculate and overwrites the storage area.

Modifier 1	Description
/calculate	Calculate the data base for subsequent calls to /list, /udata, or /plot.
/udata	Copy the data to the udata data base in the specified column.
/plot	Plot the data out to the specified value of radius.
/level	Calculate the radius which contains the specified relative energy.

Modifier 2	Description
`calculate/energy`	Calculate the encircled energy.
`calculate/profile`	Calculate the average radial profile.
`list/screen`	List to the screen.
`list/disk`	List to disk file (filename).

Modifier 3	Description
`calculate/.../middle`	Calculate encircled energy or average radial profile referenced to the center of the array (default).
`calculate/.../centroid`	Calculate encircled energy or average radial profile referenced to the centroid of the irradiance distribution.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`min`, `max`	Minimum and maximum numbers of data points to be displayed by `/list`.	All points.
`nskip`	Number of data points to be skipped by `/list`.	`max`/20
`column`	Column number to be used by `/udata`.	`1`
`radius`	Maximum radius to be displayed by `/plot`.	Full field.
`level`	Relative energy level to be used by `/level`.	0.865

System Variable Data	Description
`fitxcent`, `fitycent`	X- or y-beam-center.
`fitencir`	Radius of aperture encircling specified relative energy from `/level`.
`fitxomega`, `fityomega`	X- or y-radii of equivalent gaussian beam.
`fitxrad`, `fityrad`	X- or y-transverse radius of equivalent gaussian beam.
`fitxsig`, `fitysig`	X- or y-standard deviation of equivalent gaussian beam.

Example

Calculate and plot encircled energy.

```
encircled/calculate/energy # calculate data set
encircled/plot # plot encircled energy
encircled/list 1 10 # list first 10 values
encircled/calculate/profil # calculate average radial profile
encircled/plot # plot average radial profile
encircled/udata 1 # put data in column 1 of UDATA
plot/udata # plot udata to show same data
encircled/level 1 .5 # find radius containing 50% of energy
variab/set radius fitencir # put radius into a variable
```

END — End and/or restart GLAD. — Begin-end

Command Forms(s): **END**

```
end
```

Description: END

If called interactive from the Interactive Input window, `End` reinitializes GLAD. If called from a disk file or macro `end` stops reading the file or macro (the same as `read/back`). See also `exit`.

Also see `initialize` to restart GLAD to with initial values without ending the program.

ENERGY Calculate the total energy (or power). Diagnostics

Command Forms(s): ENERGY

```
energy/list            ibeams
energy/ginversion      ibeams
energy/norm            kbeam enorm [list]
```

Description: ENERGY

`Energy/list` writes all beam energies and photon counts. The energy in the beam is found by,

$$\text{Energy} = \sum\sum|A(x, y)|^2 \Delta x \Delta y\,, \tag{60}$$

where $A(x, y)$ is the complex amplitude and Δx and Δy are the beam units. The summation is taken over all points in the array.

`Energy/ginversion` integrates the population inversion over a gain array to yield j/cm.

The `/norm` modifier will normalize the energy of a unique beam. The percent loss is printed. Percent loss is defined to be

$$\text{Percent loss} = 100*(\texttt{enorm} - Eold)/Enorm \tag{61}$$

where *Eold* is the energy before the renormalization.

Modifier 1	**Description**
`/list`	List energy values.
`/ginversion`	List the population inversion integrated over a gain array to yield [j/cm]. The array must be polarized. Negative energies are permitted when there is no inversion. Setting the section number to 0 for 3D arrays will cause integration over all sections and output in [j] after multiplication by z-units.
`/norm`	Normalizes total energy of beam `kbeam` to `enorm`.

Parameter	**Description**
`list`	List `energy/norm` values.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`kbeam`	Single beam number.	1
`enorm`	Normalize distribution to have this energy.	`1`

System Variable Data	Description
energy	Integrated flux density of kbeam.

EXIT End and/or restart GLAD. Begin-end

Command Forms(s): **EXIT**

```
exit
```

Description: EXIT

The exit command terminates all GLAD programs: glad.exe, ide.exe, and watch.exe. Also see end.

EXTRUDE Extrudes a 1D distribution. Operator

Command Forms(s): **EXTRUDE**

```
extrude/row/straight/set    kbeami kbeamo
extrude/row/straight/add    kbeami kbeamo
extrude/column/straight/set kbeami kbeamo
extrude/column/straight/add kbeami kbeamo
extrude/row/path/set        kbeami kbeamo kbeamp
extrude/row/path/add        kbeami kbeamo kbeamp
extrude/column/path/set     kbeami kbeamo kbeamp
extrude/column/path/add     kbeami kbeamo kbeamp
```

Description: EXTRUDE

Extrudes the 1D distribution of kbeami along a row or column to form a 2D distribution in kbeamo. Kbeamp gives a path of deflection of the extrusion.

Modifier 1	Description
/row	Extrudes along the rows (default).
/column	Extrudes along the columns.

Modifier 2	Description
/straight	Straight extrusion with no deflections (default).
/path	Extrusion with deflections from kbeamp.

Modifier 3	Description
/set	Set the values of kbeamo (default).
/add	Add extruded values to kbeamo.

Numerical Values	Description	Defaults
kbeami	Beam containing the distribution to extrude, must be N × 1.	1
kbeamo	Output beam for extruded distribution.	2
kbeamp	Beam containing deflection from straight path.	3

FIBER Initalize with an analytical fiber mode for step index fiber. Begin-end

Command Forms(s): **FIBER**

```
fiber                  kbeam radius core cladding azdeg
```

Description: FIBER

Initalize with an analytical fiber mode for step index fiber, HE(1,1).

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`radius`	Radius of the core.	
`core`	Index of core region of fiber.	
`cladding`	Index for cladding (top layer) for /eigenmode.	
`azdeg`	Azimuth angle clockwise from top of beam (degrees).	

FIELD Displays table of complex amplitude values. Diagnostics

Command Forms(s): **FIELD**

```
field/x                kbeam jyline ixstart ixend istep
field/y                kbeam ixline jystart jyend jstep
```

Description: FIELD

Prints complex amplitude and intensity values of the beam array with no interpolation. A useful diagnostic tool for programmers who are debugging field modifiers. `Field` uses the internal GLAD definition of row and column indices. This convention is transposed from the mathematical convention.

field values = A(I, J)

where J is the row index and I is the column index. The equations defining the relationship between I, J and X, Y are

$$\mathrm{Y} = \left[\left(\frac{\mathrm{NlineY}}{2}+1\right)-J\right]\mathrm{UnitsY}+\mathrm{DecenY} \tag{62}$$

$$\mathrm{X} = \left[I-\left(\frac{\mathrm{NlineX}}{2}+1\right)\right]\mathrm{UnitsX}+\mathrm{DecenX} \tag{63}$$

$$\mathrm{J} = \left(\frac{\mathrm{NlineY}}{2}+1\right)-\left(\frac{\mathrm{Y}-\mathrm{DecenY}}{\mathrm{UnitsY}}\right) \tag{64}$$

$$\mathrm{I} = \left(\frac{\mathrm{X}-\mathrm{DecenX}}{\mathrm{UnitsX}}\right)-\left(\frac{\mathrm{NlineX}}{2}+1\right) \tag{65}$$

where J and I are calculated using truncation of real values to integers. The largest Y-value is at J = 1. The smallest Y-values is at J = NlineY. The center row is chosen by default.

Modifier 1	**Description**
`/x`	Scan across x-direction (default).
`/y`	Scan across y-direction.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`jyline`	Row number in array.	NlineY/2+1
`ixstart`	Starting column number in array.	1
`ixend`	Ending column number in array.	NlineX
`ixline`	Column number in array.	NlineX/2+1
`jystart`	Starting column number in array.	1
`jyend`	Ending column number in array.	NlineX
`istep, jstep`	Increment between display data.	NlineY/16

FILELIST Lists the open beam files. Diagnostics

Command Forms(s): **FILELIST**

```
filelist/list
filelist/get        (filename)
filelist/set        (filename) attribute
filelist/units
filelist/memory
```

Description: FILELIST

`/list` lists the open beam files.

Modifier 1	**Description**
`/list`	Lists the open beam files.
`/get`	Determines file security attributes.
`/set`	Sets file security attributes.
`/units`	Scans over all possible arrays listing IO units.
`/memory`	Scans over all possible memory locations listing arrays and IO units.

Numerical Values	**Description**	**Defaults**
`attribute`	Security attribute to be set (MS Windows only). Binary number formed by archive*8 + system*4 + hide*2 + read/only. Chose 1 or zero. to turn on or off feature. For example. 6 would select system and hidden status.	

String	**Description**
filename	Filename for `/get` or `/set`.

FITBOX Fit bounding box at specified level. Diagnostics

Command Forms(s): **FITBOX**

```
fitbox/spatial     kbeam level
fitbox/msquared    kbeam level
```

Description: FITBOX

Fits a bounding box according to the intensity level. Similar to `fitlevel` .

Modifier 1	Description
`/spatial`	Computes spatial domain only (default).
`/msquared`	Computes the FWHM in both spatial and frequency domains.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`level`	Relative intensity level to compute bounding box.	0.5

System Variable Data	Description
`fitxfwhm/width`	X-width of bounding box.
`fitxfwhm/left`	Left side.
`fitxfwhm/right`	Right side.
`fityfwhm/width`	Y-width of bounding box.
`fityfwhm/top`	Top side.
`fityfwhm/bottom`	Bottom side.
`fitxcent`, `fitycent`	X- or y-beam center.
`fitxomega`, `fityomega`	X- or y-radii of equivalent gaussian beam.
`fitxrad`, `fityrad`	X- or y-transverse radius of equivalent gaussian beam.
`fitxsig`, `fitysig`	X- or y-standard deviation of equivalent gaussian beam.
`fitxsigf`, `fitysigf`	X- or y-standard deviation in frequency space of equivalent gaussian beam.
`msqx`, `msqy`	M^2 in the x- and y-directions.

FITEGAUSS Fit embedded gaussian from M^2 theory. Diagnostics

Command Forms(s): **FITEGAUSS**

`fitegaus/automatic/`
`(list` or `setgeodata)/`
`(separate` or `equal)`
	`kbeam threshold [averagewidth` or `msquared]`

`fitegaus/udata/x`, `y`,
`fillx`, or `filly`
	`kbeam steps zcenter halfwidth col1 col2`
	`[averagewidth` or `msquared]`

`fitegauss/data`	`point zreff xomega yomega`
`fitegauss/list`	
`fitegauss/calculate`	

Command Forms(s): **FITEGAUSS (Continued)**

`fitegauss/set/(x` or `y)  kbeam`
`/`(modifier 3)
`fitegaus/reset`

Description: FITEGAUSS

Fits a gaussian beam to a data set of transverse radius vs. axial position. GLAD fits the waist size, waist location, and effective wavelength to the data set using damped least squares optimization. It has been argued that aberrated beams may be fit an embedded gaussian beam with a fictitious wavelength and that propagation of the embedded gaussian through an optical system will give beam sizes that are similar to the size of the actual beam which it represents. The choice `/automatic` performs a full through focus test requiring six propagation steps. While this method is slow it works for all cases—even those for which the phase radius of curvature is not well defined such as speckled beams.

For more detailed control, up to 10 set of data may used to determine the three variables of the embedded gaussian beam using `fitegauss/data`. If explicit data values are included on the command line, these will be used. If no values are given, then the current system variables `zreff`, `fitxsig`, `fitysig` are used. This allows the user to fit the spot size using `fitfwhm`, `fitgeo` , `fitknife`, or `pib/level`. The beam distributions may be derived from GLAD calculations or by reading in experimental data.

Once the data set has been built, `fitegauss /calc` will calculate the embedded gaussian. The size and position of the waist are computed as well as a synthetic wavelength. The data are accessible by

`variable/set` (Variable) `fitegaus/`(Modifier)

where the modifier takes the values `zwaist`, `yzwaist`, `waist`, `ywaist`, `lambda`, `ylambda`. `fitegauss /set` will build a gaussian beam with the specified properties.

Related commands: `fitfwhm` , `fitgeo`, `fitmsquared` , `fitknife`, `fitlevel` , `pib /level`.

Modifier 1	**Description**
`/automatic`	Perform `/data` and `/calculate` and optionally set surrogate gaussian values for `kbeam` if `/setgeodata` is selected.
`/udata`	Calculate beam half width and array half width for number of steps (`steps`) and over the number of times the Rayleigh range (`times_rayleigh`) and place data in `udata` columns `col1` and `col2`. Data may be listed or plotted. See command `udata` and `plot/udata` .
`/data`	For more detailed control than with `/automatic`. Build data set. Data may be explicitly defined or, if no data values are given, the data values are derived from the current values of `zreff`, 2*`fitxsig`, and 2*`fitysig` (See the `variables /set`description).
`/list`	List data set.
`/calculate`	Find beam intensity centroid for beam center (default).
`/set`	Build embedded gaussian in specified beam. Second modifier of `/x` or `/y` specifies whether x- or y-values should be used.
`/reset`	Reset data for a new evaluation.

Modifier 2	Description
set/x	Use x-values for building embedded gaussian (default).
set/y	Use y-values for building embedded gaussian.
automatic/list	List surrogate gaussian values but do not set (default).
automatic/setgeodata	Calculate and set surrogate gaussian values.
x, y, fillx, or filly	X or y: beam half widths put in col1 and array half widths in col2. Fillx or filly: beam half widths put in col1 and relative filling in col2.

Modifier 3	Description
set/(x or y)/constant	Use current units for embedded gaussian.
set/(x or y)/rescale	Resize units for equal size in spatial and frequency domain.
automatic/setgeodata/separate	X- and y-values may be set separately (default).
automatic/setgeodata/equal	Force y-values to be the same as x-values.

Parameter	Description
averagewidth	Fit data using average width values to compute approximation to standard deviation (default).
msquared	Fit data from msquared values using standard deviation.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
threshold	Minimum relative value of distributions to be used with /setgeodata.	0.
point	Data set to be addressed.	
xomega, yomega	X- and y-transverse radii at specified position.	2*fitxsig,
zreff	Axial position where transverse radii are measured.	zreff
steps	number of steps for /udata.	9
zcenter	Center of the region.	3
halfwidth	Halfwidth of the region.	
col1	Udata column for beam width versus position using either average half width (averagerradius) or 2*standard deviation (msquared). No data is set if col1 = 0.	1
col2	Udata column for array half width versus position. No data is set if col2 = 0.	2

System Variable Data	Description
fitegauss/(lambda or ylambda)	X- or y-effective wavelength of embedded gaussian.
fitegauss/(waist or ywaist)	X- or y-waist size of embedded gaussian.
fitegauss/(zwaist or yzwaist)	Axial position of waist.
fitegauss/(msqx or msqy)	M^2 in the x- and y-directions.
fitegauss/(widthx or widthy)	Widths of beam at current Zreff positon.
fitegauss/(radiusx or radiusy)	Radi of beam at current Zreff position.

FITFOCUS Fits and/or removes focus and astigmatism. Diagnostics

Command Forms(s): **FITFOCUS**

`fitfocus/list`	`kbeam`
`fitfocus/remove/`(Modifier 2)	`kbeam [nolist` or `list]`
`fitfocus/convert/`(Modifier 2)	`kbeam [nolist` or `list]`

Description: FITFOCUS

Displays the amount of focus error. Optionally the focus may be removed by giving `/remove` as the second modifier. `/correct` will remove the focus and alter the geometric radius of curvature to preserve the net optical power. An intensity weighted linear solution technique is used. The terms are not orthogonal so the method is not perfect for arbitrary intensity distributions. Also, see `fitphase` .

Modifier 1	**Description**
`/list`	List focus terms for x and y (default).
`/remove`	Remove focus error (`/focus`) or focus and astigmatism (`/astigmatism`).
`/convert`	Remove focus error (`/focus`) or focus and astigmatism (`/astigmatism`) and change geometric radius of curvature so that the net optical power is perserved.

Modifier 2	**Description**
`/focus`	Solve for focus. Fit equal phase radius in the x- and y-direction (default).
`/astigmatism`	Allow different values for x- and y- radius of curvature.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1

Parameter	**Description**
`nolist` or `list`	Controls listing of results when executing removal or correction. Default is `nolist`.

System Variable Data	**Description**
`fitpiston`	Piston value from last call of command.
`fitxfocus`, `fityfocus`	X- and y-defocus errors from last call of command.
`fitxtilt`, `fitytilt`	Polynomial coefficients after last call of command.

FITFWHM Fit full-width-half-maximum to distribution. Diagnostics

Command Forms(s): **FITFWHM**

```
fitfwhm/spatial        kbeam level
fitfwhm/msquared       kbeam level
```

Description: FITFWHM

Computes the full-width-half-maximum (FWHM) value of the beam. For `/msquared` also computes the FWHM in the frequency domain and computes an approximate value for m-squared. The standard deviation of a gaussian having the same FWHM is computed by,

$$\sigma \approx \frac{1}{2\sqrt{-2\ln(\mathrm{FWNM})}} \tag{66}$$

The standard deviations of the equivalent gaussian beam are accessible by

`Variable/set` (Variable) (Expression)

where “Expression” takes the forms: `fitxsig`, `fitysig`, `fitxsigf`, and `fitysigf`.

Related commands: `fitegauss`, `fitgeo`, `fitknife`, `fitlevel`.

Modifier 1	**Description**
`/spatial`	Computes spatial domain only (default).
`/msquared`	Computes the FWHM in both spatial and frequency domains.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`level`	Relative intensity level at which full-width is to be calculated.	`0.5`

System Variable Data	**Description**
`fitxcent`, `fitycent`	X- or y-beam center.
`fitxfwhm/(width`, `left`, `right)`	Full-width-half-maximum (x-direction) or full width at relative intensity specified by `Level`. Left and right give the respective side values.
`fityfwhm/(width`, `left`, `right)`	Full-width-half-maximum (y-direction) or full width at relative intensity specified by `Level`. Top and bottom give the respective limits in the vertical direction.
`fitxomega`, `fityomega`	X- or y-radii of equivalent gaussian beam.
`fitxrad`, `fityrad`	X- or y-transverse radius of equivalent gaussian beam.
`fitxsig`, `fitysig`	X- or y-standard deviation of equivalent gaussian beam.
`fitxsigf`, `fitysigf`	X- or y-standard deviation in frequency space of equivalent gaussian beam.
`msqx`, `msqy`	M^2 in the x- and y-directions.

FITGEO Calculates beam width by average radius Diagnostics

Command Forms(s): **FITGEO**

`fitgeo/spatial` `kbeam threshold [nolist` or `list]`

`fitgeo/both/`(Modifier 2) `kbeam threshold [nolist` or `list]`

Command Forms(s): **FITGEO (Continued)**

```
fitgeo/msquared/(Modifier 2)    kbeam threshold [nolist or list]
```

Description: FITGEO

Calculates spatial width, frequency width, and M-squared by average width, with optional correction of focus and astigmatism before making calculation.. Also, see `fitmsquared` and `fitegauss`.

Modifier 1	**Description**
`/spatial`	Calculate and update only spatial parameters based on average radius. Very fast with no FFT. (default)
`/both`	Calculate both spatial and frequency domain parameters based on average radius. Requires an FFT step.
`/msquared`	Calculate both spatial and frequency domain parameters based on second moment. Requires an FFT step.

Modifier 2	**Description**
`/focus`	Correct focus error before calculating frequency domain and M-squared parameters (default).
`/astigmatism`	Correct focus and astigmatism error before calculating frequency domain and M-squared parameters.
`/nocorrection`	Do not correct phase errors.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`threshold`	Ignore relative intensity below this value.	0.

Parameter	**Description**
`nolist` or `list`	Controls listing of results when executing removal or correction. Default is `nolist`.

System Variable Data	**Description**
`fitxcent`, `fitycent`	X- or y-beam center.
`fitxomega`, `fityomega`	X- or y-radii of equivalent gaussian beam.
`fitxrad`, `fityrad`	X- or y-transverse radius of equivalent gaussian beam.
`fitxsig`, `fitysig`	X- or y-standard deviation of equivalent gaussian beam.
`fitxsigf`, `fitysig`	X- or y-standard deviation, frequency space.
`msqx`, `msqy`	M^2 in the x- and y-directions.

FITKNIFE Fit beam width by knife-edge test data. Diagnostics

Command Forms(s): **FITKNIFE**

```
fitknife/spatial          kbeam
fitknife/msquared         kbeam
```

Description: FITKNIFE

Computes the beam size by a knife edge scan. /msquared computes frequency width as well to calculate M-squared (only valid for collimated beams). The beam width is taken to be the distance between the 16% and 84% points of the knife edge scan. Related commands are fitfwhm, fitegauss, fitgeo, fitlevel, fitbox, pib /level.

Modifier 1	Description
/spatial	Computes spatial domain only (default).
/msquared	Computes in both spatial and frequency domains.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1

System Variable Data	Description
fitxcent, fitycent	X- or y-beam center.
fitxomega, fityomega	X- or y-radii of equivalent gaussian beam.
fitxrad, fityrad	X- or y-transverse radius of equivalent gaussian beam.
fitxsig, fitysig	X- or y-standard deviation of equivalent gaussian beam.
fitxsigf, fitysig	X- or y-standard deviation in frequency space of equivalent gaussian beam.
msqx, msqy	M^2 in the x- and y-directions.

FITLEVEL Fits beam width to level of energy or intensity. Diagnostics

Command Forms(s): **FITLEVEL**

```
fitlevel/spatial          Kbeam relenergy
fitlevel/msquared         Kbeam relenergy
fitlevel/truncate         kbeam threshold
```

Description: FITLEVEL

Fitlevel computes the beam size by finding the relative intensity level with the specified energy level. The width of the distribution at that intensity level is calculated and used to define the beams size. Fitlevel calls fitfwhm to calculate the beam width at the specified energy level. Fitlevel/truncate clips the intensity at the previously calculated relative intensity if threshold is not defined or at threshold if it is defined. Related commands are fitbox, fitfwhm, fitegauss, fitgeo, fitknife, pib /level.

Modifier 1	Description
/spatial	Computes spatial domain only (default).
/msquared	Calculate both spatial and frequency domain parameters to calculate M-squared. Valid only for collimated beams.
/truncate	Clips the intensity at threshold, if specified, or at the previous value of relenergy if not specified.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
relenergy	Relative energy of relative intensity level to be calculated.	0.865
threshold	Relative intensity for intensity clipping with /truncate.	

System Variable Data	Description
fitxcent, fitycent	X- or y-beam center.
fitxrad, fityrad	X- or y-average radius calculated from beam width, assuming a gaussian.
fitxomega, fityomega	X- or y-radii of equivalent gaussian beam.
fitxsig, fitysig	X- or y-standard deviation of equivalent gaussian beam.
fitlevel	Relative intensity level calculated.

FITMSQUARED Calculates beam width and M-squared. Diagnostics

Command Forms(s): **FITMSQUARED**

```
fitmsquared/spatial            kbeam threshold [nolist or list]
fitmsquared/both/(Modifier 2)  kbeam threshold [nolist or list]
```

Description: FITMSQUARED

Calculates spatial width, frequency width, and M-squared with optional correction of focus and astigmatism before making calculation. M-squared is calculated by product of spatial and frequency standard deviations. Also, see fitgeo and fitegauss .

Modifier 1	Description
/spatial	Calculate and update only spatial parameters.. Very fast with no FFT. This choice does not calculate M-squared values as no frequency information is calculated. (default)
/both	Calculate both spatial and frequency domain parameters. Requires an FFT step.

Modifier 2	Description
/focus	Correct focus error before calculating frequency domain and M-squared parameters (default).
/astigmatism	Correct focus and astigmatism error before calculating frequency domain and M-squared parameters.
/nocorrection	Do not correct phase errors.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
threshold	Ignore relative intensity below this value.	0.

Parameter	Description
nolist or list	Controls listing of results when executing removal or correction. Default is nolist.

System Variable Data	Description
fitxcent, fitycent	X- or y-beam center.
fitxomega, fityomega	X- or y-radii of equivalent gaussian beam.
fitxrad, fityrad	X- or y-transverse radius of equivalent gaussian beam.
fitxsig, fitysig	X- or y-standard deviation of equivalent gaussian beam.
fitxsigf, fitysig	X- or y-standard deviation, frequency space.
msqx, msqy	M^2 in the x- and y-directions.

FITPHASE Fits tilt, focus, and astigmatism. Diagnostics

Command Forms(s): **FITPHASE**

fitphase/(Modifier 1)/(Modifier 2) kbeam [Parameter]

Description: FITPHASE

Display the low order phase. Optionally the phase may be removed by giving /remove as the second modifier. This command computes piston, tilt, and focus. If the phase of the beam is strongly altered by aberrations in the system, the phase bias used in the diffraction calculations should be refit using fitphase to avoid aliasing problems. An intensity weighted linear solution technique is used. The terms are not orthogonal for arbitrary intensity distributions, so the method is imperfect. Also, see fitfocus.

Modifier 1	Description
/both	Fit both tilt and focus terms (default).
/tilt	Fit only tilt terms.
/focus	Fit only focus term(s).

Modifier 2	Description
/sphere	Use spherical focus term (default).
/cylinder	Use cylindrical focus terms for the two directions.
/remove	Deletes low order phase, leaving surrogate gaussian beam unchanged.
/list	Compute and list phase fit data without changing beam data.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1

Parameter	Description
list or nolist	Controls listing of results when executing corrections. Default is /nolist.

System Variable Data	Description
fitpiston	Piston value from last call to fitphase.
fitxfocus, fityfocus	X- and y-defocus errors from last call to fitphase.
fitxtilt, fitytilt	Polynomial coefficients after last call to fitphase.

FITSLIT Fits beam width from slit response curve. Diagnostics

Command Forms(s): **FITSLIT**

```
fitslit/(Modifier 1)   kbeam
fitslit/udata          col1 col2
```

Description: FITSLIT

Computes the geometric size of the beam based on a slit scan at 0.16 relative values. See the related commands `fitfwhm`, `fitegauss`, `fitknife`, `fitlevel`, `fitbox`, `pib`/`level` or `encircled`/`level`.

Modifier 1	**Description**
`/spatial`	Computes spatial domain only (default).
`/msquared`	Computes in both spatial and frequency domains.
`/udata`	Copy the data to the `udata` data base in the specified columns for the x- and y-scans.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`col1`, `col2`	Columns of `udata` for x- and y-scans.	

Parameter	**Description**
`list` or `nolist`	Controls listing of results when executing corrections. Default is `/nolist`.

System Variable Data	**Description**
`fitxcent`, `fitycent`	X- or y-beam center.
`fitxomega`, `fityomega`	X- or y-radii of equivalent gaussian beam.
`fitxrad`, `fityrad`	X- or y-transverse radius of equivalent gaussian beam.
`fitxsig`, `fitysig`	X- or y-standard deviation of equivalent gaussian beam.
`fitxsigf`, `fitysig`	X- or y-standard deviation in frequency space of equivalent gaussian beam.
`msqx`, `msqy`	M^2 in the x- and y-directions.

FITZERN Fits Zernike polynomials to wavefront. Diagnostics

Command Forms(s): **FITZERN**

```
fitzern/(Modifier 1)/standard   kbeam nrad nsin ncos rnorm rignore
fitzern/(Modifier 1)/fringe     kbeam norder rnorm rignore
fitzern/(Modifier 1)/radial     kbeam norder rnorm rignore
```

Description: FITZERN

Fits a Zernike polynomial to the phase front of a beam. The beam is copied to the scratch array, and the Zernike fit is removed. The original and residual rms wavefront errors are listed. With the `list` modifier, the residual is retained in the scratch beam (-1) and may be copied into another beam with the `copy` command. Two polynomial types are permitted, as given in Table 1 and Table 2.

Modifier 1	**Description**
`/list`	Compute and list the best fit Zernike polynomial without changing the specified beam. The residual beam is retained in the scratch beam (-1).
`/remove`	Copy the residual beam from the scratch array into the specified beam. The original beam data is lost.

Modifier 2	**Description**
`/standard`	Set of polynomials organized by radial order. All azimuthal terms are included (default).
`/fringe`	Set of 37 polynomials organized by polynomial order based on the sum of radial and azimuthal orders. Used in many interferometric reduction programs. `/fringe` has more radial terms and fewer azimuthal terms.
`/radial`	Set of 8 radial polynomials.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`nrad`, `nsin`, `ncos`	`/standard` radial, sine, and cosine orders, ≤ 8.	`4, nrad, nrad`
`norder`	`/radial` maximum radial order ≤ 12.`/fringe`, sum of radial and azimuthal orders, ≤ 12.	12 (See Table 2)
`rnorm`	Normalization radius (cm).	X-beam size
`rignore`	Data cutoff radius (cm).	`rnorm`

Table. 1. Standard set of Zernike Polynomials.

Term	**Rad**	**Sin**	**Cos**	**Polynomial**
1	0	0	0	1
2	1	1	0	$\rho\sin(\phi)$
3	1	0	1	$\rho\cos(\phi)$
4	2	0	0	$2\rho^2 - 1$
5	2	2	0	$\rho^2\sin(2\phi)$
6	2	0	2	$\rho^2\cos(2\phi)$
7	3	1	0	$(3\rho^3 - 2\rho)\sin(\phi)$
8	3	3	0	$\rho^3\sin(3\phi)$
9	3	0	1	$(3\rho^3 - 2\rho)\cos(\phi)$
10	3	0	3	$\rho^3\cos(3\phi)$
11	4	0	0	$6\rho^4 - 6\rho^2 + 1$
12	4	2	0	$(4\rho^4 - 3\rho^2)\sin(2\phi)$
13	4	4	0	$\rho^4\sin(4\phi)$

Table. 1. Standard set of Zernike Polynomials. (Continued)

Term	Rad	Sin	Cos	Polynomial
14	4	0	2	$(4\rho^4 - 3\rho^2)\cos(2\phi)$
15	4	0	4	$\rho^4\cos(4\phi)$
16	5	1	0	$(10\rho^5 - 12\rho^3 + 3\rho)\sin(\varphi)$
17	5	3	0	$(5\rho^5 - 4\rho^3)\sin(3\phi)$
18	5	5	0	$\rho^5\sin(5\phi)$
19	5	0	1	$(10\rho^5 - 12\rho^3 + 3\rho)\cos(\varphi)$
20	5	0	3	$(5\rho^5 - 4\rho^3)\cos(3\varphi)$
21	5	0	5	$\rho^5\cos(5\phi)$
22	6	0	0	$20\rho^6 - 30\rho^4 + 12\rho^2 - 1$
23	6	2	0	$(15\rho^6 - 20\rho^4 + 6\rho^2)\sin(2\phi)$
24	6	4	0	$(6\rho^6 - 5\rho^4)\sin(4\varphi)$
25	6	6	0	$\rho^6\sin(6\phi)$
26	6	0	2	$(15\rho^6 - 20\rho^4 + 6\rho^2)\cos(2\phi)$
27	6	0	4	$(6\rho^6 - 5\rho^4)\cos(4\varphi)$
28	6	0	6	$\rho^6\cos(6\phi)$
29	7	1	0	$(35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho)\sin(\phi)$
30	7	3	0	$(21\rho^7 - 30\rho^5 + 10\rho^3)\sin(3\phi)$
31	7	5	0	$(7\rho^7 - 6\rho^5)\sin(5\varphi)$
32	7	7	0	$\rho^7\sin(7\phi)$
33	7	0	1	$(35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho)\cos(\phi)$
34	7	0	3	$(21\rho^7 - 30\rho^5 + 10\rho^3)\cos(3\phi)$
35	7	0	5	$(7\rho^7 - 6\rho^5)\cos(5\varphi)$
36	7	0	7	$\rho^7\cos(7\phi)$
37	8	0	0	$70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$
38	8	2	0	$(56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2)\sin(2\phi)$
39	8	4	0	$(28\rho^8 - 42\rho^4 + 15\rho^2)\sin(4\phi)$
40	8	6	0	$(8\rho^8 - 7\rho^6)\sin(6\varphi)$
41	8	8	0	$\rho^8\sin(8\phi)$

Table. 1. Standard set of Zernike Polynomials. (Continued)

Term	Rad	Sin	Cos	Polynomial
42	8	0	2	$(56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2)\cos(2\phi)$
43	8	0	4	$(28\rho^8 - 42\rho^4 + 15\rho^2)\cos(4\phi)$
44	8	0	6	$(8\rho^8 - 7\rho^6)\cos(6\varphi)$
45	8	0	8	$\rho^8\cos(8\phi)$

Table. 2. Fringe set of Zernike Polynomials. Polynomial order is the sum of the radial and azimuthal orders.

Order	Term	Rad	Sin	Cos	Polynomial
0	1	0	0	0	1
2	2	1	0	1	$\rho\cos(\phi)$
2	3	1	1	0	$\rho\sin(\phi)$
2	4	2	0	0	$2\rho^2 - 1$
4	5	2	0	2	$\rho^2\cos(2\phi)$
4	6	2	2	0	$\rho^2\sin(2\phi)$
4	7	3	0	1	$(3\rho^3 - 2\rho)\cos(\phi)$
4	8	3	1	0	$(3\rho^3 - 2\rho)\sin(\phi)$
4	9	4	0	0	$6\rho^4 - 6\rho^2 + 1$
6	10	3	0	3	$\rho^3\cos(3\phi)$
6	11	3	3	0	$\rho^3\sin(3\phi)$
6	12	4	0	2	$(4\rho^4 - 3\rho^2)\cos(2\phi)$
6	13	4	2	0	$(4\rho^4 - 3\rho^2)\sin(2\phi)$
6	14	5	0	1	$(10\rho^5 - 12\rho^3 + 3\rho)\cos(\varphi)$
6	15	5	1	0	$(10\rho^5 - 12\rho^3 + 3\rho)\sin(\varphi)$
6	16	6	0	0	$20\rho^6 - 30\rho^4 + 12\rho^2 - 1$
8	17	4	0	4	$\rho^4\cos(4\phi)$
8	18	4	4	0	$\rho^4\sin(4\phi)$
8	19	5	0	3	$(5\rho^5 - 4\rho^3)\cos(3\varphi)$
8	20	5	3	0	$(5\rho^5 - 4\rho^3)\sin(3\varphi)$
8	21	6	0	2	$(15\rho^6 - 20\rho^4 + 6\rho^2)\cos(2\phi)$
8	22	6	2	0	$(15\rho^6 - 20\rho^4 + 6\rho^2)\sin(2\phi)$
8	23	7	0	1	$(35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho)\cos(\phi)$

Table. 2. Fringe set of Zernike Polynomials. Polynomial order is the sum of the radial and azimuthal orders.

Order	**Term**	**Rad**	**Sin**	**Cos**	**Polynomial**
8	24	7	1	0	$(35\rho^7 - 60\rho^5 + 30\rho^3 - 4\rho)\sin(\phi)$
8	25	8	0	0	$70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$
10	26	5	0	5	$\rho^5\cos(5\phi)$
10	27	5	5	0	$\rho^5\sin(5\phi)$
10	28	6	0	4	$(6\rho^6 - 5\rho^4)\cos(4\varphi)$
10	29	6	4	0	$(6\rho^6 - 5\rho^4)\sin(4\varphi)$
10	30	7	0	3	$(21\rho^7 - 30\rho^5 + 10\rho^3)\cos(3\phi)$
10	31	7	3	0	$(21\rho^7 - 30\rho^5 + 10\rho^3)\sin(3\phi)$
10	32	8	0	2	$(56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2)\cos(2\phi)$
10	33	8	2	0	$(56\rho^8 - 105\rho^6 + 60\rho^4 - 10\rho^2)\sin(2\phi)$
10	34	9	0	1	$(126\rho^9 - 280\rho^7 + 210\rho^5 - 60\rho^3 + 5\rho)\cos(\varphi)$
10	35	9	1	0	$(126\rho^9 - 280\rho^7 + 210\rho^5 - 60\rho^3 + 5\rho)\sin(\varphi)$
10	36	10	0	0	$252\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$
12	37	12	0	0	$924\rho^{12} - 2772\rho^{10} + 3150\rho^8 - 1680\rho^6 + 420\rho^4 - 42\rho^2 + 1$

Table. 3. Radial set of Zernike Polynomials.

Term	**Rad**	**Polynomial**
1	0	1
2	2	$2\rho^2 - 1$
3	4	$6\rho^4 - 6\rho^2 + 1$
4	6	$20\rho^6 - 30\rho^4 + 12\rho^2 - 1$
5	8	$70\rho^8 - 140\rho^6 + 90\rho^4 - 20\rho^2 + 1$
6	10	$252\rho^{10} - 630\rho^8 + 560\rho^6 - 210\rho^4 + 30\rho^2 - 1$
7	12	$924\rho^{12} - 2772\rho^{10} + 3150\rho^8 - 1680\rho^6 + 420\rho^4 - 42\rho^2 + 1$
8	14	$3432\rho^{14} - 12012\rho^{12} + 16632\rho^{10} - 11550\rho^8 + 4220\rho^6 - 756\rho^4 + 56\rho^2 - 1$
9	16	$12870\rho^{16} - 51480\rho^{14} + 84084\rho^{12} - 72072\rho^{10} + 34650\rho^8 - 9240\rho^6 + 1260\rho^4 - 72\rho^2 + 1$
10	18	$48620\rho^{18} - 218790\rho^{16} + 411840\rho^{14} - 420420\rho^{12} + 252252\rho^{10} - 90090\rho^8 + 18480\rho^6 - 1980\rho^4 + 90\rho^2 - 1$

Table. 3. Radial set of Zernike Polynomials. (Continued)

Term	Rad	Polynomial
11	20	$184756\rho^{20} - 923780\rho^{18} + 1969110\rho^{16} - 233760\rho^{14} + 1681680\rho^{12} - 756756\rho^{10} + 210210\rho^{8} - 34320\rho^{6} + 2970\rho^{4} - 110\rho^{2} + 1$

FLIP Flip the distribution in the array. Operator

Command Forms(s): **FLIP**

```
flip/(modifier 1)          ibeams
```

Description: FLIP

Flips beam field data. Does not alter global information for the beam.

Modifier 1	Description
`/x`	Flips beam field data such that +x side becomes -x side.
`/y`	Flips beam field data such that +y side becomes -y side.

Modifier 2	Description
`/standard`	Flips about the N/2 + 1 point. Leaves a zero row or column. (Default)
`/halfpixel`	Flips about the numerical center of the array. Leaves no zero row or column. Use with Ex77.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`

FOCUS Find or move to paraxial focus or waist. Operator

Command Forms(s)\: **FOCUS**

```
focus/list                    kbeam
focus/apply/abcd/x            kbeam
focus/apply/abcd/y            kbeam
focus/apply/abcd/average      kbeam
focus/apply/waist/x           kbeam
focus/apply/waist/y           kbeam
focus/apply/waist/average     kbeam
```

Description: FOCUS

Propagate to focus based on ABCD matrix (-A/C) or waist position.

Modifier 1	Description
`/list`	List the focal positions for `/abcd` or `/waist` (default).
`/apply`	Move to the focal position.

Modifier 2	Description
/abcd	Propagate to paraxial focus based on ABCD matrix.
/waist	Propagate to waist position.

Modifier 2	Description
/x	Propagate based on x-direction.
/y	Propagate based on y-direction.
/focus	Propagate based on average of x- and y-directions.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1

FUNCTIONS Various operators on beam data. Operator

Command Forms(s): **FUNCTIONS**

```
functions/(Modifier 1)      kbeam
functions/inverse           kbeam beta
```

Description: FUNCTIONS

Applies various operations to the data in the specified array and places the functional values in the real word of the array.

Modifier 1	Description
/intensity	Place intensity (absolute value squared) in real word.
/waves	Places wavefront data in real word.
/phase	Place phase data in real word.
/real	Sets imaginary word to zero.
/aimaginary	Puts imaginary data in real word and sets imaginary word to zero.
/preal	Puts real word of second polarization state in real word of first state.
/paimaginary	Puts imaginary word of second polarization state in real word of first state.
/log	Places natural log of intensity in real word.
/log10	Places log base 10 of intensity in real word.
/material	Generates real values corresponding to number of material type.
/invert	Change all non-zero values to zero and all zero values to one. Useful for creating the complement of an aperture or obscuration.
/inverse	Computes the solution to $\frac{dI(x,y)}{dz} = \alpha I(x,y)^2$, $I(x,y,z) = [1-\beta I(x,y,0)]^{-1} I(x,y,0)$, where $\beta = \alpha z$. Solution: $a(x,y) \Rightarrow \begin{cases} (1-\beta\lvert a(x,y)\rvert^2)^{-1/2} a(x,y) & \beta\lvert a(x,y)\rvert^2 < 1 \\ 0 & \beta\lvert a(x,y)\rvert^2 > 1 \end{cases}$.

Modifier 1	Description (Continued)
/exp/intensity	Make new irradiance equal to “e” to the power of the current irradiance, $I(x, y) \to e^{I(x, y)}$.
/exp/real	Make new complex amplitude equal to “e” to the power of the current real component of complex amplitude, $a(x, y) \to e^{Re[a(x, y)]}$.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
beta	Coefficient for inverse.	

GAIN Laser gain. Also see BEER. Laser gain

Command Forms(s): **GAIN**

```
gain/converge/set           eps1 eps2 npoints
gain/converge/test          ibeams nstore
gain/converge/list
gain/eigenvalue/set         kbeam
gain/eigenvalue/show        kbeam
gain/gthree
gain/rate
gain/ruby
gain/three
gain/semiconductor
gain/coherent
gain/absorber
gain/sheet
```

Description: GAIN

Implements laser gain models and convergence criteria. The gain interface calculates the gain resulting from the varying intensity of the beam at a sheet and applies the resultant gain to the field matrix for the beam. gain/rate models laser gain by the rate equation model. See the beer command, for a simpler gain model.

Modifier 1	Description
/converge	Sets criteria by which the convergence of a resonator solution may be tested and tests whether the stated criteria have been met.
/eigenvalue	Records initial field data and computes eigenvalues for a resonator. This option works a bit weirdly. It may be modified in the future. Consider the use of mult /mode as in Example Ex56.
/rate	Implements rate equation physics (see gain/rate). GLAD is required.
/ruby	Implements ruby laser—a three level gain medium.
/sheet	Implements gain sheet (see gain/sheet). GLAD is required.

Modifier 1	**Description (Continued)**
/three	Rate equation gain for three level model, single upper level.
/gthree	General three level gain with manifolds for upper and lower levels.
/coherent	Coherent pulse propagation model suitable for short pulses.

Modifier 2	**Description**
/set	Sets convergence criteria or initial eigenvalue data.
/test	Tests for resonator convergence.
/show	Calculates and displays eigenvalues.
/list	Lists the average energy value from the last npoints.

Numerical Values	**Description**	**Defaults**
eps1	Fractional change in energy convergence criterion.	0.
eps2	Criterion based on change in absolute value of field of center point. If the change in energy or field is less than the appropriate criterion, convergence is considered to have occurred. If both criteria are set, both must be met for convergence.	0.
npoints	Number of iterations over which the energy change is computed.	5
nstore	Variable name or integer register address where the convergence returned. One is returned if the convergence criteria are met, zero if not.	1
ibeams	Beam selector. If 1 <= ibeams <= current number of beams then beam number ibeams is selected. If ibeams = 0, all active beams are selected.	0
zstep	Distance through gain medium.	

Example of gain/converge/test

```
variab/dec count
gain/conv/set eps1=.2 npoints=4
macro/def step/o
 count = count + 1
 arg = 1 - exp(-count/5)
 energy/norm 1 arg
 gain/conv/test 1 x
 variab/set Energy 1 energy
 udata/set count count Energy
 if x=1 macro/exit/all
macro/end
macro step/9
udata/list
c We see that the Energy at pass 6 was .698814
c and at pass 9 was .834717. The relative energy change is
c
c rel energy change .162813 = (.834717 - .698814)/.834717
c
c Since .162813 is less than eps1 = .2, the process convergesc on the 9th pass
```

GAIN/GTHREE Rate equation gain for general three level atom. Laser gain

Command Forms(s): GAIN/GTHREE

`gain/gthree/set`	`width cavity offset`
`gain/gthree/list`	
`gain/gthree/(noise` or `nonoise)`	
`gain/gthree/step`	`zstep time`
`gain/gthree/pump/(set` or `add)`	`kbeami kbeamo wavelength`
`gain/gthree/n2level/(set` or `add)`	`kbeami kbeamo wavelength`
`gain/gthree/ntotal/(set` or `add)`	`kbeami kbeamo wavelength`

`gain/gthree/upper`	`freq0 degeneracy freq1 freq2 freq3`
	`freq4 freq5 freq6 freq7 freq8 freq9`

`gain/gthree/lower`	`freq0 degeneracy freq1 freq2 freq3`
	`freq4 freq5 freq6 freq7 freq8 freq9`

`gain/gthree/temperture/constant`	`temperature`

Description: GAIN/GTHREE

This routine applies general three-level gain according to rate equation formulation. The GLAD is required. The rate equations treatment can model mode competition for different resonator cavity conditions, including time-varying cavities. In the general three level atom, both the upper and lower states may be represented by a manifold of lines. Only a single line from the upper state and a single line from the lower state are assumed to laser. However the manifold is assumed to very rapidly redistribute the manifold back to the Boltzman distribution.

`Gain/gthree` does not implement diffraction propagation, which must be done separately. This allows the medium to exhibit saturation due to multiple passes through the medium. `gain/gthree` must be used with the `pack` commands. See Theory Manual, Sect. 9.7. (theory.pdf), for a description of the physics of the general three-level rate equations. See Ex69i for an example of how to use the commands.

GLAD stores the pump rate $R(x, y)h\nu$ and the energy densities of the upper and lower states $h\nu N_2(x, y)$ and $h\nu N_1(x, y)$, where ν is the laser frequency. The local temperature effects the gain of the laser, as shown in the equations below. These values are stored in a beam array, which should be defined as a polarized beam and which should not be propagated (set array attribute to data). The medium array is always taken to be the last beam defined with the `pack/set` command. The real and imaginary parts of the two polarization states take the form shown below in Table 4.

Table. 4. Contents of each point of the medium array which is defined as a polarized beam. The four words of data are stored: real and imaginary, first polarization; real and imaginary second polarization.

Pump rate, $R(x, y)h\nu$ w/cm^3, laser wavelength	Level 2 times $h\nu$, $h\nu N_2(x, y)$, J/cm^3	Total density times $h\nu$, $h\nu N_{tot}(x, y)$, J/cm^3	

Modifier 2	**Description**
`/set`	Setup initial conditions.
`/list`	List parameters for rate equations.
`/noise`	Calculates contribution of optical noise due to spontaneous emission.

Modifier 2	Description (Continued)
/nonoise	Turns off calculation of spontaneous emission noise (default).
/step	Take a step of length zstep with pumping time.
/pump	Transforms the irradiance of kbeami into the real part of kbeamo to set or add to the pumping rate into Level 2. Enter the pumping rate as the product of the pump irradiance times the cross section. The dimensions are watts.
/n2level	Transforms the irradiance of kbeami into the imaginary part of the first polarization state of kbeamo to set or add to the population of Level 2, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
/ntotal	Transforms the irradiance of kbeami into the real part of the second polarization state of kbeamo to set or add to the total population, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
/upper	Wavelength of upper lasing level, degeneracy, and wavelength of other lines in the upper manifold.
/lower	Wavelength of lower lasing level, degeneracy, and wavelength of other lines in the lower manifold.

Modifier 3	Description
/constant	Set the temperature to be constant for all points.
/set	Sets the temperature distribution of kbeamo to kbeami.
/add	Adds the temperature distribution of kbeami to kbeamo.

Numerical Values	Description	Defaults
sigma	Cross section in cm^2.	
width	$\Delta\nu$, atomic line width, Hz.	
cavity	$\Delta\nu_c$, frequency spacing between longitudinal modes.	
offset	$\Delta\nu_{off}$, frequency offset of 0th longitudinal mode.	
time	Δt, time for pumping the medium. See Fig. 15.	0.
zstep	L, total length of gain medium. See Fig. 15.	0.
temperature	Constant value of temperature in Kelvin. Used in calculating the Boltzmann distribution—a relatively weak effect.	300
kbeami, kbeamo	Input and output beam numbers for copying real part of kbeami to kbeamo, without changing other values, to swap pump rate.	1, 2
freq0	Lasing line for /upper or /lower level.	
degeneracy	Degeneracy of the lasing line for /upper or /lower level.	1
freq1 to freq9	Non-lasing lines in the manifold. The lines are assumed to redistribute so rapidly that the levels in the manifold are maintained according to the Boltzmann distribution.	

GAIN/RATE Rate equation laser gain. Laser gain

Command Forms(s): **GAIN/RATE**

```
gain/rate/set                width center tspont t20 t10 cavity offset
                             n1pump sigmapump sigmalaser
```

Command Forms(s): **GAIN/RATE (Continued)**

```
gain/rate/list
gain/rate/(noise or nonoise)
gain/rate/step                  zstep time [list]
gain/rate/steady                [list]
gain/rate/n2pump/(set or add)   kbeami kbeamo wavelength
gain/rate/n2level/(set or add)  kbeami kbeamo wavelength
gain/rate/n1level/(set or add)  kbeami kbeamo wavelength
gain/rate/n1pump/(set or add)   kbeami kbeamo wavelength
gain/rate/inversion             kbeami kbeamo zstep
```

Description: GAIN/RATE

This routine applies gain according to the rate equations. The GLAD is required. It is similar to `gain/sheet` except that the pumping transverse distribution and the population inversion distribution are saved. The rate equations treatment can model mode competition for different resonator cavity conditions, including time-varying cavities. `gain/sheet` does not implement diffraction, which must be done separately. This allows the medium to exhibit saturation due to multiple passes through the medium. `gain/rate` must be used with the `pack` commands. See Theory Manual, Sect. 9.3 (theory.pdf), for a description of the physics of the rate equations. `gain/rate /step` is illustrated in Fig. 15.

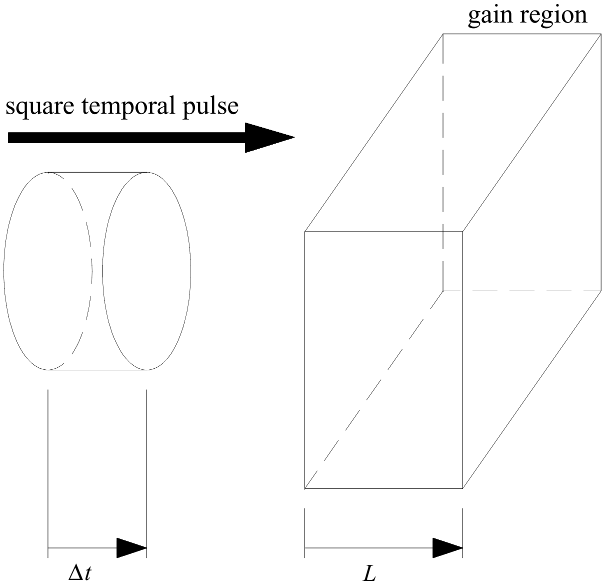


Fig. 15. For the command `gain/rate/step`, a time slice of the pulse of length Δt has energy density $I(0)\Delta t$. It interacts with a gain region of length L = `zstep`, having energy density $\Delta N(0)$•$h\nu$•`zstep`/0.5.

GLAD stores the pump rate $R_2(x, y)h\nu$ into level 2 and the energy densities of the upper and lower states $h\nu N_2(x, y)$ and $h\nu N_1(x, y)$, where ν is the laser frequency. These values are stored in a beam array, which should be defined as a polarized beam and which should not be propagated (set array attribute to data). The medium array is always taken to be the last beam defined with the `pack /set` command. See Example Ex56 for an example of the use of rate equations kinetics. The real and imaginary parts of the two polarization states take the form shown below in Table 5. The data storage is for `sigmapump` not equal to zero, as illustrated in Table. 6. `slab/pump` may be used for side pumping.

Table. 5. Contents of each point of the medium array which is defined as a polarized beam. The four words of data are stored: real and imaginary, first polarization; real and imaginary second polarization. For default condition with `/nopumpsaturate` selected.

pump rate, $R_2(x,y)h\nu$ w/cm^3, laser wavelength	Level 2 times $h\nu$, $h\nu N_2(x,y)$, J/cm^3	Level 1times $h\nu$, $h\nu N_1(x,y)$, J/cm^3	N1pump(x,y), $R_1(x,y)$

Table. 6. For `sigmapump` not equal to zero. Contents of each point of the medium array which is defined as a polarized beam. The four words of data are stored: real and imaginary, first polarization; real and imaginary second polarization

max pump rate, $R_2(x,y)h\nu$ w/cm^3, laser wavelength	Level 2 times $h\nu$, $h\nu N_2(x,y)$, J/cm^3	Level 1 times $h\nu$, $h\nu N_1(x,y)$, J/cm^3	N1pump(x,y), $R_1(x,y)$

Modifier 2	**Description**
`/set`	Setup initial conditions.
`/list`	List parameters for rate equations.
`/noise`	Calculates contribution of optical noise due to spontaneous emission.
`/nonoise`	Turns off calculation of spontaneous emission noise (default).
`/step`	Take a step of length `zstep` with pumping time.
`/steady`	Steady-state gain based on closed-form solution. See GLAD Theory Manual, Sect. 9.3 (theory.pdf). Should be inside `pack/in`, `pack/out` block. See Ex69j .
`/n2pump`	Transforms the irradiance of `kbeami` into the real part of `kbeamo` to set or add to the pumping rate into Level 2, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
`/n2level`	Transforms the irradiance of `kbeami` into the imaginary part of the first polarization state of `kbeamo` to set or add to the population of Level 2, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
`/n1level`	Transforms the irradiance of `kbeami` into the real part of the second polarization state of `kbeamo` to set or add to the population of Level 1, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
`/n1pump`	Transforms the irradiance of `kbeami` into the imaginary part of the second polarization state of `kbeamo` to set or add to the pumping rate into Level 1, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
`/inversion`	Calculate the stored energy density of `kbeami` (for two-level model) by $0.5(N_2 - N_1)h\nu$ and store in `kbeamo` for gain sheet length of `zstep`.

Modifier 3	**Description**
`/set`	Set the specified parameter.
`/add`	Add to the specified parameter.

Parameter	Description
list	List overall parameters and center point properties for gain/rate/steady and gain/rate/step.

Numerical Values	Description	Defaults
width	$\Delta\nu$, atomic line width, Hz.	
center	Center of the atomic line, Hz.	
tspont	τ_{spont}, spontaneous emission time constant.	0.
t20	τ_{20}, decay time from Level 2 to 0	
t10	τ_{10}, decay time from Level 1 to 0	
cavity	$\Delta\nu_c$, frequency spacing between longitudinal modes.	
offset	$\Delta\nu_{off}$, frequency offset of 0th longitudinal mode.	
time	Δt, time for pumping the medium. See Fig. 15. This is often half the round trip time. The round trip time may be obtained by using the variable from resonator/roundtriptime.	0.
zstep	L, total length of gain medium. See Fig. 15.	0.
n1pump	Ratio of pumping into Level 1 vs. Level 2. The imaginary part of the second polarization state is initially set to a constant value N1pump. It may be modified using gain/rate/n1pump, so that it may have an arbitrary spatial distribution.	0.
kbeami, kbeamo	Input and output beam numbers for copying real part of kbeami to kbeamo, without changing other values, to swap pump rate.	1, 2
wavelength	Laser wavelength to be used so population densities are properly expressed as power densities.	
sigmapump	Models pump saturation. See Table 6. sigmapump is the ratio of the maximum population of level 2 to the maximum pumping per increment of time Δt = time from gain/rate/set. The local pump rate is $R_2(x, y) = \max\left(0, R_{2_{max}}(x, y) - \frac{\sigma N_2(x, y)}{\Delta t}\right)$. The maximum pumping rate is $R_{2_{max}}(x, y)$. The minimum pumping rate is 0. The maximum population of the upper level is $N_2(x, y)\big\vert_{max} = \frac{1}{\sigma}\Delta t R_{2_{max}}(x, y)$.	0.
sigmalaser	Cross section for amplification replaces Einstein B-coefficient, cm^2.	0.

GLAD solves the rate equations, see Sect. 9.3, GLAD Theory Manual (theory.pdf). The medium is of length zstep and the interaction time is time, as defined by gain/rate /step. The time is often half the round trip time. GLAD input values are written non-italicized. For each step we have

populations of level 1 and 2 N_1 and N_2 (67)

pumping rate R (68)

decay rate of level 2 $$\frac{1}{\tau_2} = \frac{1}{\mathtt{t20}} + \frac{1}{\mathtt{tspont}} \tag{69}$$

pump drives level 2, 1/2 here and 1/2 at end $$\Delta N_{2_{\text{pump}}} = \frac{1}{2}R(1 - \mathtt{n1pump})\mathit{time} \tag{70}$$

pump drives level 1, 1/2 here and 1/2 at end $$\Delta N_{1_{\text{pump}}} = \frac{1}{2}R \bullet \mathtt{n1pump} \bullet \mathit{time} \tag{71}$$

half of pump effect $$N_2 \to N_2 + \Delta N_{2_{\text{pump}}} \tag{72}$$

half of pump effect $$N_1 \to N_1 + \Delta N_{1_{\text{pump}}} \tag{73}$$

level 2 decay due to spontaneous emission $$\Delta N_2 = N_2\left(1 - e^{-\frac{time}{\mathtt{tspont}}}\right) \tag{74}$$

intensity-independent decay of level 2 $$N_2 \to N_2 e^{-\frac{time}{t_2}} \tag{75}$$

intensity-independent decay and increase of level 1 $$N_1 \to N_1 e^{-\frac{time}{\mathtt{t10}}} + \Delta N_2 \tag{76}$$

stimulated emission effect on population inversion due to all modes $$\Delta N_{\text{sun}} = 0 \tag{77}$$

Process all optical modes, indicated by *k*

---

intensity of mode k, I_k (78)

spontaneous emission noise, added as random complex amplitude noise, 7 is the gain-narrowing term

$$\Delta I_k = \frac{1}{7}\frac{1}{4\pi}\frac{\lambda_k^2}{\Delta x \Delta y}\frac{N_2}{\mathtt{tspont}}h\nu_k\mathtt{zstep} \tag{79}$$

frequency shift for linewidth function $$\Delta\nu_k = \mathtt{offset} + (k-1)\mathtt{cavity} \tag{80}$$

linewidth function $$g(\Delta\nu_k) = \frac{\mathtt{width}}{2\pi}\frac{1}{\Delta\nu_k^2 + \left(\frac{\mathtt{width}}{2}\right)^2} \tag{81}$$

Einstein B coefficient of mode *k*

$$B_k = \frac{\lambda_k^2}{8\pi \bullet \texttt{tspont}} g(\Delta\nu_k) \tag{82}$$

current population difference for single beam

$$\Delta N_2 = N_2 - N_1 \tag{83}$$

Perform either Eq. (84) for small gain, or Eq. (85)–(87) for large gain

increase in optical field (small gain)

$$\Delta I_k = I_k\left(e^{B_k \Delta N \texttt{zstep}} - 1\right) \tag{84}$$

or

maximum population difference

$$N_{k_{\max}} = (N_2 - N_1) + 2I_k \frac{\texttt{time}}{\texttt{zstep} \bullet h\nu_k} \tag{85}$$

maximum intensity

$$I_{k_{\max}} = \frac{1}{2}\frac{\texttt{zstep} \bullet h\nu_k}{\texttt{time}}(N_2 - N_1) + I_k \tag{86}$$

large gain

$$I_k(\text{new}) = \frac{I_{k_{\max}} I_k(\text{old})}{I_k(\text{old}) + (I_{k_{\max}} - I_k(\text{old}))e^{B_k N_k \texttt{zstep}}} \tag{87}$$

$$\Delta I_k = I_k(\text{new}) - I_k(\text{old}) \tag{88}$$

accumulated change in population difference

$$\Delta N_{\text{sun}} \rightarrow \Delta N_{\text{sun}} + 2\Delta I_k \frac{\texttt{time}}{\text{zstep} \bullet h\nu_k} \tag{89}$$

For multiple beams solve the equations

$$N_{k_{\max}} = (N_2 - N_1) + \frac{2 \bullet \texttt{time}}{\texttt{zstep} \bullet h} \sum_k \frac{I_k(0)}{\nu_k} \tag{90}$$

$$\frac{\partial I_k(z)}{\partial z} = B_k\left(N_{k_{\max}} - \frac{2 \bullet \texttt{time}}{\texttt{zstep} \bullet h} \sum_k \frac{I_k(z)}{\nu_k}\right) I_k(z) \tag{91}$$

$$\Delta N_{\text{sun}} \rightarrow \Delta N_{\text{sun}} + \frac{2 \bullet \texttt{time}}{\texttt{zstep} \bullet h} \sum_k \frac{I_k(z)}{\nu_k} \tag{92}$$

End processing of all optical modes

include second half of pump effect $$N_2 \rightarrow N_2 + \Delta N_{2_{\text{pump}}} \tag{93}$$

include second half of pump effect $$N_1 \rightarrow N_1 + \Delta N_{1_{\text{pump}}} \tag{94}$$

depletion of level 2 due to stimulated emission $$N_2 \rightarrow N_2 - \frac{1}{2}\Delta N_{\text{sum}} \tag{95}$$

increase of level 1 due to stimulated emission $$N_1 \rightarrow N_1 + \frac{1}{2}\Delta N_{\text{sum}} \tag{96}$$

Example of gain rate routines

```
beams/on 1 2 # Beams 1 and 2 are the two competing modes
beams/off 3 # Beam 3 contains pump and inversion
clear 1 1e-4 # initialize power density of Beams 1 and 2
clear 2 1e-4
clear 3 1.39e6 # initialize pump rate distribution watts/cm**2
irradiance 3 # store pump rate in real part of Beam 3
c
c Setup gain medium parameters
c
gain/rate/set 1.45e13 3.57e14 3e-9 3e-1 1e-8 5e11 0 0
pack/set 1 2 3 # setup beams 1 and 2, beam 3 contains medium values
 # beam 3 must be defined as a polarized beam
c
c Do one diffraction step
c
pack/in # pack beams
 gain/rate/step zstep=.89 time=1e-10 nstep=10 # gain step
pack/out # unpack beams
prop .89 # propagate Beams 1 and 2
c
c continue rest of cavity
```

GAIN/RUBY Rate equation gain for ruby laser. Laser gain

Command Forms(s): **GAIN/RUBY**

```
gain/ruby/set                       width cavity offset aw
gain/ruby/list
gain/ruby/(noise or nonoise)
gain/ruby/step                      zstep time
gain/ruby/pump/(set or add)         kbeami kbeamo wavelength
gain/ruby/n2level/(set or add)      kbeami kbeamo wavelength
gain/ruby/ntotal/(set or add)       kbeami kbeamo wavelength
gain/ruby/temperture/(set or add)   kbeami kbeamo wavelength
```

Description: GAIN/RUBY

This routine applies three-level gain according to rate equation formulation. The GLAD is required. The rate equations treatment can model mode competition for different resonator cavity conditions, including time-varying cavities. `Gain/ruby` does not implement diffraction, which must be done separately. This allows the medium to exhibit saturation due to multiple passes through the medium. `gain/ruby` must be used with the `pack` commands. See Theory Manual, Sect. 9.5. (theory.pdf), for a description of the physics of the three-level rate equations. See ExEx69b for an example of how to use the commands.

GLAD stores the pump rate $R(x, y)h\nu$ and the energy densities of the upper and lower states $h\nu N_2(x, y)$ and $h\nu N_1(x, y)$, where ν is the laser frequency. The local temperature effects the gain of the ruby laser, as shown in the equations below. These values are stored in a beam array, which should be defined as a polarized beam and which should not be propagated (set array attribute to data). The medium array is always taken to be the last beam defined with the `pack/set` command. See Example Ex69 for an example of the use of rate equations kinetics. The real and imaginary parts of the two polarization states take the form shown below in Table 7.

Table. 7. Contents of each point of the medium array which is defined as a polarized beam. The four words of data are stored: real and imaginary, first polarization; real and imaginary second polarization.

Pump rate, $R(x, y)h\nu$ w/cm^3, laser wavelength	Level 2 times $h\nu$, $h\nu N_2(x, y)$, J/cm^3	Denisty total times $h\nu$, $h\nu N_{tot}(x, y)$, J/cm^3	Temperature, $T(x, y)$

Modifier 2	Description
`/set`	Setup initial conditions.
`/list`	List parameters for rate equations.
`/noise`	Calculates contribution of optical noise due to spontaneous emission.
`/nonoise`	Turns off calculation of spontaneous emission noise (default).
`/step`	Take a step of length `zstep` with pumping time.
`/steady`	Steady-state gain. See Theory Manual, Sect. 9.5, (theory.pdf).
`/pump`	Transforms the irradiance of `kbeami` into the real part of `kbeamo` to set or add to the pumping rate into Level 2. Enter the pumping rate as the product of the pump irradiance times the cross section. The dimensions are watts.
`/n2level`	Transforms the irradiance of `kbeami` into the imaginary part of the first polarization state of `kbeamo` to set or add to the population of Level 2, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
`/ntotal`	Transforms the irradiance of `kbeami` into the real part of the second polarization state of `kbeamo` to set or add to the total population, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
`/temperature`	Transforms the irradiance of `kbeami` into the imaginary part of the second polarization state of `kbeamo` to set or add to the temperature.

Modifier 3	Description
`/set`	Set the specified parameter.
`/add`	Add to the specified parameter.

GLAD solves the rate equations:

Numerical Values	**Description**	**Defaults**
`width`	$\Delta\nu$, atomic line width, Hz.	
`cavity`	$\Delta\nu_c$, frequency spacing between longitudinal modes.	
`offset`	$\Delta\nu_{\mathrm{off}}$, frequency offset of 0th longitudinal mode.	
`aw`	Coefficient for change in atomic linewidth due to temperture.	
`time`	Δt, time for pumping the medium. See Fig. 15. This is often half the round trip time. The round trip time may be obtained by using the variable from `resonator/roundtriptime`.	`0.`
`zstep`	L, total length of gain medium. See Fig. 15.	`0.`
`kbeami`, `kbeamo`	Input and output beam numbers for copying real part of `kbeami` to `kbeamo`, without changing other values, to swap pump rate.	`1`, `2`
`wavelength`	Laser wavelength to be used so population densities are properly expressed as power densities.	

$$\frac{\partial}{\partial t}N' = -\alpha(\nu)\frac{I}{h\nu}N', \tag{97}$$

$$\frac{\partial I}{\partial z} = \alpha(\nu)N'I. \tag{98}$$

where $K(x, y) = \exp\left(-\frac{\Delta E}{kT}\right)$ and $\frac{\Delta E}{k} \approx 0.87$ for ruby, $\alpha = \sigma_{21}\frac{3+K}{2(1+K)}$ and $\beta = -\frac{\sigma_{21}}{2}$, and $N' = N_2 - \frac{\beta}{\alpha}N_{\mathrm{tot}}$.

The medium is of length `zstep` and the interaction time is `time`, as defined by `gain/ruby/step`. GLAD input values are written non-italicized, Courier font. For each `nstep` we have

incremental time step $$time = \frac{\mathtt{time}}{\mathtt{nstep}} \tag{99}$$

incremental distance step $$zstep = \frac{\mathtt{zstep}}{\mathtt{nstep}} \tag{100}$$

populations of level 1 and 2 $$N_1 \text{ and } N_2 \tag{101}$$

pumping rate $$R \tag{102}$$

pump drives level 2, 1/2 here and 1/2 at end $$\Delta N_{2_{\mathrm{pump}}} = \frac{1}{2}R \bullet N_1 \bullet \mathtt{time} \tag{103}$$

decay of level 2 $$N_2 \rightarrow N_2 e^{-\frac{\mathtt{time}}{t_2}} \tag{104}$$

Process all optical modes, indicated by *k*

--

intensity of mode *k*, I_k (105)

spontaneous emission noise, added as random complex amplitude noise, 7 is gain-narrowing term

$$\Delta I_k = \frac{1}{7}\frac{1}{4\pi}\frac{\lambda_k^2}{\Delta x \Delta y}\frac{N_2}{t_{21}}h\nu_k \mathtt{zstep} \tag{106}$$

decay time for level 2 to level 1 $\tau_{21} = 0.00511 - 1.057\times10^{-5}(T - 293°K)$ (107)

wavelength of atomic linewidth versus temperature $\lambda(T) = 0.694325\mu + 0.00068(T - 293°K)\mu$ (108)

shift in center wavelength of atomic line versus temperature, $\lambda(293°K) = 0.694325\mu$

$$\frac{\Delta\lambda(T)}{\lambda(293°K)} = 9.7937\times10^{-5}(T - 293°K) \tag{109}$$

center of atomic linewidth versus temperature $\nu_0(T) = \dfrac{c}{\lambda(T)}$ (110)

shift in center wavelength of atomic line versus temperature, $\nu(293°K) = 4.317754\times10^{14}\mathrm{sec}^{-1}$ (111)

frequency shift for k^{th} line at $\Delta\nu_k = \mathtt{offset} + (k-1)\mathtt{cavity}$ (112)

frequency shift for k^{th} line vs. temperature $\Delta\nu_k \to \Delta\nu_k - 4.2287\times10^{10}(T - 293°K)$ (113)

$$\Delta\, v(T) = \mathtt{width} + \mathtt{aw}\bullet(T - 293°K) \tag{114}$$

linewidth function $g(\nu_k, T) = \dfrac{\Delta\nu(T)}{2\pi}\dfrac{1}{\Delta\nu_k^2 + \left(\dfrac{\Delta\nu(T)}{2}\right)^2}$ (115)

cross section $B_k(\nu_k, T) = \sigma_{21}(\nu_k, T) = \dfrac{\lambda(T)^2}{8\pi n^2\tau_{21}(T)}g(\nu_k, T)$ (116)

$$K = \frac{N_2(2A)}{N_2(E)} = \exp\left(-\frac{\Delta E}{kT}\right) \approx 0.87 \text{ at } 300°K \tag{117}$$

$$\alpha(\nu, T) = \sigma_{21}(\nu, T)\frac{3+K}{2(K+1)} \tag{118}$$

$$\frac{\partial\phi}{\partial z} = \alpha(\nu, T)\phi\left(N_2 + \frac{K+1}{K+3}N_{\mathrm{tot}}\right) \tag{119}$$

$$N' = N_2 - \frac{\beta}{\alpha}N_{\mathrm{tot}} \text{ and } \phi = \frac{I}{h\nu} \tag{120}$$

$$\frac{\partial I}{\partial z} = \alpha(\nu, T)N'I \tag{121}$$

----

for single beam perform either (122) for small gain, or (125) for large gain

increase in optical field (small gain) $\Delta I_k = e^{\alpha N' \mathtt{zstep}}$ (122)

or

maximum population difference $N_{k_{\mathrm{max}}}{}' = N_k{}' + I_k\frac{\mathtt{time}}{\mathtt{zstep}h\nu_k}$ (123)

maximum intensity $I_{k_{\mathrm{max}}} = \frac{\mathtt{zstep}h\nu_k}{\mathtt{time}}N_k{}' + I_k$ (124)

$$I_k(\mathrm{new}) = \frac{I_{k_{\mathrm{max}}}I_k(\mathrm{old})}{I_k(\mathrm{old}) + (I_{k_{\mathrm{max}}} - I_k(\mathrm{old}))e^{\alpha(\nu, T)N_{k_{\mathrm{max}}}\mathtt{zstep}}} \tag{125}$$

$$\Delta I_k = I_k(\mathrm{new}) - I_k(\mathrm{old}) \tag{126}$$

accumulated change in population difference $\Delta N_2 = \Delta N_2{}' = -\frac{\Delta I\mathtt{time}}{h\nu\mathtt{zstep}}$ (127)

for multiple beams solve the differential equations for each of the *k* longitudinal modes

----

$$N_{k_{\mathrm{max}}}{}' = N_k{}' + \frac{\mathtt{time}}{\mathtt{zstep}\bullet h}\sum_k\frac{I_k(0)}{\nu_k} \tag{128}$$

$$\frac{\partial I_k(z)}{\partial z} = B_k\left(N_{k_{\max}}' - \frac{\texttt{time}}{\texttt{zstep}\bullet h}\sum_k \frac{I_k(z)}{\nu_k}\right) I_k(z) \tag{129}$$

$$\Delta N = \Delta N' = \frac{\texttt{time}}{\texttt{zstep}\bullet h}\sum_k \frac{I_k(z)}{\nu_k} \tag{130}$$

End processing of all optical modes

----

include second half of pump effect $N_2 \rightarrow N_2 + \Delta N_{2_{\mathrm{pump}}}$ (131)

depletion of level 2 due to stimulated emission $N_2 \rightarrow N_2 - \frac{1}{2}\Delta N_{\mathrm{sum}}$ (132)

GAIN/THREE Rate equation gain for three level model. Laser gain

Command Forms(s): **GAIN/THREE**

```
gain/three/set                         width center tspont t20 cavity offset
gain/three/list
gain/three/(noise or nonoise)
gain/three/step                        zstep time
gain/three/pump/(set or add)           kbeami kbeamo wavelength
gain/three/n2level/(set or add)        kbeami kbeamo wavelength
gain/three/ntotal/(set or add)         kbeami kbeamo wavelength
```

Description: GAIN/THREE

This routine applies three-level gain according to rate equation formulation. The GLAD is required. The rate equations treatment can model mode competition for different resonator cavity conditions, including time-varying cavities. `Gain/three` does not implement diffraction, which must be done separately. This allows the medium to exhibit saturation due to multiple passes through the medium. `gain/three` must be used with the `pack` commands. See Theory Manual, 9.6 . (theory.pdf), for a description of the physics of the three-level rate equations. See ExEx69g for an example of how to use the commands.

GLAD stores the pump rate $R(x, y)h\nu$ and the energy densities of the upper and lower states $h\nu N_2(x, y)$ and $h\nu N_1(x, y)$, where ν is the laser frequency. The local temperature effects the gain of the laser, as shown in the equations below. These values are stored in a beam array, which should be defined as a polarized beam and which should not be propagated (set array attribute to data). The medium array is always taken to be the last beam defined with the `pack/set` command. The real and imaginary parts of the two polarization states take the form shown below in Table 8.

See Chap. 9.6 for an explanation of the theory. Example Ex69g provides a numerical example.

Table. 8. Contents of each point of the medium array which is defined as a polarized beam. The four words of data are stored: real and imaginary, first polarization; real and imaginary second polarization.

Pump rate, $R(x, y)h\nu$ w/cm^3, laser wavelength	Level 2 times $h\nu$, $h\nu N_2(x, y)$, J/cm^3	Total denisty times $h\nu$, $h\nu N_{\mathrm{tot}}(x, y)$, J/cm^3	Temperature, $T(x, y)$

Modifier 2	**Description**
`/set`	Setup initial conditions.
`/list`	List parameters for rate equations.
`/noise`	Calculates contribution of optical noise due to spontaneous emission.
`/nonoise`	Turns off calculation of spontaneous emission noise (default).
`/step`	Take a step of length `zstep` with pumping time.
`/steady`	Steady-state gain. See Theory Manual, Sect. 9.5, (theory.pdf).
`/pump`	Transforms the irradiance of `kbeami` into the real part of `kbeamo` to set or add to the pumping rate into Level 2. Enter the pumping rate as the product of the pump irradiance times the cross section. The dimensions are watts.
`/n2level`	Transforms the irradiance of `kbeami` into the imaginary part of the first polarization state of `kbeamo` to set or add to the population of Level 2, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.
`/ntotal`	Transforms the irradiance of `kbeami` into the real part of the second polarization state of `kbeamo` to set or add to the total population, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.

Modifier 3	**Description**
`/set`	Set the specified parameter.
`/add`	Add to the specified parameter.

Numerical Values	**Description**	**Defaults**
`width`	$\Delta\nu$, atomic line width, Hz.	
`center`	Center of the atomic line, Hz.	
`tspont`	τ_{spont}, spontaneous emission time constant.	
`t20`	τ_{20}, decay time from Level 2 to 0.	
`cavity`	$\Delta\nu_c$, frequency spacing between longitudinal modes.	
`offset`	$\Delta\nu_{\mathrm{off}}$, frequency offset of 0th longitudinal mode.	
`time`	Δt, time for pumping the medium. See Fig. 15. This is often half the round trip time. The round trip time may be obtained by using the variable from `resonator/roundtriptime`.	`0.`
`zstep`	L, total length of gain medium. See Fig. 15.	`0.`
`kbeami, kbeamo`	Input and output beam numbers for copying real part of `kbeami` to `kbeamo`, without changing other values, to swap pump rate.	`1, 2`

GAIN/SEMICONDUCTOR Semiconductor gain. Laser gain

Command Forms(s): **GAIN/SEMICONDUCTOR**

```
gain/semiconductor/cavity                width center cavity offset
```

Command Forms(s): **GAIN/SEMICONDUCTOR (Continued)**

```
gain/semiconductor/set                  gain0_semi ntr ns a b c beta
gain/semiconductor/step                 zstep tstep nstep
gain/semiconductor/list
gain/semiconductor/pgen/(set or add)    kbeami kbeamo wavelength
gain/semiconductor/nlevel/(set or add)  kbeami kbeamo wavelength
```

Description: GAIN/SEMICONDUCTOR

This routine applies semiconductor gain, based on Coldren and Corzine. See Sect. 9.4, GLAD Theory Manual. The GLAD feature set is required. `gain/semiconductor` must be used with the `pack` commands. The medium array may be an unpolarized array with parameters stored as shown in Table. 9.

Table. 9. Contents of each point of the medium array which is defined as an unpolarized beam. The two words of data are stored in the real and imaginary parts.

Pump rate, $P(x,y)h\nu$w/cm^3, ν at laser wavelength.	Carrier-hole density, times $h\nu$: $h\nu N(x,y)$J/cm^3

The gain equations derived in Sect. 9.4, GLAD Theory Manual are sumarized below,

Population change by generation (P_{gen}) and rcombination (R_{rec}): $$\frac{\partial N}{\partial t} = P_{\text{gen}} - R_{\text{rec}} \tag{133}$$

Generation rate in terms of efficiency η_i, current I, charge q, and volume V: $$P_{\text{gen}}(x, y) = \frac{\eta_i I}{qV} \tag{134}$$

Recombination rate from spontaneous and stimulated effects: $$R_{\text{rec}} = \frac{N(x, y)}{\tau[N(x, y)]} + R_{\text{st}} \tag{135}$$

Rate of change of population: $$\frac{\mathrm{d}N(x, y)}{\mathrm{d}t} = P_{\text{gen}}(x, y) - g[N(x, y)]I(x, y) - \frac{N(x, y)}{\tau[N(x, y)]} \tag{136}$$

Carrier decay: $$\frac{1}{\tau} = \mathtt{a} + \mathtt{b}N(x, y) + \mathtt{c}N(x, y)^2 \tag{137}$$

Gain varies with population: $$g[N(x, y)] = \mathtt{gain0} \times \ln\left(\frac{N(x, y) + \mathtt{ns}}{\mathtt{ntr} + \mathtt{ns}}\right) \tag{138}$$

Effective spontaneous emission rate: $$R_{\text{eff}} = \beta_{\text{sp}} R_{\text{sp}} = \mathtt{beta} \times \mathtt{b} \times N(x, y)^2 \tag{139}$$

Rate of increase of optical intensity: $$\frac{\mathrm{d}I}{\mathrm{d}z} = g(N)I + h\nu\Delta\Omega R_{\text{eff}} \tag{140}$$

Solid angle is a property of the array sampling: $$\Delta\Omega = \frac{\lambda^2}{\Delta x \Delta y} .. \tag{141}$$

Modifier 2	Description
/cavity	Set cavity and atomic line width parameters.
/set	Set parameters for semiconductor gain.
/step	Propagate within pack/in and pack/out. Optical and media beams are defined by pack/set such that the last beam is the media beam.
/list	List parameters for rate equations.
/pgen	Transforms the irradiance of kbeami into the real part of kbeamo to set or add to the generation rate density. Enter the pumping rate as the product of the pump irradiance times the cross section. The dimensions are watts per cm^3. In the case of illumination by a field of intensity I_{pump} (dimensions of w/cm^2) and pump absorption coefficient α (dimension of cm^{-1}) the generation rate density (in the case of weak absorption) will be approximately αI_{pump} (units of w/cm^3). GLAD will be divide the power form of generate rate density by $h\nu$ to give the pump rate density in terms of excitation entities.
/nlevel	Transforms the irradiance of kbeami into the imaginary part of the first polarization state of kbeamo to set or add to the generation rate, modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.

Modifier 3	Description
/set	Set /pgen or /nlevel.
/add	Add to/pgen or /nlevel.

Numerical Values	Description
width	Δν, atomic line width, Hz.
center	Center of the atomic line, Hz.
cavity	$\Delta\nu_c$, frequency spacing between longitudinal modes.
offset	$\Delta\nu_{off}$, frequency offset of 0th longitudinal mode.
zstep	Propagation distance. Diffraction propagation is included.
tstep	Increment of time for pumping and losses of the inversion.
gain0	Base gain in cm^{-1}. See Eq. (138). This is the gain at $N(x,y)$ = e×ntr. That is gain0 = g(e×ntr).
ntr	Transparency population density, excitations per cm^3. Used in Eq. (138).
ns	Numerical adjustment to keep the argument of the logarithm positive (Eq. 138).
a	Nonradiative recombination coefficient for decay rate of inversion per Eq. (137).
b	Bimolecular recombination coefficient for decay rate of inversion per Eq. (137).
c	Auger recombination rate for decay rate of inversion per Eq. (137).
beta	Ratio of mode bandwidth to spontaneous emission bandwidth, β_{sp}.
xrad, yrad	Halfwidth of rectangular region for which gain is to be applied.

GAIN/COHERENT[/Dest Coherent pulse propagation—short pulses. Laser gain

Command Forms(s): **GAIN/COHERENT**

```
gain/coherent/set                    sigma decay center
```

Command Forms(s): GAIN/COHERENT (Continued)

```
gain/coherent/list
gain/coherent/(noise or nonoise)
gain/coherent/step                   zstep time [list]
gain/coherent/pump/(set or add)      kbeami kbeamo wavelength
gain/coherent/inversion/(set or add) kbeami kbeamo wavelength
```

Description: GAIN/COHERENT

This routine applies gain according to tcoherent pulse propagation theory. See Sect. 9.15 . For short pulses, the rate equation approximation approach may predict the release of energy from the population inversion too quickly. `Gain/coherent` does not implement diffraction, which must be done separately. This allows the medium to exhibit saturation due to multiple passes through the medium. `gain/three` must be used with the `pack` commands. See Theory Manual, 9.6 . (theory.pdf), for a description of the physics of the three-level rate equations. See Ex Ex69 g for an example of how to use the commands.

GLAD stores the pump rate $R(x, y)h\nu$ and the population inversion $h\nu(N_2(x, y) - N_1(x, y))$ where ν is the laser frequency. The local temperature effects the gain of the laser, as shown in the equations below. These values are stored in a beam array, which should be defined as a polarized beam and which should not be propagated (set array attribute to data). The medium array is always taken to be the last beam defined with the `pack/set` command. The real and imaginary parts of the two polarization states take the form shown below in Table 8.

Table. 10. Contents of each point of the medium array which is defined as a polarized beam. The four words of data are stored: real and imaginary, first polarization; real and imaginary second polarization.

Pump rate, irradiance times absorption times $h\nu$, $R(x, y)h\nu$ w/cm^3, laser wavelength	Population inversion times $h\nu$, $h\nu(N_2(x, y) - N_1(x, y))$, j/cm^3	Real part, moving average of E-field times population inversion for internal use.	Imaginary part, moving average of E-field times population inversion for internal use.

Modifier 2	**Description**
`/set`	Setup initial conditions.
`/list`	List parameters for rate equations.
`/noise`	Calculates contribution of optical noise due to spontaneous emission.
`/nonoise`	Turns off calculation of spontaneous emission noise (default).
`/step`	Take a step of length `zstep` with pumping time.
`/pump`	Transforms the irradiance of `kbeami` into the real part of `kbeamo` to set or add to the pumping rate into Level 2. Enter the pumping rate as the product of the pump irradiance times the absorption. The dimensions are watts/cm^3.
`/inversion`	Transforms the real part of `kbeami` into the imaginary part of the first polarization state of `kbeamo` to set or add to the population inversion modified by the ratio of wavelength of the input beam divided by the wavelength of the laser.

Modifier 3	**Description**
`/set`	Set the specified parameter.
`/add`	Add to the specified parameter.

Parameter	Description
`list`	List overall parameters and center point properties for `gain/coherent/step`.

Numerical Values	Description	Defaults
`sigma`	Cross section in cm^2.	
`decay`	Decay time for coherent gain. Inverse of atomic line width.	
`center`	Center of the atomic line, Hz.	
`time`	Δt, time for pumping the medium. See Fig. 15. This is often half the round trip time. The round trip time may be obtained by using the variable from `resonator/roundtriptime`.	`0.`
`zstep`	L, total length of gain medium. See Fig. 15.	`0.`
`kbeami`, `kbeamo`	Input and output beam numbers for copying real part of `kbeami` to `kbeamo`, without changing other values, to swap pump rate.	`1, 2`

GAIN/ABSORBER Saturable absorber. Laser gain

Command Forms(s): **GAIN/ABSORBER**

```
gain/absorber/set              gs_sigma es_sigma gamma transmission t2
gain/absorber/list
gain/absorber/step             length time [list]
gain/absorber/n0               kbeami kbeamo
```

Description: GAIN/ABSORBER

This command models a saturable absorber based on the Cr^{4+} that is commonly used for passive Q-switching of lasers. Figure 16 illustrates the four level system. Laser light can be absorbed between Levels 1 and 3 with cross section σ_{gs} for ground state absorption. Laser light can also be absorbed betwen Levels 2 and 4 with cros section σ_{es} for excited state absorption. Level 3 decays rapidly to Level 2 and Level 4 decays rapidly and non-radiatively to Level 2..

The real and imaginary parts of the two polarization states take the form shown below in Table 11.

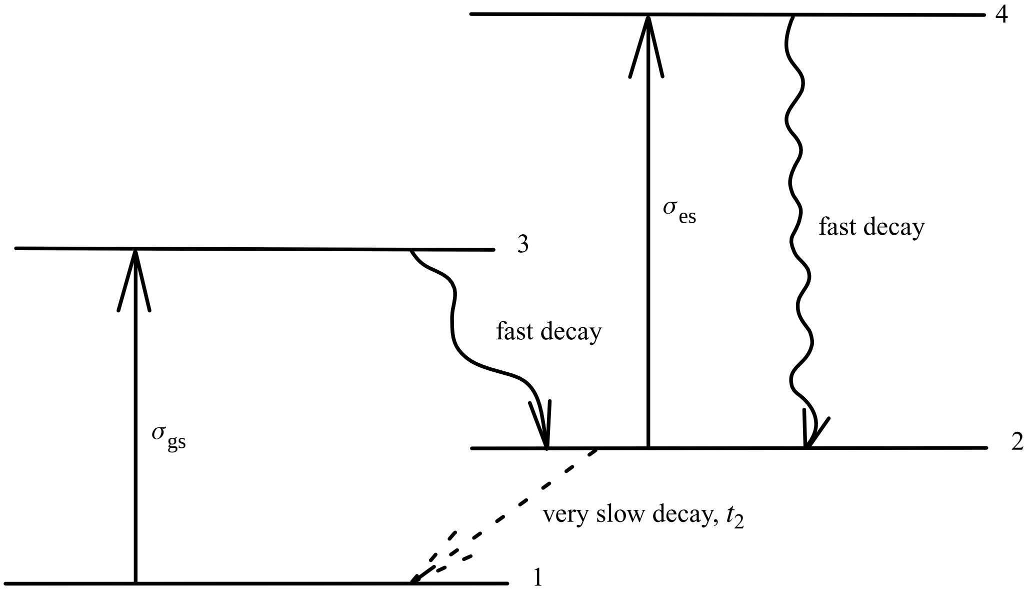


Fig. 16. Four levels of a Cr^{4+}saturable absorber. The primary mechanism for laser absorption is the transition from Level 1 to Level 3—ground state absorption. It is assumed that Level 3 decays very quicly to Level 2. Excited state absorption occurs between Level 2 to Level 4. It is assumed that Level 4 decays by some non-radiative process.

Table. 11. Contents of each point of the medium array.

Total population of Cr^{4+}ions, n_0.	Population of excited state. n_2.

Modifier 2	**Description**
`/set`	Setup initial conditions.
`/list`	List parameters for rate equations.
`/length`	Implement a saturable absorber of specified length with pumping time.
`/n0`	Population density of Cr^{4+}ions stored in real word of array.

Parameter	**Description**
`list`	List overall parameters and center point properties for `gain/coherent/step`.

Numerical Values	**Description**	**Defaults**
`gs_sigma`	Ground state absorption cross section in cm^2.	
`es_sigma`	Excited state absorption cross section in cm^2.	
`gamma`	Inversion reduction factor which depends on degeneracy.	
`transmission`	Transmission of component including surfaces losses and bulk absorption unrelated to the saturable effect.	
`t2`	Decay time from Level 2.	4×10^{-6} s

Numerical Values	Description (Continued)	Defaults
`time`	Δt, time for laser light to change the population density. This is often half the round trip time. The round trip time may be obtained by using the variable from `resonator/roundtriptime`.	`0.`
`zstep`	L, total length of absorber.	`0.`
`kbeami`, `kbeamo`	Input and output beam numbers for copying real part of `kbeami` to `kbeamo` and sets imaginary word to 0. for n_2.	`1, 2`

GAIN/SHEET Gain sheet formulation for multiple beams. Laser gain

Command Forms(s): **GAIN/SHEET**

```
gain/sheet/multibeam    zstep
gain/sheet/point        zstep
```

Description: GAIN/SHEET

This routine applies a gain sheet step. The GLAD feature set is required. It is similar to the `beer /noprop` command except saturation is based on the intensities of multiple beams. `gain/sheet` does not implement diffraction, which must be done separately. This allows the medium to exhibit saturation due to multiple passes through the medium. `gain/sheet` must be used with the `pack` commands. For example, to calculate gain with the saturation based on the sum of intensities in Beams 1 and 2 do the following,

```
beer/set g0=.02 es=1. # establish gain medium parameters
pack/set 1 2 # set up beams 1 and 2
pack/in # implement packing with current beam intensities
gain/sheet/multi 30. # gain sheet step of 30 cm.
pack/out # reestablish normal state
```

The gain takes the form,

$$g = \frac{g_0(x, y)}{\left(1 + \frac{\sum I_k}{I_s}\right)^q} \tag{142}$$

where

$g_0(x, y)$ is the local small signal gain
I_k are the intensities to be summed from the various beams
I_s is the saturation intensity
q is 1 for homogeneous and $1/2$ for inhomogeneous broadening

The small signal gain, $g_0(x, y)$, is determined according to the spatial limitations determined by `beer/set`.

Modifier 1	Description
`/multibeam`	Use 2nd and additional beams from `pack /set` to add to saturation intensity (default).

Modifier 1	Description (Continued)
`/point`	For three beams defined with `pack` `/set`, the first beam is to be amplified, the 2nd beam has the distribution for small signal gain $g_0(x, y)$ in the real word. Negative values are allowed for the 2nd beam using the real word. The 3rd beam has the distribution $I_s(x, y)$. For more than three beams, the additional beams between 1st and the last two contribute to saturation intensity in the same manner as with `/multibeam`.

Numerical Values	Description	Defaults
`zstep`	Length of gain medium.	0.

Example of use of `gain/sheet/point`

```
clear 1 100           # uniform intensity for propagating beam
gaus 2 g0 20          # gaussian distribution for small signal gain
irradiance 2          # Set real word for gain
gaus 3 es 20          # gaussian distribution for saturation intensity
pack/set 1 2 3        # beam 1, g0, es distributions
pack/in
 gain/sheet/point 10  # 10 cm. of gain
pack/out
prop 10               # diffraction propagation of 10 cm.
```

See gainsheet.inp and gainsheet1.inp among the examples.

GAUSSIAN — Set beam to gaussian function. — Begin-end

Command Forms(s): **GAUSSIAN**

```
gaussian/cir      ibeams pkflu r0 sgxp decx decy radx rady
gaussian/sqr      ibeams pkflu r0 sgxp decx decy radx rady
gaussian/ell      ibeams pkflu r0x r0y sgxp decx decy radx rady
gaussian/rec      ibeams pkflu r0x r0y sgxp sgyp decx decy radx rady
gaussian/half     kbeam pkflu l0x r0x lsgxp rsgxp decx decy
```

Description: GAUSSIAN

Defines a gaussian spherical wave for the beam(s). Defines geometric data such as beam center, coordinates, waist size and location, and zeros out tilt angle. By default the units are computed automatically. The polarization state is set to be linearly polarized in the x-direction. Alterations to the polarization state may be made with the `jones` command. See also `halfgaussian` .

Modifier 1	Description
`/cir`	Circular distribution. $\sqrt{\texttt{pkflu}}\exp\left[-\left(\frac{x^2+y^2}{\texttt{ro}^2}\right)^{sgxp}\right]$

Modifier 1	Description (Continued)
/sqr	Square distribution. $\sqrt{\mathtt{pkflu}}\exp\left[-\left(\frac{x^2}{\mathtt{ro}^2}\right)^{sgxp}-\left(\frac{y^2}{\mathtt{ro}^2}\right)^{sgxp}\right]$
/ell	Elliptical distribution. $\sqrt{\mathtt{pkflu}}\exp\left[-\left(\frac{x^2}{\mathtt{rox}^2}+\frac{y^2}{\mathtt{roy}^2}\right)^{sgxp}\right]$
/rec	Rectangular distribution. $\sqrt{\mathtt{pkflu}}\exp\left[-\left(\frac{x^2}{\mathtt{rox}^2}\right)^{sgxp}-\left(\frac{y^2}{\mathtt{roy}^2}\right)^{sgyp}\right]$
/half	Gaussian with difference for left and right x-half planes $\begin{cases}\sqrt{\mathtt{pkflu}}\exp\left[-\left(\frac{x^2+y^2}{\mathtt{rox}^2}\right)^{rsgxp}\right] & x>0\\ \sqrt{\mathtt{pkflu}}\exp\left[-\left(\frac{x^2+y^2}{\mathtt{lox}^2}\right)^{lsgxp}\right] & x<0\end{cases}$

Modifier 2	Description
/noadjust	Do not change geometric data no matter how small the aperture (default).
/con	Conserve current units.
/res	Rescale: compute new units prior to generating field.
/equalxy	Force geometric data for y to be the same as x (except if rox ≠ roy).

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
pkflu	Peak irradiance.	1.
r0	Amplitude radius or half-width (cm).	1.
r0x	Amplitude radius in x-direction (cm).	1.
l0x	Left side amplitude radius in x-direction (cm).	
r0y	Amplitude radius in y-direction (cm).	r0x
sgxp	Gaussian/supergaussian exponent in x-direction.	1.
sgyp	Gaussian/supergaussian exponent in y-direction.	sgxp
rsgxp	Right side x-exponent for /half.	1.
lsgxp	Left side x-exponent for /half.	1.
decx, decy	Coordinates of beam center (cm).	0., 0.
radx, rady	Phase radii of curvature for gaussian spherical wave. Plane wave by default.	

GEODATA Output table of surrogate gaussian properties. Diagnostics

Command Forms(s): **GEODATA**

```
geodata/list                  kbeam
```

Command Forms(s): GEODATA (Continued)

`geodata/set/msquared/values`	`kbeam m2x m2y`
`geodata/set/msquared/continuousunits`	`kbeam`
`geodata/set/ waist`	`kbeam waistx waisty`
`geodata/set/beamsize`	`kbeam wsx wsy`
`geodata/set/all`	`kbeam zwaistx zwaisty waistx waisty iplanx iplany eqwstx eqwsty`
`geodata/fit/(separate` or `equal)`	`kbeam threshold [msquared` or `averageradius]`

Description: GEODATA

This command lists or sets the geometric data associated with the surrogate gaussian beam. This data is used by GLAD to control the choice of diffraction algorithms. Generally this information is automatically set by the `gaussian`, `clap`, `lens`, and `mirror` commands. In certain applications such as unstable resonators, it may be necessary to reset the geometric data. In stable resonators, the starting geometric data should be selected so that it is reproduced in one round trip.

Modifier 1	Description
`set`	Sets the data.
`list`	Lists all coefficients.
`fit`	Perform fit of surrogate gaussian radius using the `fitegauss` procedure.

Modifier 2	Description
`fit/separate`	Allow x- and y-values to be different.
`fit/equal`	Set y-values to be the same as x-values.
`set/msquared`	Set M^2 values and recalculate waist size and location using local beam size and radius of curvature.
`set/waist`	Set waist position to current beam poistion. Set waist size to current beam half width (default) or input values for `waistx` and `waisty`. Reference surface is assumed to be flat.
`set/beamsize`	Set local beam half widths and recalculate waist size and location assuming phase radius of curvature is unchanged.
`set/all`	Sets all parameters. The user is responsible for choosing reasonable values. This is an old form of the command and is included for backward compatibility.

Modifier 3	Description
`msquared/values`	Set m^2 to specified values and recompute surrogate gaussian waist size and location.
`msquared/continuousunits`	Calculate and set M^2 to have constant units based on current sampling. Beam is propagated to current waist, M^2 is reset, and the beam is propagated back to original position. Radius of curvature and units may be adjusted.

Parameter	Description
`msquared`	Perform fit using M-squared values for `geodata /fit`.

Parameter	**Description (Continued)**
averageradius	Perform fit using average radius for geodata /fit.

Numerical Values	**Description**	**Defaults**
kbeam	Single beam number.	1
zwaistx, zwaisty	Locations of x- and y-waists.	0., 0.
waistx, waisty	Waist size for x- and y-directions.	
wsx, wsy	Local beam half widths.	
m2x, m2y	Explicitly set M^2 values used for determining surrogate gaussian waist location and size. For a converging beam, larger M^2 values expand the effective Rayleigh range and shift the location of the waist upstream.	
threshold	Threhsold used in calculating M-squared or average radius for /fit.	0.
iplanx, iplany	1 if plane reference surface, 0 if curved.	
eqwstx, eqwsty	Gaussian equivalent radius factor.	

GEODATA/LIST Table Values	**Description**
zwaistx, zwaisty	Locations of x- and y-waists for surrogate gaussian.
waistx, waisty	Transverse radius of surrogate gaussian waist.
m2x, m2y	M-squared values for x and y.
radx, rady	Phase radius of surrogate gaussian.
zrayx, zrayy	Axial half-width of Rayleigh range.
zdistx, zdisty	Axial location of surrogate gaussian waist.
iplanx, iplany	1 if plane reference surface, 0 if curved reference surface.
wsx, wsy	Local transverse radius of surrogate gaussian waist.

Variables geodata/**(mod)**	**Description**
zwaistx, zwaisty	Locations of x- and y-waists for surrogate gaussian.
waistx, waisty	Transverse radius of surrogate gaussian waist.
iplanx, iplany	1, plane reference surface, 0 curved reference surface (zdistx and zdisty).
m2x, m2y	M-squared values for x and y.
radx, rady	Phase radius of surrogate gaussian.
zrayx, zrayy	Axial half-width of Rayleigh range.
zdistx, zdisty	Axial location of surrogate gaussian waist.
insidx, insidy	1 if beam is inside Rayleigh range, 0 if curved.
wsx, wsy	Local transverse radius of surrogate gaussian.

GLASS Properties of optical glass for Lensgroup. Component

Command Forms(s): **GLASS**

```
glass/beam/(list or set)          (glass name)  kbeam
```

Command Forms(s): **GLASS (Continued)**

`glass/wavelength`	(glass name) `lambda`
`glass/coefficients`	(glass name)
`glass/set`	`type a0 a1 a2 a3 a4 a5`
`glass/index`	`index`

Description: GLASS

Extracts information from glass catalog.

Modifier 1	Description
`/beam`	Use the wavelength of `kbeam` for calculating refractive index.
`/wavelength`	Use lambda for calculating refractive index.
`/coefficients`	List the dispersion coefficients of given glass name.
`/set`	Set the user-defined glass type identified as "`glass`" in the `lensgroup` surface definition lines.
`/index`	Set the user-defined glass type identified as "`glass`" in the `lensgroup` surface definition lines to have the specified index.The same as "`glass/index 5 a0`".

Modifier 2	Description
`beam/list`	List index of refraction based on beam wavelength.
`beam/set`	Set index of refraction of beam based on beam wavelength.

Character String	Description
(glass name)	Name of the glass or material from the lensgroup tables. glass will use the coefficients from the last glass defined in `lensgroup/define`.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`lambda`	Wavelength in microns.	
`type`	Dispersion type for "`glass`". See definition of dispersion types given with the `lensgroup` command.	
`a0,a1,a2,a3,a4,a5`	Dispersion coefficients. Definition depends on glass `type`.	
`index`	Index of refraction for "`glass`".	

Example of specifying just the index of refraction

```
lensgroup/def mylens/o
   index 3.5
   surface 1000 .1 glass
   surface 1e10 air
   image focus
lensgroup/end
lensgroup/run mylens
```

GLOBAL Initialize global positioning. Positioning

Command Forms(s): **GLOBAL**

```
global/define          ibeams x y z rx ry rz
global/operator        ibeams x y z rx ry rz parity
global/list            ibeams
global/opl/list        ibeams
global/opl/add         ibeams opl yopl ppl
global/opl/set         ibeams opl yopl ppl
```

Description: GLOBAL

The `global` command is used to define and list the global coordinate system. Each beam is assigned a global position vector and a ray coordinate matrix. The global position vector defines where the center of the beam is. The ray coordinate matrix defines a set of (x, y, z) coordinates that identify the relation of the information stored in the array and the global coordinate system. The ith global position vector is gr(3,i) and $rgr(3, 3, i)$ is the ith ray coordinate matrix. The ray coordinate matrix is composed of three column vectors

$$rgr(3, 3, i) = [(\hat{\boldsymbol{x}}_i)(\hat{\boldsymbol{y}}_i)(\hat{\boldsymbol{z}}_i)] \qquad (143)$$

where $\hat{\boldsymbol{x}}_i$, $\hat{\boldsymbol{y}}_i$, and $\hat{\boldsymbol{z}}_i$ are unit vectors.

The vectors $\hat{\boldsymbol{x}}_i$ and $\hat{\boldsymbol{y}}_i$ define the transverse coordinate system on which the complex amplitude is defined. The vector $\hat{\boldsymbol{z}}_i$ is the ray direction vector (or k-vector).

Modifier 1	Description
/define	If ibeams = 0 then all beam position vector are set to (x, y, z).
/operator	Global position is shifted from current position by x, y, z, rx, ry, rz. No diffraction takes place (nonphysical).
/list	Lists position vectors and OPL and PPL values of all beams if kbeam = 0 single beam if kbeam ≠ 0. OPL is the optical path length and PPL is the physical path length. These parameters are maintained internally in double precision but displayed in single precision.
/opl	List or define optical and physical path lengths.

Modifier 2	Description
/list	List OPL values.
/add	Add specified values to OPL or PPL.
/set	Set specified OPL and PPL values.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
x,y,z	Translation coordinates.	0.,0.,0.
rx,ry,rz	Starting rotation angles (deg.).	0.,0.,0.
parity	+1, normal, -1 flips k-vector direction 180° after rotation.	+1

Numerical Values	**Description (Continued)**	**Defaults**
`opl`, `yopl`, `ppl`	Optical path length for x- and y-directions and physical path length.	

System Variable Data	**Description**
`Opl`, `Oply`, `Ppl`	Optical, y-optical, and physical path lengths.

GRATING Diffractin grating. Component

Command Forms(s): **GRATING**

`grating/cosine/absorption`	`ibeams period mod trans azdeg phi xdec ydec`
`grating/square/absorption`	`ibeams period mod trans duty azdeg phi xdec ydec`
`grating/cosine/phase`	`ibeams ewav period azdeg phi xdec ydec irefbeam`
`grating/square/phase`	`ibeams ewav period duty azdeg phi xdec ydec irefbeam`
`grating/blazed/phase`	`ibeams blazeerror period azdeg phi xdec ydec irefbeam`
`grating/global/cosine/phase`	`ibeams ewav period order irefbeam`
`grating/global/square/phase`	`ibeams ewav period order duty irefbeam deltalambda`
`grating/global/blazed/phase`	`ibeams blazeerror period order irefbeam deltalambda`
`grating/global/cosine/absorption`	`ibeams period order mod trans deltalambda`
`grating/global/square/absorption`	`ibeams period order mod trans duty deltalambda`
`grating/global/ramp/absorption`	`ibeams period order mod trans duty deltalambda`

Description: GRATING

This command applies a transmission grating to the beam. The equation is

`/cosine/absorption`

$$A_2 = A_1\sqrt{\mathtt{trans}\left(\left(1-\frac{\mathtt{mod}}{2}\right)+\frac{\mathtt{mod}}{2}\cos\left[\frac{2\pi(x-\mathtt{xdec})}{\mathtt{period}}+\mathtt{phi}\right]\right)} \tag{144}$$

`/square/absorption`

$$A_2 = A_1\sqrt{\mathtt{trans}\left(1-\frac{\mathtt{mod}}{2}-\mathtt{mod}\bullet\mathrm{sign}(0.5, s)\right)} \tag{145}$$

$$s = \left|\mathrm{mod}\left(\frac{x-\mathtt{xdec}}{2}+\frac{\mathtt{phi}}{360}+\frac{1}{2},1\right)-\mathrm{sign}\left(0.5,\frac{x-\mathtt{xdec}}{2}+\frac{\mathtt{phi}}{360}+\frac{1}{2}\right)\right|-\frac{\mathtt{duty}}{2} \tag{146}$$

for the x-direction. `Azdeg` rotates the distribution counterclockwise. `/square` gives a square or rectangular profile grating. Also see `aberration`/(ripple).

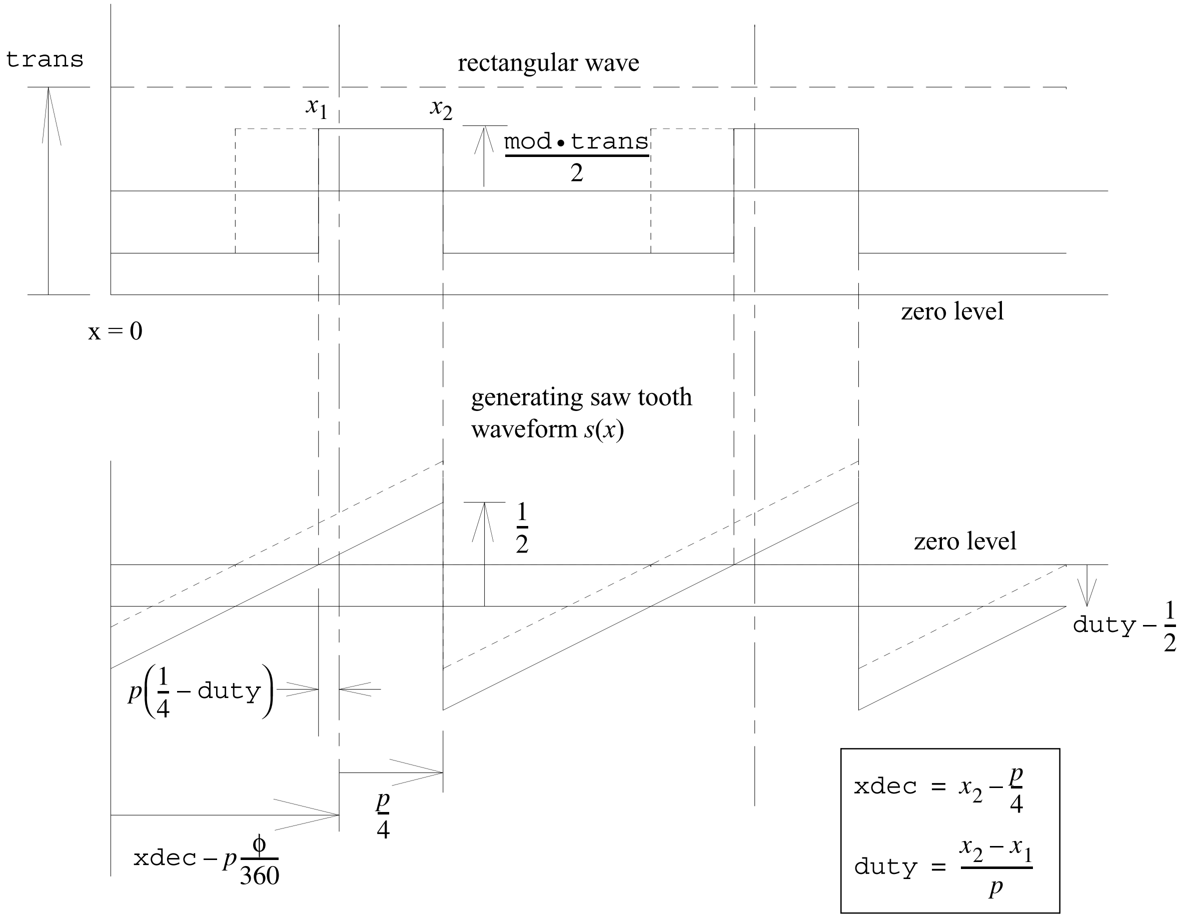

trans
rectangular wave
x_1
x_2
$\frac{\mathtt{mod}\bullet\mathtt{trans}}{2}$
x = 0
zero level
generating saw tooth waveform $s(x)$
$\frac{1}{2}$
zero level
$\mathtt{duty}-\frac{1}{2}$
$p\left(\frac{1}{4}-\mathtt{duty}\right)$
$\frac{p}{4}$
$\mathtt{xdec}-p\frac{\phi}{360}$
$\mathtt{xdec} = x_2-\frac{p}{4}$
$\mathtt{duty} = \frac{x_2-x_1}{p}$

Fig. 17. Definition of square grating parameters.

`/cosine/phase`

$$W(x,y) = \mathtt{ewav}\bullet\sin\left\{[y\cos(\mathtt{azdeg})+x\sin(\mathrm{azdeg})]\frac{1}{\mathtt{period}}+\mathtt{phi}\right\} \tag{147}$$

`/square/phase`

$$W(x,y) = \mathtt{ewav}\bullet\mathrm{sqr}\left\{[y\cos(\mathtt{azdeg})+x\sin(\mathrm{azdeg})]\frac{1}{\mathtt{period}}+\mathtt{phi}\right\} \tag{148}$$

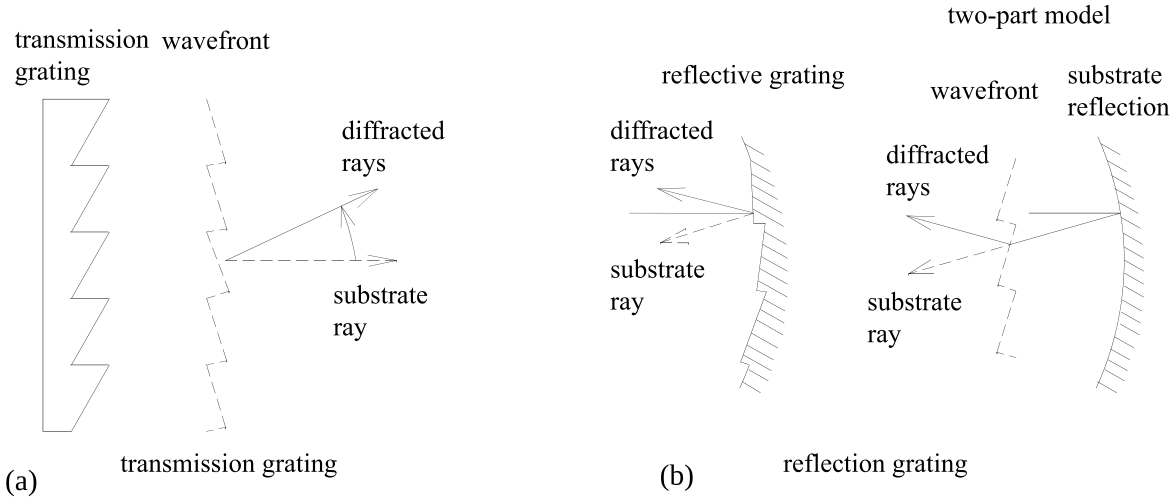


Fig. 18. Concept for `grating/global`. Both refractive and reflective gratings can be treated with the same mode. The optimum blazing angle lines up the diffracted ray from the grating with the refracted ray considering the optical effect of the refraction at the blazed facet. (a) Shows a refractive grating. The resulting wavefront effect is shown with dashed lines. (b) A reflective grating may be considered as two parts: a simple reflecting substrate (no grating) and a refractive grating of comparable wavefront deformation (no substrate). This mirror should be implemented with the `global/mirror` command followed with the `global/grating` command.

where "sqr" indicates a square wave.

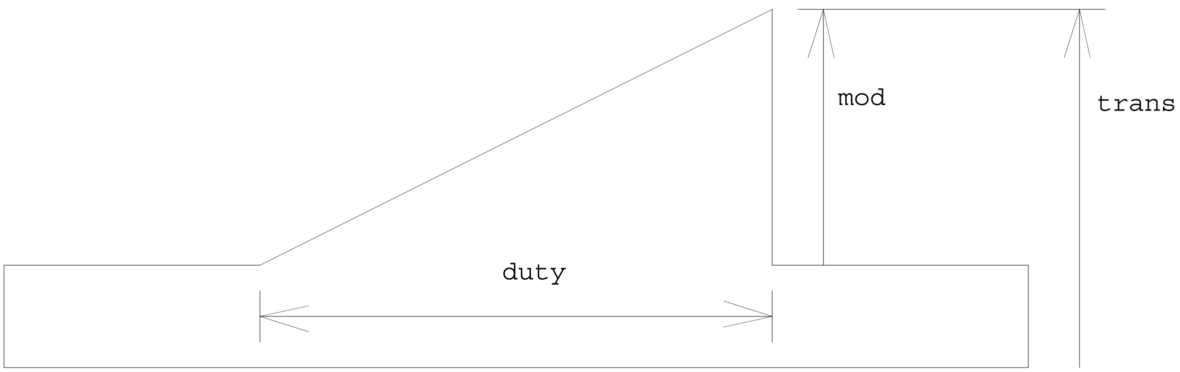


Fig. 19. Concept for `grating/global/ramp/absorption`. An absorption grating with a ramp function for transmission. By default the duty cycle is set to 1.0 for ramp gratings.

Modifier 1	**Description**
`/cosine`	Cosine waveform.
`/square`	Square or rectangular wave grating.

Modifier 1	Description (Continued)
/blazed	Blazed grating. Grating is defined in terms existing wavefront modulation: (n-1)×surface modulation. Grating lines are tilted facets at specified angle (after refraction or reflection). In ideal design, the blazing angle is selected so, considering only one facet, the exiting light is aligned with the angle of the diffracted order.
/global	Phase grating is defined by global coordinates using preceeding vertex/rotate commands. Grating is assumed to be located at current beam position (no automatic propagation to vertex/locate position, use prop if necessary). Only specified order is considered. Treatment is unresolved, i.e., it is not necessary to have sufficient sampling density to resolve individual grating line structure. The efficiency is calculated for the single diffractive order indicated and the beam is redirected to satisfy the grating equation upon exiting from the grating.

Modifier 2	Description
/absorption	Absorption grating.
/phase	Phase grating.
/square	Square shape for global grating.
/cosine	Cosine shape for global grating.
/blazed	Blazed shape for global phase grating.
/ramp	Saw tooth shape for amplitude grating.

Modifier 3	Description
/absorption	Absorption global grating.
/phase	Phase global grating.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
mod	Modulation, 1 gives full modulation.	1.
period	Grating period.	
order	Diffracted order for grating/global.	0
ewav	Wavefront modulation in waves.	
blazeerror	Error of blazing angle of wavefront. For default value of 0, GLAD uses optimum blazing angle which matches refracted or reflected ray due to grating facets with the diffracted ray based on grating period and order.	0.
duty	Duty cycle for rectangular wave.	0.5, square 1., ramp
trans	Peak transmission.	1.
azdeg	Azimuth angle measured counterclockwise (degrees).	0.
phi	Phase of grating in the center (degrees).	0.
xdec, ydec	Coordinates of grating center.	0., 0.
ewav	Aberration coefficient (waves).	0.
irefbeam	Reference beam number for wavelength for phase grating.	ibeams
deltalambda	Inceremental wavelength difference (cm) from beam value. Treated as a phase tilt rather than a change in global data.	

HALFGAUSSIAN Gaussian with different left and right sides. Begin-end

Command Forms(s): **HALFGAUSSIAN**

```
halfgauss        kbeam peak leftwidth rightwidth xdec ydec nl nr
```

Description: HALFGAUSS

Defines a gaussian which has different properties on the left ($x < \texttt{xdec}$) and right ($x > \texttt{xdec}$) sides.

$$I(x, y) = Peak \exp\left[-2\left(\frac{x^2 + y^2}{\texttt{rightwidth}}\right)^{\texttt{nr}}\right], x > \texttt{xdec} \tag{149}$$

$$I(x, y) = Peak \exp\left[-2\left(\frac{x^2 + y^2}{\texttt{rightwidth}}\right)^{\texttt{nl}}\right], x < \texttt{xdec}, \tag{150}$$

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`peak`	Peak intensity value.	`1.`
`rightwidth`	Width for right half-plane.	
`leftwidth`	Width for left half-plane.	
`xdec`, `ydec`	Coordinates of beam center (cm).	
`nl`, `nr`	Left and right supergaussian exponents.	

HELP Activates text-based Help (see PDF manuals). Language

Command Forms(s): **HELP**

help (string)

Description: HELP

Activates a menu driven help file. Superior forms of help are now available as described below. May be run as a command line in GLAD or as a separate program gladhelp.exe. The data file help.sor must be in the current directory. If a command-modifier string is given, for example, `plot/xslice` , GLAD will look up that sequence. Otherwise, help begins with the top-level menu.

Online help is available in three forms. Both IDE.EXE and WATCH.EXE have MS Windows Help files available from the main menu bar to describe operation of these windows programs. You can also access the full set of GLAD manuals in online form from the Help item on the IDE.EXE menu bar. These online documents use the Adobe Acrobat Reader 7.0 and provide high quality online viewing and support printing of selected pages with high resolution Postscript. There is also a character based search program called gladhelp.exe, which may be accessed through the `help` command or run independently. This program is still provided primarily for backward compatibility as the online documentation is superior.

String	Description
(string)	Optional command-modifier sequence for help to look up.

HERMITE Initialize beam to Hermite polynomials. Begin-end

Command Forms(s): **HERMITE**

`hermite/(con, noadjust, ibeams energ xrad yrad xnor ynor xdec ydec`
or `res)`

Description: HERMITE

Defines an initial Hermit-Gaussian field distribution. Sets geometric data such as beam center, waist size and location, and reference surface shape (plane). By default the units are automatically computed. The transverse modes of ideal stable resonators take the form of Hermite-gaussian polynomials or Lagurerre-gaussian. The general polynomial form of the Hermite-gaussian functions is

$$u_n = \left(\frac{2}{\pi}\right)^{1/4}\left(\frac{1}{2^n n!\omega_o}\right)^{1/2} H_n\left(\frac{\sqrt{2x}}{\omega_o}\right)\exp\left(-\frac{x^2}{\omega_0}\right) \tag{151}$$

where n is the order of the polynomial, ω_0 is a waist radius parameter similar to the gaussian beam and $H_n(x)$ are the Hermite functions. The two-dimensional functions may be described by multiplying two one-dimensional functions. The order and waist parameters may be different for the two directions.

Modifier 1	Description
`/con`	Conserve current units (default).
`/noadjust`	Conserve current units, do not reset surrogate gaussian. Always selected in resonator mode.
`/res`	Rescale: compute new optimum units prior to generating file.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`energ`	Total beam energy (mw).	`1.`
`xrad`, `yrad`	Reference radius, ω_0.	Beam size (cm).
`xnor`, `ynor`	Hermitian order in specified direction.	`1.`
`xdec`, `ydec`	Coordinates of beam center (cm).	

HIGHNA High numerical aperture lens. Component

Command Forms(s): **HIGHNA**

```
highna/focus        kb1 kb2 focallength
highna/collimate    kb1 kb2 focallength
```

Description: HIGHNA

This command models a high numerical aperture lens using vector diffraction. A dipole projection model, which is described in GLAD Theory Manual Sect. 6.4, (theory.pdf), is used. The dipole projection model divides the optical field into a transverse mode and an axial mode. See Example Ex90 for a simple example. Beam `kb1` is the incident beam, which must be polarized. After the lens, `Kb1` contains the transverse mode. `Kb2` must be unpolarized and, after the lens, will contain the axial mode.

Modifier 1	Description
`/focus`	Applies vector diffraction to form a three-dimensional focus.
`/collimate`	Applies vector diffraction to propagate a bean from a three-dimensional focus to a following pupil and recollimates the beam. Beam `kb2` contains no useful information after this operation.

Numerical Values	Description	Defaults
`kb1`	Incident beam, must be polarized. After the lens contains the transverse mode.	1
`kb2`	Contains the axial mode after the lens. Must be unpolarized but of the same size as `kb1`.	
`focallength`	Focal length of the lens.	

HOMOGENIZER Beam homogenizer. Component

Command Forms(s): **HOMOGENIZER**

```
homogenizer/largescale      kb1 kb2 magnification kb3
homogenizer/finescale       kb1 kb2 cycles focallength kb3 icent jcent
```

Description: HOMOGENIZER

This function models the microstructure of an idealized beam homogenizer. Useful for determining the magnitude of coherent artifacts that would arise in a lenslet array beam homogenizer (see Fig. 20). Lenslet apertures are assumed to be rectangular. The function divides the pixels width in `kb1` by the pixel with of `kb2` to find the number of lenslet elements (powers of 2). For example if Kb1 is 512 × 512 and `kb2` is 64 × 64 there will be a lenslet array of 8 × 8 lenses. To get an array of 10 x 10, use a 16 × 16 array and mask off the outer 2 lens elements on each side with a rectangular aperture. The units with the `finescale` choice are

$$\Delta x' = \frac{\texttt{cycles}}{N}\frac{\lambda f}{N\Delta x} \tag{152}$$

as compared with the units after an ordinary lens $\Delta x' = \lambda f/N\Delta x$, where N is the array length.

The `largescale` view overlaps the distributions at each lenslet incoherently to show the envelope smoothing. `Finescale` calculates the coherent effects. Neighboring lenslets create interference fringes. These effects are very fine scale according to the angles of the lenslet beams as they intersect at the target plane. The smaller the coherence width (autocorrelation size) of the distribution the smaller the magnitude of the coherence effects.

Modifier 1	Description
`/largescale`	Calculates large scale features due to incoherent summations.
`/finescale`	Calculates microstructure due to coherent and partially coherent effects.

Numerical Values	**Description**	**Defaults**
kb1	Source beam.	1
kb2	Beam for coherent sum (starts from zero each time). The number of elements is the line width of kb1 divided by the line width of kb2, so beams must be of different size. For example, nline(kb1) = 512 and nline(kb2) = 64. The units of kb2 are set to $\Delta x_2 = \frac{\mathtt{cycles}\lambda f}{N^2\Delta x_1}$ where N is the width of the array in pixels of kb2.	2
magnification	Magnification of homogenizer. Sets scale of output array.	
cycles	The number of cycles of the microstructure to be observed. The number of cycles and the focal length determine the units for kb2 and kb3.	
focallength	Focal length of large lens of homogenizer. Sets scale of output array.	
kb3	Optional beam for cumulative incoherent sum (not reset). Must be the same dimensions as kb2 (which is reset for each call).	
icent, jcent	Relative point in the plane of the mask (measured in pixels) where the coherence effects are to be observed.	M/2+1, N/2+1

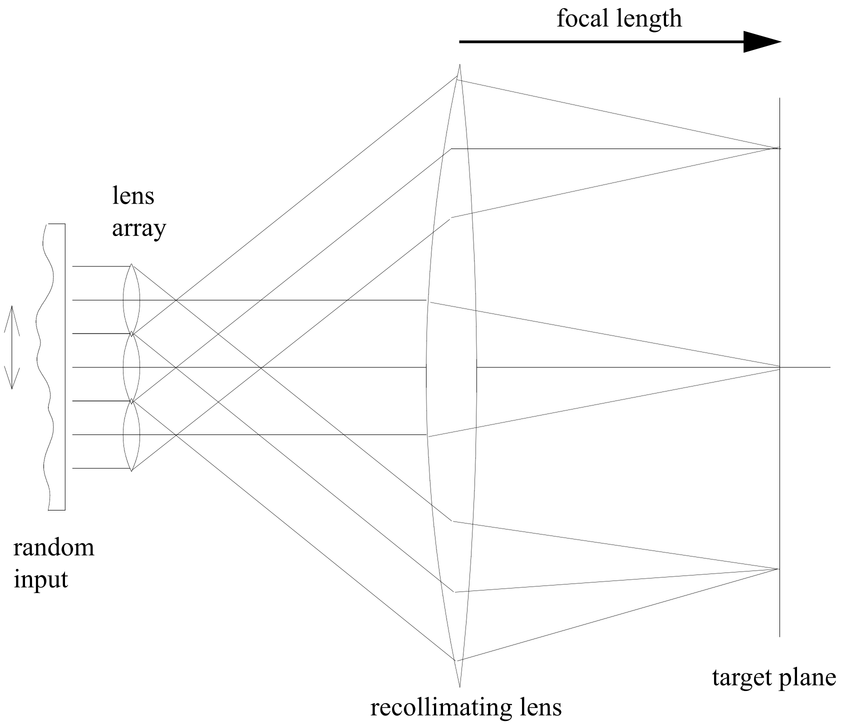


Fig. 20. A lens array is positioned in an optical beam. A smoothed random input is incident on the lenslet array. A recollimating lens results in the beams overlapping at the target plane (plane of a mask for photolithography. The target plane is not precisely conjugate to the plane of the input. However, the effects of propagation are usually negligible at the target plane. The principal coherent diffraction effect is due to the relative angles of the overlapping beam determined by the angle of the chief rays from the various apertures.

HTML — Control HTML viewer. — Language

Command Forms(s): **HTML**

```
html/info
html/start/(browser, nobrowser)
html/stop
html/browser/(start, stop)
html/browser/executable                                     (name with full path)
html/output/ (hide, normal, list)
html/picture/(hide, normal, list)
html/location/(off, current, bottom, absolute, relative)
html/polling/off
html/polling/pause                                          ipause
html/polling/period                                         seconds_polling
html/maximum_lines                                          maximum_lines
html/svg/(on, off, list)
html/svgz/(on, off, list)
html/wmf/(on, off, list)
```

Description: HTML

Output will be written to an HTML file and displayed in the user's default browser (tested with Internet Explorer, Firefox, and Corel). Output is in the form of text, tables, and plots. Table items have tooltips (popup definitions) that provide definitions when the mouse is placed over the item. This action is called a mouse-over. The output line information is placed below the source line and dynamically and automatically updated, so that the user may easily see the program progress through a macro. Output information may optionally be hidden or displayed with the "[-]" and "[+]" controls. Graphics are displayed at the output information at the point they are generated. The new scalable vector graphics (SVG) are the default plot format for HTML graphics. The SVG graphics may be scaled to double size or hidden. When the same plot name is used multiple times each version is saved. By default the most recent version is displayed but the user may select any version using the "<" and ">" controls in the HTML plot name.

Optionally the user may use `/location` to cause the browser to keep the current line (along with other choice) in view as the output lines are generated. The browser view may be "refreshed" but the "back" control of the browser does not work on this type of dynamically generated HTML files.)

Modifier 1	**Description**
`/info`	List information on the HTML state.
`/start`	Start output to GladOut.html and browser and turn on SVG graphics and set \location\current.
`/stop`	Stop writing HTML output.
`/browser`	Start up browser to view entry html file: (installation folder)\html\GladOut.html.
`/output`	Optionally hide the HTML output text and tables. Hidden output may be displayed by clicking the [+] control to display more information.

Modifier 1	Description (Continued)
/picture	Optionally hide pictures in HTML output. Hidden pictures may be displayed by clicking the '[+]' control.
/location	Sets the view of the browser to always show a particular line. Default is locate/off.
/polling	Controlls the polling of the HTML browser that checks for updates. Rapid polling can hinder interactive use. Can be manually turned on by the user. Default is “off”.
/maximum_lines	Turn on or off creation of Scalable Vector Graphics (svg) graphic files.
/svg	Turn on or off creation of Scalable Vector Graphics (svg) graphic files.
/svgz	Turn on or off creation of compressed Scalable Vector Graphics (svgz) graphic files. Does not work with FireFox.
/wmf	Turn on or off creation of Microsoft Windows Metafile File (wmf) graphic files. Only works with Internet Explorer.

Modifier 2	Description
/(on or off)	Turn feature on or off.
/(start or stop)	/start manually starts the HTML browser and directs it to .\html\gladout.html. html/start will start the browser automatically. /stop closes the browser manually.
/executable	Set the browser to use by giving its exact path and executable name enclosed in single quotes. Common browsers include iexplore.exe, opera.exe, safari.exe, and chrome.exe. (FireFox does not process SVG graphics from local files.)
/(browser or nobrowser)	Start with browser or start without activating browser. If the user starts the browser manually, it should be directed to: (installation folder)\html\GladOut.html.
/list	Display status of this feature.
/(hide, normal, list)	Optionally output text, tables, or pictures in hidden mode. Select “[+]” to expand a hidden item. Use /normal to revert to normal condition or /list to display status.
/(off, pause, period)	The HTML files are operated by Javascript controls. The Javascript checks to see if the page should be updated periodically. The use may turn polling off, pause once for specified seconds, or set the polling period in seconds. The default polling period is one second.

Numerical Values	Description	Defaults
ipause	Seconds for one-time pause with html/polling/pause.	10
seconds_polling	Interval between browser polling events. One second is the default and the minimum value.	1
maximum_lines	Maximum number of HTML lines allowed in output. Each output line is dynamically and automatically placed below the source line. For very long runs the number of lines could consume excessive disk space.	1000

IF Logical branching in the command file. Language

Command Forms(s): **IF**

if Num1 (Relop) Num2 (input line)

Command Forms(s): **IF (Continued)**

```
if  Num then
  (command lines)
endif
if  Num1 (Relop) Num2 then
  (command lines)
else
  (command lines)
endif
if  Num (input line)
if  [math expression]  then
  (command lines)
endif
if  [math expression]  then
  (command lines)
else
  (command lines)
endif
if  [math expression]  (input line)
```

Description: IF

Allows conditional command execution. If the logical expression “num1 relop num2” is true, then (input line) is processed. Otherwise, no operation takes place. The input line may be a command or a variable assignment but not another `if` command. Num1 and Num2 are numbers, variables, or mathematical expressions. The `if` command may also be used in BLOCK-IF form where the commands between `then` and `endif` are executed only if the condition evaluates as “true”. See if.inp included in the examples folder.

Examples:

```
if x > y status # (x and y must be predefined)
if 2*3>4 then; status; endif
```

Parameter	**Description**
(Relop)	Operator < less than, > greater than, = equal to, <= less or equal to, >= greater or equal to, <> not equal to, != not equal to (alternate form).
(input line)	On a single line `if` statement, any GLAD command except another `if` may be used.
(command lines)	In an IF-ENDIF block any command lines may be used including another IF-ENDIF block up to 8 levels.
math expression	Any math expression. Must be enclosed in brackets.
Num	Single number. 0 values results in false. True for non-zero values.
Num1	First operand.
Num2	Second operand.

INFILE — Reads beam data from an external file. — Input-output

Command Forms(s): **INFILE**

`infile/beam/sqr`	(Filename) `kbeam nline units color radref ipolz attribute zreffrad`
`infile/intensity/sqr`	(Filename) `kbeam nline units color radref ipolz attrib zreffrad`
`infile/real/sqr`	(Filename) `kbeam nline units color radref ipolz attrib zreffrad`
`infile/intphase/sqr`	(Filename) `kbeam nline units color radref ipolz attributge zreffrad`
`infile/intwave/sqr`	(Filename) `kbeam nline units color radref ipolz attribute zreffrad`
`infile/phase/sqr`	(Filename) `kbeam nline units color radref ipolz attribute zreffrad`
`infile/wavefront/sqr`	(Filename) `kbeam nline units color radref ipolz attribute zreffrad`
`infile/beam/rec`	(Filename) `kbeam nlinx nliny unitx unity color radrefx radrefy ipolz attribute zreffrad`
`infile/intensity/rec`	(Filename) `kbeam nlinx nliny unitx unity color radrefx radrefy ipolz attribute zreffrad`
`infile/real/rec`	(Filename) `kbeam nlinx nliny unitx unity color radrefx radrefy ipolz attribute zreffrad`
`infile/intphase/rec`	(Filename) `kbeam nlinx nliny unitx unity color radrefx radrefy ipolz attribute zreffrad`
`infile/intwave/rec`	(Filename) `kbeam nlinx nliny unitx unity color radrefx radrefy ipolz attribute zreffrad`
`infile/phase/rec`	(Filename) `kbeam nlinx nliny unitx unity color radrefx radrefy ipolz attribute zreffrad`
`infile/wavefront/rec`	(Filename) `kbeam nlinx nliny unitx unity color radrefx radrefy ipolz attribute zreffrad`

Description: INFILE

`Infile` allows entry of an array of data from a user supplied file to define a beam field distribution.

Modifier 1	**Description**
`/beam`	Reads in amplitude in real-imaginary complex form.
`/intensity`	Reads in intensity as a real number and sets phase to zero. (except for byte format).
`/real`	Reads in real part of complex amplitude and leaves imaginary part unchanged of beam intensity (except for byte format).
`/aimaginary`	Reads in imaginary part of complex amplitude and leaves real part unchanged of beam intensity (except for byte format).
`/intphase`	Reads in intensity and phase (radians) in intensity-phase complex form.
`/intwave`	Reads in intensity and wavefront (wavelengths) in intensity-wave complex form, waves = - phase/2/π.

Modifier 1	**Description (Continued)**
`/phase`	Reads in and applies phase as real numbers. Intensity is left unchanged.
`/wavefront`	Readis in and applies wavefront as real numbers. Intensity is left unchanged. waves = - phase/2/π.

Modifier 2	**Description**
`/sqr`	Axially symmetric or square geometric data.
`/rec`	Asymmetric or rectangular geometric data.

String	**Description**
(Filename)/(Modifier 1)/(Modifier 2)	Name of data file to input. Enclose name in single quotes to allow special characters. The filename is preceded by a path name if one has been defined with `set/path`.

FileName Modifier 1	**Description**
`/header`	Geometric data is on data file. Geometric data is all data after `kbeam`.
`/noheader`	Existing data is used or taken from command line.

FileName Modifier 2	**Description**
`/list`	Data is read in list directed format (default) `read (Filename,*) list`
`/comma` or `/excel`	Comma delimited format with N elements on a row and M rows to make an N x M array. Inputs real-imaginary data pairs for “beam” input. Same as Excel *.csv format. May be written by `/comma` or `/excel` formats with `outfile`.
`/80`	Data is written in 80 column format (1x,4E18.10).
`/blankdelimited`	Similar to comma delimited except commas are replaced with blanks.
`/binary`	Data is read as binary file.
`/byte`	Data is read as an integer map of intensity values. 256 gray levels. `/noheader` and `/intens` must be selected.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	Required

Header values	**Description**	**Defaults**
`nline`	Dimension of the square array.	nlinx(kbeam)
`nlinx`	X-dimension of the rectangular array.	`nlinx(kbeam)`
`nliny`	Y-dimension of the rectangular array.	`nlinx`
`units`	Units.	`units(kbeam)`
`unitx`	X-units.	unitsx(kbeam)
`unity`	Y-units.	unitx
`color`	Wavelength in microns.	color(kbeam)
`radref`	Radius of the spherical phase bias.	1e20
`radrefx`	X-radius of the toric phase bias.	1e20
`radrefy`	Y-radius of the toric phase bias.	radrefx
`ipolz`	0 for one polarization state. 1 for two polarization states.	0

Header values	Description (Continued)	Defaults
`attribute`	Array attribute. See `array` command.	1 (beam)
`zreffrad`	Used for axicon modes.	0.

The data file should be structured as described below

```
   A(i,j)                                - complex array
   R(i,j)                                - real part of complex array
```

Record 1

If Modifier 2 is `/sqr`

```
   read ngeo (ngeo = 7)
   read nline units color radref ipolz attrib zreffrad
```

If Modifier 2 is `/rec`

```
   read ngeo (ngeo = 10)
   read nlinx nliny unitx unity color radrefx radrefy ipolz attrib zreffrad
```

Computer Array Records

(If ipolz=1, then GLAD reads the second polarization state after the first state is read.)

If Modifier 1 is `/beam`

```
   do j = 1, nlinys
                                         read (a(i,j),i=1,nlinxs)
```

If Modifier 1 is `/intens`

```
   do j = 1, nlinys
                                         read (r(i,j)),i=1,nlinxs)
```

The intensity values are stored in the real part of the array

fortran program to create a a file for `infile`

```
 program out
c
c create unformatted, no header outfile
c
c read with:
c infile out.dat/no/unf 1
c
c an array of 64 x 64 is created with a circle of radius 10
c set to (1.,0.) and all other points zero.
c
c the file size created is 33280 bytes in size.
c

 complex a(64,64)
 data kout/1/
 data nsize/64/
 open(kout,file='out.dat',status='new',form='unformatted')
 jc = nsize/2 + 1
 ic = nsize/2 + 1
 do 20 j=1,nsize
 y = jc - j
 do 10 i=1,nsize
 x = i - ic
 a(i,j) = (0.,0.)
 if ((x**2 + y**2).le.100.) a(i,j) = (1.,0.)
 10 continue
c
c output a complete row of complex numbers with fortran
c unformatted write
```

```
c
 write(kout)(a(i,j),i=1,nsize)
 20 continue
 end
```

C program to create a file for connect or `infile`

```
/*
program to create a file to be read by either CONNECT or INFILE

This program assumes a 32 bit word.

The format for CONNECT is a simple binary file of length 32768 bytes.

input data with
connect out.dat 1

**** the connect command is a destructive read operation
**** make a copy of the file to be read if it is to be reused

The format for INFILE may be written and read in binary format

input data with

 infile out.dat/no/binary 1

an array of 64 x 64 is created with a circle of radius 10
set to (1.,0.) and all other points zero.

*/
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>
#ifdef __STDC__
buf_write(long nbytes, int binary, float *buffer);
#endif

FILE *kout; /* output handle */

main()
{
   float areal, aimag;   /* real and imaginary parts of complex number */
   float x, y;           /* x and y coordinates */
   int i,j;              /* indices for scanning array */
   int ic,jc;            /* center point of array */
   int nsize=64;         /* number of complex words in a row */
   int binary;           /* 0 selects binary, 1 selects FORTRAN unformatted */
   long nbytes;          /* number of bytes to send */
   char input[10];       /* character array for input */
   char name[8];         /* character array for file name */
   float *p;             /* buffer pointer*/
   float buffer[128];    /* data buffer */

   printf("Program to make file for either CONNECT or INFILE\n");
   printf("Select format: 0 CONNECT (default), or 1 INFILE. (0 or 1) ");
   (void) gets(input);   /* get format selection */
   binary = atoi(input);
   if (binary>1||binary<0) binary = 0;
   if (binary==1) {
      printf("Writing out.dat.  Read with\ninfile out.dat/no/binary 1\n");
      strcpy(name,"out.dat");
   }
else {
      printf("Writing outs.bea.  Read with\n connect out 1\n");
      strcpy(name,"outs.bea");
   }
   kout = fopen(name,"wb");
   if (kout==0)
   {
      printf("error in opening %s\n",name);
      exit(0);
   }
/*
   nbytes = number of complex words * bytes per complex word
*/
   nbytes = nsize*8;
   jc = nsize/2 + 1;        /* find center point of array */
   ic = nsize/2 + 1;
   for (j=1;j<=nsize;j++)   /* loop over rows */
   {
       y = jc - j;           /* write from top to bottom */
       p = buffer;
       for (i=1;i<=nsize;i++)   /* loop over columns */
       {
          x = ic - i;       /* write from left to right */
          areal = 0.;
          aimag = 0.;
          if ((x*x + y*y)<=100.)
          {
             areal = 1.;  /* set center points to (1.,0.) */
          }
          *p++ = areal; /* write real */
          *p++ = aimag; /* write imag. */
      }  /* end of column loop */
         (void) buf_write(nbytes,binary,buffer);
   }  /* end of row loop */
   return 0;
}
buf_write(long nbytes, int binary, float *buffer)
{
   if (fwrite(buffer, nbytes, 1, kout)!=1) {
      printf("Failed to write data\n");
      exit(0);
   }
   return 0;
}
```

INITIALIZE Reinitialize to starting condition. Operator

Command Forms(s): **INITIALIZE**

```
initialize
```

Description: INITIALIZE

Reinitialize to original starting condition except for top level input and output. May be used from command file. Should only be called interactively or from a command file called by just one level of `read/disk`.

Example of command file

```
nbeam 2                         # set two two beams
mult/beam 1 2                   # multiply intensity of beam 1 by 2
energy                          # energy of beam 1 should be 8192
mult/beam 2 4                   # multiply intensity of beam 2 by 4
initialize                      # reinitialize to initial state, except for top level IO
nbeam                           # should just be one beam now
energy                          # energy should be reinitialized to 4096
```

INT2PHASE, INT2WAVES Converts irradiance to phase screen. Operator

Command Forms(s): INT2PHASE, INT2WAVES

```
int2phase/one         kbeam alpha
int2waves/one         kbeam alpha
int2phase/two         kbeam1 kbeam2 alpha
int2waves/two         kbeam1 kbeam2 alpha
```

Description: INT2PHASE, INT2WAVES

This commands converts an intensity distribution into a phase screen so that the rich selection of intensity setting and modifying commands can be used to establish phase distributions. The complex amplitude will take the form,

`int2phase/one` $$a(x, y) \to e^{j\alpha I(x, y)} \quad (153)$$

`int2waves/one` $$a(x, y) \to e^{-j2\pi\alpha I(x, y)} \quad (154)$$

`int2phase/two` $$a_1(x, y) \to a_1(x, y)e^{j\alpha I_2(x, y)} \quad (155)$$

`int2waves/two` $$a_1(x, y) \to a_1(x, y)e^{-j2\pi\alpha I_2(x, y)} \quad (156)$$

where α is the conversion factor for power per square centimeter to radians, $I(x, y)$ is the starting intensity map, and $a(x, y)$ is the resulting amplitude distribution. The complex amplitude distribution may then be used with the `mult/beam` command to impose the phase distribution.

Also see `real2phase` and `real2waves`).

Modifier 1	Description
`/one`	Transform intensity into a phase screen using a single beam.

Modifier 1	Description (Continued)
/two	Multiply the amplitude of Beam 1 by a phase screen based on the intensity of Beam 2.

Numerical Values	Description	Defaults
kbeam	Single beam number for /one.	1
kbeam1, kbeam2	Beam numbers for /two.	1, 2
alpha	Coefficient for converting power density to phase in radians (int2phase) or wavelengths (int2waves).	0.

INTEGRATE — Integrates intensity or amplitude. — Operator

Command Forms(s): **INTEGRATE**

```
integrate/irradiance/x      kbeam
integrate/irradiance/y      kbeam
integrate/amplitude/x       kbeam
integrate/amplitude/y       kbeam
```

Description: INTEGRATE

Integrate the irradiance or amplitude in the x- or y-direction.

Modifier 1	Description
/irradiance	Integrate irradiance.
/amplitude	Integrate amplitude.

Modifier 2	Description
/x	Integrate in x-direction.
/y	Integrate in y-direction.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1

INTENSITY — Makes table of irradiance values. — Diagnostics

Command Forms(s): **INTENSITY**

```
intensity/xslice/(Modifier 2)   kbeam xyline start end imax
intensity/yslice/(Modifier 2)   kbeam xyline start end imax
intensity/yslice/(Modifier 2)   kbeam xpoint ypoint start end imax
```

Description: INTENSITY

Prints intensity and phase of beam along an x or y-slice. Printed data is selected from the row or column nearest to the coordinate specified by xyline. Data is interpolated to points specified by start and end.

Entire field array is switched to intensity/phase format in order to improve interpolation accuracy. This conversion may affect field data below a threshold amplitude of 1.e-10.

Modifier 1	Description
`/xslice`	Prints field data for a horizontal x-slice (default).
`/yslice`	Prints field data for a vertical y-slice.
`/zslice`	Prints field data for a z-slice through a 3D array.

Modifier 2	Description
`/wavefront`	Prints phase information in waves (default) $\mathtt{waves} = -\frac{\text{phase}}{2\pi}$.
`/phase`	Prints phase information in radians.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`xyline`	Coordinate of row or column (cm).	Beam center.
`xpoint`	Coordinate of row, 1 to N. (integer)#1	Beam center.
`ypoint`	Coordinate of column, 1 to N. (integer)#1	Beam center.
`start`	Left or lower side of data (cm).	Field edge.
`end`	Right or upper side of data (cm).	Field edge.
`imax`	Maximum number of points printed.	`16`

INTMAP Simple integer intensity map. Diagnostics

Command Forms(s): **INTMAP**

```
intmap/intensity   kbeam icycl
intmap/absolute    kbeam
```

Description: INTMAP

Prints an integer map of the beam `kbeam` or absolute value map if `/abs` is specified. The intensity values are displayed as single integers (0 to 9) in a rectangular map. Each integer corresponds to a 10% range of intensity values. The top 1% values are shown by an asterisk. Logarithmic display may be selected by specifying `icycl` to set the number of cycles (`/int` mode only).

Modifier 1	Description
`/intensity`	Plot intensity values.
`/absolute`	Plot absolute amplitude values.

Modifier 2	Description
`/nohead`	Leave off top and bottom column labels.
`/head`	Add top and bottom column labels.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`icycl`	Number of logarithmic cycles. (for `/int` modifier only) `icycl` = 0 gives linear plot.	linear

INVERSE Calculates inverse of beam distribution. Operator

Command Forms(s): **INVERSE**

```
inverse             kbeam
```

Description: INVERSE

This routine inverts the complex amplitude.

$a(i) \to \frac{1}{a(i)}$ If $a(i) = 0$, the inverse is set to 0 also. This routine is used in Ex14 to make a beam shaping filter.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1

IRRADIANCE Takes absolute value squared of beam data. Operator

Command Forms(s): **IRRADIANCE**

```
irradiance          kbeam
```

Description: IRRADIANCE

This command squares the complex amplitude distribution in the array to give the irradiance distribution.

$$a(i) \to |a(i)|^2 \tag{157}$$

Caution should be exercised not to propagate the irradiance distribution.

Also see `amplitude` command.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1

JABERR Jones calculus polarization aberrations. Aberration

Command Forms(s): **JABERR**

```
jaberr/radius                rx ry tx ty
jaberr/zeroth/pauli          a00 a01 a02 a03 p00 p01 p02 p03
jaberr/second/pauli          a20 a21 a22 a23 p20 p21 p22 p23
jaberr/zeroth/jones          ar ai br bi cr ci dr di
```

Command Forms(s): **JABERR (Continued)**

```
jaberr/second/jones          ar ai br bi cr ci dr di
jaberr/list/pauli
jaberr/list/jones
jaberr/surf                  kbeam
jaberr/medium                kbeam deltaz
jaberr/clear
```

Description: JABERR

This command models a surface using a zeroth and second order approximation to the sensitivity to the local incidence angle at each point on the surface. The coefficients may be listed with `/list`. The surface radii and tilt angles must be explicitly set by the user. In later versions these will be better integrated into the other features of the program.

The Jones matrix may be directly defined using the `/jones` modifier or defined in terms of Pauli spin matrices. See Sect. 14.3, GLAD Theory Manual (theory.pdf).

Modifier 1	**Description**
`/radius`	Defines the radii of the surface.
`/zeroth`	Zeroth order coefficient matrix.
`/second`	Second order coefficient matrix.
`/surf`	Apply matrix as a surface effect.
`/medium`	Apply matrix as an exponential effect.
`/list`	List parameter.
`/clear`	Set radii to infinity and other coefficients.

Modifier 2	**Description**
`/jones`	Jones matrices are set directly or displayed if `/jones` is called the Pauli form is recalculated.
`/pauli`	Pauli spin matrices are used to set Jones matrix the corresponding Jones matrix is calculated each time the `/pauli` command is called. If several calls are used to build up the Pauli matrix.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`rx, ry`	Radii of the surface (cm).	`1e20`
`anm`	Amplitude coefficients.	`a00 = 1`, all others `0`
`tx, ty`	Transverse position in x and y.	
`pnm`	Phase coefficients (deg).	
`ar,ai,br,bi,cr,ci,di`	Real and imaginary components of Jones matrix.	
`deltaz`	Distance along propagation distance direction.	

JONES Jones calculus operations. Operator

Command Forms(s): **JONES**

```
jones/set            ar ai br bi cr ci dr di
jones/list
jones/multiply       kbeam
jones/exponential    kbeam z
jones/linpol         kbeam theta
jones/left           kbeam
jones/right          kbeam
jones/retard         kbeam azimuth phi
jones/optact         kbeam theta
jones/orthogonal     k1 k2
jones/faraday        kbeam theta
jones/kerr           kbeam
```

Description: JONES

This command models a surface using a zeroth and second order approximation to the sensitivity to the local incidence angle at each point on the surface. The general Jones matrix may be set with the `/set` modifier and may be listed with `/list`. The general matrix may be directly applied by the `/multiply` modifier.

$$\mathbf{E}_2 = \begin{bmatrix} (A_r, A_i) & (B_r, B_i) \\ (C_r, C_i) & (D_r, D_i) \end{bmatrix} \mathbf{E}_1 \qquad (158)$$

The exponential operation may be applied by the modifier `/exponential`. This models the effect of a continuous medium with polarization-active effects. The coefficients are assumed to be in cm. The exponential operator

$$\mathbf{E}_2 = e^{z \begin{bmatrix} (A_r, A_i) & (B_r, B_i) \\ (C_r, C_i) & (D_r, D_i) \end{bmatrix}} \mathbf{E}_1 \qquad (159)$$

The exponential of a matrix is found from the series

$$e^{\mathbf{A}} = \sum_{k=0}^{\infty} \frac{\mathbf{A}^k}{k!} \qquad (160)$$

The operators for left and right circular polarizers, linear polarizers, retardance, optical activity and Faraday rotation, and Kerr (or Pockels cells) are applied directly as they are defined and leave the general Jones matrix in with the revised form. Optical activity is distinguished from Faraday rotation by having the sign of the rotation reversed for beams of left-handed parity. Parity is reversed each time the beam hits a mirror.

Modifier 1	**Description**
`/set`	Set general Jones matrix coefficients.
`/list`	List general Jones coefficients.
`/multiply`	Apply general Jones matrix.
`/exponential`	Jones matrix for distributed medium.
`/linpol`	Linear polarizer.
`/left`	Left circular polarizer.
`/right`	Right circular polarizer.
`/retard`	Retarder.
`/optact`	Optical activity.
`/orthogonal`	Separates perpendicular and orthogonal components of beam `k1` relative to beam `k2`.
`/faraday`	Faraday rotator.
`/kerr`	Kerr or Pockels cell.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	Required
`k1`, `k2`	Input beam numbers for `/orthogonal`. returns the part of `k1` perpendicular to `k2` in `k1` and the part of `k1` parallel to `k2` in `k2`.	
`azimuth`	Azimuth rotation angle of component.	0.
`phi`	Phase of retarder (degrees).	0.
`theta`	Rotation of optical activity or in Faraday (degrees).	0.
`z`	Propagation distance for exponential operator.	0.

JSURF Fresnel transmission and reflection coefficients. Component

Command Forms(s): **JSURF**

```
jsurf/fresnel/(Modifier 2)   kbeam n1 n2 rx ry tx ty kappa
jsurf/goos/(Modifier 2)      kbeam n1 n2 tx ty kappa
jsurf/single/(Modifier 2)    kbeam ni nf ns thick rx ry tx ty rdx rdy tdx tdy
```

Description: JSURF

This command models refractive and reflective polarization effects due to Fresnel or single layer interference filter coefficients at a surface. See Polarization, Chap. 14, GLAD Theory Manual (theory.pdf). The incidence angles are computed using a combination of real and paraxial angles as illustrated in Fig. 21. See Example Ex37 for examples of these features.

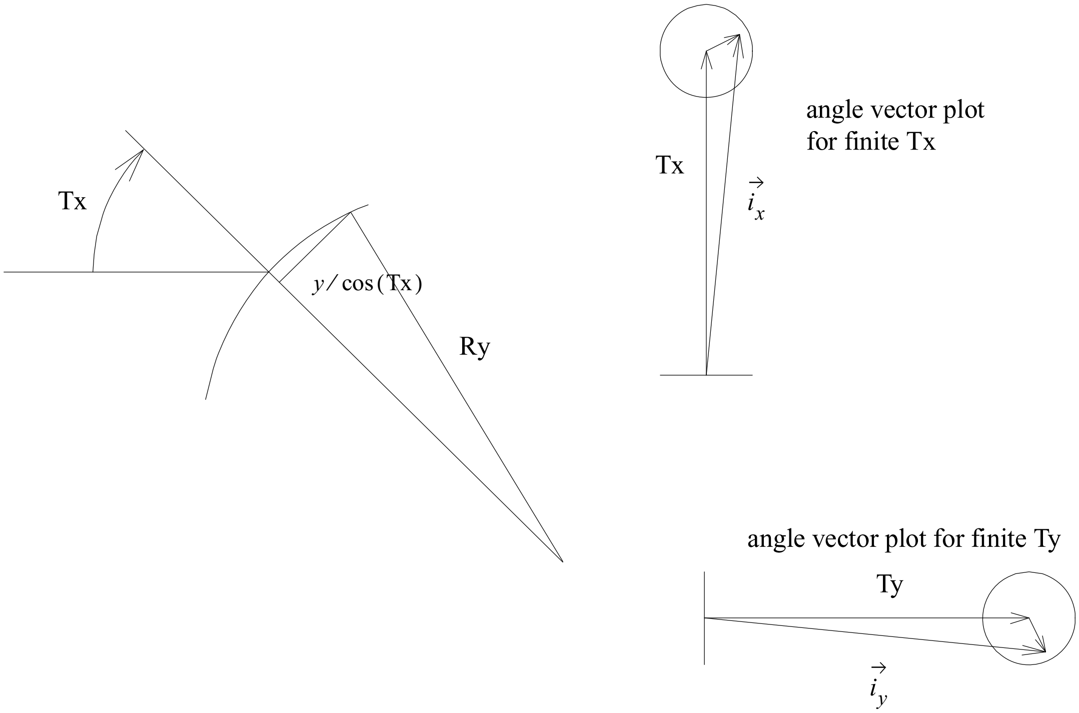


Fig. 21. `jsurf` allows a large tilt angle in either the x- or y-directions and paraxial angles due to surface curvature as shown by angle vector plots shown on the right for Tx (top) and Ty (bottom). The pupil is indicated by a circular region. Tx and Ty are real angles measured as rotations about the x- or y-axes respectively. The angles due to surface curvature are treated as paraxial angles.

Modifier 1	**Description**
`/fresnel`	Fresnel surface.
`/goos`	Goos-Hanchen shift. Jones operations implemented in the far-field.
`/single`	Single layer thin file coating.

Modifier 2	**Description**
`/trans`	Transmission coefficients.
`/refl`	Reflection coefficients.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`n1`	Index of incident medium.	`1.`
`n2`	Index of following medium.	`1.`
`ni`	Medium of incident medium.	1.
`nf`	Thin film index.	1.
`ns`	Substrate index, index of propagation is set to this value after `jsurf`.	1.
`thick`	Thickness of film.	0.
`rx,ry`	Radii of surface.	1e20, 1e20

Numerical Values	Description (Continued)	Defaults
`tx,ty`	Real tilt angles of the surface (in degrees) about the respective axes. Only one of `tx` of `ty` may be specified. For transmission the units will be adjusted at the end of `jsurf`.	0., 0.
`rdx`, `rdy`	Radii of film thickness allowing film to be slightly thinner or thicker at the edges than at the center.	∞, ∞
`tdx`, `tdy`	Tilt of film thickness (radians). thickness = $\texttt{thick} + \frac{x^2}{2 \bullet \texttt{rdx}} + \frac{y^2}{2 \bullet \texttt{rdx}} + x \bullet \texttt{tdx} + y \bullet \texttt{tdy}$	0., 0.
`kappa`	Component for complex index of refraction in reflection for `/fresnel/refl.` The complex index of refraction is $n + \mathrm{j} n \kappa$.	`0.`

LAGUERRE Initializes beam to Laguerre-Gaussian. Begin-end

Command Forms(s): **LAGUERRE**

```
laguerre/cir    ibeams energ rad nor por phi xdec ydec pradx prady
laguerre/ell    ibeams energ xrad yrad nor por phi xdec ydec pradx prady
```

Description: LAGUERRE

Defines an initial Laguerre-gaussian field distribution. Sets geometric data such as beam center, waist size and location, and reference surface shape (plane). By default the units are automatically computed. The transverse modes of ideal stable resonators take the form of Hermite-gaussian polynomials or Laguerre-gaussian. The Laguerre-gaussian functions are described in cylindrical coordinates.

$$u_{pm}(r, \theta) = \sqrt{\frac{2p!}{(1+\delta_{0_m})\pi(m+p)!}}\frac{e^{i(2p+m+1)}}{\omega_0}\left(\frac{\sqrt{2}r}{\omega(z)}\right)^m L_p^m\left(\frac{2r^2}{\omega_0^2}\right)e^{-r^2/\omega_0^2}e^{im(\theta-\phi)} \qquad (161)$$

where θ is the azimuthal variation, p is the radial order, m is the azimuthal order; δ_{0_m} a delta function with the value 1 for $m = 0$ and 0 otherwise, and L_p^m is the Laguerre polynomial.

Modifier 1	Description
`/cir`	Circular configuration.
`/ell`	Elliptical configuration.

Modifier 2	Description
`/noadjust`	Conserve current units, do not reset surrogate gaussian. Always selected in resonator mode.
`/con`	Conserve current units.
`/res`	Rescale: compute new optimum units prior to generating file.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`

Numerical Values	Description (Continued)	Defaults
energ	Total beam energy (mw).	1.
rad, xrad, yrad	Reference radius.	Beam size (cm).
nor, por	Radial and azimuthal orders (maximum of 20).	0., 0.
phi	Azimuthal angle.	
xdec, ydec	Coordinates of beam center (cm).	
pradx, prady	Phase radius of curvature in x- and y-directions.	•, •

LENS — Implements ideal lens. — Component

Command Forms(s): **LENS**

lens/sph/element/(Modifier 3)	ibeams fl
lens/xcyl/element/(Modifier 3)	ibeams xfl
lens/ycyl/element/(Modifier 3)	ibeams yfl
lens/toric/element/(Modifier 3)	ibeams xfl yfl
lens/sph/surface/(Modifier 3)	ibeams radius index [(glass)]
lens/xcyl/surface/(Modifier 3)	ibeams xradius index [(glass)]
lens/ycyl/surface/(Modifier 3)	ibeams yradius index [(glass)]
lens/toric/surface/(Modifier 3)	ibeams xradius yradius index [(glass)]
lens/flat/surface	ibeams index
lens/grin	ibeams gamma zstep

Description: LENS

Models an ideal lens with specified focal length. See lensgroup for a detailed surface by surface description with aberration analysis. If no vertex has been defined, the specified lens is applied at the current beam position. If a vertex has been defined, the beam is moved to the vertex by an internal call to prop/vertex and the lens is then applied as an ideal element, always rotated to be aligned with the beam to which it is applied. The vertex must be redefined after each propagation step. See the vertex command. The imaged waist size and location are recomputed after the lens.

Modifier 1	Description
/sph	Rotationally symmetric thin lens (2nd order accuracy).
/xcyl	Cylindrical thin lens.
/ycyl	Cylindrical thin lens.
/toric	Toric thin lens (2nd order accuracy).
/flat	Surface element having a flat surface. Changes index of refraction.
/grin	Gradient index lens.

Modifier 2	Description
/element	Lens defined by focal length (default).
/surface	Single surface defined by radius and index of refraction.

Modifier 3	Description
`/geometric`	Lens modifies geometric radii of curvature (default), as displayed by `geodata`.
`/phase`	Lens treated as phase object. Only long focal lengths will be adequately sampled. Check for wavefront aliasing by plotting wavefront.

Parameter	Description
glass	Name of glass for `/surface`. May use glass named in Table L.1 or "glass" as defined by the `glass` command. The index for the wavelength of the beam will be calculated. If glass name is not given, the index may be defined by the index variable and will apply to all beams without regard to wavelength.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`fl`	Focal length of rotationally symmetric thin lens.	`1e20`
`xfl`	Focal length of x-cylindrical thin lens.	`1e20`
`yfl`	Focal length of y-cylindrical thin lens.	`1e20`
`radius`	Surface radius.	`1e20`
`xradius`	X-radius of cylinder or toric surface.	`1e20`
`yradius`	Y-radius of cylinder or toric surface.	`1e20`
`index`	Index of refraction if not defined by glass name parameter.	
`gamma`	Coefficient of index profile for GRIN lens. Index distribution is assumed to take the form:. $n(r) = n_0 - \frac{1}{2}\gamma^2 r^2$ The ABCD solution takes the form: $\mathrm{ABCD}(z) = \begin{bmatrix} \cos(\gamma z) & \sin((\gamma z))/\gamma \\ -\gamma\sin(\gamma z) & \cos(\gamma z) \end{bmatrix}$	
`zstep`	Length of the GRIN lens.	`0.`

LENSARRAY Array of lenses. Component

Command Forms(s): **LENSARRAY**

```
lensarray/hexagonal/set        piston xtilt ytilt focus omega
lensarray/hexagonal/all        kbeam width focallength iseed
lensarray/hexagonal/element    kbeam xcell ycell width focallength iseed
lensarray/hexagonal/clear      kbeam xcell ycell width value
lensarray/hexagonal/paste/     kbeam1 kbeam2 xcell ycell width
element
lensarray/hexagonal/paste/all  kbeam1 kbeam2 width
lensarray/hexagonal/multilevel kbeam width n1 n2 n3 n4iseed
lensarray/rectangular/set      piston xtilt ytilt focus omega
lensarray/rectangular/all      kbeam xwidth ywidth focallength iseed
```

Command Forms(s): **LENSARRAY (Continued)**

```
lensarray/rectangular/element  kbeam xcell ycell xwidth ywidth
                               focallength iseed
lensarray/rectangular/paste/   kbeam1 kbeam2 xcell ycell xwidth ywidth
element
lensarray/rectangular/paste/   kbeam1 kbeam2 xwidth ywidth
all
lensarray/rectangular/clear    kbeam xcell ycell xwidth ywidth value
lensarray/rectangular/         kbeam xwidth ywidth n1 n2 n3 n4 iseed
multilevel
```

Description: LENSARRAY

This routine models an array of lenses. If the `/all` modifier is used, a complete array is produced, each with the same focal length. Random errors for piston, tilt, and defocus may be specified by the `/set` modifier. A single element may be cleared by the `/clear` modifier or modified by the `/element` modifier.

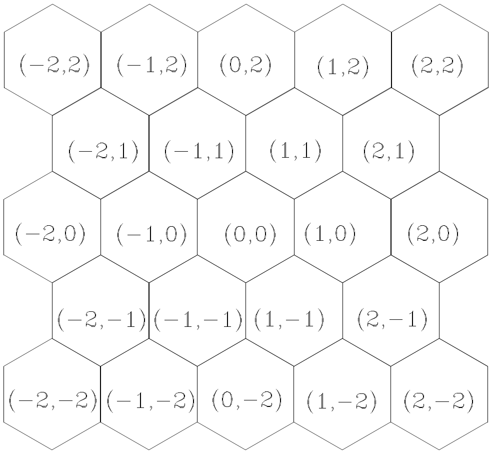


Fig. 22a. Hexagonal array showing numbering system.

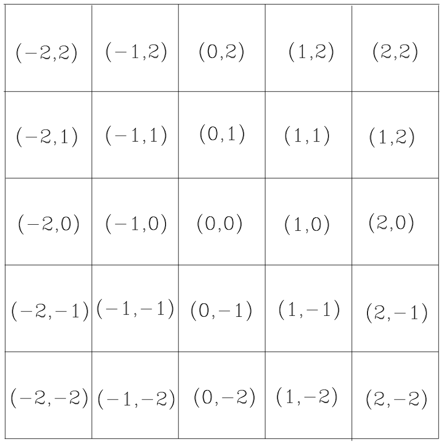


Fig. 22b. Rectangular array showing numbering system.

The aberrations are defined to have peak aberration values as specified for the x-width for either hexagonal or rectangular shapes. The `/multilevel` modifier puts in random piston, tilt, or defocus in discrete levels. No focal length (other than that of defocus) is added in `/multilevel` mode.

Modifier 1	**Description**
`/hexagonal`	Hexagonal shape as defined by the x-width.
`/rectangular`	Rectangular shape as defined by x- and y-width.

Modifier 2	**Description**
`/set`	Sets random errors and intensity roll-off coefficient. Also, sets values to be used by `/element` where they are used exactly.
`/all`	Implements complete lens array.
`/clear`	Clears the specified cell and resets transmission to value.

Modifier 2	**Description (Continued)**
/element	Sets values only for the specified cell. Effects are additive.
/paste	Paste the complex amplitude values of beam kbeam2 into kbeam1 within the region defined by the cell address and width. Matches the center of kbeam2 to the center of the cell and uses linear interpolation. The beams may be of different size, for example, the beam to be pasted in may be just large enough to cover one cell.
/multilevel	Selects multilevel mode. Random aberrations are added based on the /set values and using levels defined by n1, n2, n3, and n4.

Modifier 3	**Description**
/element	Paste a single element by cell address for /paste (default).
/all	Paste all elements for /paste.

Numerical Values	**Description**	**Defaults**
piston	Random phase piston in degrees.	
kbeam	Single beam number.	1
kbeam1, kbeam2	For /paste kbeam1 is the lensarray. kbeam2 contains the values to be pasted.	
width	x-width of hexagon.	3 x-units
xwidth, ywidth	x-width and y-widths of rectangle	3 x-units, 3 y-units
xtilt, ytilt	Random tilt values, coefficient sets value at x-half-width; also tilt values for /element.	
focus	Random defocus value, coefficient sets value at x-half-width; also piston value for /element.	0.
omega	Exponential fall off of transmission based on coordinates of the center of the cell. $I(x_{c_k}, y_{c_k}) = \exp\left(-\frac{x_{c_k}^2 + y_{c_k}^2}{\omega^2}\right)$, where x_{c_k} and y_{c_k} are the center coordinates of the kth element. Transmission applies uniformly to entire cell.	
n1, n2, n3, n4	Number of levels for /multilevel mode for piston, xtilt, ytilt, and defocus. If the number of levels is 0, the corresponding aberration is not added.	0, 0, 0, 0
value	Transmission value for /clear. Transmission applies uniformly to entire cell.	1.
xcell, ycell	Cell coordinates (see Figs. 22a and 22b) for /clear and /multilevel.	
focallength	Focal length of lens element in cm.	1e20
iseed	Random seed.	self-seeding.

LENSGROUP Exact ray tracing analysis of lenses and mirrors. Component

Command Forms(s): **LENSGROUP**

lensgroup/run/(standard, fringe, radial)	(name) kbeam nrays rnorm cutoff
lensgroup/trace	
lensgroup/build	(name) kbeam nrays rnorm cutoff
lensgroup/define	(name)/(overwrite status)
lensgroup/end	
lensgroup/dir	
lensgroup/init	
lensgroup/list	(name)
lensgroup/add	(name) first last
lensgroup/change	(name) first last
lensgroup/delete	(name) first last
lensgroup/close	
lensgroup/append	(filename)

Description: LENSGROUP

The lensgroup command implements a system of lenses in traditional geometrical optics form. The lensgroup command requires implementation of the GLAD feature set is required. The user may specify radius, thickness, and index of refraction.

Modifier 1	Description
/run	Implements the lens file on beam kbeam. With Ver. 5.5 and higher the physical optics equivalent lens (see Chap. 20, GLAD Theory Manual) that has already been built by lensgroup/build or a previous call to lensgroup/run, may be directly accessed. For example if a lens called “mylens” has previously been built for Beam 1, the physical optical equillavent system may be accessed from the file “lenlib” by lensgroup/run _mylens_001. Directly accessing the physical optics equivalent lens saves time by eliminating the “build” step. The user must make sure that the same beam number and incident radius of curvature exist. The physical optics equilavent system may be examined by lensgroup/list (for example lensgroup/list _mylens_001) or by using a text processor to examine “lenlib” when GLAD is not running.
/trace	Evaluate lens performance using either /default to accept default wavelength and paraxial values or /beam to use beam values.
/build	Trace rays through the system and build the equivalent system to be used by /run. Called automatically by /run.
/define	Creates a new lens file. Subsequent commands will not be executed, but will be placed in the macro being defined. Terminate /define mode with lensgroup/end or “]” as the first character in the line.
/end	If a log-file lens file is being created that file will be closed. If a lens file is being executed, it will be terminated.
/dir	Lists names in lens library with starting line number.

Modifier 1	Description (Continued)
/init	Recalculates the lens directory by reading the lens library and resetting the starting numbers.
/list	Lists the lens or physical optics equivalent lens such as _mylens_001. Line numbers for reference in editing.
/add	Adds the new line numbers from first to last. GLAD prompts for the lines which must be typed in by the user.
/change	Replaces lines.
/delete	Deletes lines from first to last. (Deletion of the entire lens is described in the list of parameter modifiers below.)
/close	Closes file LENLIB so it can be edited by a system editor. See command system for using system functions from within GLAD. LENLIB will automatically be reopened at the next call to vertex.
/append	(Not currently active.) Append lens deck file to library. The lensgroup is given the same name as the file given, less the suffix. If a lensgroup of the same name already exists, it is replaced. File names of the form *.GRP are interpreted as being in GLAD format. File names of the form *.ZMX are assumed to be in Zemax format and are copied into *.GRP format before appending to library.

Modifier 2	Description
run/fringe	Set of 37 polynomials organized by polynomial order based on the sum of radial and azimuthal orders (default). Used in many interferometric reduction programs. /fringe has more radial terms and fewer azimuthal terms. See fitzern , Table 2.
run/standard	Set of 45 polynomials organized by radial order. All azimuthal terms are included. See fitzern , Table 1.
run/radial	Set of radial polynomials up to 20th order. See fitzern , Table 3.

Character String	Description
(Name)	Lens name (character string).
(Name)/nooverwrite	Used with /define. If input is currently from a terminal and the name exists, the user is asked if the file should be overwritten.
(Name)/overwrite	Used with /define. If the file specified exists, the file is overwritten by the new macro.
(Name)/delete	Deletes the named lensgroup, e.g., lensgroup/define xxx/delete # deletes macro XXX

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
first	First line number of lens as displayed by lensgroup/list.	
last	Last line number of lens as displayed by lensgroup/list.	
nrays	Number of rays across the diameter of the pupil to be used in calculating aberrations.	nrays
rnorm	Normalizing radius.	Beam size from geodata

Numerical Values	Description (Continued)	Defaults
`cutoff`	Cutoff for Zernike aberration coefficients to be used.	0.002

LENSGROUP/APPEND Adds a lens deck file to the lens library. Component

Command Forms(s): **LENSGROUP/APPEND**

```
lensgroup/append                    (Filename)
```

Description: LENSGROUP/APPEND

The command `lensgroup/append` adds a lens deck file to the lens library. The lens deck file may be in GLAD format or in the format of one of the other lens design programs supported by GLAD. The file type determined by the file suffix. GLAD will create a lens in the library using the same name as the file (stripped of the suffix). If a lens group of the same name already exists it is deleted before appending the new lens group.

For non-GLAD formats, the first and last surfaces are assumed to be the object and image surfaces and are deleted. At present, pickups and solves are not processed.

String	Description
Filename	File name of input lens deck to be adds to library. The name should be in the form “name.grp”.

LENSGROUP/BUILD Build the physical optics equivalent of a lens. Component

Command Forms(s): **LENSGROUP/BUILD**

```
/build/default/(modifier 3) (name) xo_rel yo_rel lambda nrays rnorm cutoff
                            [(listing type)]
/build/beam/(modifier 3)    (name) kbeam nrays rnorm cutoff [(listing type)]
```

Description: LENSGROUP/BUILD

The command `lensgroup/build` builds a physical optics equivalent of the designated lensgroup by tracing rays through the system. It is called automatically by `lensgroup/run` if the equivalent system has not been defined or has changed.

Modifier 2	Description
`/beam`	Use actual beam data, requires `kbeam`. Object point and wavelength are determined by incident beam (default).
`/default`	Use paraxial data from object line of lens data. Wavelength may be changed by setting lambda.

Modifier 3	Description
`/fringe`	Set of 37 polynomials organized by polynomial order based on the sum of radial and azimuthal orders (default). Used in many interferometric reduction programs. `/fringe` has more radial terms and fewer azimuthal terms. See `fitzern` , Table 2.
`/standard`	Set of 45 polynomials organized by radial order. All azimuthal terms are included. See `fitzern` , Table 1.
`/radial`	Set of radial polynomials up to 20th order. See `fitzern` , Table 3.

Character String	Description
name	Lensgroup name.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`lambda`	Wavelength for `/default`. Default value is taken from the object line of the lens definition.	
`xo_rel`, `yo_rel`	Rays are traced with respect to relative paraxial object position for `/default`.	0., 0., 0., 0.
`nrays`	Number of rays across the diameter of the pupil to be used in calculating aberrations.	
`rnorm`	Normalizing radius.	Beam size from geodata
`cutoff`	Cutoff for Zernike aberration coefficients to be used.	0.002

LENSGROUP/DEFINE Define a lens group. Component

Command Forms(s): **LENSGROUP/DEFINE**

`lensgroup/define` (name)/(overwrite status)

Description: LENSGROUP/DEFINE

A geometrical optics calculation is used to calculate the change in paraxial values, aberrations, and diffraction propagation length, which are applied to the beam. Apertures in the lens deck defined by clap act to vignette the beam. The `vertex/locate` and `vertex/rotate` commands locate the lens in space. Default field size, numerical aperture, and wavelength are defined to be used by the geometrical analysis with lensgroup$trace`lensgroup/trace` .

The surface curvature in terms of z as a function of transverse coordinates x and y is

$$z = \frac{cr^2}{1 + [1 - c^2 r^2 (1 + \kappa)]^{1/2}} + a_4 r^4 + a_6 r^6 + \ldots \qquad r^2 = x^2 + y^2 , \qquad (162)$$

where z is the distance along the axis (the sag of the surface), x and y are the transverse coordinates, c is the curvature of the surface (the inverse of the surface radius), κ is the conic constant, a_4, a_6, etc. are the general aspheric coefficients, If `surface/zernike` is specified the coefficients are interpreted as Zernike coefficients. See Table 3. The conic constant is related to the eccentricity of the conic, $\kappa = -\varepsilon^2$. For a simple spherical surface $\kappa = 0$ and the general aspheric coefficients are zero.

The glass may be selected from Schott, Hoya, Ohara, infrared, and miscellaneous catalogs listed in the attached tables. GLAD uses one of the following dispersion equations,

Type 1: Schott
$$N^2 = A_0 + A_1\lambda^2 + A_2\lambda^{-2} + A_3\lambda^{-4} + A_4\lambda^{-6} + A_5\lambda^{-8} \tag{163}$$

Type 2: Sellmeier 1
$$N^2 - 1 = \frac{K_1\lambda^2}{\lambda^2 - L_1} + \frac{K_2\lambda^2}{\lambda^2 - L_2} + \frac{K_3\lambda^2}{\lambda^2 - L_3} = \frac{A_0\lambda^2}{\lambda^2 - A_1} + \frac{A_2\lambda^2}{\lambda^2 - A_3} + \frac{A_4\lambda^2}{\lambda^2 - A_5} \tag{164}$$

Type 3: Hertzberger
$$N = A + BL + CL^2 + D\lambda^2 + E\lambda^4 + F\lambda^6 \tag{165}$$
$$= A_0 + A_1 L + A_2 L^2 + A_3\lambda^2 + A_4\lambda^4 + A_5\lambda^6 \qquad L = \frac{1}{\lambda^2 - 0.028}$$

Type 4: Sellmeier 2
$$N^2 - 1 = A + \frac{B_1\lambda^2}{\lambda^2 - L_1} + \frac{B_2\lambda^2}{\lambda^2 - L_2} = A_0 + \frac{A_1\lambda^2}{\lambda^2 - A_2} + \frac{A_3\lambda^2}{\lambda^2 - A_4} \tag{166}$$

Type 5: Conrady
$$N = N_0 + \frac{A}{\lambda} + \frac{B}{\lambda^{3.5}} = A_0 + \frac{A_1}{\lambda} + \frac{A_2}{\lambda^{3.5}} \tag{167}$$

Type 6: Inverse power
$$N = N_0 + \frac{A}{\lambda^2} + \frac{B}{\lambda^4} = A_0 + \frac{A_1}{\lambda^2} + \frac{A_2}{\lambda^4} \tag{168}$$

Lensgroup Command Form(s)

`object`	`lambda yfield yna zsurf zpupil xfield xna` [(glass name)]
`surface_lensgroup/conic`	`radius thickness cc a4 a6 a8 a10 a12 a14 a16 a18 a20 curvature` [(glass name)]
`surface_lensgroup/zernike`	`radius thickness cc a4 a6 a8 a10 a12 a14 a16 a18 a20 curvature` [(glass name)]
`clap_lensgroup/(cir, sqr`, or `hex)`	`rad xdec ydec`
`clap_lensgroup/(ell` or `rec)`	`xrad yrad xdec ydec`
`obs_lensgroup/(cir, sqr`, or `hex)`	`rad xdec ydec`
`obs_lensgroup/(ell` or `rec)`	`xrad yrad xdec ydec`

Lensgroup Command Form(s) (Continued)

```
vertex/rotate       rx ry rz
vertex/locate       xshift yshift zshift
glass               type a0 a1 a2 a3 a4 a5
index               index
image               radius thickness cc a4 a6 a8 a10 a12a14 a16 a18 a20
                    curvature [focus]
lensgroup/end
```

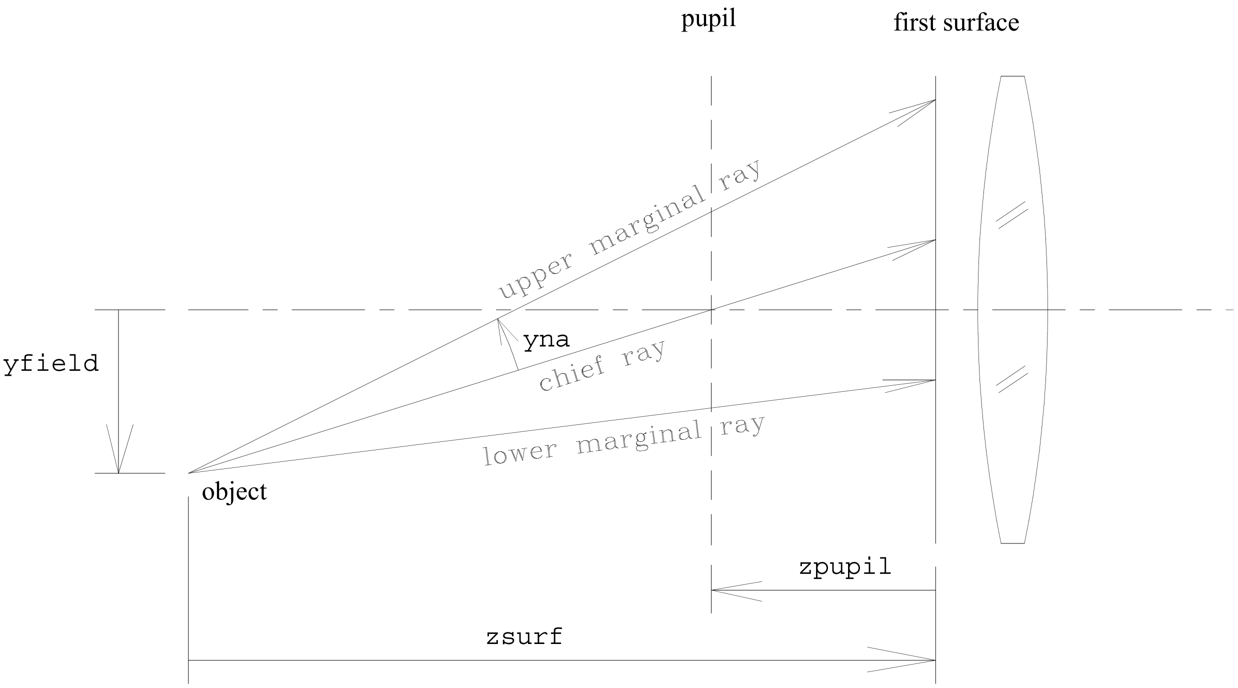


Fig. 23. Paraxial coordinates are defined with respect to the first surface.

Lensgroup commands	**Description**
`object`	Default wavelength and paraxial values in object space.
`surface_lensgroup`	Spherical surface.
`lensgroup/end`	Terminates lens data entry.
`clap_lensgroup`	Same as `clap` command, except the beam number is omitted.
`obs_lensgroup`	Same as `obs` command, except the beam number is omitted.
`vertex/rotate`	Rotation angles of coordinate break in degrees with respect to lens group axis. All elements will be referenced to new coordinates.
`vertex/locate`	Coordinate break of lens group axis. All subsequent surfaces will be referenced to new coordinates. Translations are performed in the global coordinate system.

Lensgroup commands	**Description (Continued)**
`glass`	Specify glass coefficients in the form `glass type a0 a1 a2 a3 a4 a5` Refer to this glass by the name “glass” in the `surface` command.
`index`	Same as `glass 5 a0` to set value for glass. Use parameter glass on subsequent surface.
`image`	Image surface. The image surface may be curved and an incremental thickness is allowed.

Lensgroup command modifiers	**Description**
`conic`	Conic surface with even power aspheric coefficients.
`zernike`	Conic surface with radially symmetric Zernike coefficients.
`cir`, `sqr`, `ell`, or `hex`	Aperture or obscuration shapes.
`vertex/rotate/add`	Add values to internal vertex rotation.
`vertex/rotate/set`	Set values for intenal vertex rotation.
`vertex/locate/add`	Add values to internal vertex location.
`vertex/locate/set`	Set values for intenal vertex location relative to front vertex.
`glass`	Specify glass coefficients in the form `glass type a0 a1 a2 a3 a4 a5`

Modifier 3	**Description**
`/element`	Paste a single element by cell address for `/paste` (default).
`/all`	Paste all elements for `/paste`.

Parameter	**Description**
(glass name)	Glass name: air, reflector, glass, or a glass name from one of the glass catalogs in the accompanying Tables 12 to 16.
`focus`	Causes GLAD to calculate paraxial image distance.

Numerical Values	**Description**	**Defaults**
`yfield`	Half-width of object field, y-direction.	
`yna`	Numerical angle in object space, y-direction.	`0.`
`zsurf`	Distance from object to first surface.	`1e20`
`zpupil`	Distance from first surface to pupil.	`0.`
`xfield`	Half-width of object field, x-directions.	yfield
`xna`	Numerical angle in object space, x-direction.	yna
`radius`	Radius of curvature (default type for first parameter). Either Radius or Curvature may be specified.	
`curvature`	Alternate definition of surface curvature. Variable assignment must be used.	
`thickness`	Distance to next surface measured in current vertex coordinates. thickness on the image line is added in front of the image.	

Numerical Values	Description (Continued)	Defaults
cc, a4, a6, a8, a10, a12, a14, a16, a18, a20	Conic constant and 4th through 20th order aspheric coefficients. If surface/zernike is specified the coefficients are interpreted as Zernike terms. See Table 3.	
type	Dispersion type for glass. See dispersion types (199).	
a0, a1, a2, a3, a4, a5	Dispersion coefficients for glass.	

Examples 1: Simple lens

```
lensgroup/def demo/o
 object lambda=.589 yfield=1.745e8 yna=1e-10 zsurf=1e10 air
 surface 100. .2 bk7 # radius 100, thickness .2, BK7
 clap/cir 1.0 # clear aperture of 1 cm radius
 surface cur=.02 0. air # curvature .02, thickness 0, AIR
 image focus
lensgroup/end
color 1 1.06
c
c start with a gaussian beam having a width of .005, after
c 100 cm, the beam width is .67484 at the lens
gauss/c/c 1 1 .005
vertex/locate/rel 0 0 100 # translate 100 cm
vertex/rotate 1 0 0 # tip lens 1 degree about x-axis
lensgroup/run demo 1 # implement lens
```

Example 2: Forward and backward through a lens

```
R1 = 200
T1 = 2
R2 = -300
T2 = 4.5
R3 = -200
T3 =  4
R4 = -350
alias glass1 bk7
alias glass2 air
alias glass3 bk7
thick = T1 + T2 + T3

lensgroup/def forward/o
  surface R1 T1 @glass1
  surface R2 T2 @glass2
  surface R3 T3 @glass3
  surface R4 0 air
  image focus
lensgroup/end
c
c Write lens in reverse order
c
lensgroup/def backward/o
  surface -R4 T3 @glass3
  surface -R3 T2 @glass2
  surface -R2 T1 @glass1
  surface -R1 0 air
  image focus
lensgroup/end
c
c Now set up a mirror to retro-reflect to illustrate procedure
vertex/locate/abs 0 0 Z_start
```

```
lensgroup/run first 1
vertex/locate/abs 0 0 Z_mirror
prop/vertex
c
c Just to illustrate find a mirror radius that will exactly retro-reflect
c
variab/set Prad _beam_no prad list
mirror/global -Prad
vertex/locate/abs 0 0 Z_start+thick # start at the back of the lens
vertex/rotate/set 180 0 0 # rotate lens show rear surface faces the beam
lensgroup/run backward 1
```

Table. 12. Schott glasses available from GLASS.CAT.

BAF3	1.583 46.5	BAF4	1.606 43.9	BAF5	1.607 49.4
BAF8	1.624 47.0	BAF9	1.643 48.0	BAF12	1.639 45.2
BAF13	1.669 45.0	BAF50	1.683 44.5	BAF51	1.652 44.9
BAF52	1.609 46.4	BAF53	1.670 47.1	BAF54	1.667 48.2
BAFN6	1.589 48.5	BAFN10	1.670 47.1	BAFN11	1.667 48.4
BAK1	1.572 57.5	BAK2	1.540 59.7	BAK4	1.569 56.1
BAK5	1.557 58.7	BAK6	1.574 56.4	BAK50	1.568 58.0
BALF3	1.571 52.9	BALF4	1.580 53.7	BALF5	1.547 53.6
BALF6	1.589 53.0	BALF8	1.554 51.2	BALF50	1.589 51.4
BALF51	1.574 52.1	BALK1	1.526 60.0	BALKN3	1.518 60.2
BASF1	1.626 39.0	BASF2	1.664 35.8	BASF5	1.603 42.5
BASF6	1.668 41.9	BASF10	1.650 39.2	BASF12	1.670 39.2
BASF13	1.698 38.6	BASF14	1.700 35.0	BASF50	1.710 36.6
BASF51	1.724 38.1	BASF52	1.702 41.0	BASF54	1.736 32.2
BASF55	1.700 34.7	BASF56	1.657 36.7	BASF57	1.651 41.9
BASF64	1.701 39.6	BASF64A	1.704 39.4	BK1	1.510 63.5
BK3	1.498 65.1	BK6	1.531 62.2	BK7	1.517 64.2
BK8	1.520 63.7	BK10	1.498 66.9	F1	1.626 35.7
F2	1.620 36.4	F3	1.613 37.0	F4	1.617 36.6
F5	1.603 38.0	F6	1.636 35.3	F7	1.625 35.6
F8	1.596 39.2	F9	1.620 38.1	F13	1.622 36.0
F14	1.601 38.2	F15	1.606 37.8	FK1	1.471 67.3
FK3	1.464 65.8	FK5	1.487 70.4	FK51	1.487 84.5
FK52	1.486 81.8	FK54	1.437 90.7	FN11	1.621 36.2
K3	1.518 59.0	K4	1.519 57.4	K5	1.522 59.5
K7	1.511 60.4	K10	1.501 56.4	K11	1.500 61.4
K50	1.523 60.2	K51	1.505 59.5	KF1	1.540 51.1
KF3	1.515 54.7	KF6	1.517 52.2	KF9	1.523 51.5
KF50	1.531 51.1	KZF6	1.527 51.1	KZFN1	1.551 49.6
KZFN2	1.529 51.6	KZFS1	1.613 44.3	KZFS6	1.592 48.5
KZFS7A	1.681 37.4	KZFS8	1.720 34.6	KZFSN2	1.558 54.2
KZFSN4	1.613 44.3	KZFSN5	1.654 39.6	KZFSN7	1.681 37.2
KZFSN9	1.599 46.9	LAF2	1.744 44.7	LAF3	1.717 48.0
LAF9	1.795 28.4	LAF11A	1.757 31.7	LAF13	1.776 37.8
LAF20	1.682 48.2	LAF21	1.788 47.4	LAF22	1.782 37.1

Table. 12. Schott glasses available from GLASS.CAT. (Continued)

LAF22A	1.782	37.2	LAF25	1.784	41.3	LAF26	1.746	40.0
LAFN7	1.750	35.0	LAFN8	1.735	41.6	LAFN10	1.784	44.0
LAFN11	1.757	31.8	LAFN21	1.788	47.5	LAFN23	1.689	49.7
LAFN24	1.757	47.8	LAFN28	1.773	49.6	LAK8	1.713	53.8
LAK9	1.691	54.7	LAK10	1.720	50.4	LAK11	1.658	57.3
LAK16A	1.734	51.8	LAK20	1.693	51.6	LAK21	1.640	60.1
LAK23	1.669	57.4	LAK28	1.744	50.8	LAK31	1.697	56.4
LAK33	1.754	52.4	LAKL12	1.678	54.9	LAKL21	1.640	59.8
LAKN6	1.643	58.0	LAKN7	1.652	58.5	LAKN12	1.678	55.2
LAKN13	1.694	53.3	LAKN14	1.697	55.4	LAKN16	1.734	51.7
LAKN22	1.651	55.9	LASF3	1.808	40.6	LASF8	1.807	31.6
LASF11	1.802	44.3	LASF13	1.855	36.6	LASF14A	1.822	37.5
LASF32	1.803	30.4	LASF33	1.806	34.2	LASF35	2.022	29.1
LASF36A	1.797	35.1	LASFN9	1.850	32.2	LASFN15	1.878	38.1
LASFN18	1.913	32.4	LASFN30	1.803	46.4	LASFN31	1.881	41.0
LF1	1.573	42.6	LF2	1.589	40.9	LF3	1.582	42.1
LF4	1.578	41.6	LF5	1.581	40.8	LF6	1.567	42.8
LF7	1.575	41.5	LF8	1.564	43.8	LGSK2	1.586	61.0
LLF1	1.548	45.8	LLF2	1.541	47.2	LLF3	1.560	47.2
LLF4	1.561	45.2	LLF6	1.532	48.8	LLF7	1.549	45.4
PK1	1.504	66.9	PK2	1.518	65.1	PK3	1.525	64.7
PK50	1.521	69.7	PK51A	1.529	77.0	PSK2	1.569	63.1
PSK3	1.552	63.5	PSK50	1.558	67.3	PSK52	1.603	65.4
PSK53A	1.620	63.5	PSK54	1.586	64.6	SF1	1.717	29.5
SF2	1.648	33.8	SF3	1.740	28.2	SF4	1.755	27.6
SF5	1.673	32.2	SF6	1.805	25.4	SF7	1.640	34.6
SF8	1.689	31.2	SF9	1.654	33.7	SF10	1.728	28.4
SF11	1.785	25.8	SF12	1.648	33.8	SF13	1.741	27.6
SF14	1.762	26.5	SF15	1.699	30.1	SF16	1.646	34.0
SF17	1.650	33.7	SF18	1.722	29.2	SF19	1.667	33.0
SF50	1.655	32.9	SF51	1.660	32.9	SF52	1.689	30.6
SF53	1.728	28.7	SF54	1.741	28.1	SF55	1.762	27.0
SF56	1.785	26.1	SF56A	1.785	26.1	SF57	1.847	23.8
SF58	1.918	21.5	SF59	1.952	20.4	SF61	1.751	27.5
SF62	1.681	31.9	SF63	1.748	27.7	SFL4	1.755	27.2
SFL6	1.805	25.4	SFL56	1.785	26.1	SFL57	1.847	23.6
SFN64	1.706	30.3	SK1	1.610	56.7	SK2	1.607	56.7
SK3	1.609	58.9	SK4	1.613	58.6	SK5	1.589	61.3
SK6	1.614	56.4	SK7	1.607	59.5	SK8	1.611	55.9
SK9	1.614	55.2	SK10	1.623	56.9	SK11	1.564	60.8
SK12	1.583	59.5	SK13	1.592	58.3	SK14	1.603	60.6
SK15	1.623	58.1	SK16	1.620	60.3	SK18A	1.639	55.4
SK19	1.613	57.4	SK20	1.560	61.2	SK51	1.621	60.3
SK52	1.639	55.5	SK55	1.620	60.1	SKN18	1.639	55.4
SSK1	1.617	53.9	SSK2	1.622	53.2	SSK3	1.615	51.2

Table. 12. Schott glasses available from GLASS.CAT. (Continued)

SSK4	1.618 55.1	SSK4A	1.618 55.1	SSK50	1.618 52.6
SSK51	1.604 53.6	SSK52	1.658 50.9	SSKN5	1.658 50.9
SSKN8	1.618 49.8	TIF1	1.511 51.0	TIF2	1.533 46.0
TIF3	1.548 42.2	TIF4	1.584 37.0	TIF6	1.617 31.0
TIFN5	1.594 35.5	TIK1	1.479 58.7	TISF1	1.673 28.9
UBK7	1.517 64.3	UK50	1.523 60.4	ULTRAN20	1.487 84.5
ULTRAN30	1.548 74.2	ZK1	1.533 58.0	ZK5	1.534 55.3
ZKN7	1.508 61.2	FPL51	1.497 81.6		

Table. 13. Hoya glasses available from GLASS.CAT.

FC1	1.471	67.3	FC3	1.464	65.8	FC5	1.487	70.4
FCD1	1.497	81.6	FCD10	1.457	90.8	PC1	1.504	66.9
PC2	1.518	65.2	PC3	1.525	64.6	PCS1	1.517	69.7
PCD2	1.569	63.1	PCD3	1.552	63.4	PCD4	1.618	63.4
PCD5	1.617	62.8	PCD53	1.620	63.5	BSC1	1.510	63.4
BSC3	1.498	65.1	BSC4	1.500	66.0	BSC6	1.531	62.1
BSC7	1.517	64.2	BACL1	1.526	60.1	BACL3	1.518	60.4
C2	1.516	56.8	C3	1.518	59.0	C5	1.522	59.5
C7	1.511	60.5	C10	1.501	56.3	C12	1.523	58.6
C40	1.523	60.4	ZNC1	1.533	58.1	ZNC7	1.508	61.3
BAC1	1.572	57.5	BAC2	1.540	59.7	BAC4	1.569	56.0
BAC5	1.557	58.6	BAC6	1.574	56.4	BACD1	1.610	56.7
BACD2	1.607	56.7	BACD3	1.609	58.9	BACD4	1.613	58.6
BACD5	1.589	61.2	BACD6	1.614	56.4	BACD7	1.607	59.5
BACD8	1.611	55.8	BACD9	1.614	55.1	BACD10	1.623	56.9
BACD11	1.564	60.8	BACD12	1.583	59.5	BACD13	1.592	58.3
BACD14	1.603	60.7	BACD15	1.623	58.1	BACD16	1.620	60.3
BACD18	1.639	55.5	BACD50	1.607	55.0	BACED1	1.617	53.9
BACED2	1.622	53.1	BACED3	1.615	51.2	BACED4	1.618	55.2
BACED5	1.658	50.8	BACED9	1.620	49.8	BACED20	1.648	53.0
LACL1	1.641	56.8	LACL2	1.650	55.7	LACL3	1.665	53.4
LACL4	1.670	51.7	LACL5	1.694	50.8	LACL6	1.640	60.2
LACL7	1.670	57.3	LACL8	1.678	53.4	LACL9	1.678	50.5
LACL60	1.640	60.2	LAC6	1.643	58.0	LAC7	1.652	58.4
LAC8	1.713	53.9	LAC9	1.691	54.7	LAC10	1.720	50.3
LAC11	1.658	57.3	LAC12	1.678	55.5	LAC15	1.697	56.1
FDS9	1.847	23.8	LAC13	1.694	53.3	LAC14	1.697	55.5
TAC1	1.726	53.4	TAC2	1.741	52.6	TAC4	1.734	51.0
TAC6	1.755	52.3	TAC8	1.729	54.7	CF2	1.526	51.0
CF3	1.515	54.6	CF4	1.534	51.5	CF5	1.523	51.0
CF6	1.517	52.2	SBF1	1.551	49.5	SBF2	1.529	51.6
SBF5	1.521	52.8	BAFL2	1.571	50.9	BAFL3	1.571	53.0
BAFL4	1.580	53.7	BAFL6	1.589	52.9	FEL1	1.548	45.8
FEL2	1.541	47.2	FEL3	1.560	47.1	FEL4	1.561	45.2
FEL6	1.532	48.8	FEL7	1.549	45.4	BAF2	1.570	49.4

Table. 13. Hoya glasses available from GLASS.CAT. (Continued)

BAF3	1.583	46.5	BAF4	1.606	43.9	BAF5	1.607	49.3
BAF6	1.589	48.5	BAF7	1.608	46.2	BAF8	1.624	47.0
BAF9	1.643	47.9	BAF10	1.670	47.2	BAF11	1.667	48.3
BAF12	1.639	45.1	BAF13	1.669	44.9	BAF20	1.686	43.9
BAF21	1.664	48.9	BAF22	1.683	44.7	BAF23	1.652	44.9
FL1	1.573	42.6	FL2	1.589	41.0	FL3	1.582	42.0
FL4	1.578	41.7	FL5	1.581	40.9	FL6	1.567	42.8
FL7	1.575	41.5	FL57	1.576	41.4	F1	1.626	35.7
F2	1.620	36.3	F3	1.613	37.0	F4	1.617	36.6
F5	1.603	38.0	F6	1.636	35.3	F7	1.625	35.6
F8	1.596	39.2	F9	1.620	38.1	F11	1.621	36.0
F15	1.606	37.9	BAFD1	1.626	39.1	BAFD2	1.664	35.9
BAFD3	1.607	40.4	BAFD4	1.651	38.3	BAFD5	1.603	42.4
BAFD6	1.668	41.9	BAFD7	1.702	41.2	BAFD8	1.723	38.0
BAFD10	1.650	39.3	BAFD14	1.700	34.9	BAFD15	1.702	40.2
BAFD16	1.600	42.5	FD1	1.717	29.5	FD2	1.648	33.8
FD3	1.740	28.2	FD4	1.755	27.5	FD5	1.673	32.2
FD6	1.805	25.5	FD7	1.640	34.6	FD8	1.689	31.2
FD9	1.654	33.7	FD10	1.728	28.3	FD11	1.785	25.7
FD12	1.648	33.8	FD13	1.741	27.8	FD14	1.762	26.5
FD15	1.699	30.0	FD18	1.722	29.2	FD19	1.667	33.1
FD20	1.720	29.3	FD41	1.751	27.7	FD60	1.805	25.5
FD140	1.762	26.6	FDS1	1.923	20.9	FDS2	1.728	28.7
FDS3	1.785	26.1	FDS5	1.762	26.9	FDS30	1.785	26.1
FD110	1.785	25.7						

Table. 14. Ohara glasses available from GLASS.CAT.

APL1	1.517	69.6	BAH10	1.670	47.2	BAH11	1.667	48.3
BAH13	1.669	45.0	BAH22	1.664	35.8	BAH24	1.651	38.2
BAH26	1.668	41.9	BAH27	1.702	41.2	BAH28	1.723	38.0
BAH30	1.650	39.4	BAH32	1.670	39.3	BAH51	1.682	44.7
BAH53	1.686	44.0	BAH54	1.695	42.2	BAH71	1.702	40.1
BAH77	1.702	41.2	BAH78	1.723	38.0	BAL2	1.571	50.8
BAL3	1.571	53.0	BAL4	1.580	53.7	BAL5	1.547	53.5
BAL6	1.589	53.2	BAL7	1.589	51.2	BAL11	1.573	57.8
BAL12	1.540	59.5	BAL14	1.569	56.3	BAL15	1.557	58.7
BAL16	1.574	56.5	BAL21	1.548	62.8	BAL22	1.569	63.2
BAL23	1.552	63.8	BAL35	1.589	61.2	BAL41	1.564	60.7
BAL42	1.583	59.4	BAL50	1.560	61.2	BAM1	1.557	48.5
BAM2	1.570	49.3	BAM3	1.583	46.4	BAM4	1.606	43.7
BAM5	1.607	49.2	BAM6	1.589	48.6	BAM8	1.624	47.1
BAM9	1.643	47.8	BAM12	1.639	44.9	BAM21	1.626	39.2
BAM23	1.607	40.3	BAM25	1.603	42.3	BPH5	1.654	39.7
BPH8	1.720	34.7	BPH35	1.644	40.8	BPH40	1.676	37.5
BPH45	1.719	33.5	BPH50	1.740	31.7	BPM4	1.613	43.8

Table. 14. Ohara glasses available from GLASS.CAT. (Continued)

BPM51	1.613	44.2	BSL1	1.510	63.6	BSL3	1.498	65.0
BSL4	1.500	66.0	BSL6	1.531	62.5	BSL7	1.516	64.2
BSL10	1.498	66.8	BSL12	1.519	64.5	BSL21	1.504	66.8
BSL22	1.518	65.0	BSL23	1.525	64.6	BSM1	1.610	56.5
BSM2	1.607	56.8	BSM3	1.609	59.0	BSM4	1.613	58.8
BSM6	1.614	56.4	BSM7	1.607	59.4	BSM8	1.611	55.9
BSM9	1.614	55.0	BSM10	1.623	57.1	BSM14	1.603	60.7
BSM15	1.623	58.2	BSM16C	1.620	60.3	BSM16	1.620	60.3
BSM18	1.639	55.4	BSM19	1.613	57.4	BSM21	1.617	54.0
BSM22	1.622	53.2	BSM23	1.615	51.2	BSM24	1.618	55.0
BSM25	1.658	50.9	BSM28	1.618	49.8	BSM29	1.620	49.5
BSM36	1.642	58.4	BSM71	1.648	53.0	BSM81	1.640	60.1
BSM93	1.641	56.9	FPL51	1.497	81.6	FPL52	1.456	90.3
FPL53	1.439	95.0	FSL1	1.471	67.4	FSL3	1.464	65.9
FSL5	1.487	70.2	FTL8	1.511	51.0	FTL10	1.501	56.4
FTM8	1.533	45.9	FTM16	1.593	35.3	LAH51	1.786	44.2
LAH52	1.800	42.2	LAH53	1.806	41.0	LAH54	1.816	44.4
LAH55	1.835	42.7	LAH57	1.863	41.5	LAH58	1.883	40.8
LAH59	1.816	46.6	LAH60	1.834	37.2	LAH62	1.803	46.7
LAH63	1.804	39.6	LAH64	1.788	47.4	LAH65	1.804	46.6
LAH66	1.772	49.6	LAH67	1.795	45.3	LAH71	1.850	32.3
LAH75	1.874	35.3	LAL7	1.652	58.5	LAL8	1.713	53.8
LAL9	1.691	54.8	LAL10	1.720	50.2	LAL11	1.658	57.3
LAL12	1.678	55.3	LAL13	1.694	53.2	LAL14	1.697	55.5
LAL18	1.729	54.7	LAL52	1.670	57.3	LAL53	1.670	51.6
LAL54	1.651	56.2	LAL55	1.658	53.4	LAL56	1.678	50.7
LAL57	1.678	53.4	LAL58	1.693	50.8	LAL59	1.734	51.5
LAL60	1.726	53.6	LAL61	1.741	52.7	LAL64	1.697	56.5
LAM2	1.744	44.8	LAM3	1.717	47.9	LAM7	1.749	35.3
LAM8	1.735	41.1	LAM51	1.700	48.1	LAM52	1.720	43.7
LAM53	1.735	49.8	LAM54	1.757	47.8	LAM55	1.762	40.1
LAM56	1.686	49.2	LAM57	1.713	43.2	LAM58	1.720	42.0
LAM59	1.697	48.5	LAM60	1.743	49.3	LAM61	1.720	46.0
LAM62	1.783	36.2	LAM65	1.749	35.0	LAM66	1.801	35.0
NSL1	1.510	62.1	NSL2	1.516	56.8	NSL3	1.518	59.0
NSL5	1.522	59.8	NSL7	1.511	60.5	NSL21	1.526	60.0
NSL23	1.518	60.3	NSL31	1.540	51.0	NSL32	1.526	51.2
NSL33	1.515	54.7	NSL34	1.534	51.6	NSL35	1.523	50.8
NSL36	1.517	52.4	NSL50	1.523	60.0	NSL51	1.523	58.5
PBH1	1.717	29.5	PBH3W	1.740	28.3	PBH3	1.740	28.3
PBH4W	1.755	27.5	PBH4	1.755	27.5	PBH6W	1.805	25.4
PBH6	1.805	25.4	PBH10	1.728	28.5	PBH11	1.785	25.7
PBH11W	1.785	25.7	PBH13W	1.741	27.8	PBH13	1.741	27.8
PBH14W	1.762	26.5	PBH14	1.762	26.5	PBH18	1.722	29.2
PBH21	1.923	20.9	PBH23W	1.785	26.2	PBH23	1.785	26.2

Table. 14. Ohara glasses available from GLASS.CAT. (Continued)

PBH25	1.762	27.1	PBH25W	1.762	27.1	PBH51	1.720	29.3
PBH53	1.847	23.9	PBH53W	1.847	23.9	PBH54	1.751	27.7
PBH71	1.923	21.3	PBH72	1.915	21.2	PBL1	1.548	45.8
PBL2	1.541	47.2	PBL3	1.560	47.0	PBL4	1.561	45.2
PBL6	1.532	48.9	PBL7	1.549	45.6	PBL21	1.573	42.6
PBL22	1.589	41.1	PBL23	1.582	42.1	PBL24	1.578	41.5
PBL25	1.581	40.8	PBL26	1.567	42.8	PBL27	1.575	41.5
PBL28	1.564	43.8	PBM1	1.626	35.7	PBM2	1.620	36.3
PBM3	1.613	37.0	PBM4	1.617	36.6	PBM5	1.603	38.0
PBM6	1.636	35.4	PBM8	1.596	39.2	PBM9	1.620	38.1
PBM10	1.624	36.5	PBM11	1.621	35.9	PBM22	1.648	33.8
PBM25	1.673	32.1	PBM27	1.640	34.5	PBM28W	1.689	31.1
PBM28	1.689	31.1	PBM29	1.654	33.6	PBM32	1.648	33.8
PBM35	1.699	30.1	PBM39	1.667	33.0	PHM51	1.617	62.8
PHM52	1.618	63.4	PHM53	1.603	65.5	SSL2	1.529	51.7
SSL4	1.570	48.1	SSL5	1.521	52.5	SSL6	1.527	51.1
TIH6	1.805	25.4	TIH11	1.785	25.7	TIH14	1.762	26.5
TIH23	1.785	26.3	TIH53	1.847	23.8	TPH55	1.756	25.1
YGH51	1.755	52.3	YGH52	1.786	50.0	ZSL1	1.533	58.0
ZSL4	1.512	58.1	ZSL5	1.534	55.5	ZSL7	1.508	60.8

Table. 15. Miscellaneous glasses available from GLASS.CAT.

ACRYLIC	1.492	57.4	CAFL	1.434	95.0	KDP-EXT	1.463	755.6
KDP-ORD	1.503	229.2	LIF	1.393	74.1	POLYCARB	1.585	29.9
POLYSTYR	1.590	30.9	QUARTZ-E	1.553	68.8	QUARTZ-O	1.544	70.1
SAN	1.567	34.8	SAPPHIRE	1.768	72.2	SILICA	1.458	67.8
CAF2	1.434	94.3	SPINEL	1.723	-35.3	SFS01	1.923	21.3

Table. 16. Infrared glasses available from GLASS.CAT.

AMTIR-1	2.532	0.0	GERMANIUM	4.024	0.0	IRGN6	1.528	0.0
IRTRAN1	1.353	0.0	IRTRAN2	2.250	0.0	IRTRAN3	1.410	0.0
IRTRAN4	2.438	0.0	IRTRAN5	1.668	0.0	IRTRAN6	2.688	0.0
CDTE	2.688	0.0	SILICON	3.934	6.2	GAP	3.362	3.5
GAAS								

LENSGROUP/RUN Implement the lens group. Component

Command Forms(s): **LENSGROUP/RUN**

`lensgroup/run/`(modifier 2) (name) `kbeam nrays rnorm cutoff`

Description: LENSGROUP/RUN

The command `lensgroup/run` implements the lens at the current point in the beam train. An equivalent lens is created by GLAD and added to LENLIB. This equivalent lens is used in physical optics propagation. Modifier 2 defines the polynomial set used to characterize the aberration.

Modifier 2	Description
/fringe	Set of 37 polynomials organized by polynomial order based on the sum of radial and azimuthal orders (default). Used in many interferometric reduction programs. /fringe has more radial terms and fewer azimuthal terms. See fitzern , Table 2.
/standard	Set of 45 polynomials organized by radial order. All azimuthal terms are included. See fitzern , Table 1.
/radial	Set of radial polynomials up tp 20th order. See fitzern , Table 3.

Character String	Description
(name)	Lens group name.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
nrays	Number of rays across the diameter for lens evaluation.	
rnorm	Normalizing radius.	Beam size from geodata
cutoff	Cutoff for Zernike aberration coefficients to be used.	0.002

LENSGROUP/TRACE Single ray, fan, and spot traces of lensgroup. Component

Command Forms(s): **LENSGROUP/TRACE**

```
/trace/paraxial/default      (name) lambda [surface]
/trace/paraxial/beam         (name) kbeam [surface]
/trace/seidel/default        (name) lambda [surface]
/trace/seidel/beam           (name) kbeam [surface]
/trace/oneray/default        (name) xo_rel yo_rel xp_rel yp_rel lambda
                             [surface]
/trace/oneray/beam           (name) kbeam xp_rel yp_rel [surface]
/trace/(xfan or              (name) xo_rel yo_rel lambda nrays [(listing type)]
yfan)/default
/trace/(xfan or yfan)/beam   (name) kbeam nrays [(listing type)]
/trace/spot/default          (name) xo_rel yo_rel lambda nrays [(listing type)]
/trace/spot/beam             (name) kbeam nrays [(listing type)]
```

Description: LENSGROUP/TRACE

The command lensgroup/trace traces the lens group designated by name, using either the default or actual beam data to specify the object location, numerical aperture, and stop location.

Modifier 2	Description
/paraxial	Calculate paraxial ray trace. Assumes object lies in y-z plane.
/oneray	Calculate single ray trace.
/seidel	Calculate Seidel aberration polynomials. Assumes object lies in y-z plane.
/xfan, /yfan	Calculate a ray fan in the x- or y-direction.

Modifier 2	**Description (Continued)**
/spot	Calculate spot diagram.

Modifier 3	**Description**
/default	Use paraxial data from default lens data line. Wavelength may be changed by setting lambda.
/beam	Use actual beam data, requires kbeam. Object point and wavelength are determined by incident beam.

Character String	**Description**
name	Lensgroup name.

Parameter	**Description**
surface	List intermediate surface data for /seidel and /oneray.
listing type	Type of surface-by-surface data to be listed. Choices are relative, global, and vertex.

Numerical Values	**Description**	**Defaults**
kbeam	Single beam number.	1
lambda	Wavelength for /default. Default value is taken from the default line of the lens definition.	
xo_rel, yo_rel	Paraxial relative object position for ray with /default.	0., 0.
xp_rel, yp_rel	Paraxial relative pupil position for ray /oneray.	
nrays	Number of rays across the diameter of the pupil for either /fans or /spot.	

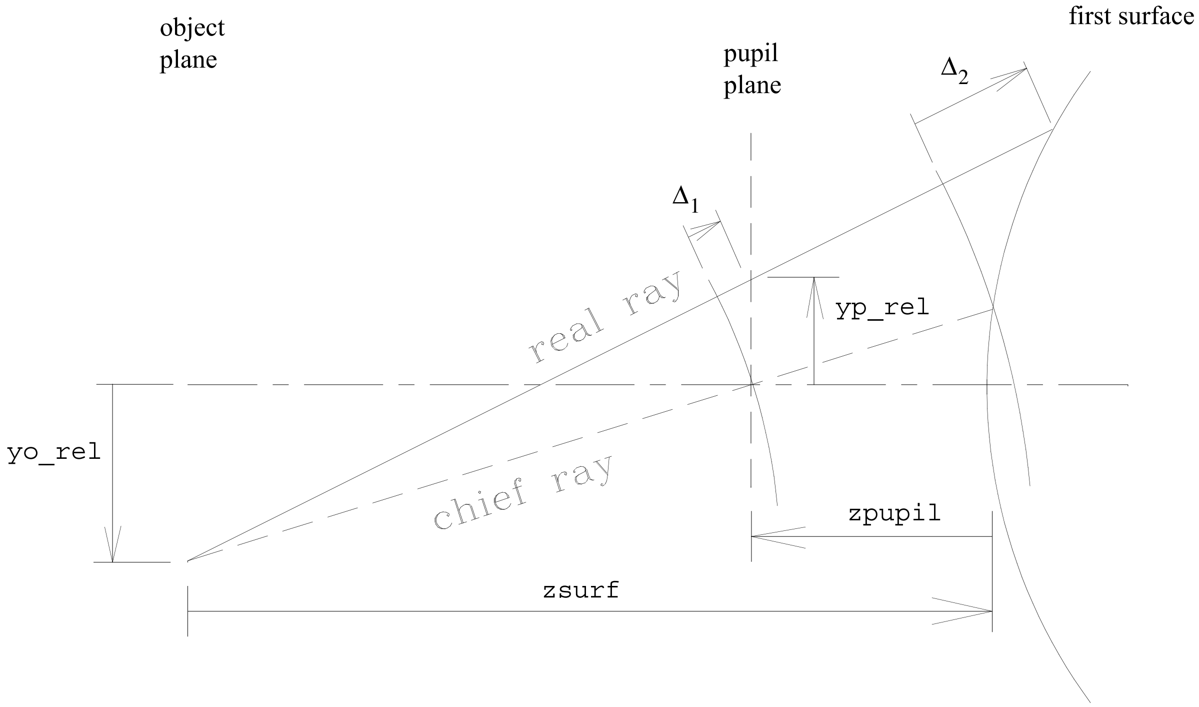


Fig. 24. Optical path differences at entrance pupil plane, Δ_1, and at first surface, Δ_2 .

LINE Display source line number. Language

Command Forms(s): **LINE**

```
/line
```

Description: LINE

Displays source line number. Useful for debugging by identifying the line number of specific commands. Also see the system variable `line` in `variables` that stores the current line number into a variable.

LORENTZIAN Initialize beam with generalized Lorentzian function. Begin-end

Command Forms(s): **LORENTZIAN**

```
/full            kbeam peak width xdec ydec power
/half            kbeam peak leftwidth rightwidth xdec ydec lpower rpower
```

Description: LORENTZIAN

This command initializes the beam to a generalized Lorentzian function or a generalized half-Lorentzian. The generalized form allows for a power of the spatial argument other than 2. The half-Lorentzian allows construction of different Lorentzians in the left and right half-planes (about the `xdec` point).

$$I(x, y) = \frac{\mathtt{peak}}{\left(1 + \frac{x^2}{\mathtt{width}^2}\right)^{\mathtt{power}}} \qquad (169)$$

Modifier 1	Description
`/full`	Normal Lorentzian.
`/half`	The half-Lorentzian allows construction of different Lorentzians in the left and right half-planes (about the `xdec` point).

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`peak`	Peak value of function.	
`width`	Width of the Lorentzian.	
`xdec`, `ydec`	Position of the center of the Lorentzian.	
`power`	Exponent for the generalized Lorentzian.	
`leftwidth`	Width for left half plane of half-Lorentzian.	
`rightwidth`	Width for right half plane of half-Lorentzian.	
`lpower`	Exponent of left half plane of half-Lorentizian.	
`rpower`	Exponent of right half plane of half-Lorentizian.	

MACRO Controls macros of commands. Language

Command Forms(s): **MACRO**

`macro/run`	(name)`/icount`
`macro/define`	(name)
`macro/end`	
`macro/exit`	
`macro/status`	
`macro/dir`	
`macro/list/screen`	(name)
`macro/list/disk`	(filename) (name)

Description: MACRO

Creates, executes, or terminates a macro file and maintains a macro library. Macros act like subroutines or functions and are the primary tool for modeling repetitive operations.

The macro library window may be shown with set/maclib/show or hidden with set/maclib/hide. This window can be read but directly written to. When highlighting is active, the lines in maclib are highlighted in parallel with the lines in the source files in GladEdit.

Modifier 1	**Description**
/run	Executes the commands in a macro file.
/define	Creates a new macro file. Subsequent commands will not be executed, but will be placed in the macro being defined. Terminate /define mode with macro/end or "]" as the first character in the line.
/end	If a macro is being created indicates the end of the macro,. If a macro file is being executed, it will be terminated.
/exit	Unconditional termination.
/exit/current	Unconditional termination of current macro (default).
/exit/all	Unconditional termination of all macros.
/status	Lists data on active macro's including macro name, last line number read.
/dir	Lists names in macro library with starting line number.
/list	Lists the designated macro.

Modifier 2	**Description**
/screen	List macro to the screen. Viewing file maclib directly may be more convenient. See set/maclib/show.
/disk	List to the disk file filename.
dir/library	List macros in library (default).
dir/editor	List macros defined in editor.

Character String	**Description**
name	Macro name (character string).
(name)/icount	Used with /run operation. icount is a numerical value that specifies the number of times the macro is executed.
(name)	Used with /define to give the name of the macro being defined.
(filename)	Disk file used with /list/disk.

Numerical Values	**Description**	**Defaults**
icount	Number of times to run macro.	1

Variables macro/**(mod)**	**Description**
iteration	Current iteration number of executing macro. Starts at 1. Convenient for setting special conditions for the first pass through a macro.
maxiteration	Maximum iteration of executing macro.
remaining	Remaining iterations. Ends at 0 for last loop through the macro. Convenient for setting special conditions for the last pass through a macro.

MAGNIFY Applies magnification to the beam. Operator

Command Forms(s): **MAGNIFY**

```
magnify          ibeams xmag ymag
```

Description: MAGNIFY

Magnifies the beam including correction of the geometrical factors. Also, see `rescale`.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`xmag`, `ymag`	Magnification factor(s).	`1.`

MANUAL Open PDF document from command line. Language

Command Forms(s): **MANUAL**

```
manual/destination         '(document name)' '(named destination)' xoff yoff
                           xsizw ysize
manual/pagenumber          page xoff yoff xsize ysize
manual/closedocument       '(document name)'
manual/terminatereader
```

Description: MANUAL

Open one of the Adpbe PDF manual pages: commands.pdf, theory.pdf, examples.pdf, or other non-AOR PDF documents to a specific page by “named destination” or page number. The `manual` command may be included in hyperlinks in RTF-formated command files. Single qoutes are required if the strings contain blanks’. Hyperlinks are written as regular GLAD commands except that backslashes that may appear in file paths must be written as double backslashes to be compatible with RTF files. See the GladEdit Help file on the GladEdit window menu and Sect 1.3.1.2, GladEdit (17).

GLAD PDF manuals have named destination for major topics. Note that all named destinations must be written with exact lower or upper case.

For commands.pdf the named destinations are “contents”, paragraph numbers, commands (lower case), comand/modifier combinations that have their own page, and “index”. For a page with a command/modifier title, the destination is written with “$” replacing the slash, e.g. plot$xslice.

For theory.pdf the named destinations are “contents”, chapter numbers, (e.g. 9), section numbers (e.g. 9.9), and “index”.

For examples.pdf the named destinations are “contents”, example chapters (e.g. Ex33, note upper case “E” is required), input for examples listings (e.g. ex33a.inp), and “index”. You can also open AOR PDF documents according to the printed page number (e.g. P.150) as a named destination or the PDF page number (number given in the Acrobat Reader display) using `/pagenumber`.

Other non-AOR PDF documents may also be opened to PDF page numbers using `/pagenumber` or named destinations if the author of the document has added them. Consult Adobe Acrobat documentation for information on inserting named destinations in PDF documents.

Non-PDF documennts may be opened with system /launch.

Numerical Values	Description	Defaults
page	Document is set to this PDF page number.	1
xoff, yoff, xsize, ysize	X- and y-offset and x- and y-size of the Acrobat Reader window in pixels when the Reader is opened. To resize it is necessary to terminate the Acorbat Reader and give new parameters for either /nameddestination or /pagenumber. You can also reset the Acrobat Reader window by hand adjustment.	

Modifier 1	Description
/destination	Open document and go to named destination. See below.
/pagenumber	Open document and go to page number.
/closedocument	Close the document leaving the Acrobat Reader open.
/terminatereader	Close Acrobat Reader.

Character String	Description
document name	Name of a PDF document such as commands.pdf, theory.pdf, or examples.pdf located in the GLAD installation folder. The single letter “c” is expanded into commands.pdf, “e” is expanded into examples.pdf, and the “t” is expanded into theory.pdf. You can also give the full path to address files in other folders. Use single quotes if the string includes blanks.
named destination	Document is set to this named destination in PDF file. All commands have a named destination of the same name. For pages headings using a command and modifier, replace the “/” with “$” to form the named destination, e.g., plot/xslice has the named destination plot$xslice. Printed page numbers are preceeded by “P.”, e.g. P.150, P.iii. See description above for more details.

Examples:

```
manual/destination commands.pdf energy
manual/dest c energy
manual/dest commands.pdf plot$sxlice
manual/dest ‘d:\program files\AOR\47\commands.pdf’ P.150
manual/pagenumber commands.pdf 20
manual/dest theory.pdf 9.9
manual/dest t 9.9
manual/dest examples.pdf Ex33
manual/dest examples.pdf ex33b.inp
```

Slide show with GLAD running and Acrobat Reader displaying pages in myslides.pdf:

```
varialbe/dec/int count
manual/page myslides.pdf 1            # Open PDF file first time.
pause                                 # Pause to allow time to adjust Reader window
                                      # size and position if necessary.

macro/def system/o
   count = count + 1
   prop 10
   manual/page myslides.pdf count     # display PDF file at page = count
   pause 10                                 # wait 10 seconds for slide to show and be read
macro/end
count = 0
macro/run system/10
```

MEMORY Sets properties of dynamic memory allocation. Begin-end

Command Forms(s): **MEMORY**

```
memory/set          mbytes
memory/maximum      mbytes
memory/free
memory/contents
memory/list
memory/testspeed
memory/remove       kbeam
```

Description: MEMORY

This command lists, sets, or limits the maximum memory allocation. As of Ver. 5.1, the memory is expanded automatically, as required, up to the maximum physical memory available or to the maximum defined by memory/max. Expanding the memory at the beginning of the calculation, when the memory is largely unset, is faster than the automatic memory expansion occuring later in the command file when memory is full of information and must be copied to and from memory locations or even disk. If there is insufficient memory available, GLAD will use its built-in virtual memory management routines to do the calculations, with some decrease in calculation speed.

For the 64 bit version of GLAD, the number of CPU's will automatically be set to the maximum number of processors available from 1, 2, 4, 8, and 16 processors (powers of 2). For the 32 bit version use command set/cpu 2 to use 2 processors (if available) to increase speed from 30% to 40% for large arrays.

Modifier 1	Description
/set	Set memory allocation to specified value. Use at the beginning of the comand file — faster than automatic allocation. Automatic allocation will still expand above this value, if required.
/maximum	Set maximum memory allocation. Automatic allocation will not exceed this value. Memory will be reduced if required.
/free	Free maximum size restriction of memory after memory/maximum.
/list	Display current values of memory usage. The memory offset is primarily for AOR diagnostic information.
/contents	Lists the contents of memory. The size and starting addresses of each of the beams currently in memory is listed.
/testspeed	Test speed of memory relative to first test with a small memory allocation. If the memory allocation is set too high, the speed decreases.
/remove	Remove selected beam from memory. Beam is left unchanged. Primarily for AOR diagnostic pruposes.

Numerical Values	Description	Defaults
mbytes	Normally (mbytes = 0) GLAD will allocate memory, as required, up to the maximum available physical memory. If memory/max is used to set mbytes to some non-zero value, GLAD will use no more than mbytes even if more physical memory is available. One megabyte = 1,048,576 bytes.	0
kbeam	Single beam number.	

Variables memory/**(mod)**	Description
total	Total physical memory. May not report correct value for memory above 2 GB.
allocated	Amount of memory allocated to GLAD.
free	Amount of unallocated memory available. May be unreliable as the operating system can swap programs and data between memory and disk.
maximum	Maximum memory allocation set by user.
speedratio	Ratio of current memory speed, with expanded memory, and initial speed with a low memory allocation. Same value as calculated by memory/testspeed. If the ratio drops substantially below 1.00, this is an indication that the operating system can not provide the requested allocation without swapping. It is best to reduce the memory allocation.

MIRROR Ideal mirror. Component

Command Forms(s): **MIRROR**

```
mirror/sph          ibeams radius xdec ydec
mirror/sph          ibeams radius xdec ydec [xonly]
mirror/sph          ibeams fl xdec ydec [focallength]
mirror/abr          ibeams radius xdec ydec
mirror/abr          ibeams radius xdec ydec [xonly]
mirror/abr          ibeams fl xdec ydec [focallength]
mirror/flat         ibeams
mirror/xcyl         ibeams xradius xdec ydec
mirror/xcyl         ibeams xradius xdec ydec [xonly]
mirror/xcyl         ibeams xfl xdec ydec  [focallength]
mirror/ycyl         ibeams yradius xdec ydec
mirror/ycyl         ibeams yradius xdec ydec [xonly]
mirror/ycyl         ibeams yfl xdec ydec [focallength]
mirror/toric        ibeams xradius yradius xdec ydec
mirror/toric        ibeams xradius yradius xdec ydec [xonly]
mirror/toric        ibeams xradius yradius xdec ydec [focallength]
mirror/global
```

Description: MIRROR

This command models an ideal mirror of specified radius. See mirror/global for an exact model of a mirror including aberrations calculation. If no vertex has been defined, the mirror is located at the current beam position when the command is issued. If a vertex has been defined, the mirror is located at the vertex position and an internal prop/vertex is issued to bring the beam to that position. The mirror is always rotated to be aligned with the beam to which it is applied. The vertex must be redefined after each propagation step. See the vertex command. The imaged waist size and location are recomputed after the lens.

The mirror command is normally specified by the radius of curvature. The sign of the radius is defined in vertex coordinates. A positive radius has the center of curvature to the positive side of the vertex. A mirror may be defined by focal length by including the parameter, focallength, any where on the command line after the command/modifier group.

Modifier 1	Description
/sph	Spherical surface (2nd order accuracy).
/abr	Forces mirror to be treated as a flat mirror and phase object.
/flat	Flat mirror.
/xcyl	Cylindrical surface curved about y-axis (2nd order accuracy).
/ycyl	Cylindrical surface curved about x-axis (2nd order accuracy).
/toric	Toric surface (2nd order accuracy).
/global	Orientation of surface and beams are controlled through the commands global and vertex . See description under mirror/global .

Modifier 2	Description
/con	Prevents rescaling (default).
/res	Permits rescaling when needed.

Parameter	Description
focallength	rad, xrad, and yrad are interpreted as focal lengths.
xonly	Used to accomplish a figure of rotation in radial mode. It is equivalent to having a toric mirror where the radius of the mirror in the y-direction (which represents the azimuthal direction in radial mode) is exactly the same as the radius of the cylindrical wave in the y-direction.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
rad	Radius of spherical surface.	1e20
xrad	Radius of x-cylindrical surface.	1e20
yrad	Radius of y-cylindrical surface.	1e20
xdec	X-decenter.	0.
ydec	Y-decenter.	0.

The convention is to use a positive radius if the center of curvature is in the positive global z-direction. The focal length is positive if the light is made more converging after the beam hits it. The sign of the focal length must be set with knowledge of the beam direction. The sign of the radius may be defined independently of knowledge of the beam direction, however a beam will be more converging striking from one side, and more diverging from the other.

MIRROR/GLOBAL Mirror with global positioning and aberration. Component

Command Forms(s): **MIRROR/GLOBAL**

```
mirror/global/flat
mirror/global/conic   radius cc order iskip jskip a4 a6 a8 a10 a12 a14
                      a16 a18 a20 [(parameters)/(mod)] [alternate]
mirror/global/zernike radius cc order iskip jskip z4 z6 z8 z10 z12 z14
                      z16 z18 z20 [parameter/(mod)] [alternate]
```

Description: MIRROR/GLOBAL

The GLOBAL modifier uses three-dimensional global coordinates to orient the beams and mirror. The parameter `exact` requires the GLAD feature set. It also computes the change in ray direction and optical path lengths. The mirror may be translated or rotated using the `vertex` commands. The number of beams affected is determined by the `beams` command. GLAD propagates each beam forward along the chief ray until it strikes the surface of the mirror. If the beam has already passed the mirror location then that beam misses the mirror. If there are two intercepts of the surface then the first intercept is selected by default. When the parameter `alternate` is specified then the second intercept is selected.

The radius is positive if the center of curvature is in the positive direction in vertex coordinates. When using the default vertex rotation command `vertex/rotate/relative` with no angles specified, the code will rotate the vertex system so that the z-axis of the component will be aligned with the k-vector of the beam. The parameter, `infoonly`, may be used to set data of the chief ray intercept at the surface for use by the `surface` command.

The `exact` parameter causes GLAD to trace real rays to determine the optical path difference (OPD) errors. If the mirror is expected to cause only astigmatism and defocus, then the `astigmatic` parameter will save execution time. The `exact/polynomials` parameter causes the OPD data to be smoothed by Zernike polynomials to remove low amplitude, but high spatial frequency phase noise introduced by ray tracing.

The equation for conic mirrors, including aspheric coefficients is

$$z = \frac{cr^2}{1 + [1 - c^2 r^2 (1 + \kappa)]^{1/2}} + \sum_{i=4}^{20} a_i r^i , \qquad (170)$$

Modifier 2	Description
`/flat`	Flat mirror.
`/conic`	Conic mirror.
`/zernike`	Same as `/conic` except the aspheric terms are the radial Zernike polynomials. See Table 3.

Parameter	**Description**
astigmatic	2nd order accuracy modeling (Default). Field curvatures are applied to phase bias and/or the field. XY astigmatism is applied to the field.
alternate	Selects alternate surface intersection.
exact	Exact ray trace modeling of aberrations. Effects only the conic mirror.

Parameter Modifier 1	**Description**
exact/polynomials	Use Zernike polynomials to smooth OPD values (default). This procedure eliminates low amplitude, but high spatial frequency phase noise which causes intensity noise upon subsequent propagation. The variable norder specifies the maximum order of polynomial to be used and iskip and jskip enable coarse sampling of the data to reduce calculation time. The parameter exact requires the GLAD feature set.
exact/rays	Use OPD values directly. The parameter exact requires the GLAD feature set.

Parameter Modifier 2	**Description**
exact/polynomials /standard	Use “standard” set of polynomials (see aberration/zernike).
exact/polynomials /fringe	Use “fringe” set of polynomials (see aberration/zernike).
exact/polynomials /radial	Use only radial polynomial terms (see aberration/zernike).

Numerical Values	**Description**	**Defaults**
radius	Radius of conic surface. Radius is positive if convex relative to vertex coordinate system.	1e20
cc	Conic constant.	0.

order	Maximum polynomial order used with exact/polynomials. Choices,
	norder=4 gives 4 2 2
	norder=6 gives 6 4 4
	norder=8 gives 8 6 6
	(see fitzern for description of polynomial representation.	

iskip, jskip	Allows skipping data points in calculating interpolating polynomials with exact/polynomials.	
a4, a6, a8, a10, a12, a14 , a16, a18, a20	4th through 20th order aspheric coefficients.	
z4, z6, z8, z10, z12, z14, z16, z18, z20	4th through 20th order Zernike aspheric coefficients. See Table 3.	

Table. 17. Apply a flat mirror to Beam 7. Rotate the mirror 45 degrees, so an incident horizontal beam exits upward.

`global/define`	(Define global coordinate system.)
`vertex/rotate/set 45`	(Rotate beam about x-axis.)
`vertex/list`	(List vertex coordinates.)
`beams/off`	(Set all beams off. See BEAMS.)
`beams/on 7`	(Set Beam 7 on.)
`mirror/global/flat`	
`vertex/derotate/absolute 45`	(Return to original vertex system.)
`global/list`	(List global coordinates.)

MULT Multiply the beam by a constant or another beam. Operator

Command Forms(s): **MULT**

`mult/scalar`	`ibeams fac [list]`
`mult/complex`	`ibeams r1 i1 r2 i2 [list]`
`mult/phase`	`ibeams fac [list]`
`mult/beam/two`	`kbeam mbeamx [list]`
`mult/beam/onebyone`	`kbeam mbeamx mbeamy [list]`
`mult/beam/jones`	`kbeamc kbeama kbeamb`
`mult/mode/correlation/complex`	`kbeam mbeamx`
`mult/mode/correlation/intensity`	`kbeam mbeamx`
`mult/mode/parallel/(both,x,y)`	`kbeam mbeamx`
`mult/mode/orthogonal/(both,x,y)`	`kbeam mbeamx`
`mult/mode/reflector`	`kbeam xradius yradius index tiltdeg azdeg`

Description: MULT

Multiplies the intensity by a scalar, the phase by a factor, or one beam by another. `Mult/mode` computes mode coupling.

$$\alpha = \frac{\int \psi_2(x,y)^* \psi_1(x,y)\mathrm{d}A}{\sqrt{\int|\psi_2(x,y)|^2\mathrm{d}A\int|\psi_1(x,y)|^2\mathrm{d}A}} \tag{171}$$

$$\psi_{1\|}(x,y) \Rightarrow \alpha\psi_2(x,y)\,. \tag{172}$$

where $\psi_{1\|}$ is the parallel component. The orthogonal distribution $\psi_{1\perp}$ may be calculated from the parallel distribution:

$$\psi_{1\perp}(x,y) \Rightarrow \psi_1(x,y) - \psi_{\|}(x,y)\,. \tag{173}$$

`Mult/mode/./x` and `mult/mode/./y` compute one dimensional coupling functions $\alpha_x(y)$ or $\alpha_y(x)$ as:

$$\alpha_x(y) = \frac{\int \psi_2(x,y)^* \psi_1(x,y)\mathrm{d}x}{\sqrt{\int |\psi_2(x,y)|^2 \mathrm{d}x \int |\psi_1(x,y)|^2 \mathrm{d}x}} \text{ and } \alpha_y(x) = \frac{\int \psi_2(x,y)^* \psi_1(x,y)\mathrm{d}y}{\sqrt{\int |\psi_2(x,y)|^2 \mathrm{d}y \int |\psi_1(x,y)|^2 \mathrm{d}y}}\,. \tag{174}$$

The x- and y-parallel components are calculculated as:

$$\psi_{1\|_x}(x,y) \Rightarrow \alpha_x(y)\,\psi_2(x,y) \qquad \psi_{1\|_y}(x,y) \Rightarrow \alpha_y(x)\,\psi_2(x,y) \tag{175}$$

The corresponding orthogonal distributions are calculated according to Eq. (173).

/mode/reflector

For the the `/mode/reflector` feature. The coupling of the reflected mode into the incident mode is calculated. The calculation only measures the correlation of a hypothetical reflected mode. The surface is not introduced into the beam. If the radius of curvature of the reflecting surface exactly matches the radius of the propagating mode at the surface and there is no tilt of the reflecting surface, the amplitude correlation will be due only to the index of refractions:

$$\alpha = \frac{n_1 - n_2}{n_1 + n_2}\,. \tag{176}$$

The absolute value squared of the amplitude correlation $|\alpha|^2$ will be about 4% for a typical air-glass interface where the glass has index of 1.5. To avoid adverse effects of reflections back into a laser, $|\alpha|^2$ should be significantly less than 1%.

The wavefront error between the incident and reflected modes is

$$W = \frac{2\pi}{\lambda}\frac{1}{2}\left(\frac{1}{R'} - \frac{1}{R}\right)\,. \tag{177}$$

The reflected wavefront radius is found from hypothetical surface curvature R_s the Lens Law:

$$\frac{N'}{R'} - \frac{N}{R} = \frac{N' - N}{R_s}\quad, \tag{178}$$

applied to case of a reflecting surface where $N_2 = -N_1$, and the difference in inverse wavefront radii is:

$$\frac{1}{R'} - \frac{1}{R} = 2\left(\frac{1}{R_s} - \frac{1}{R}\right)\,. \tag{179}$$

where R_s indicates the radius of the hypothetical surface. Adapting Eq. (171), the coupling coefficient is:

$$\alpha = \frac{n_1 - n_2}{n_1 + n_2}\frac{\iint I(x, y)\exp\left\{-j\frac{2\pi}{\lambda}\left[x^2\left(\frac{1}{R_{s_x}} - \frac{1}{R_x}\right) + y^2\left(\frac{1}{R_{s_y}} - \frac{1}{R_y}\right) + \frac{\pi}{180}\mathtt{tiltdeg}y'\right]\right\}\mathrm{d}x\mathrm{d}y}{\iint I(x, y)\mathrm{d}x\mathrm{d}y} \qquad (180)$$

where

$$y' = x\sin(\mathtt{azdeg}) + y\cos(\mathtt{azdeg}) . \qquad (181)$$

If the mode is rotationally symmetric, the azimuthal angle does not matter.

Modifier 1	**Description**
`/scalar`	Multiplies intensity by `fac`.
`/complex`	Multiply by a complex coefficient of the form complex(`fac1`, `fac2`).
`/phase`	Multiply phase by `fac`.
`/beam`	Multiplies complex amplitude of `kbeam` by `mbeam`.
`/mode`	Modal operations: correlation and parallel and orthogonal extraction.

Modifier 2	**Description**
`/correlation`	Calculates the correlation as real-imaginary and amplitude-phase for the complex data for `/complex` and the correlation of the intensity data for `/intensity`.
`/parallel`	Part of `kbeam` which is mode matched to `mbeam`.
`/orthogonal`	Part of `kbeam` which is orthogonal to `mbeamx`.
`/reflector`	Calculates the magnitude of the coupling and the coupling power of the mode reflected from the dielectric surface of specified radius, index, and tilt for array `kbeam`.
`/two`	`Mult/beam` with `mbeamx` multiplying `kbeam`.
`/onebyone`	`Mult/beam` with `kbeam` formed by multiplying an $N \times 1$ beam by a $1 \times M$ beam to create a separable array of dimensions $N \times M$.
`/jones`	Multiplication of form C = A*B. Array A is of form $N \times M \times 4$ where each of the four z-components form a Jones matrix (a_{11}, a_{12}, a_{21}, a_{22}). Arrays C and B are either 2D polarized arrays or 3D arrays of form $N \times M \times 2$. `copy/section` may be used to create the four sections of the $N \times M \times 4$ array—each corresponding to the distribution for the respective element of the Jones matrices.

Modifier 3	**Description**
`correlation/ complex`	Calculates the correlation as real-imaginary and amplitude-phase for the complex data.
`correlation/ intensity`	Calculates the correlation of the intensity data.
`both`	`Mbeamx` is general two-dimensional correlation function in `mbeamx`.
`x`	`Mbeamx` is mode-matched separately in x-direction for each row. See Eqs. (174) and (175) and the description of `mbeamx` (p224).

Modifier 3	Description (Continued)
y	Mbeamx is mode-matched separately in y-direction for each column. See Eqs. (174) and (175) and the description of mbeamx (p224).

Parameter	Description
nolist	Inhibit writing output (default).
list	Write output.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
fac	Intensity multiplication factor for /scalar or phase multiplication for /phase.	0.

r1, i1, r2, i2	Real and imaginary coefficients for s- and p-polarizations (x- and y-directions) for /complex. a_s = (r1,i1)*$a_{s,}$ a_p = (r1,i1)*a_p	r1 = 1., i1 = 0.,
		r2 = 1., i2 = 0.

kbeam	Beam to be multiplied by mbeamx (or created by mult/beam/onebyone).	
mbeamx	Multiplying beam. Must be of form $N \times 1$ for mult/beam/onebyone. For x- and y-correlations, mbeamx should be separable in the form f(x)g(y) where g(y) is constant for third modifier/x and f(x) is constant for third modifier/y. Mbeamx may be constructed with mult/beam/onebyone.	
mbeamy	Second multiplying beam used with mult/beam/onebyone. Must be of form $1 \times M$.	
kbeamc, kbeama, kbeamb	Beams forming the product: C = A*B. Beam C of N x M x 2 is formed by multiplying Array A of N X M x 4 (a11, a12, a21, a22) by Array B of N X M x 2. C and B may not be identical beams.	
xradius	X-radius of surface for /mode/reflector. Distance from the surface to the center of curvature.	1e20
yradius	Y-radius of surface for /mode/reflector. Distance from the surface to the center of curvature.	xradius
index	Index of refraction for /mode/reflector. Reflection coefficient is calculated from current index of kbeam and the specified index of the dielectric reflector.	
tiltdeg	Tilt angle in degrees (if any).	0.
azdeg	Azimuth angle clockwise from top of beam (degrees). Azdeg does not matter if the transverse distribution is circularly symmetric.	0.

Systen Variable Data	Description
abscorr	Correlation magnitude.
angcorr	Correlation angle (degrees).
corra	Complex correlation. May be set to a predefined complex variable.
corrr	Real part of correlation.

Systen Variable Data	Description (Continued)
corri	Imaginary part of correlation.
pcorra	Complex correlation without normalization.
pcorrr	Real part of correlation without normalization.
pcorri	Imaginary part of correlation without normalization.

NBEAM — Resets the number of active beams. — Begin-end

Command Forms(s):

```
nbeam/2d        nbeam nlinx nliny ipol [(parameter)]
nbeam/3d        nbeam nlinx nliny nlinz ipol [(parameter)]
```

Description:

Changes the number of arrays. For an increase of arrays, nbeam adds arrays with the same characteristics as the current highest number array. To add arrays with specific characteristics, specify the relevant paramters.

Modifier 1	Description
/2d	Two dimensional array (default).
/3d	Three dimensional array. Must be of attribute data.

Parameter	Description
beam	Array represents the complex amplitude of an optical beam and may propagated. This state is listed as attrib = 1 in status/p listing.
data	Array represents non-beam data and can not be propagated by either prop or dist. This state is listed as attrib = 2 in status /p listing.
radial	Radial beam for axicon commands. (attrib = 3).
annular	Annular beam with normal intensity. (attrib = 4).
annular2	Annular beam with area weighted intensity. (attrib = 5).
circular	One-dimensional array representing rotationally symmetrical beam. (attrib = 7).

Numerical Values	Description	Defaults
nbeam	Number of beams. GLAD will increase or decrease number of beams, as necessary.	
nlinx	Array dimension in x-direction.	Nlinx(nbeam-1)
nliny	Array dimension in y-direction.	Nliny(nbeam-1)
nlinz	Array dimensions in z-direction (must be attribute data).	Nlinz(nbeam-1)
ipol	Determines polarization state, 0 for one polarization state 1 for two polarization states.	Ipol(nbeam-1)

NOISE Sets properties of dynamic memory allocation. Component

Command Forms(s): **NOISE**

```
noise/deltacorrelated   kbeam coef seed
noise/smoothed/gaussian kbeam coef xomega yomega seed
noise/smoothed/rect     kbeam coef xwidth ywidth seed
noise/smoothed/sinc     kbeam coef xwidth ywidth seed
```

Description: NOISE

The `/deltacorrelated` command adds random uncorrelated amplitude noise to the existing distribution. Note that `/deltacorrelated` is adds to the existing distribution while `/smoothed` replaces the existing distribution. Use `/add/coh/con` to add noise from this array to some other array.

`/smoothed` initializes the array with smoothed noise. The smoothing is implemented in the Fourier domain by applying a filter function to uniform white noise. For example `/gaussian` is implemented by the transfer function

$$A(\xi, \eta) = A(\xi, \eta)e^{-\pi^2\omega_x^2\xi^2 - \pi^2\omega_y^2\eta^2} \tag{182}$$

where ω_x and ω_y correspond to `xomega` and `yomega` and $A(\xi, \eta)$ is the Fourier transform of the complex amplitude distribution. For gaussian smoothing the autocorrelation sizes are $\sqrt{2}\omega_x$ and $\sqrt{2}\omega_y$. For `/rect` the smoothing is done with a sinc function of the form:

$$A(\xi, \eta) = A(\xi, \eta)\frac{\sin(\pi\xi L_x)}{\pi\xi L_x}\frac{\sin(\pi\eta L_y)}{\pi\eta L_y} \tag{183}$$

where L_x and L_y are the widths of the rect function. Either operation results in smoothing of the distribution.

You may check that the distribution has the proper form. Consider a square function of half-width of 100 as shown below. Note that the autocorrelation function is a triangle of half-width = 200 as expected.

```
mem/set/b 8
array/s 1 1024
noise/smooth/rect 1 1 100          # set smoothing to half-width = 100
autocorrelation 1                  # form autocorrelation function
plot/x/real 1 le=-200 ri=200       # check that for a triangle shape.
```

Modifier 1	**Description**
`/deltacorrelated`	Unsmoothed noise is added to the beam (default). Adds to existing distribution.
`/smoothed`	The beam is set to smoothed noise (replaces initial distribution). Replaces existing distribution.

Modifier 2	**Description**
`/gaussian`	Gaussian smoothing (default).
`/rect`	Smoothing by a rectangle function in the pupil.

Modifier 2	Description (Continued)
/sinc	Smoothing by a sinc function in the pupil.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
coef	Average noise intensity.	
xomega, yomega	$1/e^2$ radii of gaussian smoothing function for /smoothed.	
xwidth, ywidth	For /sinc the half-width to the first zero. For /rect the half-width of the smoothing rectangle.	
seed	Positive integer which sets seed for random number generator.	

NOOP Do-nothing command. Language

Command Forms(s): **NOOP**

```
noop
```

Description: NOOP

Command that does nothing.Useful to terminate data input, e.g., with aberration/zernike/number.

NORMALIZE Normalizes non-zero values in beam. Operator

Command Forms(s): **NORMALIZE**

```
normalize/one    kbeam threshold
normalize/two    kbeam1 kbeam2
```

Description: NORMALIZE

Normalizes the intensity to unity on a point-by-point basis for all non-zero points in the array. /two normalizes kbeam1 using the irradiance of kbeam2. The phase of the beam is preserved.

Modifier 1	Description
/one	Normalize single beam.
/two	Normalize kbeam1 by irradiance of kbeam2.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
kbeam1, kbeam2	Receiving and normalizing beam numbers.	1, 2
threshold	Intensity values above threshold are normalized. Values below threshold are set to zero.	0.

OBS Implement obscuration. Component

Command Forms(s): **OBS**

```
obs/cir         ibeams rad xdec ydec azdeg [(parameter)]
obs/sqr         ibeams rad xdec ydec azdeg [(parameter)]
obs/pentagon    ibeams rad xdec ydec azdeg [(parameter)]
obs/ell         ibeams xrad yrad xdec ydec azdeg [(parameter)]
obs/hex         ibeams xrad yrad xdec ydec azdeg [(parameter)]
obs/rec         ibeams xrad yrad xdec ydec azdeg [(parameter)]
obs/gen/screen  ibeams xdec ydec xscale yscale theta azdeg [(parameter)]
obs/gen/disk    (Filename)ibeams xdec ydec xscale yscale theta [(parameter)]
```

Description: OBS

Places an obscuration in the beam(s). The general obscuration /gen is defined by specifying a series of points that generate a polygon. The command parameters can be used to offset, rescale, and rotate the polygon to fit the required size and position of the current beam. The x-coordinate of point is xo(i) = Xdec + X(i) * Xscale. If a rotation angle is specified, the rotation is counterclockwise about the centroid of the data points.

The general obscuration data has the format

```
npts
x(1),y(1)
.
.
.
x(npts),y(npts)
```

where: npts = number of data points.

Modifier 1	Description
/cir	Circle.
/sqr	Square.
/hex	Hexagon.
/pentagon	Pentagon.
/ell	Ellipse.
/rec	Rectangle.
/gen	General.

Character String	Description
(Filename)	Local file containing data to define obscuration.

Parameter	Description
beam_obs	Enables viewing obscuration with orthographic plot (default).

Parameter	Description (Continued)
vertex	Aperture is defined in vertex coordinates. Beam is propagated to the vertex before applying aperture (if beam attribute allows propagation: attribute beam or axicon). The projeced size of the aperture on the beam transverse plane is applied to the beam. Note that vertex rotations obey the right hand rule, but that azdeg is measured clockwise as defined above.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam
rad	Radius of aperture. Half-width for square, rectangular, or hexagonal. Center to corner distance for pentagonal.	
xrad, yrad	Radius or half-width x, y (cm). Half-width for square or rectangular.	
xdec, ydec	Decentering parameters.	Beam center.
xscale	Scale in x-direction.	1.
yscale	Scale in y-direction.	1.
theta	Rotation angle (deg).	
azdeg	Azimuthal rotation of aperture. Implemented by an internal call to rotate and involves an interpolation step. The rotation angle is measured clockwise from vertical. The rotation is performed after any decenters.	0.

OPO Optical parametric oscillator. Laser gain

Command Forms(s): **OPO**

```
opo/constant     zstep kappa nstep chi2 [pattern][list]
opo/variable     zstep nstep [pattern]
```

Description: OPO

This command implements an optical parametric oscillator. The command models nonlinear interaction between three beams: pump, signal, and idler as described in Chap. 9, GLAD Theory Manual (theory.pdf).

See Example Ex95 for examples of the use of this command. All three beams must have plane reference surfaces for correct calculation and should be used with the pack/set, pack/in, and pack/out commands to insure the array points overlay precisely. A series of relatively small steps should be taken through the nonlinear crystal to insure the combination effects of OPO amplification and diffraction are incorporated into split steps. The step length should be a fraction of the Talbot length associated with the highest spatial frequency to be modeled. See the GLAD Theory Manual for a discussion of this issue.

One may define the gain either by the phenomenological gain coefficient κ or the second order nonlinear electric susceptibility with chi2. See ex95cy.inp for a comparison of hand calculations with GLAD numerical results for the small signal case.

Modifier 1	Description
/constant	Kappa is a constant for all transverse points (default).

Modifier 1	Description (Continued)
`/variable`	Kappa is a function of x and y. The kappa distribution is defined by packing a fourth beam with `pack/set`. Kappa is in the real word of the fourth beam.

String	Description
pattern	The pattern consists of three letters. The letters may be "`x`" and "`y`" to indicated x-polarization or y-polarization, or "`o`" or "`e`" to indicate o- or e-ray polarization. The three letters are used in order for the pump, signal, and idler beams respectively. Taking into account the azimuthal orientation of the crystal, GLAD will translate "`x`" and "`y`" into the appropriate o- and e-ray polarizations or "`o`" or "`e`" into the x- and y-polarizations. For example "`xyx`" and zero azumuthal angle indicates ordinary ray (x-polarization) for pump, extraordinary ray (y-polarization for signal), and ordinary ray x-polarization for idler beams.

Parameter	Description
list	List internal parameters for overall values and the center point.

Numerical Values	Description	Defaults
`zstep`	Step length.	0.
`kappa`	κ, gain coefficient for OPO in units of [$w^{-1/2}$]	
`nstep`	Number of steps to take over z_{crit_p}. The actual step length is the lessor of `zstep` and $\dfrac{z_{\mathrm{crit}_p}}{\mathtt{nstep}}$.	
`chi2`	χ^2. Alternative to the use of kappa.	

OPTIMIZE Damped least squares optimization. Language

Command Forms(s): **OPTIMIZE**

```
optimize/run/(noinfo or info)
optimize/check
optimize/constraints/add          variable constraint (inequality type)
optimize/constraints/clear
optimize/constraints/list
optimize/damp/mul                 damp
optimize/damp/max                 maximum
optimize/damp/rate                rate
optimize/damp/list
optimize/jacobian
optimize/name                     (Name of macro)
optimize/pause
optimize/reject/on
optimize/reject/off
optimize/targets/add/scalar       variable target weight
```

Command Forms(s): **OPTIMIZE (Continued)**

`optimize/targets/add/intensity_array`	`value target weight k0 k1 k2 k3 k4 k5`
`optimize/targets/add/complex_array`	`value target weight k0 k1 k2 k3 k4 k5`
`optimize/targets/clear`	
`optimize/targets/list`	
`optimize/variables/add`	`variable increment maxstep`
`optimize/variables/clear`	
`optimize/variables/list`	
`optimize/variables/old`	
`optimize/reset/all`	
`optimize/reset/merit`	

Description: OPTIMIZE

`Optimize` provides damped least squares optimization of defined variables to achieve target values. The GLAD feature set is required. Optimization uses a `macro` command to implement the system model to be modified and uses the variables to specify variables which may be used as controlling parameters and targets which are goals. The macro must be written to describe the complete system model and to properly implement the variables and targets. The registers can modify any system value. The target values must be selected from the system measures under the `variables/set/parameter` command.

`/add` puts the register indicated by its number into the table. `/clear` removes all entries from the designated table. `/list` lists the table of registers and current values. A maximum of 30 variables and 30 targets are allowed, except that only 5 variables are allowed when target arrays are used. Targets may be scalar variables or the numbers of arrays containing values to be optimized.

The command `/run` performs the following functions

- computes the baseline performance using the current variable values.
- calculates the matrix of partial derivatives (Jacobian)
- computes the solution vector using damping set by the user or calculated by the program.

GLAD does not implement the change table during `/run`. The new variable values will take effect on the next execution of `/run` or when the system macro is called. If there is doubt about the acceptability of the new solution vector, the system macro may be called and the merit function evaluated by `/target`. `/run` is the only operation that takes significant time. `/run` may be called multiple times by specifying the Times variable. The solution vector is automatically implemented on the new run.

Use of the optimization commands is illustrated in example Exs. 60 and 61.

Modifier 1	**Description**
`/run`	Optimization cycle and compute variable changes.
`/check`	Check macro to be sure target values are the same in two successive passes.
`/constraint`	Sets up constraint table. Constraints are controlled by Lagrange multipliers.
`/damp`	Set damping factor.
`/jacobian`	Calculate Jacobian matrix of partial derivatives and display results but take no action.

Modifier 1	**Description (Continued)**
`/reject`	Determine whether solution is accepted or rejected if the damping must be increased or a constraint is violated.
`/name`	Define name of macro describing system to be optimized.
`/pause`	Pauses at key points in the display of optimization output for convenient study.
`/targets`	Define table of target registers, target values, and weights.
`/variables`	Define table of variables to be used as controlling parameters with incremental values to be used in calculating the partial derivatives.
`/reset`	Resets all optimization values to program startup condition, except maximum damping and rejection switch.
`info` or `noinfo`	Display extra information or not.

Modifier 2	**Description**
`/add`	Add.
`/clear`	Clear all entries from the variables, targets, or constraints table. The table may then be rebuilt.
`/damp/list`	List information.
`/damp/mul`	Select multiplicative damping, $\Delta x \bullet \mathtt{damp}$.
`/damp/max`	Set maximum damping value, may be overridden by `/damp/mul`.
`/damp/rate`	Sets rate of damping increase.
`/reject/off`	Do not reject solutions if damping has to be increased or if a constraint is violated.
`/reject/on`	Reject solutions if damping has to be increased or if a constraint is violated (default).
`/reset/all`	Reset target, variable, and constraint tables; saved merit function; and damping.
`/reset/merit`	Resets merit function value only.
`/variables/old`	Resets variables to variable values before last optimization cycle.

Modifier 3	**Description**
`add/scalar`	Variable and target are scalar values (default).
`add/intensity_array`	Variable and target are the beam numbers of arrays. The intensity will be calculated from the complex amplitude for each point. Only one target may be an array and then only five optimization variables are allowed.
`add/complex_array`	Variable and target are the beam numbers of arrays. The real and imaginary values of each point constitute targets. Only one target may be an array and then only five optimization variables are allowed.

Parameter	**Description**
(Name of macro)	Name of the macro representing the system to be optimized. The named macro should contain the necessary connection of variables and performance targets to the variables used in the optimization variable and target tables.
(Inequality Type)	Defines inequality type for `/constraint`. Choices are: `equal`, `greater`, `less`.

Numerical Values	Description	Defaults
`variable`	Name of variable to be used in optimization function. For array targets use the array number.	
`value`	Array number of an array of values to be optimized to match the target array.	
`constraint`	Value of constraint for `/constraint`.	
`damp`	Damping factor, multiplicative damping.	`1`
`increment`	Derivative Increment.	0.0001
`maximum`	Maximum damping factor.	25
`rate`	Rate of increase of damping factor. Damping is multiplied by this factor each time the merit function is higher than previous cycle.	2.
`maxstep`	Maximum step size.	0, (not used)
`register`	Variable name from `variables` command or register number.	
`target`	Target variable for `/scalar` or array number for one of the array to be optimized.	0.0
`weight`	Weight to be applied to target.	1.
`k0`,`k1`, `k2`, `k3`, `k4`, `k5`	Work arrays are needed for each target array. The first contains a copy of the starting state of the target array.	

System Variable Data	Description
`magchgvec`	Magnitude of change vector for optimization.
`merit`	Current value of merit function for optimization.
`optdone`	1 if optimization done, 0 if not.

OTF Optical transfer function. Diagnostics

Command Forms(s): **OTF**

```
otf/pupil/cm        kbeam focallength
otf/pupil/mm        kbeam focallength
otf/image/cm        kbeam
otf/image/mm        kbeam
```

Description: OTF

Forms the optical transfer function (OTF) of the distribution in the array. The OTF doubles the width of the distribution in the array. The user should be sure that there is adequate guardband around the nonzero parts of the starting distribution. The `/pupil` modifier finds the OTF starting from a pupil distribution. The user may enter the focal length to be used for scaling the frequency. The `/image` modifier calculates the OTF assuming the starting distribution is already an image. The units in the returned array are scaled to be the correct frequency intervals for cycles per centimeters (traditionally OTF is expressed in cycles per millimeter). The frequency conversions are

`/pupil`

$$\Delta f_x = \frac{\lambda}{2\Delta x F} \qquad \Delta f_y = \frac{\lambda}{2\Delta y F}, \tag{184}$$

/image

$$\Delta f_x = \frac{1}{2\Delta x N_x} \qquad \Delta f_y = \frac{1}{2\Delta y N_y}, \tag{185}$$

where F is the focal length, λ is the wavelength, Δx and Δy are the units of the starting distribution, and N_x and N_y are the number of array points in the two directions.

Modifier 1	**Description**
/pupil	Starting distribution represents a pupil function, user may specify a focal length for proper frequency scaling.
/image	Starting distribution represents an image function, no focal length value is needed.

Modifier 2	**Description**
/cm	Express in cm.
/image	Express in mm.

Numerical Values	**Description**	**Defaults**
kbeam	Single beam number.	1
focallength	Focal length used with /pupil for proper frequency scaling.	1.

OUTFILE Writes beam data to file. Input-output

Command Forms(s): **OUTFILE**

```
outfile/beam/(modifier 2)            (Filename)/(header)/(format)  kbeam
outfile/intensity/(modifier 2)       (Filename)/(header)/(format)  kbeam
outfile/intphase/(modifier 2)        (Filename)/(header)/(format)  kbeam
outfile/intwave/(modifier 2)         (Filename)/(header)/(format)  kbeam
outfile/phase/(modifier 2)           (Filename)/(header)/(format)  kbeam
outfile/wavefront/(modifier 2)       (Filename)/(header)/(format)  kbeam
outfile/real/(modifier 2)            (Filename)/(header)/(format)  kbeam
outfile/aimaginary/(modifier 2)      (Filename)/(header)/(format)  kbeam
```

Description: OUTFILE

Write an array of data into a disk file in specified format for use by other computer codes or later retrieval.

Modifier 1	**Description**
/beam	Beam amplitude in real-imaginary complex form.
/intensity	Beam intensity as a real number (except for byte format).

Modifier 1	Description (Continued)
/intphase	Beam intensity and phase (radians) in intensity-phase complex form.
/intwave	Beam intensity and wavefront (wavelengths) in intensity-wave complex form, waves = - phase/2/π.
/phase	Beam phase as real numbers.
/wavefront	Beam wavefront as real numbers. waves = - phase/2/π.
/real	Real part of complex amplitude.
/aimaginary	Imaginary part of complex amplitude.

Modifier 2	Description
/sqr	Axially symmetric or square geometric data.
/rec	Asymmetric or rectangular geometric data.

Character String	Description
(Filename)/(Modifier 1)/(Modifier 2)	Name of data file to input. Enclose name in single quotes to allow special characters. The filename is preceded by a path name if one has been defined with set/path.

Filename Modifier 1	Description
/header	Geometric data is on data file. Geometric data is all data after kbeam.
/noheader	Existing data is used or taken from command line.

FileName Modifier 2	Description
/list	Data is read in list directed format (default) read (Filename,*) list
/comma or /excel	Comma delimited format with N elements on a row and M rows to make an N x M array. Inputs real-imaginary data pairs for “beam” input. Same as Excel *.csv format. May be written by /comma or /excel formats with outfile.
/80	Data is written in 80 column format (1x,4E18.10).
/blankdelimited	Similar to comma delimited except commas are replaced with blanks.
/binary	Data is read as binary file.
/byte	Data is read as an integer map of intensity values. 256 gray levels. /noheader and /intens must be selected.

Numerical Values	Description	Defaults
kbeam	Single beam number.	Required

Header values	Description	Defaults
nline	Dimension of the square array.	nlinx(kbeam)
nlinx	X-dimension of the rectangular array.	nlinx(kbeam)
nliny	Y-dimension of the rectangular array.	nlinx
units	Units.	units(kbeam)
unitx	X-units.	unitsx(kbeam)
unity	Y-units.	unitx
color	Wavelength in microns.	color(kbeam)

Header values	Description (Continued)	Defaults
radref	Radius of the spherical phase bias.	1e20
radrefx	X-radius of the toric phase bias.	1e20
radrefy	Y-radius of the toric phase bias.	radrefx
ipolz	0 for one polarization state. 1 for two polarization states.	0
a(i,j)	Complex array.	
attrib	Array attribute see array command.	1 (beam)
zreffrad	Used for axicon modes.	0.
index	Index of refraction	1.
indexe	Extraordinary index of refraction for birefringent material.	

Record 1

If Modifier 2 is /sqr

```
write ngeo (ngeo = 9)
write nline units color radref ipolz attrib zreffrad index indexe
```

If Modifier 2 is /rec

```
write ngeo (ngeo = 12)
write nlinx nliny unitx unity color radrefx radrefy ipolz attrib zreffrad index indexe
```

Computer Array Records

(If ipolz=1, then GLAD writes the second polarization state after the first state is written.)

If Modifier 1 is /beam

```
do j = 1, nlinys
 write (a(i,j),i=1,nlinxs)
```

If Modifier 1 is /intens

The intensity values are in the real part of the array.

```
do j = 1, nlinys
 write (real(a(i,j)),i=1,nlinxs)
```

If Modifier 1 is /intphas

The intensity and phase values are in the real and imaginary parts of the array.

```
do j = 1, nlinys
 write (a(i,j),i=1,nlinxs)
```

See examples of fortran and C programs in infile which create /nohead/unform files.

PACK Packs data for some nonlinear optic command. Propagation

Command Forms(s): **PACK**

```
pack/set        k1beam k2beam . . . k10beam
pack/list
pack/in         xrad yrad xnline ynline xdec ydec
pack/out
pack/close
```

Command Forms(s): **PACK (Continued)**

```
pack/reference   kbeam
```

Description: PACK

The pack commands are used to enable interpolation of beam arrays to a common grid. This command is required prior to using the commands raman, wave4, gain/rate /step, and snoise. The common grid size is chosen to be the same as first beam in the list of the pack/set command. See Examples Ex17 , Ex18 , Ex19 and Ex20 .

Modifier 1	Description
/set	Defines beams to be packed (maximum of 10 beams) and opens scratch arrays for packing.
/list	Lists beams which are to be packed.
/in	Invokes packing. Array parameters may be reset by numeric entries. Default condition is that the universal grid is identical to the k1beam.
/out	Unpacks arrays.
/close	Closes scratch arrays. Needed only to release system resources.
/reference	Number of beam to be used for reference units. Other beams will be interpolated to these units.

Numerical Values	Description	Defaults
k1beam...k2beam	Numbers of beams to be packed.	
kbeam	Number of beam to be used as reference for units.	k1beam or kbeam
xrad	Half width of field in X-direction.	k1beam or kbeam
yrad	Half width of field in Y-direction.	k1beam or kbeam
xnline	Number of grid points in X-direction.	k1beam or kbeam
ynline	Number of grid points in Y-direction.	k1beam or kbeam
xdec, ydec	Coordinates of grid center.	k1beam or kbeam

The following example illustrates propagation with diffraction steps of 8 cm and kinetics steps of 2 cm.

```
pack/set 1 2 #Define packing for Beams 1 and 2.
pack/in
rraman/step 1 2 2. .0001 #Raman steps.
rraman/step 1 2 2. .0001
rraman/step 1 2 2. .0001
rraman/step 1 2 2. .0001
pack/out #Diffraction step.
prop 8
pack/in
rraman/step 1 2 2. .0001 #Raman steps.
rraman/step 1 2 2. .0001
rraman/step 1 2 2. .0001
rraman/step 1 2 2. .0001
pack/out
prop 8. #Diffraction step.
```

PARABOLA Makes parabolic intensity distribution. Begin-end

Command Forms(s): **PARABOLA**

```
parabola/intensity    ibeams center sag rnorm xdec ydec
parabola/real         ibeams center sag rnorm xdec ydec
```

Description: PARABOLA

Makes a rotationally symmetric parabolic intensity distribution defined by the peak value and the sag from the center, as defined at radius `rnorm`. Redefines the array at all points. Values of the parabolic distribution which would be negative are set to zero.

Modifier 1	Description
`/intensity`	Prescribe intensity distribution.
`/norm`	Prescribe real distribution.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`center`	Value of center of the distribution.	
`sag`	Fall-off from center value at radius = `rnorm`.	
`rnorm`	Radius at which sag is defined.	
`xdec`, `ydec`	Decenter of distribution.	0., 0.

PAUSE Pauses until user hits [ENTER]. Language

Command Forms(s): **PAUSE**

```
pause/time      ipause
pause/label     (label)
```

Description: PAUSE

`Pause`, with no number, causes the code to print “pause?” to the terminal and halts execution until any character is entered from the terminal. If a value for `ipause` is entered, the code waits that number of seconds and then continues without user intervention. `Pause/label` allows a label to be used. Also see printable comments “C” and “CC” `c`.

Modifier 1	Description
`/time`	Pause specified seconds as a decimal number.
`/label`	Allows the user to add an identifying label for the pause. Variables may be included by preceeding them by the “@” symbol.

Numerical Values	Description	Defaults
`ipause`	Decimal time to pause. 0 pauses until `[enter]`	0

PEAK Sets and displays peak irradiance. Operator

Command Forms(s): **PEAK**

```
peak/list           ibeams
peak/norm/both      ibeams pnorm
peak/norm/rows      ibeams pnorm
peak/norm/columns   ibeams pnorm
```

Description: PEAK

Finds the peak intensity of the beam(s) specified by `ibeams`. The array indices and ray coordinates of the peak and the peak intensity are printed. If `/norm` is used, the peak value is reset to `pnorm` (default value is `pnorm` = 1). See Ex46 for an example of the use of this command. See also `valley` .

Modifier 1	Description
`/list`	List current keywords.
`/norm`	Normalize all values to peak and multiply by `pnorm`.

Modifier 2	Description
`/both`	Normalize using both rows and columns (default).
`/rows`	Normalize each row individually to `pnorm`.
`/columns`	Normalize each column individually to `pnorm`.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`pnorm`	Normalizing value.	`1.`

System Variable Data	Description
`peak/intensity`	Peak intensity.
`peak/xcen`	X-center of peak.
`peak/ycen`	Y-center of peak.
`peak/icen`	Pixel coordinate of center, x-direction.
`peak/jcen`	Pixel coordinate of center, y-direction.

PHASE Piston and random phase aberration. Aberration

Command Forms(s): **PHASE**

```
phase/kolmogorov          kbeam rad0 iseed outer inner
phase/piston              ibeams phsdeg
phase/piston/random       ibeams iseed
phase/random/sqr          kbeam werr arad iseed
phase/random/rec          kbeam werr xarad yarad iseed
phase/random/sep          kbeam xwerr ywerr xarad yarad iseed
phase/screen              kbeam werr arad iseed
```

Description: PHASE

Adds a phasefront to the beam array. The phasefront may be a piston error, a gaussian smoothed random wavefront, or Kolmogorov atmospheric aberration.

Modifier 1	Description
phase/piston	Constant phase front.
phase/random	Random phase front smoothed to specified autocorrelation widths.
phase/kolmogorov	Atmospheric aberration. The GLAD feature set is required.
phase/screen	Adds smoothed random phase (quick).

Modifier 2	Description
random/sqr	Autocorrelation is the same for x- and y-directions.
random/rec	Autocorrelation may be different for x- and y-directions.
random/sep	Aberration magnitude and autocorrelation may be different for x- and y-directions.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
rad0	Seeing parameter. Radius of autocorrelation function.	
iseed	Integer value to set random number generator.	
outer	Outer limit of Lutomirski correction to Kolmogorov model.	
inner	Inner limit of Lutomirski correction to Kolmogorov model.	
phasdeg	Piston error in degrees of phase.	
werr	RMS value of random error in waves.	
arad	Autocorrelation radius.	
xarad	X-half width of autocorrelation function.	
yarad	Y-half width of autocorrelation function.	

PHASE/KOLMOGOROV Atmospheric aberration, Kolmogorov model. Aberration

Command Forms(s): **PHASE/KOLMOGOROV**

```
phase/kolmogorov  kbeam rad0 iseed outer inner
```

Description: PHASE/KOLMOGOROV

Adds atmospheric aberration according to the Kolmogorov model, as modified by Von Karman to elliminate the singularity. The GLAD feature set is required. The atmospheric model assumes the power spectrum of the wavefront is

$$W^2(\rho) = \frac{0.023e^{-\rho^2 L_i^2}}{r_0^{5/3}\left(\rho^2 + \frac{1}{L_o^2}\right)^{11/6}}, \tag{186}$$

where W^2 is the power spectrum of the wavefront, r_0 is the seeing parameter, ρ is the spatial frequency, L_o is the outer scale, and L_i is the inner scale. These parameters are in radians, meters, and inverse meters respectively.

Reference

1. R.F. Lutomirski and H.T. Yura, Aperture Averaging Factor for a Fluctuating Light Signal,J. Opt. Soc. Am., Vol. 59, No. 9, pp1247-1248 (1969).

Numerical Values	Description	Defaults
`kbeam`	Single beam index number.	
`rad0`	Autocorrelation diameter of atmosphere–Fried's parameter–in cm.	
`outer`	Outer scale size of atmosphere.	1000 cm
`inner`	Inner scale size of atmosphere.	0.1 cm

PHASE/PISTON Adds piston aberration. Aberration

Command Forms(s): **PHASE/PISTON**

```
phase/piston          ibeams phsdeg
phase/piston/random   ibeams iseed
```

Description: PHASE/PISTON

Adds a constant phase (piston error) to the entire beam distribution. The phase may be a user specified constant or may be chosen randomly. For random selection, `iseed` sets the seed for the random number generator. If `iseed` is nonzero, it is used to select the seed. If `iseed` is zero, the seed will be generated randomly. One may generate a random series of piston values at different stations in a beam train by calling the command with `iseed` selected by the user for the first call and left zero for all subsequent calls.

Modifier 2	Description
`/random`	Random phase front smoothed to specified autocorrelation widths.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`phsdeg`	Phase angle (deg).	
`iseed`	Seed for random number generator.	

PHASE/RANDOM Adds smoothed random phase. Aberration

Command Forms(s): **PHASE/RANDOM**

```
phase/random/sqr/(modifier 3)   kbeam werr arad iseed
phase/random/rec/(modifier 3)   kbeam werr xarad yarad iseed
phase/random/sep/(modifier 3)   kbeam xwerr ywerr xarad yarad iseed
```

Description: PHASE/RANDOM

Adds a smoothed random wavefront aberration to the beam using gaussian frequency weighting (`/gaussian`) or truncated frequency spectrum (`/clap`). Also, see `phase/screen`

Modifier 2	Description
`/sqr`	Random phase front with same autocorrelation width in X- and Y-directions.
`/rec`	Random phase front with different autocorrelation width in X- and Y-directions.
`/sep`	Aberration is added with different wavefront variances in the two directions as well as different autocorrelation widths in the X- and Y- direction.

Modifier 3	Description
`/gaussian`	Gaussian shapped power spectrum.
`/clap`	Flat-top shapped power spectrum.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`werr`	Wavefront error (waves). RMS when `werr` > 0. Peak-to-valley when `werr` < 0.	
`xwerr`, `ywerr`	For `/sep`, separable wavefront error (waves). RMS when `werr` > 0. Peak-to-valley when `xwerr` < 0.	
`arad`	Autocorrelation radius (cm).	
`xarad`	Autocorrelation radii in X-directions (cm).	
`yarad`	Autocorrelation radii in Y-directions (cm).	xarad
`iseed`	Seed for random number generator (`iseed` = 0 does not reset seed).	

PHASE/SCREEN Adds smoothed random phase (quick). Aberration

Command Forms(s): **PHASE/SCREEN**

```
phase/screen/gaussian       kbeam werr arad iseed
phase/screen/clap           kbeam werr arad iseed
```

Description: PHASE/SCREEN

Creates a phase screen of unit irradiance with phase consisting of a smoothed random wavefront aberration using gaussian frequency weighting (`/gaussian`) or a truncated frequency spectrum (`/clap`). `phase/random` is somewhat more general in that it can add the aberration to an existing beam and can compute the wavefront statistics exactly over the non-zero aperture. `Phase/screen` can only create a phase screen but is considerably faster. Use mult `/beam` to apply the phase screen.

Modifier 2	Description
`/gaussian`	Gaussian shaped power spectrum.
`/clap`	Flat-top shaped power spectrum.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`werr`	Wavefront error (waves). RMS when `werr` > 0. Peak-to-valley when `werr` < 0.	
`arad`	Autocorrelation radius (cm).	
`iseed`	Seed for random number generator (`iseed` = 0 does not reset seed).	

PHASE2INT Converts phase distribution to intensity distribution. Operator

Command Forms(s): **PHASE2INT**

```
phase2int/one      kbeam
phase2int/two      kbeam1  kbeam2
phase2real/one     kbeam
phase2real/two     kbeam1  kbeam2
```

Description: PHASE2INT

Converts phase to an intensity or real distribution. Also see `waves2int` and `waves2real`. Waves in wavelengths is –phase/2/π (radians).

Modifier 2	Description
`/one`	Transform phase into intensity.
`/two`	Make intensity of `kbeam2` equal to phase of `kbeam1`

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`kbeam1`	Input beam for `/two`.	1
`kbeam2`	Output beam for `/two`.	2

PIB Power-in-the-bucket calculation. Diagnostics

Command Forms(s): **PIB**

```
pib/cir        kbeam xrad nbrads refinc [(parameter)]
pib/sqr        kbeam xrad nbrads refinc [(parameter)]
pib/ell        kbeam xrad yrad nbrads refinc [(parameter)]
pib/rec        kbeam xrad yrad nbrads refinc [(parameter)]
```

Command Forms(s): PIB (Continued)

```
pib/level           kbeam level
```

Description: PIB

Obsolete command see `encircled`. Generates a table of power-in-the-bucket data. A maximum of 50 points may be generated in the table. With the parameter, “`udata`”, the table may be displayed with the `plot/udata`. Related commands `fitfwhm`, `fitegauss`, `fitgeo`, `fitknife`, and `fitlevel`.

Modifier 1	Description
/cir	Circular bucket.
/sqr	Square bucket.
/ell	Elliptical bucket.
/rec	Rectangular bucket.
/level	Relative energy passed by aperture diameter whose size is to be calculated.

Modifier 2	Description
/middle	Centers the bucket at the middle of the field array.
/peak	Centers the bucket at the peak intensity point.
/centroid	Centers the bucket at the centroid of the intensity.

Parameter	Description
register	Stores the power-in-the-bucket for the reference radius in the variable defined by parameter modifier. Example of parameter and modifier: `register/tempvalue`
udata_pib	Stores entire table in user data array radius in x.

Parameter Modifier	Description
nstore	Variable or real register number.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
(x,y)rad	Reference radius (cm) in X and/or Y direction.	required
nbrads	Number of reference radii, 0 gives the single value for the reference radius. Parameter register has a default of `nbrads` = 0.	1
refinc	Increment of data as a function of reference radius.	25
level	Relative energy level for which clear aperture is to be set.	0.865

System Variable Data	Description
fitxcent, fitycent	X or y beam center.
fitencir	Radius of aperture encircling specified relative energy from `/level`.
fitxomega, fityomega	X- or y-radii of equivalent gaussian beam.
fitxrad, fityrad	X- or y-transverse radius of equivalent gaussian beam.
fitxsig, fitysig	X- or y-standard deviation of equivalent gaussian beam.

Example 1

Generate a pib plot out to 3 beam radii with 10 points per beam radius.

```
pib kbeam=1 nbrads=3 refinc=.1 udata
/xlabel radius (cm)
udata/ylabel power (w/cm**2)
title power-in-the-bucket
plot/udata
```

Example 2

```
pib/cir/middle kbeam=1 nbrads=6 refinc=.1 udata
plot/udata
```

PLOT Various graphics. Diagnostics

Command Forms(s): **PLOT**

`plot/watch`	Directs plot to disk, closes file after each plot to expedite plotting to windows, added to watch.dat for display by Watch (See `plot/disk`).
`plot/watch/print`	Printing takes place when the next file is made.
`plot/watch/relative`	Causes the plot offsets to be interpreted relative to the lower left corner of Watch.exe.
`plot/disk`	Directs plot to disk, not added to watch.dat for display by Watch. (See `plot/watch`).
`plot/bitmap`	Bitmap.
`plot/contour`	Contour plot.
`plot/elliptical`	Elliptical polarization plot.
`plot/histogram`	Histogram display.
`plot/isometric`	Isometric plots, cross hatched.
`plot/liso`	Fast isometric plot with slices in one direction,
`plot/orthographic`	Variable size diagonal elements.
`plot/plot log`	Controls file watch.dat for Watch program.
`plot/skip`	Advance plot number.
`plot/title`	Plots the title,
`plot/udata`	Plot of data from `udata` command,
`plot/vector`	Vector form of polarization display.
`plot/xslice`	Slice in x-direction
`plot/zigzag`	Displays configuration of zigzag amplifier.
`plot/print`	Causes an existing plot file to be printed by Watch.exe to the default printer.
`plot/metafile/emf`	Create MS Windows metafile, extension *.EMF.
`plot/metafile/wmf`	Create MS Windows metafile, extension *.WMF.
`plot/metafile/cgm`	Create CGM file, extension *.CGM.
`plot/metafile/ps`	Create PostScript file, extension *.PS. May be converted to PDF files with Adobe Acrobat Distiller (or similar application).

Command Forms(s): **PLOT (Continued)**

`plot/info`	Gives summary of plot state.
`plot/on`	Restores plot activities after `plot/off`.
`plot/of`	Turns off plot activities.

Description: PLOT

GLAD creates graphic metafiles which may be viewed with Watch.exe. The metafile name may be set by the command `plot/watch`. The default name is plot1.plt. One may send each successive plot to the same metafile plot name or different metafiles by selecting different metafile plot names. GLAD maintains a list of the plot files used in the current session in the file watch.dat. By default Watch uses watch.dat to determine how many windows to open and displays each of the current plot files. Watch may also be set to display only files selected interactively by deselecting “From Watch.dat” form the File menu. Watch can also print the metafile or create a windows metafile (*.wmf) from the File menu.

Color Coding

GLAD assigns colors for each beam to be used in `/liso`, `/isometric`, `/xslice`, `/yslice`, `/vector`, `/ellipse`, and `/histogram`. GLAD uses 6 colors to identify beams, according to the equation,

$$\text{color number} = \text{mod}(\text{beam number} - 1, 6) + 1 \qquad (187)$$

The default color numbers are given in Table 18.

Table. 18. Default Color mapping

Color number	**Color**
1	blue
2	green
3	cyan
4	red
5	magenta
6	yellow

These colors may be remapped with `set/map_color`. Contour plots and `plot/udata` use different color coding, as described with the respective commands.

Plot Control Commands

```
plot/watch (File name) xoff yoff xsize ysize
plot/watch/relative (File name) xoff yoff xsize ysize
```

This command creates a plot file in GLAD metafile format. The file will be added to the list of plots in watch.dat and will displayed by the Watch program. `xoff`, `yoff`, `xsize`, and `ysize` specify the plot offsets from the upper left of the screen and width an height of the screen (pixels) to be set by Watch. These position and size settings may be changed by `plot/plot_log/change`, which will change watch.dat and Watch will subsequently adjust the display. The modifier `/relative` causes `xoff` and `yoff` to be interpred relative to the lower left corner of Watch.exe.

```
plot/disk (Filename)
```

The above command creates a plot file similar to `plot/watch` except that the name of the plot is not added to watch.dat so it is not automatically displayed. This is useful to create a plot file without displaying it.

The default file name is plot1.plt. Do not include the parentheses. The filename may be written as a 20 character expression, converted to lower case (the "/" character is not allowed in the short form). Alternately an expression of up to 80 characters may be used in the form "filename", no case conversion takes place, any characters are allowed. The filename is preceded by a path name if one has been defined with `set/path`. It is preferable to set the default folder from the Controls dialog box of the Interactive Input of IDE.EXE.

```
plot/skip nskip
```

The above command advances the plot page number by `nskip`.

```
plot/screen/pause ipause
```

The above command will cause the program to wait `ipause` seconds before continuing. This replaces the usual wait for the user to enter a key. A zero value for `ipause` turns off the timed pause and returns to a wait for user entry.

```
plot/title size
```

The above command plots the title with character size determined in pixels where there are 768 pixels for the screen height.

The command

```
plot/info
```

summarizes the current plot state, graphic protocol, etc.

The commands

plot/off
plot/on

turn plotting activities off or back on respectively.

The command below

```
plot/print (Filename)
```

will cause Watch.exe to print Filename using the current printer. The current printer may be changed using the printer setup features of Watch.exe.

Windows metafile format (*.WMF) and the Enhanced metafile format are widely used vector graphic format. The EMF format allows better control of the graphic size and is preferred over WMF. The commands shown below

```
plot/metafile/emf (Filename)
plot/metafile/wmf (Filename)
```

cause Watch.exe to generate Filename into an MS Windows metafile with the suffix *.EMF or *.WMF respectively. For example, plot1.emf will be created from plot1.plt. The default name is the name of the most recently created plot.

Scalar vector graphics (SVG) and compressed scalar vector graphics (SVGZ) may be generated with the commands:

```
plot/metafile/svg (Filename)
plot/metafile/svgz (Filename)
```

These plot styles may be used in ghe GLAD HTML Files. Note that local SVGZ files can not be processed with the FireFox browser.

Computer graphic metafile (*.CGM) is an ISO standard for vector graphics. Most word processors and desk top publishing programs support it. The command below

```
plot/metafile/cgm (Filename)
```

causes Watch.exe to generate Filename into an commputer graphic metafile with the suffix *.CGM. For example, plot1.cgm will be created from plot1.plt.

Postscript files may be created by

```
plot/metafile/ps (Filename)
```

The resulting Postscript files are of size 3.25” x 2.51” (234 points x 181 points). They may be imported into Adobe Illustrator, Corel Draw, MS Word, or Ghostscript; sent directly to a PostScript printer; or distilled to PDF files with the Adobe Acrobat Distiller. These PS files have no preview, but one may be added by one of the drawing programs or Ghostscript.

The Adobe page description format (*.PDF) protocol is now very widely used, especially in Adobe software. To create PDF files for GLAD graphics, it is necessary to purchase and install the Adobe Acrobat software from Adobe. Once Acrobat is installed, Watch may be used to print to the Acrobat Distiller printer driver to create small, but accurate PDF files for importing into other software. Adobe PostScript files may also be created by using print-to-file from the Print Setup menu under Watch.

Note that for both meta files and PDF files, that line width is important. The line width may be set in the Watch program under the menu item Preferences. In the GLAD Examples manual (examples.pdf), zero line width is used for the screen version of examples.pdf to achieve maximum screen resolution. These zero-line-width graphics show high detail in the Adobe Acrobat Reader with the magnifier tool. These zero width graphics do not print well directly from examples.pdf. At AOR we prepare a special version of the Examples Manual with thick line graphics for use on our color printers.

See the `set` command for a number of commands that set various parameters for graphics.

Making movies

Graphic images may be captured using software such as Camtasia (www.camtasia.com).

Modifier 1	**Description**
`/skip`	Advace the plot number by `nskip`.
`/title`	Plots the current title.
`/print`	Sets the density of plot lines.
`/metafile`	Creates a metafile from the current or designated plot name of form EMF, WMF, CGM, or PS (PostScript).
`/on`	Sets labels of plots on (default) or off.
`/off`	Set major and minor tick marks for `plot/udata`.

Table. 19. **The following set commands alter the setting of various plot features.**

`set/color`	
`set/monochrome`	
`set/density`	`xdensity ydensity`
`set/frame/`(`on` or `off`)	
`set/label/`(`list`, `on`, or `off`)	
`set/grid`	`xmajor xminor ymajor yminor`
`set/window/center-width`	`xrad yrad xdec ydec`
`set/window/relative`	`xmin xmax ymin ymax`
`set/window/absolute`	`xmin xmax ymin ymax`
`set/windows/list`	
`set/plot_number`	`number`
`set/camera`	`elevation azimuth distance`
`set/map_color/` (`list`, `set`, or `choices`)	`color_no`
`set/plot_slice_list/` (`list`, `on`, or `off`)	

Modifier 1 for `set` commands	**Description**
`/color`	Use color in plots.
`/monochrome`	Use no color in plots.
`/density`	Sets the density of plot lines.
`/frame/`(on or `off`)	Sets frame of plots on (default) or off.
`/label/`(on or `off`)	Sets labels of plots on (default) or off.
`/grid`	Set major and minor tick marks for `plot/udata`.
`/window`	Sets the plotting window for `plot/isometric`, `plot/orthographic`, `plot/elliptical`, `plot/vector`, and `plot/contour`.
`/windows/list`	List plotting window status.
`/window/all`	Resets plotting window to entire data field.
`/window/center-width`	Sets plotting window by x- and y-halfwidths and center position (default).

Modifier 1 for `set` commands	**Description (Continued)**
`/window/rel`	Sets plotting window. Limits expressed as a percent of total field. 0 at right and bottom to 100 at left or top.
`/window/abs`	Sets plotting window. Limits expressed in user coordinates.
`/plot_number`	Sets the plot number.
`/camera`	Set camera parameters for `plot/bitmap/./`(`wireiso`, `paintiso`, or `contpaintiso`).
`/map_color`	Display or change mapping of colors to beam numbers.

`/plot_slice_list`	Causes data from `plot/xslice` and `plot/yslice` to be output. May be written to an output file using `write/disk fname`.
	`set/plot_slice_list/on`
	`write/disk/on xxx.txt/over`
	`plot/x/i 1`
	`write/disk/off/close`
	`set/plot_slice_list/off`

Modifier 2	**Description**
`/on`	Activates feature.
`/off`	Deactivates feature.
`/list`	List current values.
`/emf`, `wmf`, `cgm`, `ps`	Metafiles of type EMF, WMF, CGM, or PS (PostScript)
`/choices`	List choices of color numbers for `set/map_color`.
`/set`	Set color numbers (`color_no`) with beam numbers () for `set/map_color`.

Numerical Values	**Description**	**Defaults**
`xdensity`	The number of points to plot in the X-direction.	21
`ydensity`	The number of points to plot `xdensity` in the Y-direction.	
`xmin`, `xmax`, `ymin`, `ymax`	Plot field for `/window/abs` or `/window/rel`.	
`xrad`, `yrad`, `xdec`, `ydec`	Plot field for `/window/center-width`.	
`xmajor`, `xminor`, `ymajor`, `yminor`	Number of major and minor grid elements for horizontal and vertical axes of `plot/xslice`, `plot/yslice` and `plot/udata`.	4, 5, 5, 5
`elevation`, `azimuth`, `distance`	Camera elevation angle, azimuth angle and distance for `plot/byte/./`(`wireiso`, `paintiso`, or `contpaintiso`).	
`number`	Plot number.	
	Beam number for `set/map_color`.	
`color_no`	Set color number associated with beam number for `set/map_color`.	
`size`	Height of the plot title in pixels for `plot/title`.	
`nskip`	Number to skip for the plot number.	

PLOT/BITMAP Several styles of bitmap plots. Diagnostics

Command Forms(s): PLOT/BITMAP

```
plot/bitmap/intensity/(modifier 3)      kbeam max min
plot/bitmap/phase/(modifier 3)          kbeam max min
plot/bitmap/wavefront/(modifier 3)      kbeam max min
plot/bitmap/real/(modifier 3)           kbeam max min
plot/bitmap/aimaginary/(modifier 3)     kbeam max min
plot/bitmap/preal/(modifier 3)          kbeam max min
plot/bitmap/paimaginary/(modifier 3)    kbeam max min
plot/bitmap/material/(modifier 3)       kbeam max min
plot/bitmap/log10/(modifier 3)          kbeam max min
plot/bitmap/log/(modifier 3)            kbeam max min
plot/bitmap/ginversion/(modifier 3)     kbeam max min
```

Description: PLOT/BITMAP

Makes a bitmap plot which may be displayed in several styles. The user may specify the default style and camera angle and distance (see set/camera). These style and camera parameters may be changed interactively in Watch. The region to be displayed may be controlled with set/window.

Modifier 2	Description
/intensity	Plots the intensity of the beam.
/phase	Plots the phase of the beam.
/wavefront	Plots the phase in wavelengths: waves = -phase/(2π).
/real, /aimaginary, /preal, /paimaginary	Displays real or imaginary component of first or second polarization state.
/material	Plots the material numbers of thermal arrays.
/log10, /log	Plots intensity with log base 10 and natural logarithm.
/ginversion	Plots the population inversion for a gain array. Imaginary part of first polarization state minus real part of second polarization state.

Modifier 3	Description
/burnpattern	False color bitmap display.
/graypattern	Gray tone bitmap display.
/wireiso	Wireframe isometric.
/paintiso	Painted isometric plot. Has grid, 6 colors. See /7, /8, and /9.
/contpaintiso	Combination painted contour and painted isometric plot.
/arrayvisualizer	Activates array visualizer.
/7	Same as /paintiso. Has grid, 13 colors.
/8	Same as /paintiso. No grid, 13 colors.
/9	Same as /paintiso. No grid, 6 colors.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`min`	Lowest data value.	
`max`	Highest data value.	

PLOT/CONTOUR Several styles of bitmap plots. Diagnostics

Command Forms(s): PLOT/CONTOUR

`plot/contour/(intensity, phase, wavefront, real, aimaginary, preal, paimaginary, log10, log)`	`kbeam contours threshold peak ilab [noincrements]`
`plot/contour/(intensity, phase, wavefront, real, aimaginary, preal, paimaginary, log10, log)`	`kbeam coninc min max ilab [increments]`
`plot/contour/zeros`	`kbeam`

Description: PLOT/CONTOUR

Makes a contour plot with labeling of the contour line. The fineness of the contour plot is set by the `set/density` command.

The contour levels are specified in Table 20.

Table. 20. Colors used with `plot/contour`.

Contour number	Color number	Color name
1	5	magenta
2	1	blue
3	3	cyan
4	2	green
5	6	yellow
6	4	red
7 (same as 1, etc.)	5 repeat sequence	magenta, etc.

GLAD reassigns the 6 colors again such that level 7 has the same color as level 1.

Modifier 2	Description
`/intensity`	Plots the intensity of the beam.
`/phase`	Plots the phase of the beam.
`/wavefront`	Plots the phase in wavelengths: waves = -phase/(2π).
`/real, /aimaginary, /preal, /paimaginary`	Displays real or imaginary component of first or second polarization state.
`/zeros`	Displays the locus of real (solid) and imaginary (dashed) zeros of the distribution.
`/log10, /log`	Plots intensity with log base 10 and natural logarithm.
`/ginversion`	Plots the population inversion for a gain array. Imaginary part of first polarization state minus real part of second polarization state.

Parameter	Description
`noincrements`	Contour plot using number of contours and relative scaling (default).
`increments`	Contour plot using specified increment and absolute scaling.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`contours`	Number of contours.	`10`
`coninc`	Value of contour increments.	
`threshold`	Lowest percentage value to be included in contour plot (`noincrements`).	
`peak`	Highest percentage value to be included in contour plot (`noincrements`).	100
`min`, `max`	Minimum and maximum values.	
`ilab`	`ilab` = 1, labels on. `ilab` = 0	Labels off

PLOT/ELLIPTICAL Plot of polarization using elliptical display. Diagnostics

Command Forms(s): **PLOT/ELLIPTICAL**

```
plot/elliptical   kbeam threshold peak
```

Description: PLOT/ELLIPTICAL

The `plot/elliptical` command makes a plot of the polarizations state of the beam using the relatively common elliptical plots. Let the horizontal and vertical polarization components be described by the complex amplitudes *Ex* and E_y. The polarization plot is found by the locus of points satisfying

$$\Delta x = \mathrm{Re}[E_x e^{-j2\pi t}] \tag{188}$$

$$\Delta y = \mathrm{Re}[E_y e^{-j2\pi t}] \tag{189}$$

where Re[ ] indicates the real part of the function and *t* is a parameter which is taken from 0 to 1 to make one full cycle of the elliptical plot. The locus of points described by (Δx, Δy) is the elliptical description of polarization. An arrow is given to show the starting condition of the plot. Rotation in the clockwise direction gives right-handed polarization. Examples of polarization plots are given in Ex37 .

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`peak`	Top of intensity range in percent.	`100`
`threshold`	Bottom of intensity range in percent.	0

PLOT/HISTOGRAM Histogram of irradiance values. Diagnostics

Command Forms(s): **PLOT/HISTOGRAM**

```
plot/histogram    kbeam bars threshold peak
```

Description: PLOT/HISTOGRAM

Makes a histogram of the intensity values. The information displayed is the percentage of the area within a certain range of intensity values. The areas are normalized to the area above the value specified by threshold.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`bars`	Number of histogram bars.	8
`peak`	Top of intensity range in percent.	`100`
`threshold`	Bottom of intensity range in percent.	0

PLOT/ISOMETRIC Cross-hatch isometric. Diagnostics

Command Forms(s): **PLOT/ISOMETRIC**

```
plot/isometric/   kbeam azimuth elevation height min max first last
```
(modifier 2)

Description: PLOT/ISOMETRIC

Makes an isometric plot (sometimes called a 3-D plot) of the function defined in the second modifier. Set density of the plot lines with the command `set/density`.

Modifier 2	Description
`/intensity`	Plots the intensity of the beam.
`/phase`	Plots the phase of the beam.
`/wavefront`	Plots the phase in wavelengths: waves = -phase/(2π).
`/real`, `/aimaginary`, `/preal`, `/paimaginary`	Displays real or imaginary component of first or second polarization state.
`/log10`, `/log`	Plots intensity with log base 10 and natural logarithm.
`/ginversion`	Plots the population inversion for a gain array. Imaginary part of first polarization state minus real part of second polarization state.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`azimuth`	Horizontal view angle (in degrees), measured clockwise from the y-axis.	`45`
`elevation`	Vertical view angle (in degrees), measured from the x/y plane.	`45`

Numerical Values	Description (Continued)	Defaults
`height`	Vertical size of the plot, expressed as a fraction to the largest horizontal direction.	0.8
`max`, `min`	Maximum and minimum values to be used for scaling.	
`first`, `last`	Numbers of the first and last beam in the range to be plotted.	

PLOT/LISO Single-direction scan isometric plot. Diagnostics

Command Forms(s): **PLOT/LISO**

```
plot/liso/(modifier 2)    ibeams ibeame xrad yrad xdec ydec nslice hratio
                          thetsd max min
```

Description: PLOT/LISO

Makes an isometric plot consisting of single slices (as opposed to cross hatch plots with isometric). `liso` is several times faster than isometric and shows greater detail in one direction. `plot/liso` may also be used to plot multiple beams on the same plot. GLAD plots all to a common scale.The `/real` and `/aimaginary` modifiers may be used to display the real and imaginary parts of the array. The `/preal` and `/paimaginary` modifiers display the respective real and imaginary states of the p-polarization.

Modifier 2	Description
`/intensity`	Plots the intensity of the beam.
`/phase`	Plots the phase of the beam.
`/wavefront`	Plots the phase in wavelengths: waves = -phase/(2π).
`/real`, `/aimaginary`, `/preal`, `/paimaginary`	Displays real or imaginary component of first or second polarization state.
`/log10`, `/log`	Plots intensity with log base 10 and natural logarithm.
`/material`	Plots the thermal material distribution by the thermal material number.
`/ginversion`	Plots the population inversion for a gain array. Imaginary part of first polarization state minus real part of second polarization state.

Numerical Values	Description	Defaults
`ibeams`	Starting beam number. Will accept a beam pattern, e.g., “1,2,6:7” for beams 1, 2, 6, and 7.	
`ibeame`	Ending beam number.	
`xrad`	Half-width in x-direction.	Edge of field
`yrad`	Half-width in y-direction.	xrad
`xdec`, `ydec`	X- and y-decenter.	0., 0.
`nslice`	Number of data slices.	32
`hratio`	Relative peak plotted. Allowed range: 0.01< `hratio` < 1.	0.4
`thetad`	View angle. Allowed range: 1 < `thetad` < 40.	25
`max`	Maximum value for function plot.	
`min`	Minimum value for function plot.	

PLOT/ORTHOGRAPHIC Plots with variable size diamonds. Diagnostics

Command Forms(s): PLOT/ORTHOGRAPHIC

```
plot/orthographic/intensity   kbeam threshold peak
plot/orthographic/phase       kbeam threshold peak
plot/orthographic/wavefront   kbeam threshold peak
```

Description: PLOT/ORTHOGRAPHIC

Makes an orthographic plot of the function defined in the second modifier.

Modifier 2	**Description**
`/intensity`	Plots the intensity of the beam.
`/phase`	Plots the phase of the beam.
`/wavefront`	Plots the phase in wavelengths: waves = -phase/(2π).

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`threshold`	Bottom of intensity range in percent.	0
`peak`	Top of intensity range in percent.	`100`

PLOT/PLOT_LOG Direct control of watch.dat data. Diagnostics

Command Forms(s): PLOT/PLOT_LOG

```
plot/plot_log/on
plot/plot_log/off
plot/plot_log/list
plot/plot_log/clear
plot/plot_log/load             (filename)
plot/plot_log/add/absolute     (filename) xoff yoff xsize ysize
plot/plot_log/add/relative     (filename) xoff yoff xsize ysize
plot/plot_log/delete           (filename)
plot/plot_log/change/absolute  (filename) xoff yoff xsize ysize
plot/plot_log/change/relative  (filename) xoff yoff xsize ysize
plot/plot_log/print            (filename)
plot/plot_log/meta/wmf         (filename)
plot/plot_log/meta/cgm         (filename)
plot/plot_log/top              (filename)
```

Description: PLOT/PLOT_LOG

The graphic files are displayed by the program Watch by means of the disk file watch.dat which is maintained by the GLAD program. The command `plot/plot_log` controls the file called watch.dat.

Modifier 2	Description
/list	Display the list of current to be displayed (default).
/on	List of plot files is maintained.
/off	Discontinue updating list of plot files.
/load	Adds file names from an external file to the list of files generated in the current command file execution.
/clear	Clear all plot file names from watch.dat.
/add	Add a plot file name to the list (to include already existing plot files). Variables are not allowed in the data line. Use an “r” after offsets that are to be interpreted as being relative to Watch.exe. For example: `plot/plot_log/add plot1.plt 100r 0r 400 300`.
/delete	Delete a plot file name from the list.
/change	Change plot offsets and size in watch.dat. Watch will adjust accordingly. Variables are not allowed in the data line. Use an “r” after offsets that are to be interpreted as being relative to Watch.exe. For example: `plot/plot_log/change plot1.plt 100r 0r 400 300`.
/print	Causes Watch to print the current plot file. File must be in the list of current files.
/top	Places designated file at the top of the Watch display of plots.

Modifier 3	Description
/emf	Create an MS Windows metafile with extension *.EMF.
/wmf	Create an MS Windows metafile with extension *.WMF.
/cgm	Create a CGM file with extension *. CGM.
/ps	Create PostScript file, extension *.PS.
metafile/svg	Create uncompressed Scalar Vector Graphics, extension *.SVG.
metafile/svgz	Create compressed Scalar Vector Graphics, extension *.SVGZ.

Character String	Description
filename	For /load, disk file to be loaded to initialize list of plot names. For /add or /delete the plot file name to be added or deleted.

Numerical Values	Description	Defaults
xoff, yoff	Offset of the plot measured from the upper left of the screen (pixels).	
xsize, ysize	Size of the plot measured from the upper left of the screen (pixels).	

PLOT/UDATA Plots data in UDATA arrays. Diagnostics

Command Forms(s): **PLOT/UDATA**

```
plot/udata/123          first last left right min max nskip [(parameter)]
plot/udata/sequence     left right min max nskip [(parameter)]
plot/udata/set          [y01] [y02] [y03] [y04] [y05] [y06] [y07] [y08]
                        [y09] [y10] [y11] [y12]
plot/udata/list
plot/udata/xlabel       (xlabel string)
```

Command Forms(s): **PLOT/UDATA (Continued)**

`plot/udata/ylabel` (ylabel string)

Description: PLOT/UDATA

Makes a plot of the user defined data stored using the command `udata`. The stored data consists of three functions (`/123`) or up to twelve functions (`/sequence`) defined against a common independent variable axis. See `udata` for specifics on forming the data values. The three functions are referred to as the 1st, 2nd, and 3rd dependent data sets. The functions are identified by 1 six-color scheme, which repeats such that function 7 is given the same color as function 1. See Table 21.

Table. 21. Colors used with `plot/udata`.

Contour number	**Color name**
1	red
2	yellow
3	green
4	cyan
5	blue
6	magenta
7 (same as 1, etc.)	red, etc.

Modifier 2	**Description**
`/123`	Plot all functions from `first` to `last`.
`/sequence`	Plots functions defined by the `/set` modifier. Up to 12 functions may be used.
`/set`	Sets columns to be plotted by identifiers `y01` to `y12`. If no identifiers are specified, a list of current identifiers will be displayed.
`/list`	Lists on/off status of the 12 function columns.
`/xlabel`, `/ylabel`	Define horizontal or vertical label for the plot.

Character String	**Description**
xlabel, ylabel	Character strings for labeling the x- and y-axis of the plot.

Parameters	**Description**
`y01` to `y12`	Character parameters defining the dependent functions to be plotted.
`dash`	Use dashed lines to distinguish curves. Default is all solid curves.
`label`	Label lines with beam numbers. Default is no labels.
`spline`	Implement spline fit of data. Default is no spline fit.

Numerical Values	**Description**	**Defaults**
`first`	Number of first dependent data set to be plotted.	1
`last`	Number of last dependent data set to be plotted.	first
`left`	Minimum independent variable to be plotted.	Min. Data. Pt.
`right`	Maximum independent variable to be plotted.	Max. Data. Pt.
`min`	Minimum of the function to be plotted (absolute value, not relative).	Min. of Func.

Numerical Values	Description (Continued)	Defaults
`max`	Maximum of the function to be plotted (absolute value, not relative).	Max. of Func.
`nskip`	Number of data points to be skipped.	0

PLOT/VECTOR Plot polarization with vectors in complex plane. Diagnostics

Command Forms(s): **PLOT/VECTOR**

```
plot/vector/add            kbeam threshold peak
plot/vector/orthogonal     kbeam threshold peak
plot/vector/principle      kbeam threshold peak
```

Description: PLOT/VECTOR

The `plot/vector` command makes a plot of the polarizations state of the beam by explicitly displaying E_x and E_y in the complex plane. Unlike other plots in GLAD, in `plot/vector` the horizontal direction represents the real axis and the vertical direction represents the imaginary axis. The horizontal and vertical complex amplitudes E_x and E_y are represented by two vectors, each with half of an arrow head. E_x is represented by a vector with the half-arrow-head on the counterclockwise side of the vector. An example of `plot/vector` is shown in Ex37 .

Modifier 2	Description
`/add`	Shows x- and y-polarization states as vectors in the complex plane.
`/orthogonal`	(not complete.) Will show stress tensor.
`/principle`	(Not complete.) Will show principle components for stress tensor.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`threshold`	Bottom of intensity range in percent.	0
`peak`	Top of intensity range in percent.	`100`

PLOT/XSLICE Plot a slice through x-direction. Diagnostics

Command Forms(s): **PLOT/XSLICE**

```
plot/xslice/          ibeams slice left right fmin fmax first last
intensity             [(parameter)]
plot/xslice/phase     ibeams slice left right pmin pmax first last
                      [(parameter)]
plot/xslice/          ibeams slice left right pmin pmax first last
wavefront             [(parameter)]
plot/xslice/both      ibeams slice left right fmin fmax pmin pmax first
                      last [(parameter)]
```

Command Forms(s): **PLOT/XSLICE (Continued)**

`plot/xslice/(real, aimaginary, preal, paimaginary, log10, log)`	`ibeams slice left right fmin fmax first last` [(parameter)]
`plot/xslice/(complex` or `pcomplex)`	`ibeams slice left right fmin fmax pmin pmax first last` [(parameter)]

Description: PLOT/XSLICE

Makes a plot along an x-slice of the data specified in the second modifier.

Modifier 2	**Description**
`/intensity`	Plots the intensity of the beam.
`/phase`	Plots the phase of the beam.
`/wavefront`	Plots the phase in wavelengths: waves = -phase/(2π).
`/both`	Plots both the intensity and phase.
`/real`, `/aimaginary`, `/preal`, `/paimaginary`	Displays real or imaginary component of first or second polarization state.
`/log10`, `/log`	Plots intensity with log base 10 and natural logarithm.
`/complex` or `/pcomplex`	Plot both real and imaginary parts of first or second polarization state.
`/ginversion`	Plots the population inversion for a gain array. Imaginary part of first polarization state minus real part of second polarization state.

Parameter	**Description**
`label`	Label curves with beam number. By default a single beam has no labels and plots of more than one beam (first not equal to last) has labels.
`nolabel`	No labeling of curves with beam numbers (default).

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`slice`	Y-coordinate of the x-slice.	0.
`left`	Minimum x-coordinate to be plotted.	minimum x
`right`	Maximum x-coordinate to be plotted.	maximum x
`fmin`	Minimum of the intensity (or real or imaginary part) to be plotted (absolute value, not relative).	min. of int.
`fmax`	Maximum of the intensity (or real or imaginary part) to be plotted (absolute value, not relative).	max. of int.
`pmin`	Minimum of the phase (or imaginary part for `/complex` or `/pcomplex`) to be plotted (phase in radians).	min. of phas.
`pmax`	Maximum of the phase (or imaginary part for `/complex` or `/pcomplex`) to be plotted (phase in radians).	max. of phas.
`first`	Number of first beam in the range to be plotted.	`1`
`last`	Number of last beam in the range to be plotted.	`1`

PLOT/YSLICE Plot a slice through y-direction. Diagnostics

Command Forms(s): PLOT/YSLICE

`plot/yslice intensity`	`ibeams slice left right fmin fmax first last` [(parameter)]
`plot/yslice/phase`	`ibeams slice left right pmin pmax first last` [(parameter)]
`plot/yslice/ wavefront`	`ibeams slice left right pmin pmax first last [(parameter)]`
`plot/yslice/both`	`ibeams slice left right fmin fmax pmin pmax first last` [(parameter)]
`plot/yslice/(real, aimaginary, preal, paimaginary, log10, log)`	`ibeams slice left right fmin fmax first last` [(parameter)]
`plot/yslice/ (complex` or `pcomplex)`	`ibeams slice left right fmin fmax pmin pmax first last` [(parameter)]

Description: PLOT/YSLICE

Makes a plot along an y-slice of the data specified in the second modifier.

Modifier 2	Description
`/intensity`	Plots the intensity of the beam.
`/phase`	Plots the phase of the beam.
`/wavefront`	Plots the phase in wavelengths: waves = -phase/(2π).
`/both`	Plots both the intensity and phase.
`/real`, `/aimaginary`, `/preal`, `/paimaginary`	Displays real or imaginary component of first or second polarization state.
`/log10`, `/log`	Plots intensity with log base 10 and natural logarithm.
`/complex` or `/pcomplex`	Plot both real and imaginary parts of first or second polarization state.
`/ginversion`	Plots the population inversion for a gain array. Imaginary part of first polarization state minus real part of second polarization state.

Parameter	Description
`label`	Label curves with beam number. By default a single beam has no labels and plots of more than one beam (first not equal to last) has labels.
`nolabel`	No labeling of curves with beam numbers (default).

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`slice`	X-coordinate of the y-slice.	0.
`left`	Minimum y-coordinate to be plotted.	minimum y
`right`	Maximum y-coordinate to be plotted.	maximum y

Jump to: Theory , Examples

Numerical Values	Description (Continued)	Defaults
`fmin`	Minimum of the intensity (or real or imaginary part) to be plotted (absolute value, not relative).	min. of int.
`fmax`	Maximum of the intensity (or real or imaginary part) to be plotted (absolute value, not relative).	max. of int.
`pmin`	Minimum of the phase (or imaginary part for `/complex` or `/pcomplex`) to be plotted (phase in radians).	min. of phas.
`pmax`	Maximum of the phase (or imaginary part for `/complex` or `/pcomplex`) to be plotted (phase in radians).	max. of phas.
`first`	Number of first beam in the range to be plotted.	`1`
`last`	Number of last beam in the range to be plotted.	`1`

PLOT/ZIGZAG Plot configuration of zigzag amplifier. Diagnostics

Command Forms(s): **PLOT/ZIGZAG**

```
plot/zigzag/gain
plot/zigzag/beam
```

Description: PLOT/ZIGZAG

Displays the configuration of the zigzag amplifier in gain or beam coordinates. The starting face is in green and the ending face is in red. The gain rectangle is shown in cyan.

Modifier 2	Description
`/gain`	Plot zigzag amplifier in gain coordinates. The starting face is in green and the ending face is in red.
`/beam`	Plot zigzag amplifier in beam coordinates with the ray entering from the left. The starting face is in green and the ending face is in red.

POINT Set or display values at a point in an array. Diagnostics

Command Forms(s): **POINT**

```
point/list/ij/(Modifier 3)       ibeams i j
point/list/xy/(Modifier 3)       ibeams x y
point/record/ij/(Modifier 3)     ibeams i j
point/record/xy/(Modifier 3)     ibeams x y
point/set                        ibeams i j real aimag preal paimag
```

Description: POINT

This routine enables listing and setting complex amplitude values at a specific point.

Modifier 1	Description
`/list`	List the values at the specified point.
`/set`	Set the values at the specified point.

Modifier 1	**Description (Continued)**
`/record`	Record the results in system variables (see table below) without listing.

Modifier 2	**Description**
`/ij`	Use integer addresses corresponding to array indices 1 <= i <= nlinx (left to right), 1 <= j <= nliny (top to bottom). No interpolation is required. (default)
`/xy`	Use real addresses with (0.,0.) at the center of the array. Employs interpolation.

Modifier 3	**Description**
`/intensity`	Display intensity (default).
`/sa`, `/sr` or `/si`	Complex, real, or imaginary part of s-polarization.
`/pa`, `/pr` or `/pi`	Complex, real or imaginary part of p-polarization.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`i`, `j`	Column and row numbers for `/ij`, measured from upper left	$\left(\frac{M}{2}+1, \frac{N}{2}+1\right)$
`x`, `y`	Real coordinates of the array for `/xy`.	(0., 0.)
`real`, `aimag`, `preal`, `paimag`	Real, imaginary, y-polarization real, y-polarization imaginary.	`0.`, `0.`, `0.`, `0.`

System Variable Data	**Description (after executing `point/list`)**
`variab/set nstore point/intensity`	Intensity (default).
`variab/set nstore point/sa`	Complex s-polarization for complex variable.
`variab/set nstore point/sr`	Real part of s-polarization.
`variab/set nstore point/si`	Imaginary part of s-polarization.
`variab/set nstore point/pa`	Complex p-polarization for complex variable.
`variab/set nstore point/pr`	Real part of p-polarization.
`variab/set nstore point/pi`	Imaginary part of p-polarization.

POLES Calculate number of phase poles. Diagnostics

Command Forms(s): POLES

```
poles/count/phase          kbeam
poles/count/zeros          kbeam
poles/mark/phase           kbeam
poles/mark/zeros           kbeam
```

Description: POLES

This routine counts the phase poles in the distribution. Such phase poles can not be removed by phase unwrapping algorithms.

Modifier 1	Description
/count	Count the number of poles.
/mark	Count and mark the number of poles by setting the poles to 1 and all other points to 0. Distribution may be displayed by any of the irradiance plotting features. plot/liso/real will display positive poles and negative poles separately.

Modifier 2	Description
/phase	Finds poles by phase discontinuities. More robust but somewhat slower.
/zeros	Identify poles by the crossing point of the loci of real zeros and imaginary zeros of the complex amplitude. Works well for smooth functions such as speckle.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1

System Variable Data	Description
poles	Number of poles found.

POPTEXT Display data in popup windows. Language

Command Forms(s): **POPTEXT**

```
poptext/compose              (filename)
poptext/end
poptext/display              (filename) seconds xoff yoff
poptext/wait
```

Description: POPTEXT

Composes and displays popup text. Useful in creating a more dramatic title consisting of up to 16 lines and a maximum of 64 columns. The following example illustrates how to compose popup text (including the use of variables) and to display the poptext. poptext/display calls POPTEXT.EXE which must be in the current directory or in the path for executable files.

```
poptext/compose xxx.txt
This is an example of popup text
pass = @pass
poptext/end
poptext/display xxx.txt 10
```

This poptext/display command will display xxx.txt for 10 seconds. The file xxx.txt is a standard ASCII file and could also have been created externally to GLAD by any text editor.

Modifier 1	Description
/compose	Start of text block.
/end	End of text block.
/display	Display the designated ASCII file. The filename and number of seconds are passed literally to poptext.exe as command line arguments.

Modifier 1	Description (Continued)
`/wait`	Pause until `poptext` is finished.

Numerical Values	Description	Defaults
`seconds`	Time to display text (seconds).	
`xoff`	X-offset of text window from left (pixels).	
`yoff`	Y-offset of text window from top (pixels).	

PRIVILEGES Display and set privileges. Code and key information. Language

Command Forms(s): **PRIVILEGES**

```
privileges/list
privileges/set
privileges/register
privileges/password          (password)
privileges/upgrade           (password)
privileges/keyread
```

Description: PRIVILEGES

Lists the active options, compilation date, and warranty period. For the demo, lists the remaining cycles left. `/set` allows active options to be temporarily turned off to evaluate whether the options are necessary for a specific calculation. For /password, /update, /keyread, and /menu, alog file named keyread58.log is generated and contains information about keyread activity.

Modifier 1	Description
`/list`	List the active options.
`/set`	Set active options off. Useful for demo code to evaluate whether options are required to solve given problems.
`/register`	Generates registration information and creates a file of form XXX_YY.txt. Where XXXX is the four digit key number and YY is the two digit version number. For example 3400_50.txt for key 3400 and version 5.0. Email this file as an attachment to AOR to complete your registration.
`/password`	Set password of security key. Password is an eight-digit hexidecimal number provided by AOR to set the security key to permanent status for GLAD or GLAD privileges.
`/update`	Upgrade version number of an old security key to current GLAD version. Password is a four-digit hexidecimal number provided by AOR.

Modifier 1	Description (Continued)
`/keyread`	Runs keyread.exe to with an interactive menu to display information about the security key and to set password and label. The menu displays options for setting the password and/or upgrading the version with appropriate passwords. If the permanent password for GLAD is already set and the key version is up-to-date with the software version, only the information menu is displayed. Keyread.exe maintains a data log called keyread58.log which can be used for diagnostic purposes.

PROJECT Project sum of irradiance along y onto a single row. Language

Command Forms(s): **PROJECT**

```
project/irradiance/y   kbeami kbeamo
project/irradiance/x   kbeami kbeamo
project/amplitude/y    kbeami kbeamo
project/amplitude/x    kbeami kbeamo
```

Description: PROJECT

This routine calculates the sum of irradiance in the y-direction. Beam `kbeami` should be $N \times M$ and `kbeamo` should be $N \times 1$. See `copy/row` and `copy/column` for a method of copying one row or column of the input beam to all rows or columns of the output beam.

Modifier 1	Description
`/irradiance`	Sum the irradiance.
`/amplitude`	Sum the complex amplitude.

Modifier 2	Description
`/y`	Sum along y-direction (default).
`/x`	Sum along x-direction.

Numerical Values	Description	Defaults
`kbeami`	Input beam.	
`kbeamo`	Output beam.	

PROP Diffraction propagation in global coordinates. Propagation

Command Forms(s): **PROP**

```
prop/chief               ppl  kbeam1...kbeam9
prop/xproj/(Modifier 2)  projpl  kbeam1...kbeam9
prop/yproj/(Modifier 2)  projpl  kbeam1...kbeam9
prop/zproj/(Modifier 2)  projpl  kbeam1...kbeam9
prop/vertex/plane        kbeam1...kbeam9
prop/vertex/closest      kbeam1...kbeam9
prop/beam/plane          kbeam0  kbeam1...kbeam9
```

Command Forms(s): **PROP (Continued)**

```
prop/beam/closest     kbeam0  kbeam1...kbeam9
```

Description: PROP

The prop command supersedes the original propagation command dist. The command prop/chief applies diffraction propagation along the chief ray direction. The command is integrated with the global coordinate system defined by global. A positive value of ppl will always result in a movement in the direction of the beam propagation. The global coordinates will be correctly modified to show the new beam positions. The beams to be selected are determined by beams.

Prop/chief performs calculations by calling dist with the proper sign of the propagation step to make a positive physical path length change. Only positive values of ppl are physically real. A warning message is issued if ppl is negative.

Prop undefines the vertex position such that a new vertex command must be issued prior to the next element requiring vertex definition.

The modifiers /xproj, /yproj, and /zproj cause a diffraction step with distance projpl measured along the specified axis. The projected distances may be made relative or absolute depending on the selection of Modifier 2. The diffractive propagation is always along the chief ray. When a projection is requested, a length is calculated to achieve the specified projected length.

Warning: do not attempt to use the projection function with an axis that is close to perpendicular to the chief ray direction.

The command prop/vertex propagates along the current direction to the vertex position as specified by the previous /vertex command. Note that it is not necessary to issue a prop/vertex prior to one of the global commands: mirror/global, llensgroup , and grating /global. These commands issue there own propagation operation to bring the beam to the vertex.

Modifier 1	Description
/chief	Propagate along the chief ray (default).
/xproj	Propagate a projected distance on the x-axis.
/yproj	Propagate a projected distance on the y-axis.
/zproj	Propagate a projected distance on the z-axis.
/vertex	Propagates to the tangent plane of the vertex of next surface defined by the commands vertex/locate and vertex/rotate.
/beam	Propagate other beams to match k0beam either to i-j plane (/plane) or to point of closest approach (/closest).

Modifier 2	Description
/relative	A relative projected step is made of magnitude, projpl (default).
/absolute	A projected step to position, projpl.
/plane	Propagate to vertex plane for /vertex or beam plane for /beam.
/closest	Propagate to point of closest approach to the center of the vertex coordinate system for /vertex or beam coordinate system for /beam.

Numerical Values	Description	Defaults
ppl	Physical path length.	0.

Numerical Values	Description (Continued)	Defaults
`projpl`	Projected path length.	`0.`
`kbeam1-kbeam9`	List of beams to be propagated if “on” by the `beams` command. `kbeam1` = 0, propagates all “on” beams.	
`kbeam0`	Reference beam used for `/beam`.	

System Variable Data	Description
`xray`, `yray`, `zray`	Global position of beam along chief ray for `kbeam`.
`opl`, `ppl`	Optical path and physical path lengths for `kbeam`.
`zreff`	Current z-position of beam (cm).

Example

Assume we wish to propagate to a mirror at (0, 0, 100) centimeters, strike a flat mirror at 45 degrees and propagate a second distance of 100 centimeters. We wish to determine the global coordinates after these steps.

```
vertex/locate/abs 0 0 100             (Set mirror position.)
vertex/rotate/set 45                  (Rotate beam about x-axis.)
vertex/list                           (List vertex coordinates.)
mirror/global/flat
prop 100,                             (Advance the beam 100 cm.)
global/list                           (List global coordinates.)
```

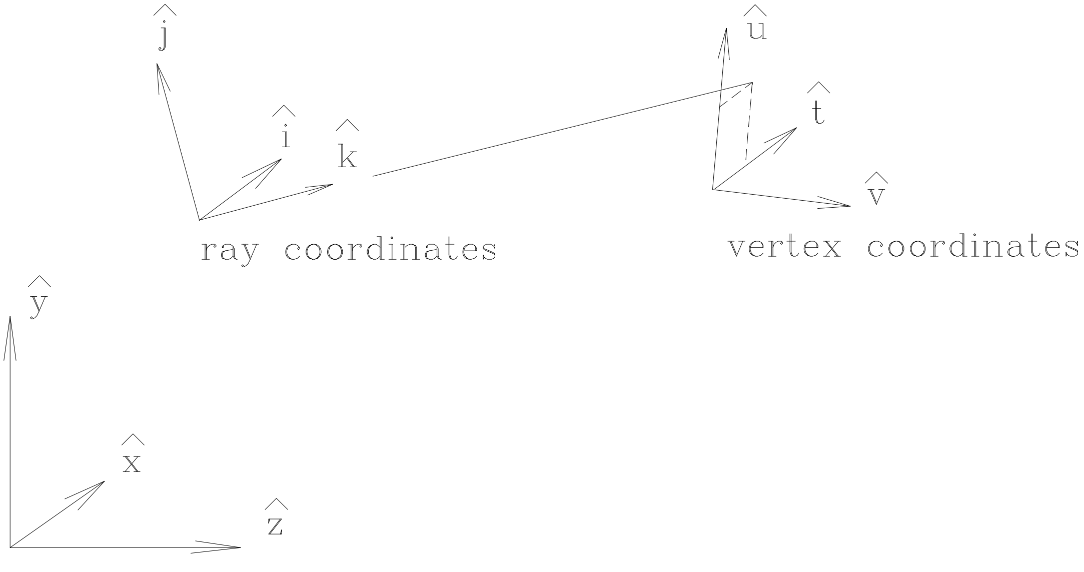


Fig. 25. Propagation to vertex plane by `prop/vertex/plane`. The k-vector is projected to intercept the u-t plane of the vertex coordinate system. Propagation to the coordinate system of another beam is similar for `prop/beam/plane`.

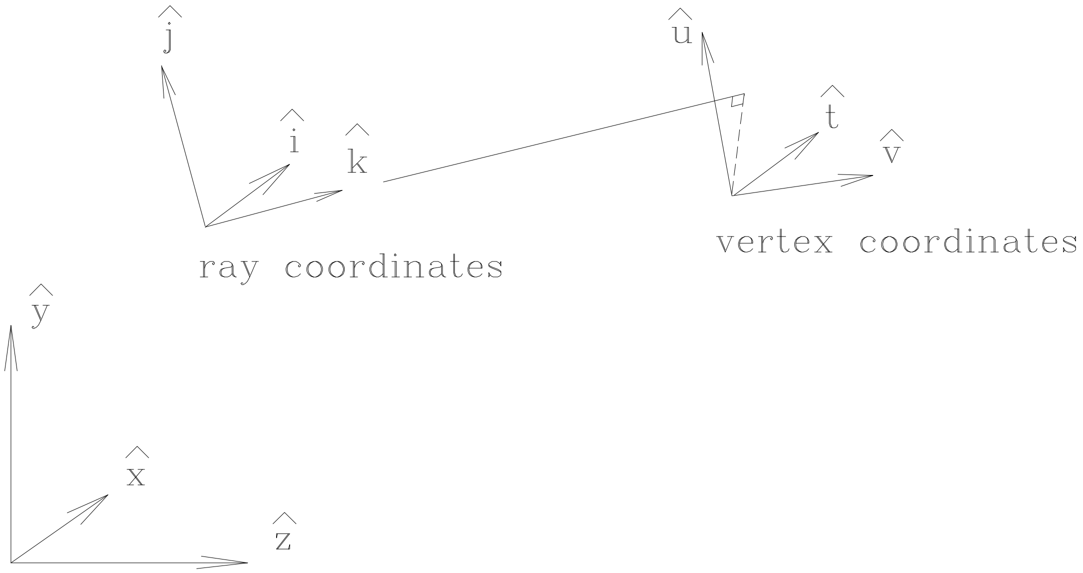


Fig. 26. Propagation to point of closest approach by `prop/vertex/closest`. The k-vector is projected to the point where it has minimum distance from the center of the vertex coordinate system. Propagation to the point of closest approach to another beam coordinate system is similar for `prop/beam/closest`.

RAMAN Raman scattering model. Laser gain

Command Forms(s): **RAMAN**

`raman/collimated/`(modifer 2)	`ipump istokes zstep rgain`
`raman/step/`(modifer 2)	`ipump istokes zstep rgain`
`raman/transient`	

Description: RAMAN

Propagates the beams using photon flux Raman theory. The GLAD feature set is required. For collimated beams (`/collimated`) the changes in the Stokes and pump beams are determined by the following equations:

$$I_s(x, y, z+\Delta z) \;=\; \frac{I_p(x, y, z) + \frac{\lambda_s}{\lambda_p} I_z(x, y, z)}{\frac{\lambda_s}{\lambda_p} + \frac{I_p(x, y, z)}{I_s(x, y, z)} \exp\left\{ -\left[I_p(x, y, x) + \frac{\lambda_s}{\lambda_p} I_s(x, y, z) \right] g\Delta z \right\}}\,, \tag{190}$$

$$I_p(x, y, z+\Delta z) \;=\; I_p(x, y, z) + \frac{\lambda_s}{\lambda_p}[I_s(x, y, z) - I_s(x, y, z+\Delta z)]\,. \tag{191}$$

where s and p indicate the seed and pump quantities, g is the small signal gain, and z is the propagation distance. See Sect. 9.8 , GLAD Theory Manual (theory.pdf).

Modifier 1	Description
`/collimated`	Closed form solution for collimated geometry (shown above) is used.
`/step`	Simple differential step is implemented.
`/transient`	Transient Raman physics treats short laser pulses and spontaneous emission.

Modifier 2	Description
`/prop`	Include diffraction propagation step (default).
`/step`	Do not include diffraction propagation step.

Numerical Values	Description	Defaults
`ipump`	Beam number of pump.	1
`istokes`	Beam number of Stokes.	2
`zstep`	Propagation length.	0.
`rgain`	Gain coefficient.	

RAMAN/TRANSIENT Transient Raman model. Laser gain

Command Forms(s): **RAMAN/TRANSIENT**

```
raman/transient/set         ipump istokes g1 g2 gamma iseed
raman/transient/step        kbeam zstep tstep
raman/transient/reststate   kbeam
raman/transient/info
```

Description: RAMAN/TRANSIENT

This command implements transient Raman theory including the finite response time of the medium and spontaneous emission due to quantum fluctuations. The GLAD feature set is required. It is assumed that a laser beam generates a Stokes beam by interaction with the medium through which it passes. A very high power beam passing through the air will experience the effects of rotational Raman. Unlike some applications such as a Raman amplifier, where the objective is to generate a high quality Stokes beam, in the case of atmospheric propagation the Raman process is a parasitic effect. The Stokes beam grows form spontaneous emission due to scattering of the laser beam from quantum fluctuations. Once, generated, the Stokes beam, if the laser is of sufficient power, will be amplified by stimulated Raman effects. The spontaneous emission grows linearly with distance but the stimulated Raman amplification is exponential (until the pump becomes depleted) and quickly becomes the dominant force. The spontaneous emission scatters in all directions but only the light which is in the forward direction gets significant amplification. This leads to some increase in the spatial coherence of the Stokes beam but for strong laser beams the generation of Stokes may occur at such short distances that even wide angles of the Stokes beam are amplified.

The medium responds in finite time. For very short pulses, the Raman gain will be much less than the steady-state Raman gain. The rotational Raman response time of the air at 0.351 microns is about 133 picoseconds. Laser pulses which are comparable or shorter than this response time will see proportionally smaller Raman gain. An arbitrary temporal waveform may be described by a series of time pulses of length `tstep`. The medium is represented by an array which must have two polarization steps. A number of medium arrays may be used along the laser beam path to represent the different states of the process. The medium array contains information on the degree of excitation of the medium and a set of random phasors which represent the response of the medium to quantum fluctuations. The medium array is initialized to the rest state with the command `/reststate`. The length of the medium array is represented by `zstep`. Diffraction propagation of the laser pump and stokes beams must be done separately. See Ex79 e.

Modifier 1	**Description**
`/set`	Set the constants used in the calculation.
`/step`	Take a kinetics step through a medium array. Diffraction must be done separately. See Ex79 .
`/reststate`	Establish the rest state of a medium array. The excitation of the medium will be set to zero and a random field of medium excitation due to quantum fluctuations.
`/info`	List constants used in the calculations.

Numerical Values	**Description**	**Defaults**
`ipump`	Beam number of pump.	1
`istokes`	Beam number of Stokes.	`2`
`zstep`	Propagation length.	`0.`
`tstep`	Time elapsed between time steps.	
`g1`	Steady-state Raman gain coefficient.	0.
`g2`	Gain coefficient for spontaneous emission.	
`gamma`	Line width of Raman response in Hertz.	
`iseed`	Positive integer to set random seed.	
`kbeam`	Beam number of medium to be operated on (must have two polarization states).	

RAY Set global position and direction. Positioning

Command Forms(s): **RAY**

```
ray         ibeams x y z rx ry rz
```

Description: RAY

Initializes the beam ray direction for global coordinates. Sets the global position and orientation. The rotations are defined in terms of the Euler angles α = `rx`, β = `ry`, γ = `rz`,

$$R_x(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix}, \tag{192}$$

$$R_y(\beta) = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\alpha \end{bmatrix}, \tag{193}$$

$$R_z(\gamma) = \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{194}$$

The composite rotation of all three angles (in the order x, y, and z) is

$$\mathbf{R}_{xyz} = \begin{bmatrix} \cos\gamma\cos\beta & \cos\gamma\cos\beta\sin\alpha - \sin\gamma\cos\alpha & \cos\gamma\sin\beta\cos\alpha + \sin\gamma\sin\alpha \\ \sin\gamma\cos\beta & \sin\gamma\sin\beta\sin\alpha + \cos\gamma\cos\alpha & \sin\gamma\sin\beta\cos\alpha - \cos\gamma\sin\alpha \\ -\sin\beta & \cos\beta\sin\alpha & \cos\beta\cos\alpha \end{bmatrix} \tag{195}$$

Modifier 1	**Description**
`/define`	Set the values for position and orientation.
`/list`	List the global values, same as `global/list`.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`x`, `y`, `z`	Global position coordinates.	`0.`, `0.`, `0.`
`rx`, `ry`, `rz`	Global Euler angles.	`0.`, `0.`, `0.`

READ Select device from which to read commands. Input-output

Command Forms(s): **READ**

`read/disk` (Filename) /(`norewind` or `rewind`)
`read/screen/`(`noclose` or `close`)
`read/back/`(`noclose` or `close`)
`read/info`
`read/continue`
`read/stack`
`read/popupmenu`

Description: READ

Sets input unit. If `read/disk` is called with a new file name, the file is rewound before reading. If `read/disk` is called a second time with the same file name, GLAD continues reading from the current position in the file. The file may be closed by `read/screen/close` to enable the file to be edited with the system editor using the `system` command to temporarily exit from GLAD. A second `read/disk` may called with a return to the previous level by `read/back` or `read/screen` to return to terminal input.

The working folder may be set through the Controls menu item in the Interactive Input Window of IDE. A pathname may be set with `set/path` to define a prefix which is concatenated in front of the filename.

Modifier 1	Description
`/screen`	Returns reading to screen terminating macro processing or reading from disk.
`/back`	Returns reading to previous input device, either screen or batch input. When reading from a second level of `read/disk`, returns to first level.
`/disk`	Reads from disk file Filename. May be issued from interactive mode or included in a disk file. No more than two successive `read/disk` commands are allowed.
`/info`	Gives read status, read levels, and active disk file names.
`/continue`	Same as `break/continue`.
`/stack`	List the files which are open for reading and macros.
`/popupmenu`	Call a dialog box from the GLAD command line for opening a file. Generally it is easier to use GladEdit.

Modifier 2	Description
`/noclose`	Leaves file open for later reading (default).
`/close`	Closes existing open disk file. Useful for editing via system call. `/close` will cause the file to be rewound if called a second time. Also see `/rewind` in the parameter modifier table.

Character String	Description
Filename	Name of input file for `/disk`. If more than 20 characters or if special characters are included, enclose in single quotes. The filename is preceded by a path name if one has been defined with `set/path`.

String/Modifier	Description
`/norewind`	Continues reading at current file position (default).
`/rewind`	Rewinds file before reading. See `/close` above.

Example of reading with two levels

Files temp.inp calls macro “system” that calls temp1.inp and temp2.inp using a macro and the variable “pass” to increment the file name. This could also be done may making temp1.inp and temp2.inp into macros.

File: temp1.inp

```
C Hello, from temp1.inp
read/back/close
```

File: temp2.inp

```
C Hello, from temp2.inp
read/back/close
```

File: temp.inp

```
variable/dec/int pass
macro/def x1/o
```

```
   pass = pass + 1 list
   read/d temp@pass.inp
macro/end
pass = 0
macro/run x1/2
```

REAL2PHASE, REAL2WAVES Real part converted to phase. Operator

Command Forms(s): REAL2PHASE, REAL2WAVES

`real2phase/one`	`kbeam alpha`
`real2waves/one`	`kbeam alpha`
`real2phase/two`	`kbeam1 kbeam2 alpha`
`real2waves/two`	`kbeam1 kbeam2 alpha`

Description: REAL2PHASE, REAL2WAVES

This commands converts a real distribution into a phase screen. The complex amplitude distribution may then be used with the mult `/beam` command to impose the phase distribution. Also see `int2phase` and `int2waves`. The imaginary component, if it exists, is discarded.

Modifier 1	**Description**
`real2phase/one`	$a(x, y) = r(x, y) + 0i \to e^{j\alpha r(x, y)}$, where $r(x,y)$ is the real distribution.
`real2waves/one`	$a(x, y) = r(x, y) + 0i \to e^{-j2\pi\alpha rx, y}$, where $r(x,y)$ is the real distribution.
`real2phase/two`	$a_1(x, y) \to e^{j\alpha r_2(x, y)}$, where $r_2(x,y)$ is the real distribution of `kbeam2`.
`real2waves/two`	$a_1(x, y) \to e^{-j2\pi\alpha r_2(x, y)}$, where $r_2(x,y)$ is the real distribution of `kbeam2`.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number (`/one`).	1
`kbeam1`, `kbeam2`	Beam numbers (`/two`).	`1, 2`
`alpha`	Coefficient for converting real values to phase in radians (`real2phase`) or wavelengths (`real2waves`).	`0.`

RESCALE Rescale the beam distribution in the array. Operator

Command Forms(s): RESCALE

`rescale/field`	`kbeam xrad yrad` [(parameter)] [(parameter)]
`rescale/beam`	`kbeam xscale yscale` [(parameter)] [(parameter)]
`rescale/units`	`kbeam xunits yunits` [(parameter)] [(parameter)]
`rescale/scale`	`kbeam xscale yscale` [(Parameter)] [(parameter)]
`rescale/shift`	`kbeam xdec ydec` [(parameter)] [(parameter)]
`rescale/copy`	`kbeami kbeamo xrad yrad decx decy`
`rescale/distort/azimuthal/` (`rescale` or `constant`)	`kbeam magnification azdeg`

Command Forms(s): **RESCALE (Continued)**

```
rescale/distort/matrix/     kbeam m11 m12 m21 m22
(rescale or constant)
```

Description: RESCALE

This command rescales the beam array. If `/field` is selected, the array will be scaled to have field half widths of `xrad` or `yrad`. If `/beam` is selected, the array is scaled so that the beam fills up the fractional field determined by `radx` and `rady`. If `radx` or `rady` is 0, the optimum units are selected based on equal near- and far-field sizes.

`Rescale/beam` is very useful to refit the array size to avoid aliasing when propagating through a strongly aberrating system where the beam would otherwise expand beyond the bounds of the array. This command calls `fitgeo` to center the beam and to reset the beam parameters to the current values as well as resizing the units to establish the desired filling of the array.

Modifier 1	**Description**
`/field`	Use half width of field to specify rescale.
`/beam`	Rescale to specified half width and use beam size as displayed by `geodata` to rescale distribution to “optimum” size. Expand or contract optimum beam size by scale factors, `xscale` and `yscale`.
`/units`	Use `units` to specify rescale.
`/scale`	Use scale factor to specify rescale.
`/shift`	Shift distribution using linear interpolation. See also, `fitzern` which uses an FFT based method.
`/copy`	Scale and copy `kbeami` to `kbeamo` with half-widths `xrad` and `yrad` and center at `xdec` and `ydec`.
`/distort`	Apply nonuniform magnification changes.

Modifier 2	**Description**
`/azimuthal`	Modifier for `/distort` to create a bulge in an arbitrary direction. $\begin{bmatrix} x' \\ y' \end{bmatrix} = \mathbf{R}(-\theta)\begin{bmatrix} m & 0 \\ 0 & 1 \end{bmatrix}\mathbf{R}(\theta)\begin{bmatrix} x \\ y \end{bmatrix}$
`/matrix`	Modifier for `/distort` to create uniform, bilateral, and bulge magnification. $\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix}$

Modifier 3	**Description**
`/rescale`	Modifier for `/distort` to allow rescaling of units for uniform magnification and bilateral magnification distortion (default).
`/constant`	Modifier for `/distort` to prohibit units change. All magnification and distortion is incorporated by interpolation.

Parameter	Description
xonly	Apply rescaling only in the x-direction. Default is both x and y for beam array attribute and x-direction only for radial and annular array attributes.
noxonly	Specifies scaling in both directions for radial and annular array attributes. (default)
polar	Convert Cartesian form of complex number ($a + bi$) to amplitude and phase form (ae^{iw}) before interpolation. Produces best results where the phase is smoothly varying (default).
rect	Do not convert to polar form. Interpolate amplitude values in Cartesian form ($a + bi$). May produce better results for discontinuous phase.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
xrad, yrad	Field radii (/field).	
xrad, yrad	Fraction that beam fills array (/beam).	“optimum units”
xunits, yunits	New units.	1., 1.
xscale, yscale	Scale factor, expands or compresses array by specified value.	1., 1.
xdec, ydec	Decenter array by factor for /shift.	0., 0.
magnification	Magnification for rescale/distort/azimuthal.	1.
azimuthal	Azimuthal orientation for rescale/distort/azimuthal.	0.
m11, m12, m21, m22	Magnification for rescale/distort/matrix.	1., 0., 0., 1.

RESONATOR Set up and run resonators. Language

Command Forms(s): **RESONATOR**

```
resonator/name             (Macro name)
resonator/eigen/test       k1...kn
resonator/eigen/list
resonator/eigen/set        beam xmode ymode
resonator/eigen/reset      kbeam
resonator/eigen/off        k1...kn
resonator/eigen/allow      [gain] [plot] [thermal] [udata] [pause]
resonator/eigen/restrict   [gain] [plot] [thermal] [udata] [pause]
resonator/eigen/clear
resonator/run              times [list]
```

Description: RESONATOR

Resonator is a controller which facilitates the analysis of resonators and periodic beam guides. The resonator is defined in a macro and the macro name is specified by the resonator/name command. resonator operates on the specified macro to calculate the paraxial properties, set appropriate initialization parameters, and assure constant numerical processing for each pass. Any system may be described in the macro.

A preliminary analysis may be performed to calculate the paraxial eigenmode behavior with the `/eigen/test` command. ABCD matrices for the specified beams are initialized to the unit matrix by the `/eigen/test` command. Only the commands `dist`, `prop`, `lens` , `lensgroup` , `mirror`, `axicon` , and `abcd` effect the ABCD calculation. Use `/noadjust` as the second modifier on the `clap` command to insure that the gaussian mode is not recalculated. If the resonator is stable, GLAD will calculate the gaussian beam which is the lowest-loss eigenmode. This requires that the correct wavelength have been specified before the resonator was run. If the resonator is unstable, the geometric eigenradii are displayed. For every unstable resonator there are two phase radii which will be reproduced in a round trip according to paraxial theory. The eigenradius which has magnification greater than unity is the logical choice for a starting wavefront to find the lowest-loss mode of the unstable resonator.

The command `/eigen/set` specifies the expanding or collapsing mode for unstable resonators. GLAD uses the units which were current when `/eigen/test` was called. Alternatively the parameter `res` may be specified on the `/eigen/set` line to cause the units to be calculated when the gaussian eigenmode is formed. The wavelength should have been correctly set before performing this analysis. For a stable resonator, the complex amplitude of the beam is set to the paraxial eigenmode. For unstable resonators, there is no preferred complex amplitude, only the phase radius is significant. GLAD does not reset the complex amplitude distribution for the unstable resonator starting condition—only the radius of curvature.

Normally the `resonator` command will reset the surrogate gaussian beam properties at the beginning of each pass. `/eigen/off` may be used to turn off resetting the surrogate parameters at the start of each pass.

The `resonator/run` command executes the macro the specified number of times. Execution of both the macro and `resonator/run` may be terminated by the `macro` `/exit` command (if the last level macro is reached), which may be placed in an `if` command to test for convergence. `resonator/run` may be interrupted with from Controls, on the Interactive Input Window. just as with `macro` `/run`. The calculation will continue to the end of the current pass and stop.

Modifier 1	**Description**
`/name`	Sets the macro name to the character string given by the parameter.
`/eigen`	Controls eigenmode and eigenradii calculations.
`/run`	Execute the macro.

Modifier 2	**Description**
`/test`	Evaluate the eigenfunctions by ABCD analysis and store the units, divergence, axial reference position, and surrogate gaussian waist size and phase radius. These values are compared with the current values at the start and end of each pass. The surrogate gaussian mode should be an eigenmode of the system for the most numerically stable calculation.
`/list`	For `/eigen/list` lists the round-trip ABCD and eigenmode properties. Also checks that the specified beams have their units, direction, and orientation returned to the initial conditions, as set by `/eigen/test`.
`/set`	Specifies the expanding mode (1) or collapsing mode (2) for an unstable resonator according to the beam sequence number used in `/eigen/test`.

Modifier 2	Description (Continued)
/reset	Reset to parameters from /set but without redefining the eigenmode distribution. Useful to trim the various operating parameters so that they do not drift.
/build	Same as /set.
/off	Turn off resetting of the specified beam at the start of each resonator pass.
/allow	Allow one or more of the following commands in the resonator/eigen/test testing operation: gain, plot, thermal, udata, and pause. These commands are restricted by default. Example: resonator/eigen/allow plot udata
/restrict	Restrict one or more of the following commands in the resonator/eigen/test testing operation: gain, plot, thermal, udata, and pause. These commands are restricted by default.
/clear	Clear resonator/eigen/test mode. Useful if the test is interrupted.

Numerical Values	Description	Defaults
k1 . . . kn	List of beams to be selected. A maximum of nine beams is allowed.	
beam	Position in the sequence of beams defined in following /eigen/test.	1
xmode, ymode	1, expanding mode for unstable resonator 2, collapsing mode for unstable resonator. Ignored for stable resonator.	1
times	Number of times to perform resonator/run.	

Systen Variable Data	Description
resonator/(mod) mod = mag, ymag, radius, yradius, ewaist, yewaist, ezwaist, yezwaist, stable, ystable, opl, oply, ppl , roundtriptime, gouy, status	Round-trip properties of macro operated with resonator. X- and y-values of magnification, phase radius, eigenwaist, eigenwaist location, stability criterion for x and y, optical path length in x and y direction for roundtrip, physical path length in round trip, round trip time, and Gouy shift. status takes the integer values: 0, not in resonator mode; 1, normal resonator mode; 3, first pass of resonator test; 4, second pass of resonator test;

Example

```
macro/def reson/o
 prop 45 # propagate 45 cm.
 mirror/sph 0 -50 # mirror of 50 cm. radius
 clap/c/n 0 .14 # .14 cm. radius aperture
 prop 45 # propagate 45 cm. along beam
 mirror/sph 0 1.e15 # flat mirror
 energy/norm 1 1 # renormalize energy
macro/end
wavelength 0 1.064 # set wavelength
units 0 .005
resonator/name reson
resonator/eigen/test 1 # test resonator macro
resonator/eigen/set 1 # set beam 2 to eigen mode
clear 1 1 # start with a plane wave in beam 2
energy/norm 1 1 # normalize energy
reson/run 100 # run resonator 100 times
```

See Example Ex13 for a more detailed example of the use of the `resonator` commands.

RMS — Calculates wavefront rms. — Diagnostics

Command Forms(s): **RMS**

```
rms/wavefront    ibeams threshold
rms/irradiance   ibeams threshold
```

Description: RMS

Calculates wavefront or irradiance RMS.

$$\text{wavefront RMS} = \sqrt{\frac{\iint I(x,y)W(x,y)^2\,\mathrm{d}x\mathrm{d}y}{\iint I(x,y)\,\mathrm{d}x\mathrm{d}y} - \left(\frac{\iint I(x,y)W(x,y)\,\mathrm{d}x\mathrm{d}y}{\iint I(x,y)\,\mathrm{d}x\mathrm{d}y}\right)^2} \qquad (196)$$

$$\text{irradiance RMS} = \sqrt{\frac{\iint I(x,y)^2\,\mathrm{d}x\mathrm{d}y}{\iint \mathrm{d}x\mathrm{d}y} - \left(\frac{\iint I(x,y)\,\mathrm{d}x\mathrm{d}y}{\iint \mathrm{d}x\mathrm{d}y}\right)^2} \qquad (197)$$

Modifier 1	Description
`/wavefront`	Calculate rms of wavefront (default).
`/irradiance`	Calculate rms of irradiance.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`threshold`	Ignore points with irradiance lower than this relative threshold value.	0.

System Variable Data	Description
`rms`	Rms wavefront error of beam, same as variance. Computed by `variance`.

ROD — Calculates effect of circular walls. — Component

Command Forms(s): **ROD**

```
rod         kbeam radius phase
```

Description: ROD

Calculate propagation in a cylindrical rod treating the cylindrical walls as perfectly reflecting. The method uses the method of images to construct an image of the region interior to radius. This gives the nearest neighbor. Higher order images may be created by using the `rod` command more than once and doubling the radius for each call after the first.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`radius`	Radius of the cylinder.	
`phase`	Phase of reflected light (degrees).	180

ROOF Roof prism. Component

Command Forms(s): **ROOF**

```
roof/ns/(modifier 2)     kbeam
roof/ew/(modifier 2)     kbeam
roof/nesw/(modifier 2)   kbeam
roof/nwse/(modifier 2)   kbeam
```

Description: ROOF

This command implements a roof mirror system. The modifiers `ns`, `ew`, `nesw`, and `nwse` give the direction of the roof axis.

Modifier 1	Description
`/ns`	Roof edge runs from (0.,1.) to (0.,-1.).
`/ew`	Roof edge runs from (-1,0.) to (1.,0.).
`/nesw`	Roof edge runs from (1.,1.) to (-1.,-1).
`/nwse`	Roof edge runs from (-1.,1.) to (1.,-1.).

Modifier 2	Description
`/global`	Acts as global mirror and must be used with other `mirror/global` and `lensgroup` (default).
`/nonglobal`	Acts as paraxial mirror and should be combined with `mirror` and `lens` commands—not with global commands.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1.

ROTATE Rotate distribution in the array. Operator

Command Forms(s): **ROTATE**

```
rotate       kbeam theta xdec ydec [(polar or rect)]
```

Description: ROTATE

This command rotates the distribution in pixel by pixel fashion by the angle `theta` around the axis of propagation. Positive rotation is counterclockwise. The rotation is about the coordinate (`xdec`, `ydec`). Rotation of large arrays is slow, because of the need to swap memory blocks.

Parameter	Description
polar	Convert Cartesian form of complex number ($a + bi$) to amplitude and phase form (ae^{iw}) before interpolation. Produces best results where the phase is smoothly varying (default).
rect	Do not convert to polar form. Interpolate amplitude values in Cartesian form ($a + bi$). May produce better results for discontinuous phase.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
theta	Rotation angle in degrees (counterclockwise).	0
(xdec, ydec)	Pivot point for rotation.	(0., 0.)

SAMPLING Check for adequate sampling and aliasing. Diagnostics

Command Forms(s): **SAMPLING**

```
sampling/list         kbeam
sampling/control/list kbeam
sampling/control/on   kbeam xlimit ylimit
sampling/control/off  kbeam
```

Description: SAMPLING

This command checks the relative power at the Nyqyist limiting frequency. Relative powers below about 1×10^{-3} generally indixate aliasing is low. Relative powers above about 1×10^{-2} generally indicate aliasing is significant.

Modifier 1	Description
/list	List relative power at Nyqyist frequency in x- and y-directions.
/control	Control sampling checking.

Modifier 2	Description
control/list	List sampling control status.
control/on	Turn sampling error checking on for specified beam.
control/off	Turn sampling error checking off for specified beam.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
xlimit	Maximum relative power at Nyquist frequency in x-direction.	
ylimit	Maximum relative power at Nyquist frequency in y-direction.	xlimit

Systen Variable Data	Description
sampling/x	Relative power at Nyquist frequency in x-direction (default).

Systen Variable Data	Description (Continued)
`sampling/y`	Relative power at Nyquist frequency in y-direction.

SERVER Controls and lists server mode status. Language

Command Forms(s): **SERVER**

```
server/start
server/end
server/list
```

Description: SERVER

Controls and displays the status of server mode. For AOR use.

Modifier 1	Description
`/start`	Start server mode.
`/end`	End server mode.
`/list`	List status of server mode.

SET Set various system values. Begin-end

Command Forms(s): **SET**

```
set/color
set/monochrome
set/density                        xdensity ydensity
set/frame/(on or off)
set/label/(list, on, off)
set/grid                           xmajor xminor ymajor yminor
set/maxopen                        maxopen
set/window/all
set/window/center-width            xrad yrad xdec ydec
set/window/relative                xmin xmax ymin ymax
set/window/absolute                xmin xmax ymin ymax
set/window/list
set/ctlc_abort/(list, on, off)
set/negedge/(list, on, off)
set/plot_number                    number
set/camera                         elevation azimuth distance
set/demobell/(list, on, off)
set/map_color/(list, set, choices) beam_no_plot color_no
set/cpu                            ncpu
set/singlestep/(list, on, off)
set/plot_slice_list(list, on, off)
```

Command Forms(s): **SET (Continued)**

```
set/section                          kbeam section
set/traceback/(list, on, off)
set/folder                           (foldername)
set/random                           type
set/negativeprop/(list, on, off)
set/numberofcolors                   number
set/decphase/(on, off)
set/strict/(on, off)
set/alias_stop/(list, on, off)
set/highlight/(list, on, off)
set/keep_log/(list, on, off)
set/gladdiagnosticlog/
(list, on, off)
set/definitions/(list, on, off)
set/cursor_track/(list, on, off)
set/maclib/(hide, show)
set/prescan/(list, on, off)
```

Description: SET

Selects parameters for various functions.

Modifier 1	Description
`/color`	Use color in plots.
`/monochrome`	Use no color in plots. Also see `set/numberofcolors`.
`/density`	Sets the density of plot lines.
`/frame/(on or off)`	Sets frame of plots on (default) or off.
`/label/(on or off)`	Sets labels of plots on (default) or off.
`/grid`	Set major and minor tick marks for `plot/udata`.
`/window`	Sets the plotting window for `plot/isometric`, `plot/orthographic`, `plot/elliptical`, `plot/vector`, and `plot/contour`.
`/windows/list`	List plotting window status.
`/window/all`	Resets plotting window to entire data field.
`/window/center-width`	Sets plotting window by x- and y-halfwidths and center position (default).
`/window/relelative`	Sets plotting window. Limits expressed as a percent of total field. 0% at right and bottom to 100% at left or top.
`/window/absolute`	Sets plotting window. Limits expressed in user coordinates.
`/window/orthographic`	Toggles orthographic mode on or off.
`/ctlc_abort`	Sets abort on double strike of Ctl-Brks on or off.
`/negedge`	Allows negative edge thicknesses (on) or not (off).
`/plot_number`	Sets the plot number.

Modifier 1	**Description (Continued)**
/camera	Set camera parameters for plot/bitmap/./(wireiso, paintiso, or contpaintiso).
/socketdelay	Sets delay to prevent GLAD from writing data too rapidly to the TCP/IP socket when connected to the IDE.
/demobell	In demonstration mode.
/map_color	Display or change mapping of colors to beam numbers.
/cpu	For the 64 bit version of GLAD, the number of CPU's will automatically be set to the maximum number of processors available from 1, 2, 4, 8, and 16 processors (powers of 2). For the 32 bit version use command set/cpu 2 to use 2 processors (if available) to increase speed from 30% to 40% for large arrays.
/singlestep	Pause before all non-interactive commands for debugging. Also see Glad Editor menu item SingleStep.
/plot_slice_list	Causes data from plot/xslice and plot/yslice to be output. May be written to an output file using write/disk fname. set/plot_slice_list/on write/disk/on xxx.txt/over plot/x/i 1 write/disk/off/close set/plot_slice_list/off
/section	Set x-y section of 3D array. So regular 2D operations may be conducted on that section.
/traceback	Turn traceback window on or off.
/folder/(list, string, popupmenu)	List or specify working folder from command line. Current folder is listed on the IDE title. Specifying a string will cause the current directory to change for GLAD, IDE, and Watch. Popupmenu initiates a dialog box for selection of the current folder.
/random	Sets random number generator routine by type.
/negativeprop	Allows propagation in negative direction to reach a vertex placed behind the current global position of the beam. Negative propagation is not recommended as it constitutes a nonphysical effect and apertures and some other components will not be correctly modeled. Many ray trace codes allow negative propagation so this feature is provided for compatibility.
/numberofcolors	Set the number of colors to 1, 6, or 13 for plot/liso , and other non-bitmap style plots. Computer display must be set to at least 256 colors for 13 color representation to work properly.
/decphase	Set on (default) or off phase decoding to remove 2π breaks in plots.
/strict	Variables must be formally declared in variables /declare statement.
/alias_stop	Stop if aberration being entered is aliased due to more than π phase change per pixel. Implemented for /abr/ast, /abr/focus, and /abr/tilt. Also, see sampling that checks current complex amplitude distribution.

Modifier 1	**Description (Continued)**
/highlight	Not active in Ver. 5.2. Turn text lighting in GladEdit on or off. The TraceBack window must be active to see highlighting. The command line currently being processed is highlighted to display program activity.
keep_log	If keep_log is set, diagnostic information will be written to glad.log. Primarily for AOR use.
gladdiagnosticlog	If gladdiagnosticlog is set, keep_log will always be set and diagnostic information will be written to glad.log. Primarily for AOR use.
/definitions	Set listing on or off of definitions of terms in the output tables.
/cursor_track	Turn cursor tracking on or off. When on cursor follows the highlighting so that the highlighted text is always visible. This mode is considerably slower than the default of (off).
/maclib	set/maclib/show makes the macro library window visible.
/prescan	Control prescan. When prescan is “on” the whole command file is checked for macro definitions and some errors before execution begins.

Modifier 2	**Description**
/on	Activates feature.
/off	Deactivates feature.
/list	List current values.
/choices	List choices of color numbers for set/map_color.
/map_color	Set color numbers (color_no) with beam numbers () for set/map_color.
/string	String for set/folder.
/popupmenu	Create dialog box for selection of current folder for GLAD, IDE and Watch.
/show	Show macro library window.
/hide	Hide the macro library window.

Numerical Values	**Description**	**Defaults**
xdensity	The number of points to plot in the X-direction.	21
ydensity	The number of points to plot in the Y-direction.	xdensity
xmin, xmax, ymin, ymax	Plot field for /window/abs or /window/rel.	
xrad, yrad, xdec, ydec	Plot field for /window/center-width.	
xmajor, xminor, ymajor, yminor	Number of major and minor grid elements for horizontal and vertical axes of plot/xslice, plot/yslice and plot/udata.	4, 5, 5, 5
maxopen	Maximum number of IO units allowed. Do not change.	
elevation, azimuth, distance	Camera elevation angle, azimuth angle and distance for plot/bitmap /./(wireiso, paintiso, or contpaintiso).	
milliseconds	Delay between writes to TCP/IP socket in milliseconds.	100
number	Plot number.	
beam_no_plot	Beam number for set/map_color.	

Numerical Values	Description (Continued)	Defaults
color_no	Set color number associated with beam number for set/map_color.	
ncpu	Number of CPU's for /set/cpu. For GLAD 32 bit the maxium number is 2. For GLAD 64 up to 16 CPU's may be used but due to thread overhead the fastest speed is usually found with 4 to 6 CPU's.	
section	Number of x-y section to be selected in 3D array.	
type	Random number type for set/random. Select 0, 1, or 2 for different random number generators. Type 2 is default and preduces good results although other types are somewhat faster.	2

SFG Sum frequency generation. Laser gain

Command Forms(s): **SFG**

```
sfg        zstep chi2 nstep deltak [(pattern)] [list]
```

Description: SFG

This command implements sum frequency generation following the development in Sect. 9.10, GLAD Theory Manual (theory.pdf). Two beams of optical frequencies ω_1 and ω_2 are mixed in a crystal to create a beam of ω_3 such that $\omega_1 + \omega_2 = \omega_3$. For example beams of 1.06 micron and 10.6 micron wavelength may be mixed to create a beam of 0.963636 micron wavelength, as illustrated in Ex107. The beams to be used are defined by pack/set.

String	Description
pattern	The pattern consists of three letters, the letters being either "o" or "e", where "o" or "e" indicates o- or e-ray polarization to be used for the pump, signal, or idler beams respectively. For example "oeo" indicates ordinary ray (x-polarization) for pump, extraordinary ray (y-polarization for signal), and ordinary ray (x-polarization) for idler beams.

Parameter	Description
list	List overall parameters and center point properties.

Numerical Values	Description	Defaults
zstep	Step length.	0.
chi2	$\chi^{(2)}$, second order nonlinear coefficient. See Sect. 9.10, GLAD Theory Manual (theory.pdf).	0.
nstep	No longer used. Always set to 1.	50
deltak	Δk to treat any mismatch of the frequency of Beam 3 in the case where Beam 3 is injected with finite magnitude. Normally this term is zero. The detuning effect of wavefront slope errors (due to aberration) on Δk are handled by using multiple diffraction steps as illustrated in Ex107.	0.

SFOCUS Self-focusing. Laser gain

Command Forms(s): **SFOCUS**

```
sfocus/one   kbeam alpha z
sfocus/two   kbeam1 kbeam2 alpha z
```

Description: SFOCUS

This command does self focusing. The GLAD feature set is required. It adds an intensity-dependent phase of the form

\one

$$a \rightarrow a e^{j\frac{2\pi}{\lambda}\mathtt{alpha}\,\mathtt{z}\,I} \tag{198}$$

\two

$$a_1 \rightarrow a_1 e^{j\frac{2\pi}{\lambda}\mathtt{alpha}\,\mathtt{z}\,I_2} \tag{199}$$

where for `/one`, I is the intensity of Beam 1 and a is the complex amplitude. For `/two`, a_1 is the complex amplitude of Beam 1, and I_2 is the intensity of Beam 2. Also see `int2phase` and `int2waves`.

Modifier 1	Description
`/one`	Self-focusing due to intensity of single beam.
`/two`	Self-focusing due to intensify of a second beam. Allows, time integration.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`kbeam1`, `kbeam2`	Phase of Beam 1 due to intensity of Beam 2.	`1, 2`
`alpha`	Self-focusing coefficient cm^2/watt.	`0.`
`z`	Propagation distance (cm).	0.

Example of self focusing

Consider the case of propagation of a beam through an optical path with axial flow of air. The thermal blooming theory assumes transverse flow so it may not be applied to this problem directly.

The index of refraction varies with temperature rise ΔT

$$\Delta n = -79\times10^{-6}\frac{P}{T^2}\Delta T \tag{200}$$

where P is in millibars and T is in degrees Kelvin. The equation may also be written

$$\Delta n = -(n_0 - 1)\frac{P_{rel}}{T_{rel}}\frac{\Delta T}{T} \tag{201}$$

where P_{rel} is the relative atmospheric pressure and T_{rel} is the relative temperature with respect to standard temperature and pressure (STP) and n_0 is the index of refraction at 10.6 μ and STP, $n_0 = 1.00027\times10^{-6}$. The temperature rise is a function of the time the air has been irradiated, which in the case of axial flow of the air is related to the position z along the axis

$$\Delta T = \frac{\alpha z}{v\rho C}I(x, y) \tag{202}$$

where

$I(x, y)$ is the intensity at point (x, y) [J/sec/m^2]

z is the position [m]

α is the attenuation constant [m$^{-1]}$

ρ is the density [kg/m^3]

C is the absolute specific heat [J/kg/deg]

v is the velocity of the air in the axial flow [m/sec]

The mean temperature rise is

$$\langle \Delta T(z)\rangle = \frac{\alpha z_{\max}}{2\rho C v}, \tag{203}$$

assuming the irradiance is not significantly depleted by the atmospheric absorption. The phase change as a function of the total path is

$$\phi = -\frac{2\pi}{\lambda}(n_0 - 1)\frac{P_{rel}}{T_{rel}}\frac{\Delta T}{T}z_{\max} \tag{204}$$

The coefficient for self-focusing with the `sfocus` command is

$$\texttt{alpha} = -(n_0 - 1)\frac{P_{rel}}{T_{rel}}\frac{\Delta T}{T} = -(n_0 - 1)\frac{P_{rel}}{T_{rel}}\frac{1}{T}\frac{\alpha z_{\max}}{2\rho C v}\ \text{m/w} = -(n_0 - 1)\frac{P_{rel}}{T_{rel}}\frac{1}{T}\frac{\alpha z_{\max}}{2\rho C v}100\ \text{cm/w} \tag{205}$$

n_0	index of refraction at STP
P_{rel}	relative pressure
T_{rel}	relative temperature with respect to 288°K
ΔT	temperature rise due to absorption
T	temperature of the atmosphere
$z_{\max}$	Propagation length

Table. 22. Physical and optical constants for air.

incremental index of refraction (10.6 μ)	2.74×10^{-4}
density [kg/m^3]	1.226
conductivity [w/mK]	0.02525
specific heat [J/kgK]	1017

SHIFT Shift distribution in the array. Operator

Command Forms(s): **SHIFT**

```
shift/polar          kbeam deltar azdeg
shift/cartesian      kbeam xdec ydec
```

Description: SHIFT

This command shifts the distribution laterally by amount `deltar` in the direction defined by the clockwise polar angle `azdeg`. The shift is done by Fourier transform methods so the movement is continuous and wraps around. Large shifts will cause the distribution to reappear on the other side of the array. See also `rescale /shift` which shifts by linear interpolation and does not wrap.

Modifier 1	**Description**
`/polar`	Polar coordinates used for shift (default).
`/cartesian`	Cartesian coordinates used for shift.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`deltar`	Magnitude of shift for `/polar`.	`0.`
`azdeg`	Polar angle defining direction of shift. (clockwise from vertical) for `/polar`.	`0.`
`xdec`, `ydec`	Cartesian coordinates of shift for `/cartesian`.	`0.,0.`

SINC Define sinc function. Begin-end

Command Forms(s): **SINC**

```
sinc          kbeam peak widthx widthy xdec ydec
```

Description: SINC

Defines a sinc function.

$$\text{amplitude,}\ \ \mathrm{sinc}(x,y) = \frac{\sin\left(\dfrac{\pi x}{\mathtt{widthx}}\right)}{\dfrac{\pi x}{\mathtt{widthx}}}\,\frac{\sin\left(\dfrac{\pi y}{\mathtt{widthy}}\right)}{\dfrac{\pi y}{\mathtt{widthy}}} \qquad (206)$$

Numerical Values	Description	Defaults
kbeam	Single beam number (/one).	1
peak	Peak intensity value.	
widthx	Width of first zero, x-direction.	
widthy	Width of first zero, y-direction.	
xdec	Decenter in x-direction.	0
ydec	Decenter in y-direction.	0

SLAB Various commands for waveguide slabs. Component

Command Forms(s): **SLAB**

slab/hoe/(cir or sqr)	clx xdec ydec zdec
slab/hoe/(ell or rec)	clx cly xdec ydec zdec
slab/hoe/ecoef	kte
slab/hoe/mcoef	ktm zktm
slab/out/(nodist or dist)	gbeam rbeam
slab/in/(nodist or dist)	rbeam1 rbeam2 gbeam
slab/list	
slab/pump/gaussian/(modifier 3)	kout peak w0 lambda absorption m2 decenter reflectance
slab/pump/coherent	kin kout absorption reflectance
slab/waveguide	kstart kindex kresult
slab/eigenmode/index/(te or tm)	kbeam halfheight film substrate cladding order
slab/eigenmode/mode/(te or tm)	kbeam halfheight film substrate cladding order
slab/normal	kbeam1 kbeam2

Description: SLAB

Slab is the general command for waveguide coupling. The GLAD feature set is required. A one dimensional array may be defined using the array command. For example,

```
array/set 1 128 1
```

defines Beam 1 to have a width of 128 elements in the x-direction and 1 element in the y-direction. The one dimensional beam may be operated upon and evaluated as with other beams. The units in the y-direction may be set to any desired value. The value affects the calculation of energy and other parameters that depend on the area associated with each matrix element.

The slab command defines the focus position of a the radiated mode resulting from diffraction of the guided mode by a focusing grating coupler. The slab/hoe command defines the location of the focus point of the grating, the aperture of the grating, and the coupling coefficient and its functional form. slab/out propagates an incident guided mode gbeam underneath the grating and creates a radiation mode rbeam. Slab/in takes an incident radiation field rbeam1 and multiplies it by the normalized mode `rbeam2` to create the guided mode `gbeam`. The guided mode `rbeam2` should be formed by creating a radiation mode with `slab/out` from a unit amplitude guided beam.

`Slab/pump` allows modeling of side pumping of a slab or gain sheet. Figure 27 shows a side pumping configuration. Side pumping may treated coherently using any starting 1D distribution or incoherently using a gaussian distribution.

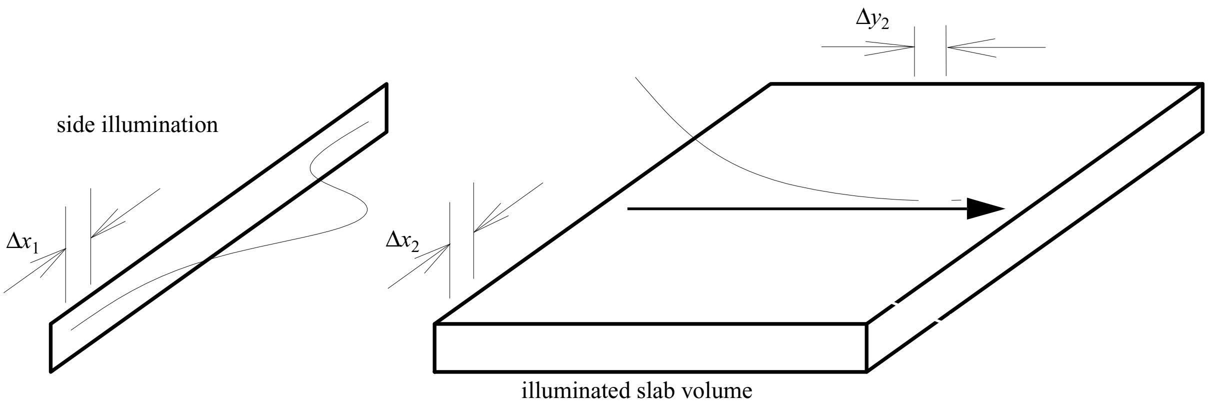


Fig. 27. A 1D beam (assumed to vary in *x* and be constant in *y*) is used to side pump a slab or a gain sheet. The pixel spacings for the x-direction should match, $\Delta x_1 = \Delta x_1$. The incident beam is propagated along the y-direction using steps of Δy_2. The incident beam $I(x)$ has units of irradiance [w/cm^2]. The absorbtion factor α results in a deposited energy density of $U(x,y)$ with units [w/cm^3]. $U(x, y) = \alpha I(x)$.

Modifier 1	**Description**
`/hoe`	Specifies properties of the grating.
`/out`	Outcoupler.
`/in`	Incoupler.
`/list`	Display properties.
`/eigenmode`	Calculate effective index or eigenmode shape for slab waveguide.
`/pump`	Model side pumping of a slab or gain sheet.
`/waveguide`	Implement 2D waveguide model.
`/normal`	Normalize `kbeam1` taking into account units of `kbeam2`.

Modifier 2	**Description**
`/cir`	Circular aperture.
`/sqr`	Square aperture.
`/ell`	Elliptical aperture.
`/rec`	Rectangular aperture.
`/ecoef`	Set coupling coefficient for TE.
`/mcoef`	Set coupling coefficients for TM.
`/dist`	Use diffraction propagation.
`/nodist`	Ignore diffraction (default).
`/index`	Calculate effective index for `/eigenmode`.
`/mode`	Calculate eigenmode shape for `/eigenmode`.

Modifier 2	**Description (Continued)**
/gaussian	Pump a 2D array (kout) with an incoherent gaussian into kout to create an energy density distribution. See Fig. 27. The gaussian beam is calculated from the values of the command line including an M^2 factor to increase the divergence.
/coherent	Pump a 2D array (kout) with a 1D beam from the side. Input beam is a line source in the x-direction and is assumed to be of infinite width in the y-direction. The input beam has dimensions of w/cm^2. The output has units of energy density, w/cm^3. See Fig. 27.

Modifier 3	**Description**
/te	Calculate for TE mode.
/sqr	Calculate for TM.
/top, /bottom, /left, /right	/slab/pump from respective direction.

Numerical Values	**Description**	**Defaults**
gbeam	Guided beam (one dimensional).	1
rbeam	Radiated beam (two dimensional).	2
rbeam1	Incident radiated beam (two dimensional).	
rbeam2	Normalized radiated mode (two dimensional).	
c0, c1x, c1y, c2	Loss per centimeter of grating Coef = $\mathtt{c0} + \mathtt{clx} \bullet x + \mathtt{cly} \bullet y + \mathtt{c2} \bullet (x^2 + y^2)$	
clx, cly	Clear aperture dimensions of grating.	
decenter	Decenter of gaussian for slab/pump/gaussian in positive x- or y-direction.	0.
xdec	X-coordinate of focus slab/hoe.	0.
ydec	Y-coordinate of focus.	0.
zdec	Z-coordinate of focus.	1.
kstart	Beam to be propagated with slab/waveguide.	1
kte	Coupling coefficient for TE.	
ktm, zktm	Coupling coefficients for TM: transverse and Ez component.	
kindex	Array of index distribution at each step through the waveguide medium for slab/waveguide.	2
kresult	Result of the calculation for slab/waveguide.	3
kbeam	Single beam number.	1
halfheight	Half height of film layer for slab for /eigenmode.	
film	Index of film for /eigenmode.	
substrate	Index of substrate for /eigenmode.	
cladding	Index for cladding (top layer) for /eigenmode.	
order	Order of mode for /eigenmode.	
kin	Input 1D beam ($N \times 1$) for slab/pump/coherent. Kin is a line source $I(x)$ varying in the x-direction and assumed to be constant in the y-direction with units of w/cm^2.	

Numerical Values	Description (Continued)	Defaults
kout	Output 2D beam for slab/pump. Kout is the output energy density in terms of w/cm^3.	
absorption	Absorption coefficient [cm^{-1}] for slab/pump.	0.
reflectance	Rear wall reflection reflection coefficient for slab/pump. If non-zero, part of the beam is reflected backward.	0.
peak	Peak of the gaussian beam for slab/pump /gaussian.	
w0	Gaussian radius for slab/pump/gaussian.	
lambda	Wavelength of the pumping light in microns.	
m2	M-squared value. m2 > 1 causes the pump beam to diverge more rapidly.	

SNOISE Spontaneous emission noise for RRAMAN (obsolete) Laser gain

Command Forms(s): **SNOISE**

```
snoise     zstep ipump istokes rchi ichi wmole press temp
```

Description: SNOISE

Applies spontaneous emission. The GLAD feature set is required. Must be preceded with pakfld command. Not complete.

Numerical Values	Description	Defaults
zstep	Distance.	
ipump	Beam number of pump beam.	
istoke	Beam number of Stoke's beam.	
rchi	Real component of Chi.	
ichi	Imaginary component of Chi.	
wmole	Molecular weight of medium.	
press	Ambient pressure (Torr).	
temp	Ambient temperature (K).	

SPIN Expand diagonal into rotationally symmetric function. Operator

Command Forms(s): **SPIN**

```
spin       kbeam real imaginary
```

Description: SPIN

Rotates the center row to generate a rotationally symmetric function. Real and imaginary define the complex fill values to pad the parts of the square array outside the circular region. A circular array may be generated, taking advantage of the faster calculation times of an N × 1 array and then copy /row used to transfer the circular array to the center row of a square array. spin will then complete the generation of the rotational distribution in the square array. See Example Ex96 .

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1
`real`, `imaginary`	Complex amplitude values used to pad outer regions of square array.	`0.`, `0.`

SPLIT Divide aperture into complementary parts. Operator

Command Forms(s): **SPLIT**

```
split/transmission    input transmission output
split/beam            input mask output
split/cir/(modifier 2)    ibeams r0 sgxp decx decy
split/sqr/(modifier 2)    ibeams r0 sgxp decx decy
split/ell/(modifier 2)    ibeams r0x r0y sgxp decx decy
split/rec/(modifier 2)    ibeams r0x r0y sgxp sgyp decx decy
```

Description: SPLIT

`Split/beam` applies a transmission factor with output (optionally) taking the residual values. spit/beam simulates a beam splitter where the splitting is specified by the irradiance values of mask.

`Split/cir`, `sqr`, `ell`, or `rec` splits the complex amplitude of the aperture into exactly complementary parts to make a “soft” aperture based on a gaussian function. The two parts can be coherently added to exactly reproduce the original function. If the second modifier is `/out` the outer portion of the aperture is retained. `/in` keeps the inner part of the beam. The command is very similar to the `gaussian` command. The complex amplitude transmission factors are given below.

Modifier 1	Description
`/transmission`	Apply multiplicative transmission factor.
`/beam`	Beam splitter with the splitting determined by the masking function.
`/cir`	Circular distribution.
`/sqr`	Square distribution.
`/ell`	Elliptical distribution.
`/rec`	Rectangular distribution.

Modifier 2	Description
`/inner`	Inner part of beam is kept.
`/outer`	Outer part of beam is kept.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`r0`	1/e amplitude radius or half-width.	`1.`
`r0x`, `r0y`	1/e amplitude radius in x- and y-direction.	1., rox

Numerical Values	Description (Continued)	Defaults
`sgxp, sgyp`	Gaussian/supergaussian exponent in x- and y-direction.	1., sgxp
`decx, decy`	Coordinates of beam center.	0., 0.
`input`	Input beam for `split/beam`.	
`mask`	Transmission function for `split/beam`.	
`transmission`	Transmission for beam splitter function.	0.
`output`	Output beam for `split/transmission` or `split/beam`. If no output beam is specified, only input beam is modified.	

SSD Calculate spectral dispersion due to EO modulation. Component

Command Forms(s): **SSD**

```
ssd          kbeam delta omegam alpha time
```

Description: SSD

Calculates a pupil modifier of the form.

$$a(x, y) \rightarrow a(x, y)e^{j\delta\sin(\omega_m t + \alpha x)} \tag{207}$$

for spatial spectral dispersion (SSD).

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1.
`delta`	Dispersion, δ.	
`omegam`	Modulation frequency, ω_m.	
`alpha`	Spatial variation coefficient, α.	
`time`	Time.	

STATION Marks HTML output with station number. Language

Command Forms(s): **STATION**

```
station/set      station number
station/list
```

Description: STATION

Write a station number to the output. Useful for making an HTML hypertext link.

Modifier 1	Description
`/set`	Increments or sets station number (default).
`/list`	List station settings.

Numerical Values	**Description**	**Defaults**
`number`	Explicitly sets the station number. If no number is given, the number will be incremented by 1 and displayed,	increment by 1

STATUS Gives status information on the beam(s). Diagnostics

Command Forms(s): **STATUS**

```
status/global
status/parax
status/gaussian
```

Description: STATUS

Prints summary information on the beams.

Modifier 1	**Description**
`/global`	Displays global position vector and orientation matrix for each beam (default).
`/parax`	Displays paraxial data for beams.
`/gaussian`	Displays surrogate gaussian beam data.

`status/global` Table Values	**Description**
beam center xg, yg, zg	Global coordinates of beam center.
xb, yb	Approximate measure of beam size. See `fitgeo` for more precise measures.
direction cosines xg, yg, zg	Global direction cosines of the beam direction of propagation.
phase bias radius radx, rady	Radius of reference beam.
parity	Right or left hand parity of the beam. Parity is flipped at each mirror reflection.

`status/global` Table Values	**Description**
beam center xg, yg, zg	Global coordinates of beam center.
xb, yb	Approximate measure of beam size. See `fitgeo` for more precise measures.
direction cosines xg, yg, zg	Global direction cosines of the beam direction of propagation.
phase bias radius radx, rady	Radius of reference beam.
parity	Right or left hand parity of the beam. Parity is flipped at each mirror reflection.

`status/parax` Table Values	**Description**
beam center (x, y)	Paraxial beam center.
beam radius (x, y	Approximate measure of beam size. See `fitgeo` for more precise measures.
field size (x,y)	Half-width of array.
zreff	Location of the beam on the paraxial system axis.
direction	Positive or negative.

status/parax Table Values	**Description (Continued)**
zwaistx, zwaisty	Location of the surrogate gaussian beam.
ip_x, ip_y	1 if beam is referenced to a plane wave.
attrib	Type of array. See the `array` command for definitions.

status/gauss Table Values	**Description**
waist radius xwaist, ywaist	Transverse radius of surrogate gaussian beam.
gaussian phase radius xprad, yprad	Phaser radius of surrogate gaussian beam.
ppl to waist xrdist, yrdist	Physical path length (PPL) to from current beam position to the surrogate gaussian waist position.

STREHL Calculates Strehl ratio. Diagnostics

Command Forms(s): **STREHL**

```
strehl      ibeams
```

Description: STREHL

Prints Strehl ratio and weighted rms wavefront error (more precisely the standard deviation of the wavefront) for specified beam(s).

$$SR = \frac{\left|\sum a(x,y)\right|^2}{\left(\sum |a(x,y)|\right)^2} \tag{208}$$

$$RMS = \sqrt{-\frac{\ln(SR)}{4\pi^2}} \tag{209}$$

where a(x,y) is the complex amplitude.

Note that all phase errors contribute to reduction of Strehl ratio. Use `fitphase` to remove tilt and/or defocus if desired. Note that some laser modes, the Airy pattern, and many other beams contain phase discontinuities as part of their optimal form. Strehl ratio will not give meaningful results when applied to such beams.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`

Systen Variable Data	**Description**
`strehl`	Strehl ratio of `ibeams`.

SURFACE All propagating beams move to global position. Positioning

Command Forms(s): **SURFACE**

```
surface/store    ksurf
surface/define   ksurf xdec ydec zdec xrot yrot zrot
surface/list
```

Description: SURFACE

GLAD has the capability to define vertex rotations about a point displaced from the vertex origin. It is frequently convenient to rotate about the point at which the chief ray intercepts a mirror to study the effects of misalignment. The command `surface` is used to store the surface intercept position and surface coordinate matrix in a table for subsequent access. This allows the user to specify the surface rotation characteristics at one chief ray intercept point and then to use the same information when beams strike the surface at a later point in the beam. The command, `mirror/global` , calculates the surface data. The parameter, `infoonly`, may be specified with `mirror/global` if the command is not to be implemented at that time. The command, `surface/store`, stores the data in a table with a user determined surface number. The command, `surface/list`, displays the table of information.

The surface information may be used by the `vertex/rotate` command by specifying the parameter, surface, and the surface number.

Modifier 1	**Description**
`/store`	Stores current `mirror/global` information in surface table.
`/define`	Store listed global information.
`/list`	Displays surface table information.

Numerical Values	**Description**	**Defaults**
`ksurf`	Surface number (up to 20 surfaces may be defined.	
`xdec`, `ydec`, `zdec`	Location of surface.	
`xrot`, `yrot`, `zrot`	Euler angles of surface rotation (degrees).	

Example

```
mirror/global/conic infoonly 20.         (Global conic mirror sets data.)
surface/store 1                          (Store data for Surface #1.)
surface/list                             (List surface data.)
vertex/rotate/relative surface 1 0 5     (Rotation about surface intercept.)
mirror/global/conic 20.                  (Rotated global conic mirror.)
```

SYSTEM Call system operations outside GLAD. Language

Command Forms(s): **SYSTEM**

```
system/copyfile                  '(source file)' '(destination file)'
system/execute/nowait or wait    'executable file arguments'
system/launch                    'document file'
```

Description: SYSTEM

Calls certain operating system functions. Also see the command `manual` that is specifically designed for opening and controlling Adobe PDF documents.

Modifier 1	Description

`/copyfile`	Copy (source file) to (destination file). Variables may be included in file names. Full path descriptions may be used. File names having internal blanks should be included in single quotes. Example:
	`variable/dec/int i1`
	`i1 = 3`
	`system/copy x.inp x@i1.inp`

`/execute`	Executes a program. May include full path. Single quotes are needed. Example: `system/execute/nowait 'watch.exe plot2.plt'`
`/launch`	Launch (or open) a document such as a *.PDF or *.DOC. The file extension must be associated with an application on users system. Example: `system/launch 'commands.pdf'`

Modifier 2	Description
`/nowait`	GLAD starts executable file and continues (default).
`/execute`	GLAD waits for executable file to be closed.

TABLE Reads a table of user-defined values. Language

Command Forms(s): **TABLE**

```
table/name          (file name)
table/read          c1 c2 c3 c4 c5 c6 c7 c8 c9
table/skip          nskip
table/close
```

Description: TABLE

This command allows numerical data to be read from a user-build file. The command `table/name` defines the file name containing the table of data. The command `table/read` inputs table values, defined by column numbers, into variables or register addresses, determined by the values associated with each column number. Records may be skipped with `table/skip`.

The data file should consists of columns of numeric data. The columns are delimited by one or more blanks or a coma and any number of blanks. A maximum of 9 columns may be used. See the example below. If a zero is entered for one of the register addresses, the associated table value is not stored anywhere.

Modifier 1	Description
`/name`	Identifies the name of the file to be read and rewinds file.
`/read`	Read a data record.
`/skip`	Skip one or more records.
`/close`	Close the table file, so that it may be changed by a text editor.

Numerical Values	Description	Defaults
c1,c2,c3,c4,c5,c6, c7,c8, c9	Variables or register addresses where the table values are to be stored.	0
nskip	Number of records to be skipped.	1

Example data file, table.dat:

```
1,2,3,4,5,6,7,8,9
10 11 12 13, 14, 15,16,17,18
19 20 21 22 23 24 25 26 27
28 29 , 30, 31, 32, 33, 34 35 36
```

Example command deck:

```
c
c define table file name, file is always rewound
c
table/name table.dat
c
c read in nine column values, into matching register numbers
c
declare/real t1 t2 t3 t4 t5 t6 t7 t8 t9
table/read t1 t2 t3 t4 t5 t6 t7 t8 t9
c
c display the 9 values
variables
pause
c
c read in 9 more values into reverse register order
c
table/read t9 t8 t7 t6 t5 t4 t3 t2 t1
variables
pause
c
c skip a table record
c
table/skip 1
c
c read column 8 into t1
c
table/read c8=t1
t1=
```

TARGET Controls target movement for BLOOM command. Aberration

Command Forms(s): **TARGET**

```
target/set   xvelocity yvelocity range
target/list
```

Description: TARGET

This routine establishes necessary values for target velocity and range for the thermal blooming routines. The GLAD feature set is required. The beam crossing velocity is determined by the target motion, the wind velocity, the target range, and the current range (or slant range). It is assumed that the beam is tracking the target so that the crossing velocity of the beam over the atmosphere is:

$$v_{x_{\text{tot}}} = v_{x_{\text{wind}}} - v_{x_{\text{target}}} \frac{\text{slant}}{\texttt{range}} \tag{210}$$

$$v_{y_{\text{tot}}} = v_{y_{\text{wind}}} - v_{y_{\text{target}}} \frac{\text{slant}}{\texttt{range}} \tag{211}$$

$v_{x_{\text{tot}}}, v_{y_{\text{tot}}}$ net beam crossing velocity components

$v_{x_{\text{wind}}}, v_{y_{\text{wind}}}$ wind velocity components

slant current distance of beam from starting point

`range` range of target

See `bloom/set` for more information on defining the thermal blooming parameters. The default modifier is list which lists the current values of the target.

Modifier 1	**Description**
`/set`	Set parameters.
`/list`	List current values.

Numerical Values	**Description**	**Defaults**
`xvelocity`, `yvelocity`	Velocity components (m/sec).	`0.`, `0.`
`range`	Target range (km).	1.

THERMAL Finite-element thermal modeling. Component

Command Forms(s): **THERMAL**

`thermal/material/add/(square` or `nosquare)`	`kb1 kb2 thickness` [(material)]
`thermal/material/register`	`kbeam thickness` [(material)] [(material)] [(material)] [(material)]
`thermal/material/list`	`kbeam`
`thermal/material/dir`	
`thermal/material/delete`	`surface`
`thermal/material/source/(square` or `nosquare)`	`kb1 kb2 coefficient`
`thermal/material/ends`	[(material)]`/temp` [(material)]`/temp`
`thermal/settle/single/(normal` or `radial)`	`kbeam time nstep factor`
`thermal/settle/group/(normal` or `radial)`	`time nstep kb1 kb2 . . . kb9 factor`
`thermal/window`	`kbeam time kb1 kb2 . . . kb9`

Command Forms(s): **THERMAL (Continued)**

```
thermal/lens                    kbeam time r1 r2 kb1 kb2 . . . kb9
thermal/indexarray/isotropic    kbeam young alpha index c1 c2 kb1 kb2
                                . . . kb16
thermal/indexarray/cubic        kbeam young alpha index c1 c2 c3 c4 kb1
                                kb2 . . . kb16
thermal/birefringence           kbeam1 kbeam2
```

Description: THERMAL

The thermal command models the thermal response of transparent optical materials. The structure of the elememt, on which thermal calculations are to be performed, is specified in terms of material arrays. Each array may consist several different types of material: transparent materials, opaque solids, fluids which are considered to be opaque if they are on the sides of the distribution, and insulators. Transparent materials are assumed to be solid (See the bloom commands for thermal blooming in gasses). Transparent materials must be initialized to some finite temperature. These materials have coefficients which define the index of refraction and the thermal expansion coefficient. Where the temperature is set to zero, the array is considered to represent a perfect insulator. The material array may also contain other solid or fluid materials to represent mounting materials, forced air cooling, liquid cooling, etc.

The material array contains the temperature distribution and the material type. The composite materials are designated by composite type numbers as show below.

Table. 23. Composite type numbers.

Composite No.	Description
4	First material added, assumed to be the transparent material (material type 1).
3	The laboratory environment. Must be fluid (material type 2). The composite type is always assumed to exist on either side of the transparent material. Must be initialized to some finite temperature value to distinguish it from an insulator. May be still air, forced air, vacuum, etc.
2	Either mounting material or fluid (material types 3 or 2).
1	Either mounting material or fluid (material types 3 or 2).
0	$T = 0$. Points with zero temperature are assumed to represent perfect thermal insulators and no heat will flow into them. This is set by the zero temperature values defined for the transparent material.

There are five composite types: the transparent material, laboratory environment defining the medium in the front of the element (and optionally the sides of the element), (optionally) two additional materials which define mounting structure and/or fluid contact, and insulator where $T = 0$.

A catalog of material characteristics is given in the file matlib. This file may be edited by the user to add or delete materials. Each material is identified by name. In addition there is a material type number which indicated whether the material is a fluid, transparent refractive element, or solid representing mounting structure.

Table. 24. Material type numbers.

Material Type	State	Transmission Properties	Description
1	solid	transparent	Conduction occurs and convection loss into surrounding fluids. Temperature varies. Usable as optical material. Specifiy heat transfer coefficient in K = KW/m°C and product of density and heat capacity as ρc = KJ/m^3°C. Also specify index of refraction and first and second derivatives of index of refraction and thermal expansion as a function of temperature with respect to some reference temperature T_0. If $T = 0$ a perfect thermal insulator is assumed and no heat will flow into or out of this material.
2	fluid	opaque	Convection but no conduction. Temperature does not vary. Usable as environment. Specify heat transfer coefficient in h= KW/m°C. A fluid is assumed to be opaque except where it is part of the laboratory environment in front of the transparent refractive material.
3	solid	opaque	Conduction but no convection. Temperature varies. Usable as mounting material or environment. Specifiy heat transfer coefficient in K = KW/m°C and product of density and heat capacity ρc = KJ/m^3°C.

Modifier 1	Description
`/material`	Build and lists material sections.
`/settle`	Solves transient thermal interactions for specified time.
`/window`	Optical interactions of `kbeam` with one or more optical sections. Phase aberrations due to the temperature distribution are included as well as absorption from the beam and associated heating of optical materials due to the absorbed laser radiation. The value time determines the time for thermal pumping from the optical beam. No settling takes place. $\Delta OPD = \frac{2\pi}{\lambda_0}\left[\frac{dN}{dT} + (N-1)\alpha\right]L\Delta T\,,\ \Delta T = \frac{I(1-e^{-\alpha L})}{\rho c L}$
`/lens`	Similar to `/window` except radii on the ends of the element may be specified. The optical power varies with the irradiance-averaged temperature of the section at the front and rear of the element.
`/stress/2d/` `greensfunction`	Calculate mechanical stress imposed by gradients in temperature distribution in `kbeam1`. Solution by Greens function approach. Stress array is stored in `kbeam2` in form: $(\sigma_x, \sigma_y)(\tau_{xy}, 0)$ for the real and imaginary words of first polarization state and the real word of the second polarization state. Both `kbeam1` and `kbeam2` should be polarized.
`/indexarray`	Forms an index of refraction array of the thermal stress birefringence effects due to thermal gradients by calculating the integral of temperature along the z-axis from the `k1`-`k9` thermal material arrays and computing Nx, Ny, and Nxy from Young's Modulus, thermal expansion coefficient, and the photoelastic constants. Thermal stress effects may be calculated for isotropic and cubic materials. See Chap. 19, GLAD Theory Manual (theory.pdf) for a description of the theoretical principles involved. The resulting array is packed as (Nx*L, transmission), (Ny*L, Nxy*L) into a polarized data array. The index

Modifier 1	Description (Continued)
`/birefringence`	Optical effect of a special z-integrated index of refraction array where each element is of the form (Nx*L, transmission), (Ny*L, Nxy*L), where the array has polarized form. Such a z-integrated index array will be formed by the `thermal/indexarray` command and includes the effects of Young's Modulus, coefficient of thermal expansion, and photoelastic coefficients. The perturbation effects Δ of index of refraction may be found from the stress components by application of the 6 × 6 photoelastic tensor. As we only need the properties in the x-y plane the tensor may be reduced to 4 × 4 form. isotropic material, $\begin{bmatrix} \tilde{\Delta}_x \\ \tilde{\Delta}_y \\ \tilde{\Delta}_{xy} \end{bmatrix} = -\frac{n_0^3}{2} \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 \\ c_{13} & c_{11} & c_{12} & 0 \\ 0 & 0 & 0 & c_{11} - c_{12} \end{bmatrix} \begin{bmatrix} \tilde{\sigma}_x \\ \tilde{\sigma}_y \\ \tilde{\sigma}_{xy} \\ \tilde{\tau}_{xy} \end{bmatrix}$. cubic material, $\begin{bmatrix} \tilde{\Delta}_x \\ \tilde{\Delta}_y \\ \tilde{\Delta}_{xy} \end{bmatrix} = -\frac{n_0^3}{2} \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 \\ c_{13} & c_{11} & c_{12} & 0 \\ 0 & 0 & 0 & c_{44} \end{bmatrix} \begin{bmatrix} \tilde{\sigma}_x \\ \tilde{\sigma}_y \\ \tilde{\sigma}_{xy} \\ \tilde{\tau}_{xy} \end{bmatrix}$. The stress components are calculated with a Green's function approach and applied in frequency space using the methods of Chap 19, GLAD Theory Manual (theory.pdf).

Modifier 2	Description
`/add`	Used to construct a composite section in `kb1`. If `kb1` = `kb2`, the array is initialized. Each subsequent `/add` adds a new material to the section at points where the section has exactly zero temperature. A maximum of four materials may be included in each section. The real word of `kb2` should contain the temperature. Use the `irradiance` command to convert normal complex amplitude form to a form with the irradiance (representing the temperature) in the real word. If the temperature is zero, that point is considered to be a perfect insulator. For refractive materials, the imaginary word may contain source power information. For a fluid the imaginary word may contain differential values to be added to the convection coefficient. A composite section may consist only of fluid material to be used as the front or rear sections in a group.
`/register`	Used to identify an array as a thermal array. Useful when using `infile` or `connect` to input an array previously created by `thermal/material/add`. `outfile` and `infile` must use unformatted or binary protocol. Must specify thickness and the material names in order as the array was originally defined.
`/dir`	Lists materials in file matlib.
`/list`	List characteristics of composite sections which have been defined.
`/delete`	Delete a thermal surface by surface number.
`/source`	Add an internal heat source to the specified composite section.
`/ends`	Optionally specify fluid characteristics at the front and back of all sections.

Modifier 2	**Description (Continued)**
`/single`	Perform transient thermal solution for a single section.
`/group`	Perform transient thermal solution for a group of sections.
`/isotropic`	Material for `thermal/indexarray` is isotropic, requiring only two independent photoelastic constants, $\begin{bmatrix} \tilde{\Delta}_x \\ \tilde{\Delta}_y \\ \tilde{\Delta}_{xy} \end{bmatrix} = -\frac{n_0^3}{2} \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 \\ c_{13} & c_{11} & c_{12} & 0 \\ 0 & 0 & 0 & c_{11} - c_{12} \end{bmatrix} \begin{bmatrix} \tilde{\sigma}_x \\ \tilde{\sigma}_y \\ \tilde{\sigma}_{xy} \\ \tilde{\tau}_{xy} \end{bmatrix}.$
`/cubic`	Material for `thermal/indexarray` is isotropic, requiring four independent photoelastic constants, $\begin{bmatrix} \tilde{\Delta}_x \\ \tilde{\Delta}_y \\ \tilde{\Delta}_{xy} \end{bmatrix} = -\frac{n_0^3}{2} \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 \\ c_{13} & c_{11} & c_{12} & 0 \\ 0 & 0 & 0 & c_{44} \end{bmatrix} \begin{bmatrix} \tilde{\sigma}_x \\ \tilde{\sigma}_y \\ \tilde{\sigma}_{xy} \\ \tilde{\tau}_{xy} \end{bmatrix}.$

Modifier 3	**Description**
`source/square`	Form absolute value squared of `kb2` and store in imaginary word of `kb1` as source power density (default).
`source/nosquare`	Do not modify the distribution. Real word of `kb2` already contains the correct value for the source power density to be put in imaginary word of `kb1`.
`single/normal`	Normal two-dimensional processing (default).
`single/radial`	Assume radial symmetry.

Parameter	**Description**
(material)	Name of a material from file matlib, where the thermal constants are defined.

Numerical Values	**Description**	**Defaults**
`kb1`, `kb2` . . . `kb9`	Beam numbers used with thermal sections.	
`kbeam`	Section to list for `material/list` or optical beam with `/window` or `/lens`.	
`time`	Time for `/settle`, `/window`, or `/lens`.	
`nstep`	Number of subdivisions of `time` for `/settle`. If `nstep` = 0, GLAD computes the number of steps based on the response time of the fastest material according to $\tau = \rho c \Delta x^2 / \kappa$ where τ is the response time, ρ is the density, c is the specific heat, Δx is the sample spacing, and k is the thermal conductivity.	
`r1`, `r2`	Radii for front and back of element for `/lens`.	
`temp`	Temperature of front or back material for `/ends`.	
`factor`	Increase or decrease automatic selection of thermal steps by `factor` for `/settle`.	0.

Numerical Values	Description (Continued)	Defaults
thickness	Thickness of the section used by settle/group.	
young	Young's Modulus in units of Newtons/cm.	
alpha	Coefficient of thermal expansion in °C^{-1}.	
c1, c2, c3, c4	Photoelastic coefficients. Only c1 and c2 are required for /isotropic. Units of cm^2/N.	
surface	Number of surface in order of definition.	
coefficient	For thermal/material/source, multiply source power of kb2 before storing in kb1.	

THRESHOLD Set low irradiance values to zero. Operator

Command Forms(s): **THRESHOLD**

```
threshold        kbeam threshold
```

Description: THRESHOLD

Sets values below a threshold value to zero. Useful for trimming irradiance noise and associated phase irregularities to zero.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1
threshold	Set values below threshold*peak to zero.	1e-8

TIME Measure elapsed time. Language

Command Forms(s): **TIME**

```
time/init
time/show
time/halt
time/resume
```

Description: TIME

This command controls and displays the elapsed time. Time/show gives the elapsed time from the last time/init.

Modifier 1	Description
/init	Reset timing clock.
/show	Display the elapsed time.
/halt	Halts the timer without resetting the timer.
/resume	Resumes the timing.

System Variable Data	Description
time	Elapsed time from last call to time/show.

TITLE Defines the plot title. Language

Command Forms(s): **TITLE**

```
title/def        (title string)
title/format     (Type) iwidth idec
title/write
```

Description: TITLE

Defines and controls the title for plots. The title may be defined by a character string enclosed in single quote marks. If no character string is given, GLAD will use the line following `title/def` as the title. Up to 64 characters may be defined. Most of the plots use less than 64 characters because of the limited space in the plot and the need to have large character sizes for clear visibility. All plots accept 32 characters. `plot/xslice` and `plot/yslice` use 40 characters. `plot/isometric` and `plot/liso` use 48. The right most characters are dropped when the full 64 characters can not be used.

Variables may be used in titles. Preceed the variable by "@". For example `title distance = @z`, will display the current value of `z` in the title. The variables values are automatically updated.

Also see the displayed comment `c`.

Modifier 1	**Description**
`/def`	Defines title by character string on the same line. A maximum of 64 characters will be read. (default)
`/format`	Establishes the format of real register values. The formats are based on Fortran conventions: F(iwidth).(idec), fixed floating point number of Width total characters and Dec numbers to the right of the decimal point; 1PE(Width).(Dec) creates a number with an exponent; 1PG(Width).(Dec) writes in fixed floating point format if the numbers will fit the width or numbers with exponent otherwise. If no format is specified, the current format is printed.
`/write`	Updates and writes the title to the output file. Also see the displayed comment `c`.

Character String	**Description**
(title string)	Character string to be used as a title.
Type	Real register format type. F, G, or E.

Numerical Values	**Description**	**Defaults**
`iwidth`	Width of the real format.	12
`idec`	Number of digits to the right of the decimal point.	4

```
x = 2
title/format e 12 4
title x = @x
plot/x 1                # title will be displayed in plot
x = 3
title/write             # title will be updated before displayed
```

Result: `x = 3.0000E+00`

TRANSPOSE Transpose the array. Operator

Command Forms(s): **TRANSPOSE**

```
transpose/yxz   kbeam
transpose/xzy   kbeam
transpose/zxy   kbeam
transpose/right kbeam
transpose/yzx   kbeam
transpose/left  kbeam
```

Description: TRANSPOSE

Transposes the array, i.e., flips the along the diagonal a diagonal for 2D arrays. See flip/x or flip/y, and rotate. See Example Ex105 for examples of 3D transposes.

Modifier 1	Description
/yxz	Transpose x- and y-directions. The normal transpose for 2D arrays (default).
/xzy	Transpose z- and y-directions. May be applied only to 3D array.
/zxy or /right	Right circular permutation of XYX to form ZXY 3D array. Same as /xzy followed by /yxz. Reverses /yzx or /left. A general 3D transpose.
/yzx or /left	Left circular permutation of XYX to form YZX 3D array. Same as /yxz followed by /xzy. Reverses /zxy. A general 3D transpose.

Numerical Values	Description	Defaults
kbeam	Single beam number.	1

UDATA Create and display summary plots. Diagnostics

Command Forms(s): **UDATA**

```
udata/list/screen            min max
udata/list/disk              (filename) minrows maxrows maxcols
udata/save/disk              (filename) minrows maxrows maxcols
udata/restore/disk           (filename) minrows maxrows maxcols
udata/(set, add, sub, mul,   nstore x y01 y02 y03 y04 y05 y06 y07 y08 y09 y10
div)/values                  y11 y12
udata/(set, add, sub, mul,   nrow ncol y
div)/address
udata/(set, add, sub, mul,   col1 col2 col3
div)/columns
udata/calc                   ncol a b
udata/radrms                 col1 col2 maxrows units
udata/sum/one                col1
udata/sum/two                col1 col2
udata/clear                  nstore
udata/maxcols                maxcols
```

Command Forms(s): UDATA (Continued)

udata/maxrows	maxrows
udata/xlabel	(string for x-label)
udata/ylabel	(string for x-label)
udata/clabel	(string for column label) column

Description: UDATA

Creates and modifies a summary file. udata maintains an x-vector and up to twelve function vectors: y01 to y12. These vectors are of maximum length 1024. They may be used to store the status of the system at various points. The parameters x, y01, y02, y03 may be constants or variables. plot/udata may be used to plot the y-values against the x-values.

/xlabel and /ylabel may be used to define plot labels. The string should be enclosed in single quote marks. (maximum 40 characters in label).

The equation “x = udata(i,j)” gives the ith row and jth column. i = 0 returns the x-values.

Modifier 1	**Description**
/list	Lists the array values.
/list/disk	Lists to disk file. Filename may be defined as a 20 character parameter without quotes or up to 80 characters when enclosed in quotes. The prefix defined by /set/path is added, if defined, in the same fashion as read/disk and other IO routines.
/save	Save data to specified disk file.
/restore	Restore data from specified disk file.
/set, add, sub, mul, div	Set, add, subtract, multiply or divide data into udata array.
/calc	Calculate Col(Ncol) = Col(Ncol)*A + B. Note that maximum and minimum values of the column may be calculated from variables/set/param udata/max and variables/set/param udata/min.
/radrms	Calculate radially weighted rms values between two columns.
/sum	Calculate sum along row for a single column (/one) or the product of two columns (/two).
/clear	Zeroes all rows.
/maxcols	Maximum number of data function columns to be used. By default, maxcols is increased whenever a functional column value is defined beyond the existing range. Maxcols may be used to reduce the number of columns listed and plotted.
/maxrows	Maximum number of rows. Allows reduction in data set.
/xlabel	Reads next line for x-label. See plot/udata/xlabel), also.
/ylabel	Reads next line for y-label. See plot/udata/ylabel, also.
/clabel	Sets the column labels for udata/list. The independent variable (normally “x”) is number 1, y01 is numbered 2, etc. If the label contains blank characters, enclose the label in single quotes. The maximum length is 13 characters.
/values	Set row values by position with udata/set(default).
/address	Specify udata by (nrow, ncol) address udata/set.

Modifier 2	Description
`/screen`	Write to screen.
`/disk`	Write to disk file filename.
`/values`	Specify column by pattern, e.g. `y01`.
`/address`	Specify column by column number.
`/columns`	Perform `set`, `add`, `sub`, `mul`, `div` operations among columns: `col1` = `col2` (operation) `col3`.
`/one`	Calculate sum along row for a single column (`/one`).
`/two`	Calculate sum as the product of two columns (`/two`).

Character String	Description
(filename)	File name for `/disk`.

Numerical Values	Description	Defaults
`minrows`, `maxrows`	Minimum and maximum `udata` rows to be listed	all defined points
`nstore`	Array point number, max 1024.	All points
`x`	Independent (x) value or operator.	
`y01` to `y12`	Dependent (y) values or operators.	
`maxcols`	Maximum number of function columns to be used, see `/maxcols`.	
`maxrows`	Maximum number of rows of data. Normally this is set by GLAD to be the maximum number of rows for which data has been defined.	
`nrow`, `ncol`	Row and column address for `/address`.	
`col1`, `col2`, `col3`	Column numbers.	
`units`	Units between rows to be used with `/radrms`.	
`y`	Value to be set by `/address`.	
`column`	The column number for `udata/clabel`. The independent variable (normally `x`) is number 1, the first dependent data column (normally `y01)` is numbered 2, etc.	

System Variable Data	Description
`udata/point`	Get value from `udata` tables, by Row (A) and Col (B).
`udata/max`	Maximum value of column of `udata` defined by A.
`udata/min`	Minimum value of column of `udata` defined by A.
`udata/radrms`	Radial weighted root sum square of two columns.
`udata/sum`	Sum of a single column (`/one`) or the product of two columns (`/two`).

UNIFORMITY Calculate irradiance nonuniformity. Diagnostics

Command Forms(s): **UNIFORMITY**

```
uniformity/cir  kbeam rad xdec ydec
uniformity/sqr  kbeam rad xdec ydec
```

Command Forms(s): **UNIFORMITY (Continued)**

```
uniformity/ell  kbeam xrad yrad xdec ydec
uniformity/rec  kbeam xrad yrad xdec ydec
uniformity/two  kbeam1 kbeam2
```

Description: UNIFORMITY

Calculates the nonuniformity of irradiance for the specified region. If no region width is specified the entire array is used. Irradiance nonuniformity is calculated by

$$\text{nonuniformity (percent)} = \frac{1}{\langle I\rangle}(\langle I^2\rangle - \langle I\rangle^2) \times 100 \qquad (212)$$

where $\langle\ \rangle$ indicates a spatial average and the irradiance is I. This definition of irradiance nonuniformity can give a value greater than 100%, A random speckle pattern has a nonuniformity of about 100%.

For `/two` the uniformity is calculated to be

$$\text{nonuniformity (percent)} = \frac{\iint (I_1 - I_2)^2 dxdy}{\sqrt{\iint I_1{}^2 dxdy \iint I_1{}^2 dxdy}} \times 100 \qquad (213)$$

where I_1 is the irradiance of `kbeam1` and I_2 is the irradiance of `kbeam2`. This allows comparison of a test function against a reference function.

Modifier 1	**Description**
`/cir`	Circle.
`/sqr`	Square.
`/ell`	Ellipse.
`/rec`	Rectangle.
`/two`	Compare a test beam against a reference beam.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	1
`kbeam1`, `kbeam2`	Test and reference beams for `/two`.	
`rad`	Radius of region (cm).	Entire array.
(`x`, `y`)`rad`	Radius of region (cm).	Entire array.
`xdec`, `ydec`	Decentering parameters.	`0.`, `0.`

System Variable Data	**Description**
`uniformity/`(mod) mod = `percent`, `sigma`, `peak`, `avgint`, `valley`,`sum`	Nonuniformity in percent from `uniformity` command. Default modifier is percent, std. dev. is `sigma`, maximum value is `peak`, `avgint` is average intensity, `valley` is minimum value, `sum` is the sum of all intensities or intensity differences for `/two`.

UNITS — Set and display sample spacing. — Begin-end

Command Forms(s): **UNITS**

```
units/list          ibeams
units/set           ibeams xunit yunit zunit
units/field         ibeams xrad yrad zrad
units/beam          kbeam1 kbeam2
units/fix/set       ibeams
units/fix/list      ibeams
units/free          ibeams
units/type/list     kbeam
units/type/set      kbeam type [(units type)]
```

Description: UNITS

Controls the selection of matrix element size of the field array.

Modifier 1	**Description**
`/list`	List the units.
`/set`	Sets units of beam `ibeams` to `xunit` in x-direction and `yunit` in y-direction.
`/field`	Sets units of beam `ibeams` such that the field half-width is `xrad` in x-direction and `yrad` in y-direction, units$_x$ = 2*`xrad`/N$_x$ and units$_y$ = 2*`yrad`/N$_y$, where N$_x$ and N$_y$ are the length of columns and rows for the array.
`/beam`	Set units of `kbeam1` to units of `kbeam2`.
`/fix`	Keeps units constant. Beam must have a plane reference surface, i.e., constant units for `units/fix` to be applied.
`/free`	Program is free to adjust units to optimum value (default condition). Cancels `/fix`.
`/type/`(`set` or `list`)	Type or list units type. May be specified by number (`type`) or by parameter. See ‘Units Type” table below.

Modifier 2	**Description**
`/list`	List the designated units state.
`/set`	Set the designated units state.

Units Type	**Description**
`cm`	Centimeters.
`cycles_per_cm`	Units for spatial frequency.
`cycles_per_mm`	Units for spatial frequency.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`kbeam1`, `kbeam2`	Set units of 1 to units of 2 for `/beam`.	
`xunit`, `yunit`, `zunit`	Distance between matrix points, x-, y-, or z-direction (cm).	

Numerical Values	Description (Continued)	Defaults
xrad, yrad, zrad	Half width of field array in x-, y-, or z-direction (cm).	
type	Number of units type: 1 “cm”, 2 “cycles/cm”, 3 “cycles/mm”.	
iseed	Integer used to set the seed of the random number generator. If not explicitly set, the seed is set the previous call to the random number generator.	

VALLEY Computes minimum irradiance in array. Diagnostics

Command Forms(s): **VALLEY**

```
valley        ibeams
```

Description: VALLEY

Finds the point of minimum intensity in the beam(s) specified by ibeams. The array indices and ray coordinates of the minimum and the value of minimum intensity are printed. Also see peak.

Numerical Values	Description	Defaults
ibeams	Beam number (0 to select all beams).	1 to nbeam

System Variable Data	Description
valley	Minimum value of beam.

VARIABLES Declare, set, and monitor variable values. Language

Command Forms(s): **VARIABLES**

```
variables/list
variables/value/real or integer          (variable)  #  (comment)
variables/lock                           (variable)
variables/free                           (variable)
variables/export
variables/set/param/real or integer      (variable)  kbeam  (parameter)
variables/set/param/real or integer      (variable)  kbeam  a  (parameter)
variables/set/param/real or integer      (variable)  kbeam  a  b  (parameter)
variables/set/param/real or integer      (variable)  a  (parameter)
variables/set/param/real or integer      (variable)  a  b  (parameter)
variable/set/random                      (variable)  a  iseed
variable/set/phaser                      (variable)  iseed
variables/declare/(real, integer, or     (variable) . . . (variable)
complex)
variables/ask                            (variable)
variables/monitor/(add or delete)        (list of variables)
```

Command Forms(s): VARIABLES (Continued)

`variables/monitor/`
(`list`, `clearall`, `hide`, or `show`)
`variables/label/real` or `integer` (variable) (label)

Description: VARIABLES

`/list` displays the values and register addresses of all defined variables. Individual variables may also be listed by entering the name followed by an equal sign:

```
a=3 # assign value to variable
a=  # list value
```

`/declare` establishes the following string as a variable of specified type5. `/set` sets the specified variable to the GLAD parameter. `/set` automatically declares the variable, if necessary, unless `set/strict/on` has been invoked. If `set/strict/on` has been invoked, an attempt to use an undeclared variable results in an error. `/monitor` provides a display of designated variables with automatic updating.

Real-time display of variables may be done with the variable monitor window, Sect. 1.3.5.

Modifier 1	**Description**
`/list`	Lists current variables (default).
`/value`	Declares and sets a single variable allowing “real” or “integer” specification. Any “#” comment will become a variable label.
`/lock`	Lock the variable to prevent inadvertent change.
`/free`	Free the variable to allow changes.
`/export`	Form of list suitable for exporting with `write /disk` (filename), followed by `variables/export; read/screen`. Variables can be read into another command file by `read /disk` (filename).
`/set`	Set variable to GLAD system value.
`/declare`	Declare variables prior to use.
`/ask`	Prompt for assignment of value to variable. Useful in macros and command file input to make real time assignment of values.
`/monitor`	Display a table of variables and their values in a separate window. Values are updated automatically.
`/label`	Add a label to a variable. The lable will apper in `variables/list` or as an added coment if the variable value is displayed in the form “`variable=`”.

Modifier 2	**Description**
`declare/real`	Declares variables as real (default).
`declare/integer`	Declares variable as integer.
`declare/complex`	Declares variables as complex numbers for example x = 1 + 2i.

Modifier 2	Description (Continued)
/add	Add a variable to monitor list. The monitor window is started when the first variable is added to the monitor list. The display will be automatically updated to show the current value of the variable. The following line adds the variable Energy to the display. variables/monitor/add Energy
/delete	Delete a variable from monitor list.
/clearall	Delete all variables from table. Also removes the monitor window.
/list	List all monitored variables.
/show	Show the variable monitor window.
/hide	Minimize the variable monitor window.
/param	Various functions (default).
/random	Random variable with gaussian statistics. The first value sets the expected value. The second value sets the random seed, if desired.
/phaser	Random angle from 0 to 360 degrees. The value sets the random seed, if desired.

Modifier 3	Description
parameter/real	If new variable declare it as real (default).
parameter/integer	If new variable declare it as integer.

Parameters	Description
(variable)	Variable name consisting of no more than 20 alphanumeric characters, “$”, “_”.
(label)	A comment after “#” to be used as a label for variable/label.

Numerical Values	Description	Defaults
kbeam	Beam number for parameter.	
a, b	Variables for parameters. For /set/random, “a” is a scale factor that multiplies the random variable.	

Table. 25. System data accessible through the variables command.
Type 1, GLAD executes all necessary commands, e.g., energy.
Type 2, User must execute a command prior to accessing variable, e.g., poles.

Parameters	Type	Description
abcd/(mod) mod = ax, bx, cx, dx, ay, by, cy, dy	1	Current ABCD properties of kbeam.
abscorr, angcorr	2	Magnitude and angle (degrees of correlation coefficient) after call to mult /mode.
avgeng	2	Average energy from gain /converge, averaged over ireg values.
bmsize, ybmsize	1	Radius of kbeam (cm).
color	1	Wavelength of kbeam.
corrr, corri, corra	2	Real, imaginary, and complex parts of correlation after call to mult /mode.
ctlc	2	1 if Ctl-c or Ctl-BRK detected, 0 otherwise.

Table. 25. System data accessible through the variables command. (Continued)
Type 1, GLAD executes all necessary commands, e.g., energy.
Type 2, User must execute a command prior to accessing variable, e.g., poles.

Parameters	Type	Description
decent, ydecent	1	Offset of kbeam (cm).
eindex	1	Index of refraction for eccentric beam for uniaxial crystal.
energy/(mod) mod = optical, ginversion	1	/optical yields the irradiance integrated over the array in w. /ginversion yields the population integrated over the array in j/cm.
fitegauss/(mod) mod = zwaist, yzwaist, waist, ywaist, lambda, ylambda	2	Embedded gaussian found from last call to fitegauss: axial position of waist, waist 1/*e* radius, equivalent wavelength.
fitencir	2	Radius of the level to be fit with encircled or pib.
fitlevel	2	Intensity level for specified relative energy from fitlevel.
fitpiston	2	Piston value from last call fitphase.
fitxcen, fitycen	2	Center of the distribution from last call to fitgeo.
fitxfwhm, fityfwhm	2	Full-width-half-maximum (or other level) from fitfwhm.
fitxfocus, fityfocus	2	X- and y-defocus errors from last call to fitphase.
fitxomega, fityomega	2	X- and y-equivalent radii from last call to fitgeo, fitfwhm, fitknife, fitlevel, and pib /level.
fitxrad, fityrad	2	X- and y-average radii from last call to fitgeo. Other definitions apply for other “fit” commands.
fitxsig, fitysig	2	X- and y-standard deviations from last call to fitgeo, fitfwhm, fitknife, fitlevel, and pib/level.
fitxtilt, fitytilt	2	X-tilt and y-tilt after last call to fitphase.
focus/(abcd or waist)	1	Sets the variable to the distance from the current position to the geometrical focus (abcd) or gaussian beam waist (waist). Similar to the focus /list command.
geodata/(mod) mod = zwaistx, zwaisty, waistx, waisty, iplanx, iplany, m2x, m2y, ewx, ewy, radx, rady, bsx, bsy, zrayx, zrayy, zdistx, zdisty, insidx, insidy, refradiusx, refradiusy, wsx, wsy, zswitchx, zswitchy	2	Displays current values of geodata for specified beam. zwaist(x,y): position of waist waist(x,y): size of waist iplan(x,y): 0, curved reference; 1, plane reference surface m2(x,y): M-squared value as determined by last call to fitmsq. ew(x,y): Effective wavelength form M-squared value. rad(x,y): Radius of phase. bs (x,y): Current beam radius. zray(x,y): Rayleigh range. zdist(x,y): Distance from zwaist to current position. insid(x,y): Inside or outside the near-far field boundary. refradius(x,y): Reference surface radius: 1e20 if not used. ws(x,y): Width of the beam at current point. zswitch(x,y): Distance from waist to point of expanding units.

Table. 25. System data accessible through the variables command. (Continued)
Type 1, GLAD executes all necessary commands, e.g., energy.
Type 2, User must execute a command prior to accessing variable, e.g., poles.

Parameters	Type	Description
global/(mod) mod = grx, gry, grz, gix, giy, giz, gjx, gjy, gjz, gkx, gky, gkz, opl, ppl, xang, yang, zang, x1ang, y1ang, z1ang, parity	1	Displays current global properties of specified beam. grx, gry, grz: current global position of waist gix, giy, giz, gjx, gjy, gjz, gkx, gky, gkz: elements of global orientation matrix (ith, jth and kth columns). opl, ppl: optical path length and physical path length xang, yang, zang: Euler angles (first solution). x1ang, y1ang, z1ang: Euler angles (alternate solution). parity: Parity of global orientation matrix.
index	1	Index of refraction.
iplane, yiplane	1	Phase bias flag of kbeam.
lensgroup/(mod) mod = xmag, ymag, oblique	2	Magnification factors due to incidence on tilted surfaces for lensgroup.
line	1	Sets variable to the current line number. Useful for debugging.
macro/(mod) mod = iteration, maxiteration, level, remaining	1	Macro loop information. Current iteration, maximum iteration, current macro level, and remaining iterations
magchgvec	2	Magnitude of change vector for optimization.
memory/(mod) mod = total, allocated, free, maximum, speedratio	1	Physical memory: total, total on system; allocated, currently allocated to GLAD; free, free physical memory (not reliable); maximum, maximum allowed memory set by user (0 if no maximum has been set); speedratio, ratio of current speed to initial speed at with small memory. The speed ratio will drop if the memory allocation is higher than 75% to 90% of total memory.
merit	2	Current value of merit function for optimization.
msqx, msqy	2	M-squared values for x- and y-directions from last call to fitgeo, fitmsquared, or fitegauss.
nbeam	1	Number of beams defined.
nline/(mod) mod = x, y, z, ipol	1	Number of pixels for x-, y-, and z-directions and polarization state, ipol = 1 indicates polarized.
optdone	2	1 if optimization done, 0 if not.
opl/(mod) mod = waves, length	1	Optical path length in x-direction in waves or cm for kbeam.
oply/(mod) mod = waves, length	1	Optical path length in y-direction in waves or cm for kbeam.
pcorrr, pcorri, pcorra	2	Real, imaginary, and complex parts of correlation after call to mult /mode without normalization.
ppl	1	Physical path length for kbeam in cm
peak/(mod) mod = intensity, xcen, ycen, picen, pjcen	1	Peak intensity of kbeam. xcen and ycen give the x- and y-coordinates of the peak and picen and pjcen give the pixel coordinates of the peak.

Table. 25. System data accessible through the `variables` command. (Continued)
Type 1, GLAD executes all necessary commands, e.g., `energy`.
Type 2, User must execute a command prior to accessing variable, e.g., poles.

Parameters	Type	Description
`photons`	1	Number of photons in `kbeam`.
`point/`(mod) mod `= intensity, sr, si, pr, pi, ginversion, principle`	1	Intensity or for s- and p-polarizations: s-real, s-imaginary, p-real, p-imaginary, and the population inversion specified point. Specify `kbeam` and `A` and `B` for x- and y-pixels. If `kbeam` is not specified, the values from the last call to `point/list` will be used. (`principle` is not used at this time.)
`poles`	2	Number of irremovable phase discontinuities (poles), obtained by running `poles` command.
`prad, yprad`	1	Surrogate gaussian beam phase radius.
`rdist, yrdist`	1	Current distance of beam from waist (cm).
`resonator/`(mod) mod `= mag, ymag, radius, yradius, ewaist, yewaist, ezwaist, yezwaist, stable, ystable, opl, oply, ppl, roundtriptime`	2	Round-trip properties of macro operated with resonator. X- and y-values of magnification, phase radius, eigenwaist, eigenwaist location, stability criterion, optical path length in waves for x- and y-directions, physical path length in cm, and the round trip time. Half the round trip time is often used for the pumping time in double pass amplifiers. The inverse of the round trip time gives the frequency separation between longitudinal modes.
`rms`	2	RMS wavefront error of beam, computed by variance.
`sampling/`(mod) mod `= x, y`	1	Compute relative power in Nyquist frequencies in x- or y-direction.
`section`	1	Section of 3D array.
`strehl`	1	Strehl ratio of `kbeam`.
`sxrot, syrot, szrot`	1	Rotation angles of most recent surface.
`thermal/`(mod) mod `= array, n0, t0, dndt, dndt2, dldt, dldt2, alpha`	1	Thermal surface data. The surface number is defined by A. `Array` is the number of the array for the thermal surface. `N0` is the index at temperature `t0`. `Dndt` is the derivative of index with temperature and `dndt2` is the second derivative. `Dldt` is the derivative of thickness with temperature and `dldt2` is the second derivative. `Alpha` is the bulk absorption.
`thermal/`(mod) mod `= rhoc, kappa, xtime, ytime`	1	Thermal surface data. The surface number is defined by A and material number in the surface is defined by B. `Rhoc` is the density*specific heat. `Kappa` is the thermal conductivity. `Xtime` and `Ytime` are the thermal time constants in the x- and y-directions.
`time`	2	Gives the elapsed time from last `time/show`.
`udata/point`	1	Get value from `udata` tables, by Row (A) and Col (B).
`udata/max`	1	Maximum value of column of `udata` defined by A.
`udata/min`	1	Minimum value of column of `udata` defined by A.
`udata/sum`	2	Result of `udata/sum/one` or `udata/sum/two`.
`udata/radrms`	2	Result of `udata/radrms`.
`units, yunits`	1	Separation of field array points for beam (cm).

Table. 25. System data accessible through the `variables` command. (Continued)
Type 1, GLAD executes all necessary commands, e.g., `energy`.
Type 2, User must execute a command prior to accessing variable, e.g., poles.

Parameters	**Type**	**Description**
`uniformity/`(mod) mod `= percent`, `sigma`, `peak`, `avgint`, `valley`, `sum`	2	Nonuniformity in percent from `uniformity` command. Default modifier is `percent`, std. dev. is `sigma`, maximum value is `peak`, `avgint` is average intensity, `valley` is minimum value, `sum` is the sum of all irradiances or irradiance differences for `/two`.
`valley`	1	Minimum value of `kbeam`.
`vxrot`, `vyrot`, `vzrot`	1	Rotation angles of last vertex.
`waist`, `ywaist`	1	Radius of beam at waist (cm).
`wavefront/`(mod) mod `= sigma`, `peak`, `average`, `valley`	1	Wavefront statistics, calls `variance` command. Default modifier is `sigma`, the std. dev., maximum value is `peak`, average is `average`, `valley` is minimum value.
`wavelength`	1	Wavelength of `kbeam`.
`xray`, `yray`, `zray`	1	Global position of beam along chief ray for `kbeam`.
`xrot`, `yrot`, `zrot`	1	Rotation angles of chief ray for `kbeam`.
`xvertex`, `yvertex`, `zvertex`		Vertex position of last vertex.
`xsurf`, `ysurf`, `zsurf`	1	Rotation angles of last surface.

`zigzag/`(mod)
mod `= width_zigzag`
`adjusted_zigzag`
`height_zigzag`
`length_zigzag`
`reflections_zigzag`
`angle_zigzag`
`beamunits_zigzag`
`gainunits_zigzag`
`step_angle`
`step_straight`
`position_zigzag`
`pixel_zigzag`
`totalsteps_zigzag`
	1	Properties of zigzag amplifier: width, adjusted width with 1/2 pixel added. height, length, number of reflections, angle of the light relative to the axis of the zigzag amplifier, units of the beam (transverse to the beam), units of the gain region, step length along the angle (optical path), step length along the amplifier axis, current position in cm, current position in pixels, total number of steps through the amplifier.

`zreff`	1	Current z-position of beam (cm).

Example

Put the wavelength of beam 2 into variable Lambda.

```
variable/set Lambda wavelength
```

VARIANCE Calculate wavefront rms error. Diagnostics

Command Forms(s): **VARIANCE**

```
variance/wavefront    ibeams threshold
variance/irradiance   ibeams threshold
```

Description: VARIANCE

Calculates the intensity weighted wavefront or irradiance rms (same as command `rms`).

$$\text{wavefront RMS} = \sqrt{\frac{\int\int I(x,y)W(x,y)^2 dxdy}{\int\int I(x,y)dxdy} - \left(\frac{\int\int I(x,y)W(x,y)dxdy}{\int\int I(x,y)dxdy}\right)^2} \tag{214}$$

$$\text{irradiance RMS} = \sqrt{\frac{\int\int I(x,y)^2 \mathrm{d}x\mathrm{d}y}{\int\int \mathrm{d}x\mathrm{d}y} - \left(\frac{\int\int I(x,y)\mathrm{d}x\mathrm{d}y}{\int\int \mathrm{d}x\mathrm{d}y}\right)^2} \tag{215}$$

The standard deviation, peak, valley, and average value of the wavefront are available with the `variables` `/set/parameter` command with the wavefront parameter.

Modifier 1	**Description**
`/wavefront`	Calculate variance of wavefront (default).
`/irradiance`	Calculate variance of irradiance.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`threshold`	Ignore points with irradiance lower than this relative threshold value.	0.

System Variable Data	**Description**
`rms`	rms wavefront error of beam, same as variance. Computed by `variance`.

VERTEX Controls vertex location and rotation. Positioning

Command Forms(s): VERTEX

```
vertex/list/global
vertex/list/beam        kbeam
vertex/locate
vertex/rotate
vertex/save
vertex/restore
vertex/undefine
```

Description: VERTEX

The `vertex` command allows the user to define and list the location and orientation of the vertex of a mirror defined with the `mirror/global` command or a lens group with `lensgroup` .

Modifier 1	**Description**
`/list`	Lists vertex values.

Modifier 1	Description (Continued)
/locate	Vertex position.
/rotate	Vertex rotation.
/save	Save current vertex coordinate state.
/restore	Restore previously saved vertex coordinate state.
/undefine	Undefine the vertex postion such that the idealized lens and mirror commands will always be applied to the current beam position of the specified beam.

Modifier 2	Description
/global	Vertex properties in global coordinates (default).
/beam	Vertex properties relative to current coordinate system of indicated beam.

Numerical Values	Description	Defaults
kbeam	Beam number to be used as reference.	

VERTEX/LOCATE Specify vertex location in global coordinates. Positioning

Command Forms(s): **VERTEX/LOCATE**

```
vertex/locate/relative  kbeam x y z
vertex/locate/absolute  x y z
```

Description: VERTEX/LOCATE

The vertex/locate command is used to define the vertex location of an optical component subsequently defined with the mirror/global or lensgroup commands.

Note that a vertex/rotate command must be issued after a vertex/locate command to set a logic switch properly to true.

Modifier 2	Description
/relative	Locate relative to beam position of kbeam. Displacement is made in the beam coordinate system.
/absolute	Set location of vertex in global coordinates.

Numerical Values	Description	Defaults
kbeam	Beam number to be used as reference.	
x, y, z	Translation coordinates (cm).	0., 0., 0.

System Variable Data	Description
xvertex, yvertex, zvertex	Vertex position of last defined vertex.

VERTEX/ROTATE Specify vertex rotation in global coordinates. Positioning

Command Forms(s): **VERTEX/ROTATE**

```
vertex/rotate/set/(mod3)    rx ry rz xoff yoff zoff [global]
vertex/rotate/add/(mod3)    rx ry rz xoff yoff zoff [global]
```

Command Forms(s): VERTEX/ROTATE (Continued)

```
vertex/rotate/set/(mod3)     rx ry rz xoff yoff zoff [vertex]
vertex/rotate/add/(mod3)     rx ry rz xoff yoff zoff [vertex]
vertex/rotate/set/(mod3)     kbeam rx ry rz xoff yoff zoff [beam]
vertex/rotate/add/(mod3)     kbeam rx ry rz xoff yoff zoff [beam]
vertex/rotate/set/(mod3)     ksurf rx ry rz xoff yoff zoff [surface]
vertex/rotate/add/(mod3)     ksurf rx ry rz xoff yoff zoff [surface]
```

Description: VERTEX/ROTATE

The vertex/rotate command is used to define the orientation of an optical component defined with the mirror/global or lensgroup commands. The component may be set to the specified angles with the /set modifier or rotated from its existing position by the /add modifier.

The rotation is made in the coordinate system specified by the parameter. If $\mathbf{R}_{xyz}$ is the rotation matrix specified by $\mathbf{R}_x$, $\mathbf{R}_y$, $\mathbf{R}_{z,}$ and $\mathbf{R}_1$ is the local coordinate matrix specified by the parameter, then the global rotation matrix is

$$\mathbf{R}_{xyz}' = \mathbf{R}_1\mathbf{R}_{xyz}\mathbf{R}_1^{-1} \tag{216}$$

The vertex may be rotated with an offset vector defined by (xoff, yoff, zoff). The offset vector is defined in the local coordinate system.

The surface parameter rotates about the point of interception of a chief ray with a surface using a previous mirror/global or llensgroup command and the surface /store command. See the description of the surface command.

Modifier 2	Description
/set	Set orientation to specified values (default). $\mathbf{R}_v = \mathbf{R}_{xyz}'$ (where $\mathbf{R}_v$ is the vertex coordinate matrix.)
/add	Rotate from current orientation. $\mathbf{R}_v \rightarrow \mathbf{R}_{xyz}'\mathbf{R}_v$

Modifier 3	Description
/forward	Rotate by $\mathbf{R}_x$(rx), $\mathbf{R}_y$(ry), $\mathbf{R}_z$(rz) in order.
/inverse	Rotate by $\mathbf{R}_z$(-rz), $\mathbf{R}_y$(-ry), $\mathbf{R}_x$(-rx) in order—the reverse of /forward.

Parameter	Description
global	Rotation and offsets in global coordinates (default).
beam	Rotation and offsets in beam coordinates.
vertex	Rotation and offsets in vertex coordinates.
surface	Rotation and offsets in surface coordinates.

Numerical Values	Description	Defaults
kbeam	Beam number to be used as reference.	
ksurf	Surface number.	

Numerical Values	Description (Continued)	Defaults
x, y, z	Translation coordinates.	0., 0., 0.
rx, ry, rz	Rotations angles in degrees.	0., 0., 0.
xoff, yoff, zoff	Offsets of rotation point.	0., 0., 0.

Rotation Definitions

rx right hand rotation about x-axis.

ry right hand rotation about y-axis.

rz right hand rotation about z-axis.

A right hand rotation is defined to be a rotation in the direction the fingers of the right hand curl when the thumb points in the positive direction of the specified axis. Rotations are applied in the order $\mathbf{R}_x$, $\mathbf{R}_y$, and $\mathbf{R}_z$.

Note that the z-axis of a beam flips when the beam strikes a mirror. The beam coordinate matrix flips from right to left handed parity. The rotations are defined with respect to the current z-axis direction.

Example

In the following example, the vertex is located 100 cm. along the chief ray of beam 1.

```
vertex/locate/relative 1 0 0 100
vertex/rotate/set 1 beam
mirror/global/flat 1
```

WATCH Controls Watch.exe from command line. Language

Command Forms(s): **WATCH**

```
watch/start
watch/close
watch/folder          (directory)
```

Description: WATCH

Controls Watch.exe from the command line..

Modifier 1	Description
/start	Start a version of Watch. Use after /close.
/close	Close the version of Watch started from GLAD.
/folder	Start Watch with specified directory.

Character string	Description
(directory)	Directory in Watch is to run.

WAVE4 Four-wave mixing. Laser gain

Command Forms(s): **WAVE4**

```
wave4/kinet  zstep ip is it patm ac bc g4w gps gst nstep2
wave4/set    zstart
```

Description: WAVE4

This command applies four-wave mixing and Raman gain. The GLAD feature set is required. The theory is described in GLAD Theory Manual, Chap. 5, (theory.pdf). The equations are summarized below. Given P, S, and T for the pump and 1st and 2nd Stokes beams, the governing equations are

Four-wave mixing

$$\frac{\partial P}{\partial z} = -\frac{g_{4w}}{2} e^{i\Delta \mathbf{k}\cdot\mathbf{z}} S^2 T^* , \tag{217}$$

$$\frac{\partial S}{\partial z} = -\frac{g_{4w}}{2} e^{-i\Delta \mathbf{k}\cdot\mathbf{z}} T S^* P + \frac{g_{4w}}{2} e^{-i\Delta \mathbf{k}\cdot\mathbf{z}} P S^* T = 0 , \tag{218}$$

$$\frac{\partial T}{\partial z} = \frac{g_{4w}}{2} e^{i\Delta \mathbf{k}\cdot\mathbf{z}} S^2 P* . \tag{219}$$

Raman equations

$$\frac{\partial P}{\partial z} = -\frac{g_{ps}}{2} |S|^2 P , \tag{220}$$

$$\frac{\partial S}{\partial z} = \frac{g_{ps}}{2} |P|^2 S - \frac{g_{st}}{2} |T|^2 S , \tag{221}$$

$$\frac{\partial T}{\partial z} = -\frac{g_{st}}{2} |S|^2 T . \tag{222}$$

Phase matching condition

$$\Delta k \cong 2\pi a_c b_c P_{atm} \left[\frac{1}{\lambda_p} + \frac{1}{\lambda_t} - 2\frac{1}{\lambda_s} \right] - \pi \left[\frac{\theta_p^3}{\lambda_p^3} + \frac{\theta_t^3}{\lambda_t^3} - 2\frac{\theta_s^3}{\lambda_s^3} \right] . \tag{223}$$

Modifier 1	Description
`kinet`	Applies the kinetics.
`set`	Resets the z-origin for four-wave mixing.

Numerical Values	Description	Defaults
zstep	Z-step distance (cm).	0.
ip	Number of pump beam.	1
is	Number of 1st Stokes beam.	2
it	Number of 2nd Stokes beam.	3
patm	Atmospheric pressure (Amagats).	3.
ac	First Cauchy coefficient.	13.6e-5
bc	Second Cauchy coefficient.	7.7e-11
g4w	Gain coefficient for four-wave mixing.	0.0001
gps	Gain coefficient for pump to 1st Stokes.	0.
gst	Gain coefficient for 1st to 2nd Stokes.	0.
nstep2	Number of steps for phase integration (set at about 5 to 10, higher numbers give higher sampling of phase matching).	

Step size parameters

$\mathtt{zmin} = \mathtt{g4w} \bullet S^2$	four-wave mixing characteristic length
$\mathtt{zdisp} = \dfrac{1}{\Delta k}$	dispersion characteristic length
$\mathtt{nstep1} = 10\dfrac{\mathtt{zdisp}}{\mathtt{zmin}} + 1$	number of steps per zstep
$\mathtt{dstep1} = \dfrac{\mathtt{zdisp}}{\mathtt{nstep1}}$	Raman integration step length
$\mathtt{nstep2} = 1 + 4\dfrac{\mathtt{dstep1}}{\mathtt{zdisp}}$	inner loop number for phase matching (if not set in command line)
$\mathtt{dstep2} = \dfrac{\mathtt{dstep1}}{\mathtt{nstep2}}$	inner loop integration step length

EXAMPLE

This example illustrate the use of wave4. 40 steps of 20 cm. are taken.

```
wave4/set zstart=0 # initializes z-position for phase matching
c
c zstep 20
c ip 1 (default)
c is 2 (default)
c ip 3 (default)
C Patm 3. (default)
C bcauchy 13.6e-5 (default)
C acauchy 7.7e-11 (default)
C G4w 4.22e-9
C Gps 5.16E-9
C Gst 3.25E-9
C Nstep2 10
C
macro/def ramstep/overwrite
 pack/in
 wave4 zstep=20 g4w=4.22e-9 gps=5.16e-9 gst=3.25e-9 nstep2=10
 pack/out
```

```
macro/end
macro/run ramstep/40
```

WAVELENGTH Set and display beam wavelength. Begin-end

Command Forms(s): **WAVELENGTH**

```
wavelength/list      ibeams
wavelength/set       ibeams lambda index eindex
```

Description: WAVELENGTH

Sets beam to vacuum wavelength (in microns) and refractive index. If both variables are zero, the command lists the current values. The wavelength in the medium is lambda = lambda vac./index.

Modifier	Description
`/list`	List wavelength and index properties.
`/set`	Set wavelength and index properties.

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`lambda`	Vacuum wavelength (microns).	`10.6`
`index`	Index of refraction.	`1.`
`eindex`	Index of refraction of eccentric beam for birefringent material. Implemented only between `crystal/uniaxial/set` and `crystal/uniaxial/clear`.	`index`

WAVES2INT Wavefront is transformed to intensity. Operator

Command Forms(s): **WAVES2INT**

```
waves2int/one      kbeam
waves2int/two      kbeam1 kbeam2
waves2real/one     kbeam
waves2real/two     kbeam1 kbeam2
```

Description: WAVES2INT

Converts wavefront to an intensity or real distribution. Also see `phase2int` and `phase2int`. Waves in wavelengths is

waves = –phase/2/π (radians).

Modifier 2	Description
`/one`	Transform wavefront into intensity.
`/two`	Make intensity of `kbeam2` equal to wavefront of `kbeam1`.

Numerical Values	Description	Defaults
`kbeam`	Single beam number.	1

Numerical Values	Description (Continued)	Defaults
kbeam1	Input beam for /two.	1
kbeam2	Output beam for /two.	2

WRITE Control writing of output data. Input-output

Command Forms(s): **WRITE**

write/screen/(on, off or clear)
write/(on or off)
write/disk/on (filename)/(nooverwrite or overwrite)
write/disk/off/(noclose or close)
write/html/on/(noclose or close) (filename)/(nooverwrite or overwrite)
write/html/off/(noclose or close)
write/info

Description: WRITE

Sets output to terminal or disk file. If the disk file already exists, new output will be written at the end of the existing information, unless /overwrite is specified. A pathname may be set with set/path to define a prefix which is concatenated in front of the filename.

Modifier 1	Description
/screen	Sets output to screen (default).
/off	Turns off all output: screen, disk, and html.
/disk	Controls output file for text.
/html	Controls output file for html. File may be viewed by any browser.
/on	Reverses write/off.
/info	Displays current write info.

Modifier 2	Description
/on	Opens output file for text output or html (default).
/off	Close output file.
/clear	For write/screen/clear, GladOut display is cleared.

Modifier 3	Description
/noclose	Leave output file open (default).
/close	Close output file, making it accessible to external programs such as editors for inspection and modification.

Character String	Description
(filename)	Name of the disk file. Do not include the parentheses. May be written as a 20 character expression (no back slashes). Alternately an expression of up to 80 characters may be used with single quotes in the form 'filename'. The filename is preceded by a path name if one has been defined with set/path.

String Modifier	Description
`/nooverwrite`	No rewind of the output file (default).
`/overwrite`	Rewinds the file before writing on it.

ZBOUND Position and size of Rayleigh range. Diagnostics

Command Forms(s): **ZBOUND**

```
zbound/list   ibeams
zbound/set    ibeams waistx waisty zwaistx zwaisty
```

Description: ZBOUND

Prints table of surrogate gaussian beam values or sets the values. See `geodata` also. The transition between constant units and expanding units takes place at `zrayx` and `zray`.

Modifier 1	Description
`/set`	Sets `zbound`.
`/list`	Lists the current values (default).

Numerical Values	Description	Defaults
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`waistx`, `waisty`	Waist size for x- and y-directions.	
`zwaistx`, `zwaisty`	Locations of x and y waists.	`0.`, `0.`

`zbound/list` Table Values	Description
`waistx`, `waisty`	Transverse radius of surrogate gaussian beam.
`zwaistx`, `zwaisty`	Position of surrogate gaussian beam.
`zrayx`, `zrayy`	Half width of Rayleigh range.

ZIGZAG Zigzag amplifier Component

Command Forms(s): **ZBOUND**

```
zigzag/list/layout
zigzag/list/global
zigzag/set            koptical kgain width_half height_half angle
                      reflections time mode optical_history
                      gain_history prism index face_normal_angle
                      transmission ncpu
zigzag/steps          steps
zigzag/image          kout step_zigzag
```

`zigzag/propagation/on` or `off`

`zigzag/noise/on` or `off`

Description: ZIGZAG

Models a zigzag amplifier. A beam is injected into an amplifier consisting of a gain region between two side walls. The beam zigs and zags as it bounces from wall to wall before exiting. See Fig. 28.

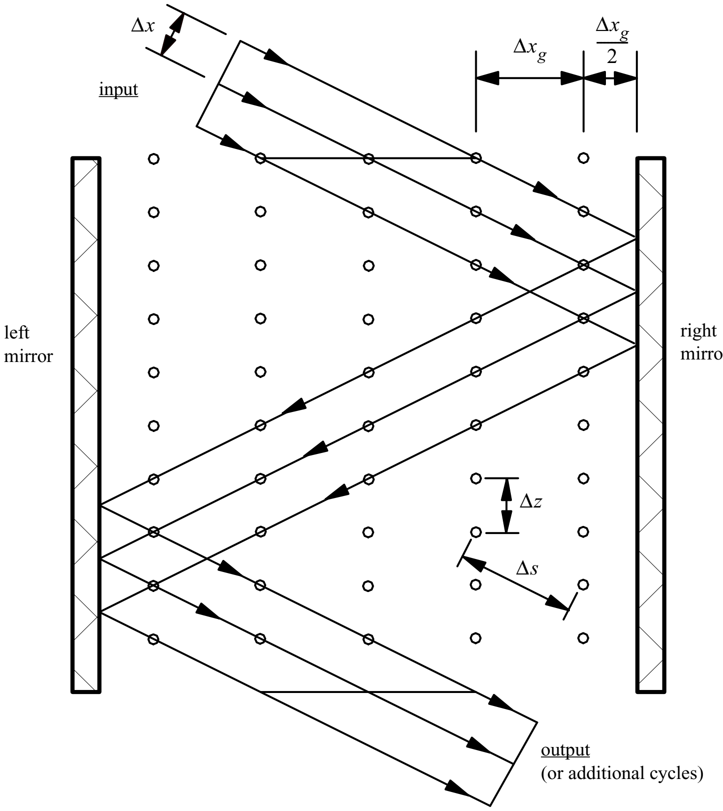


Fig. 28. Configuration for a zigzag amplifier showing one a pair of reflections forming one complete cycle. In this figure no prism faces are shown. A full cycle of two reflections is shown, but any number of reflections may be used. The beam overlaps upon reflection at each mirror, causing higher inversion depletion.

The pixels are matched to avoid interpolation and the associated errors. The optical beam, with units Δx, enters on the left at an angle α to the axis of the amplifier region. The transverse units for the amplifier should be $\Delta x_g = \Delta x/\cos(\alpha)$. The units of the amplifier along the axis should be $\Delta z = \Delta x/\tan(\alpha)$. The optical propagation along the slant line takes steps of $\Delta s = \Delta x_g/\cos(\alpha) = \Delta x/\cos^2(\alpha)$. The gain points are organized into a 3D array.

In this elementary drawing, the aperture is shown with only five pixels. The mirrors are shifted a half pixel. The length for one complete cycle is ten—twice the number of aperture pixels.

Note that we can also have an odd number of reflections and prism faces as shown in Fig. 29.

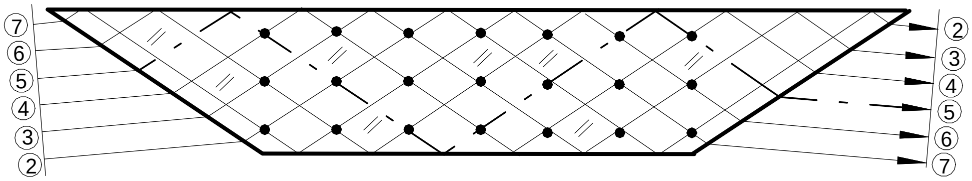


Fig. 29. An odd number of reflections may be used. In this figure, prism ends have been attached and there is refraction between the external and internal angles.

The amplifier will be oriented to the incident beam accourding to the mode number. Fig. 30 illustrates the four modes when viewed in the coordinate system of the amplifier. Fig. 31 shows that Modes 1 and 4 or Modes 2 and 3 can be used to cause a reverse pass to follow the same path as the forward path. Fig. 30 illustrates combining Mode 1 and 3 so that the reverse pass has the zigzag reversed.

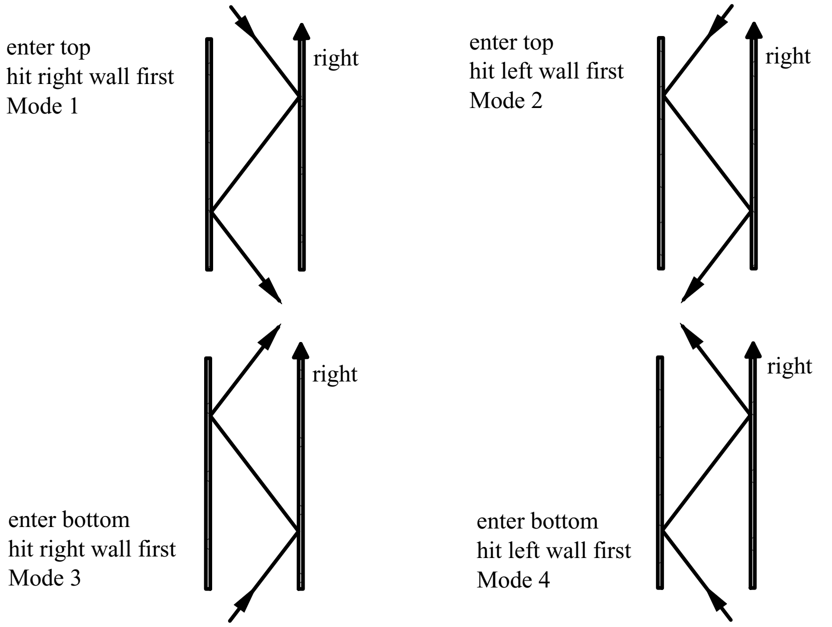


Fig. 30. Modes for the zigzag amplifier drawn in the reference frame of the amplifier.

By selecting `prism` = 1, angled ends are included in the model.

The angle from the prism face normal to the ray is *I*, the angle from the axis to the ray is *a*, and the angle from the axis to the prism surface is β. All angles are positive for a right-hand rotation about the y-axis taken in the x-z plane. See Fig. 33.

If the prism face is made shallower than the optimum folding configuration (an angle greater than internal ray angle α), some light can reflect off the back side of the prism face to create parasitic rays that will extract energy into an unwanted direction. To avoid parasitic reflection, the face angle β should be steeper than the internal ray angle, $\beta >= \alpha$.

In the prism zigzag routine, the units of the gain region Δx_g are calculated from the initial beam units Δx_0, the internal angle α, and the face angle β.

$$\Delta x_g = \frac{(\cos I)}{(\cos I_0 \cos \alpha)} \Delta x_0 \tag{224}$$

where we have the incident angle I_0, exiting angle to the surface normal *I*, and Snell's Law. The exiting angle *I* is found from:

$$\text{for general face angle } \beta,\ I = (\alpha - \beta) - 90° \tag{225}$$

Note that $\alpha - \beta$ may exceed 90° so that *I* takes on a positive value, allowing steep ray angles intercepting the mirror walls.

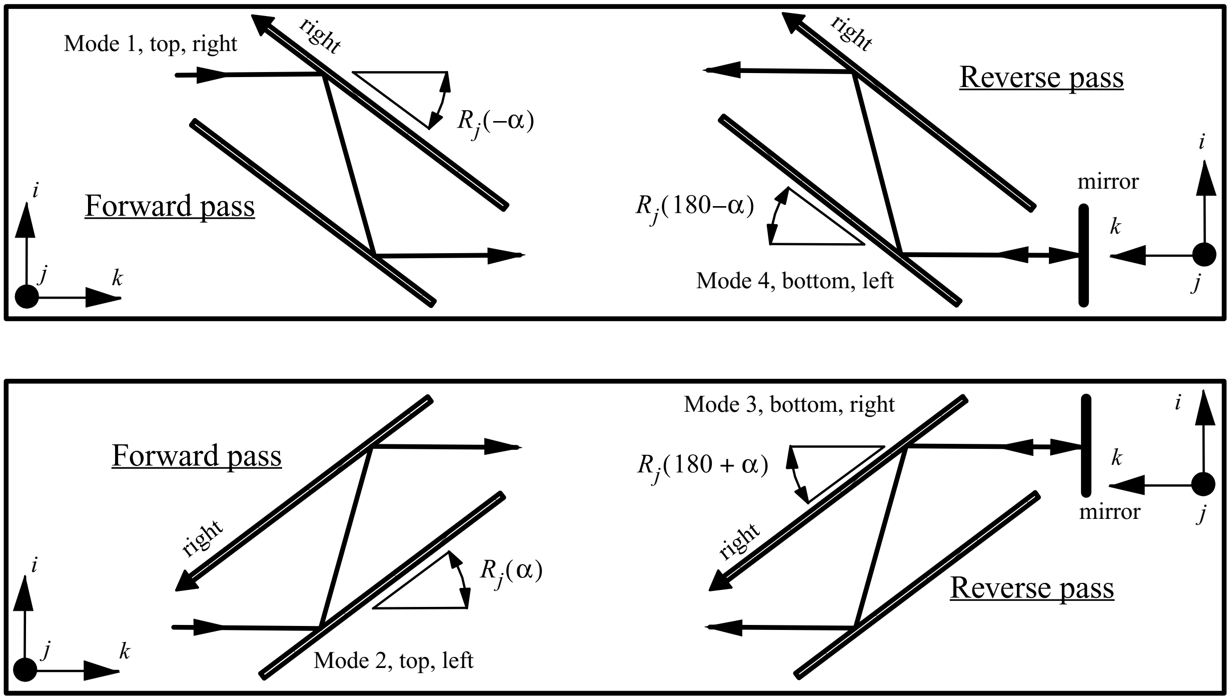


Fig. 31. The four modes for the amplifier define the orientation with respect to the incident beam. Note the *ijk* designation of the beam coordinate system. The amplifier will be positioned relative to the incident beam according to the mode number and the magnitude of the angle. The amplifier will lie in the *i*-*k* plane with the rotation defined about the *j*-unit vector and rotation matrix R_j. α is the key word `alpha` and is rotation of the amplifier in the *i*-*k* plane.

The light will enter top of the amplifier for Mode 1 or 2 and the bottom for Modes 3 or 4. The light will strike the right wall first for Mode 1 or 4 and the left wall first for Mode 2 or 3. The light will follow the same path when Mode 4 follows Mode 1 (upper frame) or when Mode 3 follows Mode 2 (lower frame).

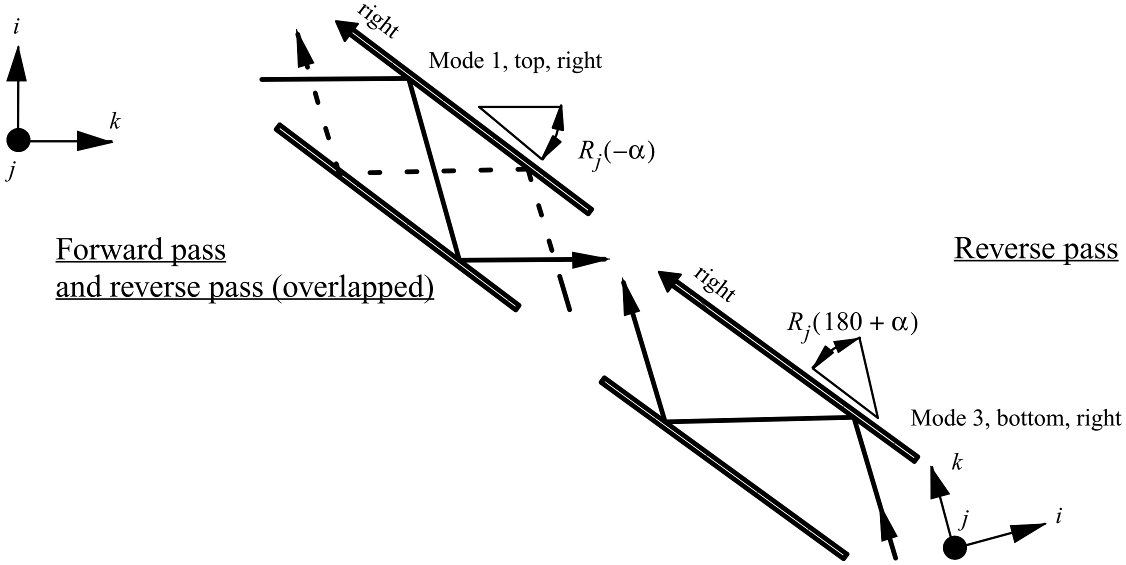


Fig. 32. After Mode 1, Mode 3 may be used for the reverse path to flip the path in the amplifier so some undepleted inversion is exploited. α is specified by the key word `alpha` and is the rotation of the amplifier in the *i*-*k* plane.

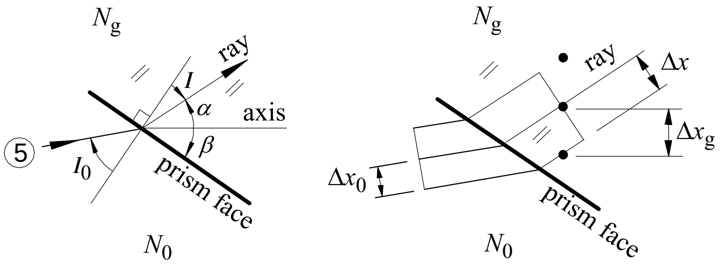


Fig. 33. The angle from the prism face normal to the ray is *I*. The angle from the axis to the ray is *a*. Th angle from the axis to the prism face is β. All angles are taken as positive for right-hand rotations about the y-axis when taken in the x-z plane. As drawn $I < 0$, $\alpha > 0$, $\beta < 0$.

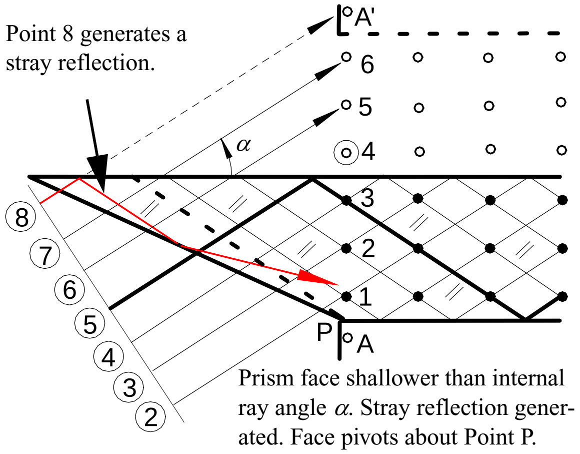

Point 8 generates a stray reflection.
A'
6
5
4
3
2
1
P
A
α
8
7
6
5
4
3
2
Prism face shallower than internal ray angle α. Stray reflection generated. Face pivots about Point P.

Fig. 34. Making the prism face steeper than the internal ray angle α, will result in light in the upper edge of the incident beam reflecting from the back side of the prism face. This light constitutes a parasitic mode that will extract energy from the gain medium without contributing to the desired mode. Note that the prism face is considered to pivot about the Point P for different choices of face angle. To avoid this parasitic mode, the prism face angle β should be equal in magnitude or steeper than α, $|\beta| >= \alpha$, or the aperture should be masked to eliminate the the problematic light.

$$\text{for optimum folding face angle } \alpha = -\beta,\ I = 2\alpha - 90° \tag{226}$$

$$\text{Snell's Law, } N_0 \sin I_0 = N_g \sin I \tag{227}$$

Equations 225 or 226 with Eq. 227 allow us to calculate I_0 and the cosine relationship Eq. 224 for conversion of external optical units to gain units.

Brewster’s Angle Example

For Brewsters’s angle operation from air to index $N_0 = 1.5$, we have two solutions:

$$\text{incident angle (air), } I_{0_B}(N_0 = 1.5) = \operatorname{atan} N_0\big|_{N_0 = 1.5} = \pm 56.3099° \tag{228}$$

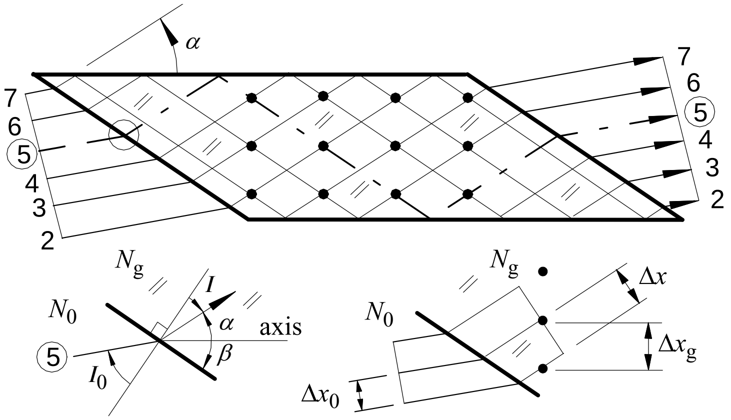


Fig. 35. Zigzag prism amplifier. From the internal ray angle α, the internal angle to the normal of the face I (the exiting angle) is $I = \alpha - \beta - 90°+$, where β is the angle from the axis to the prism face. The optimum folding condition (for maximum acceptance width and folding efficiency) is $\alpha = -\beta$. The entrance angle to the normal of the entrance face is found from the exiting angle I and Snell's Law $I_o \sin N_o = I \sin N_g$. We have the relation $\Delta x_g = \Delta x/\cos(\alpha)$, where Δx_g is the sample spacing in the gain region and Δx is the sample spacing normal to the ray direction. $\Delta x = (\Delta x_0 \cos I)/(\cos I_0)$ and $\Delta x_g = (\Delta x_0 \cos I)/(\cos I_0 \cos \alpha)$.

$$\text{exiting angle (glass), } I(N_0 = 1.5) = \operatorname{asin}\left(\frac{\sin I_{0_B}}{N_0}\right)\Bigg|_{N_0 = 1.5} = \pm 33.6901° \qquad (229)$$

The optimum folding angle at Brewster's angle has the two solutions:

$$(\alpha = -\beta) \Rightarrow \left(\alpha = \frac{90° + I}{2}\right) \Rightarrow \alpha = 28.1550°, 61.8450° \qquad (230)$$

If the face angle β is less than the magnitude of the ray angle α, there will be parasitic mode. This condition is satisfied if $I > 0$, $\alpha <= 61.8450°$ or if I <0, $\alpha <= 28.1550°$.

See example ex121. for illustrations of the use of the `zigzag` command.

Modifier 1	**Description**
`/set`	Set halfwidth of sidewalls, length of gain region, integer number of sidewall reflections, and repumping time. The angle of incidence against the sidewalls and the number of propagation step is computed.
`/list`	Lists the current values (default).
`/steps`	Number of steps to be used. Zero causes all remaining steps to be completed.
`/image`	2D Image of optical beam of zigzag amplifier formed into square array "kout" at current (or specified) step.
`/propagation`	Controls diffraction propagation.
`/noise`	Controls spontaneous emission for gain calculations.

Modifier 2	**Description**
`list/layout`	Operational properties exclusive of global locations (default).

Modifier 2	**Description (Continued)**
`list/global`	Global properties.
`/on`	Implement effect (default).
`/off`	No not implement effect.

Numerical Values	**Description**	**Defaults**
`koptical`	Optical beam that propagates.	
`kgain`	Gain array. Requires 3D, polarized definition.	
`width_half`	Half width of separation of side mirrors for zigzag amplifier, x-direction. Will be set to an integer number of pixels.	
`height_half`	Half height of side mirrors for zigzag amplifier. Mirrors are assumed to be vertical. Will be set to an integer number of pixels.	
`angle`	Angle of optical beam relative to the axis of the zigzag amplifier. The top of the amplifier faces the incident beam. The units of the gain region will be calculated from the this angle and the index of refraction of the gain region. Enter a positive value for the angle. The relative direction is determined by `mode`.	
`reflections`	Number of reflections for zig-zag gain region. Assumes the beam exits in the center	
`time`	Time for pumping medium.	
`mode`	Controls propagation (in amplifier coordinate system): 1, $R_j(-\alpha)$, beam enters top and strikes right mirror first; 2, $R_j(\alpha)$, beam enters top and strikes left mirror first; 3, $R_j(180+\alpha)$, beam enters bottom and strikes right mirror first; 4, $R_j(180-\alpha)$, beam enters bottom and strikes left mirror first.	1
`optical_history`	Optical history array. Must match x-dimension of target and the y-dimension must exceed the number of steps.	
`gain_history`	Gain history array. Must match x-dimension of target and y-dimension must exceed the number of steps and be polarized.	
`prism`	1, add prism ends, 0 no prism ends.	
`index`	Index of refraction of the gain region for the prism zigzag amplifier.	
`face_normal_angle`	Angle (deg) of the normal of the prism face from amplifier axis—positive for a right-hand y-rotation in the x-z plane. By default the surface of the face is matched to the ray angle, so the angle of the prism face normal is 90° – `angle`. This achieves an acceptance width equal to twice the gain width and gives best folding efficiency.	`90-angle`

Numerical Values	Description (Continued)	Defaults
`ncpu`	Number of CPU's to be used. For arrays less than about 256 x 256. The default of ncpu = 1 will give the best speed.	`1`
`transmission`	3D Transmission/phase array to be applied in the gain coordinate system to include bulk absorption and phase aberrations. It may have two polarization states. The complex amplitude of this array is multiplied into the beam at each gain step. The transverse x- and y-sizes of the array must match the gain array `kgain`. If the z-size is less than that of the gain array, multiple steps are taken in gain with the same transmission array before advancing to the next transmission sheet. Transmission and phase distributions should be setup to give the proper effect when applied the actual total number of gain steps. If the optical array is polarized and the transmission array is not, the transmission array is applied to both polarization states of the optical array. Otherwise the polarization states are matched up.	

Systen Variable Data	Description
`zigzag/width`	Half width of separation of side mirrors for zigzag amplifier, x-direction.
`zigzag/adjusted`	Width adjusted to be an integer number of pixels plus on half pixel.
`zigzag/height`	Half height of side mirrors for zigzag amplifier, y-direction.
`zigzag/length`	Length of zigzag gain region.
`zigzag/reflections`	Number of reflections for zig-zag gain region.
`zigzag/angle`	Angle of optical beam relative to the axis of the zigzag amplifier.
`zigzag/beamunits`	X-units for beam in zigzag amplifier.
`zigzag/gainunits`	Allow or restrict `gain` operations in `resonator/eigen/test`.
`zigzag/slantstep`	Propagation length per step along the angled optical path.
`zigzag/straightstep`	Length per step along straigh through the zigzag resonator.
`zigzag/position`	Current position along zigzag amplifier (pixels).
`zigzag/pixel`	Current translation of beam relative to the center of the zigzag amplifier.
`zigzag/totalsteps`	Total number of steps along the length of the zigzag amplifier.

ZONE Extend region of constant units. Propagation

Command Forms(s): **ZONE**

```
zone/list
zone/fix        center halfw krefbeam
zone/xyfix      xcenter ycenter xhalfw yhalfw krefbeam
zone/unfix
zone/in         kbeam
zone/out        kbeam
```

Description: ZONE

GLAD will interpolate information in arrays of different sizes so that multiple beam interactions may be calculated. The interpolation may introduce errors when the wavelengths are separated widely. The `zone` command allows the user to control the algorithms so that arrays may be kept identical in size through a focus region. `zone/fix` (or `zone/xyfix`) sets up the parameters of the zone region. The beam `krefbeam` is used for determining the proper size of the beam outside the control zone. `zone/in kbeam` caused the specified beam to be put under control. If the beam is interpolated to fit the correct beam size whether inside or outside the zone of constant units. See Example Ex81. The `prop` and `dist` commands detect the zone mode and control the diffraction algorithms as if the boundaries specified were the Rayleigh zone limits. Lenses and mirrors may not be implemented on a beam after `zone/in` is specified for that beam. See Examples Ex19 and Ex81 . Outside the zone, propagation will result in the arrays changing size linearly with their center of growth at the center of the zone. Inside the zone, the arrays keep the same size they had at the array boundary. See Fig. 36.

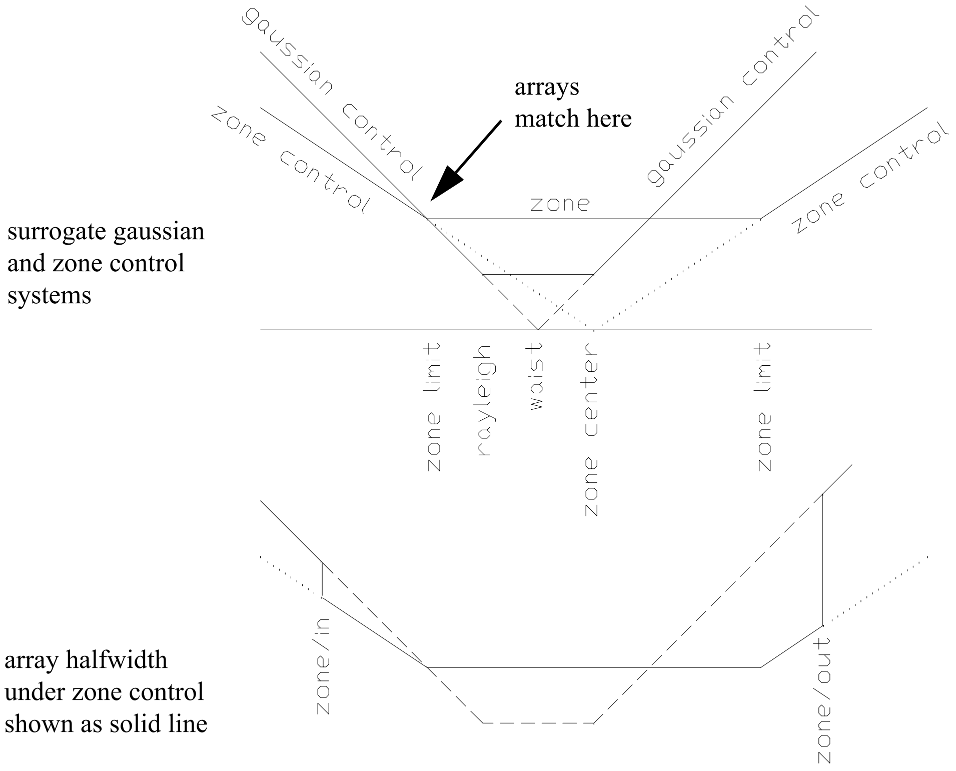


Fig. 36. The upper sketch shows the half-width of the array under both surrogate gaussian and zone control. Under surrogate gaussian control, the array scales linearly with distance from the waist if outside the Rayleigh range and is constant inside. Under zone control, the beam scales linearly with distance outside the zone and is constant inside. The two system have identical array sizes at the most negative boundary of constant zone units are identical. The lower sketch shows the halfwidth of the array as a solid line, under zone control, when the `zone/in` and `zone/out` commands are implemented at the axial points shown.

$$\text{inner region } \Delta x = \Delta(Zstart)\frac{\mathtt{xcenter} - Zwaist - \mathtt{xhalf}}{Zstart - Zwaist} \tag{231}$$

$$\text{outer region } \Delta x = \Delta(Zstart)\frac{\mathtt{xcenter} - Zwaist - \mathtt{xhalf}}{Zreff - Zwaist} \tag{232}$$

where *Zstart* is the position at which the zone is defined and *Zreff* is the current position. For an image formed by a lens of focal length *f* and starting units $\Delta(Zstart)$, we can set the zone so that the units are never less than the value at the waist. Set center to the waist position and

$$\mathtt{halfw} = \frac{\lambda}{N}\left(\frac{f}{\Delta x}\right)^2 \tag{233}$$

Modifier 1	**Description**
`list`	List zone parameters.
`/fix`	Defines zone parameters (identical for X and Y).
`/xyfix`	Defines zone parameters (may be different for X and Y).
`/unfix`	Clears zone definition.
`zone/in`	Puts specified beam under zone control. The beam is interpolated to the proper size.
`zone/out`	Ends zone control of specified beam. The beam is interpolated back to the size the beam would have been if the `zone/in` command had never been used.

Numerical Values	**Description**	**Defaults**
`kbeam`	Single beam number.	`1`
`center`	Center of zone of constant units.	0.
`halfw`	Halfwidth of the zone of constant units along the axis.	`1.`
`krefbeam`	Beam to be used to specify the array size under zone control and outside the zone of constant units.	`1`
`xcenter`	X-center of zone of constant units.	`0.`
`ycenter`	Y-center of zone of constant units.	`0.`
`xhalfw`	X-halfwidth of the zone of constant units along the axis.	1.
`yhalfw`	Y-halfwidth of the zone of constant units along the axis.	1.

EXAMPLE

The following example illustrates use of the `zone` command. The commands are taken from Example 19, which performs a through-focus Raman interaction. The zone is specified at the focus of the lens and the halfwidth is set to the Rayleigh length of the 1.06 beam.

```
nbeam 2 # Define two beams
color 1 1.06 # Define wavelength of pump beam
color 2 1.54 # Define wavelength of seed beam
array/set 0 16 # Set arrays to 16x16
units 0 .35 # Set units
gauss/cir/con 1 1.0 1.0 # Define pump distribution
```

```
gauss/cir/con 2 0.01 1.0 # Define seed distribution
lens 0 30.
zone/fix 30. .0303652 # Define waist zone
prop/zproj/abs 29.70241
zone/in 1 # Beam 1 under zone control
zone/in 2 # Beam 2 under zone control
```

(propagation and Raman commands in zone)

```
zone/out 1 # Beam 1 released
zone/out 2 # Beam 2 released
```

ZREFF Current location of beam along chief ray. Propagation

Command Forms(s): **ZREFF**

```
zreff/list      ibeams
zreff/set       ibeams zreffn [list]
zreff/save      ibeams
zreff/restore   ibeams
```

Description: ZREFF

Positions beam at *Zreff* = `zreffn`. If given with no parameters, lists current values.

Modifier 1	**Description**
`/set`	Sets the reference position (default if parameters are given).
`/list`	Lists the current reference position (default if no parameters).
`/save`	Save the current position.
`/restore`	Restore the position.

Parameter	**Description**
`list`	List values when they are changed. Default is not to list changed values.

Numerical Values	**Description**	**Defaults**
`ibeams`	Beam number (0 to select all beams).	`1` to `nbeam`
`zreffn`	Beam position.	

3. Index

4. Security Key

When installing GLAD on a new machine, install the code **before** installing the dongle. Install the software from the AOR distribution CD and be sure to select “Sentinel key driver”, so that the key driver software will be setup properly. If the key driver software is not installed, GLAD will not recognize the key. Repeat this process to install GLAD on any other computer. Your license permits you to install GLAD on as many machines as you like. Simply move the security key to the computer you wish to use. If you have files from an installation on another computer that you want to copy to a new machine, do so after installation from the CD.

The security key (dongle) will retain its password permanently. No modification of the key is needed when it is used on a new computer. The key is set to operate in temporary mode when it is shipped. In temporary mode the key will operate with full capabilities, but for a limited amount of usage. When the registration for GLAD and payment is received by AOR, the permanent password and instruction will be sent. The label for a key in temporary mode is “GLAD demonstration key”. When the key is set to permanent status, the Customer will select a new label. Damaged keys will be replaced. Lost keys will not be replaced, so protect and/or insure your key just as you would any other piece of equipment of comparable value.

Keyread.exe is a diagnostic program to set the security key and to test the key independently of GLAD. Run keyread.exe through Windows: Start, Run, “C:\program files\aor\glad57\keyread.exe”. Substitute your actual installation directory for “C:\program files\aor\glad57”. You may also run keyread.exe from GLAD with the GLAD command “privilege/keyread”. See the description of the command `privileges`.

Installation from the CD sets the Windows registry so that the location of glad.exe and watch.exe are identified and establishes *.inp and *.plt with ide.exe and watch.exe respectively.

You may request the latest version of the GLAD installation CD at any time within the one year period of technical support. Both the permanent licensed version and the demo version of GLAD are supported by the same installation CD. The behavior of the program changes according to whether GLAD finds a valid key. If no key is found, GLAD will operate in superdemo mode, for a limited amount of usage.

5. Installing GLAD

Important. Please do these three steps:

1) Install GLAD from the CD ROM **before** installing the dongle (security key).
2) Attach the dongle to a USB port.
3) Register the software. Thank you.

Registration

GLAD is ready to run when it is received, so you can begin working immediately in temporary mode that will last a month or so under typical use.

You will need a password to set the security key to permanent status for a new purchase or to upgrade the version level. AOR need registration of the key to prepare the password for your key.

To register your copy of GLAD, Run the command `privilege/register`, enter the requested contact information. Email the resulting registration file, as an attachment, to glad@aor.com, fax to 1 360 225 0347, or send by regular mail. When the registration is received and payment has been made, AOR will send the password and installation instructions by return email or fax.

How to run GLAD

From the main Windows menu select Start, Programs, GLAD 5.8, GLAD IDE. The GLAD Users Guide (guide.pdf) will pop up when GLAD first runs. Also, in this Commands Manual, see Sect. 1.3, “Using GLAD”, page 16.

First Look

For a quick look at some popular examples, select “Demo” from the main menu. Also, look through the GLAD Examples Manual (examples.pdf) accessible from the “Help” menu item.

System Requirements

GLAD requires Microsoft Windows 2000 (or higher), 20 Mbytes of disk space for GLAD, 80 Mbytes of disk space for the online documentation. A USB port is required for the security key. Adobe Acrobat Reader 7.0 is required for viewing the *.pdf files—available on the GLAD CD or from www.adobe.com (free)

← See previous page for more information
about the security key.