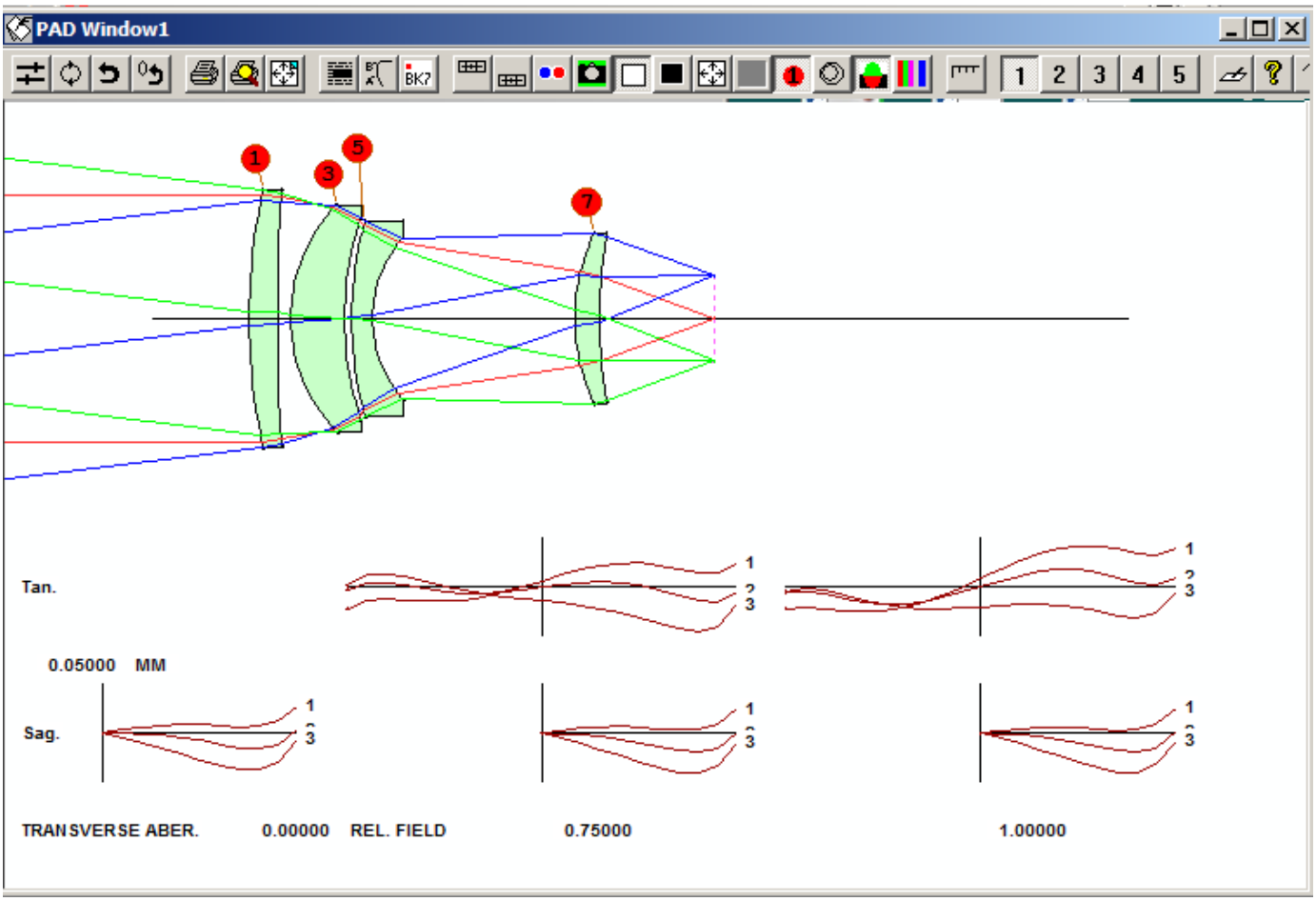
Lesson 32: Ghost Hunting

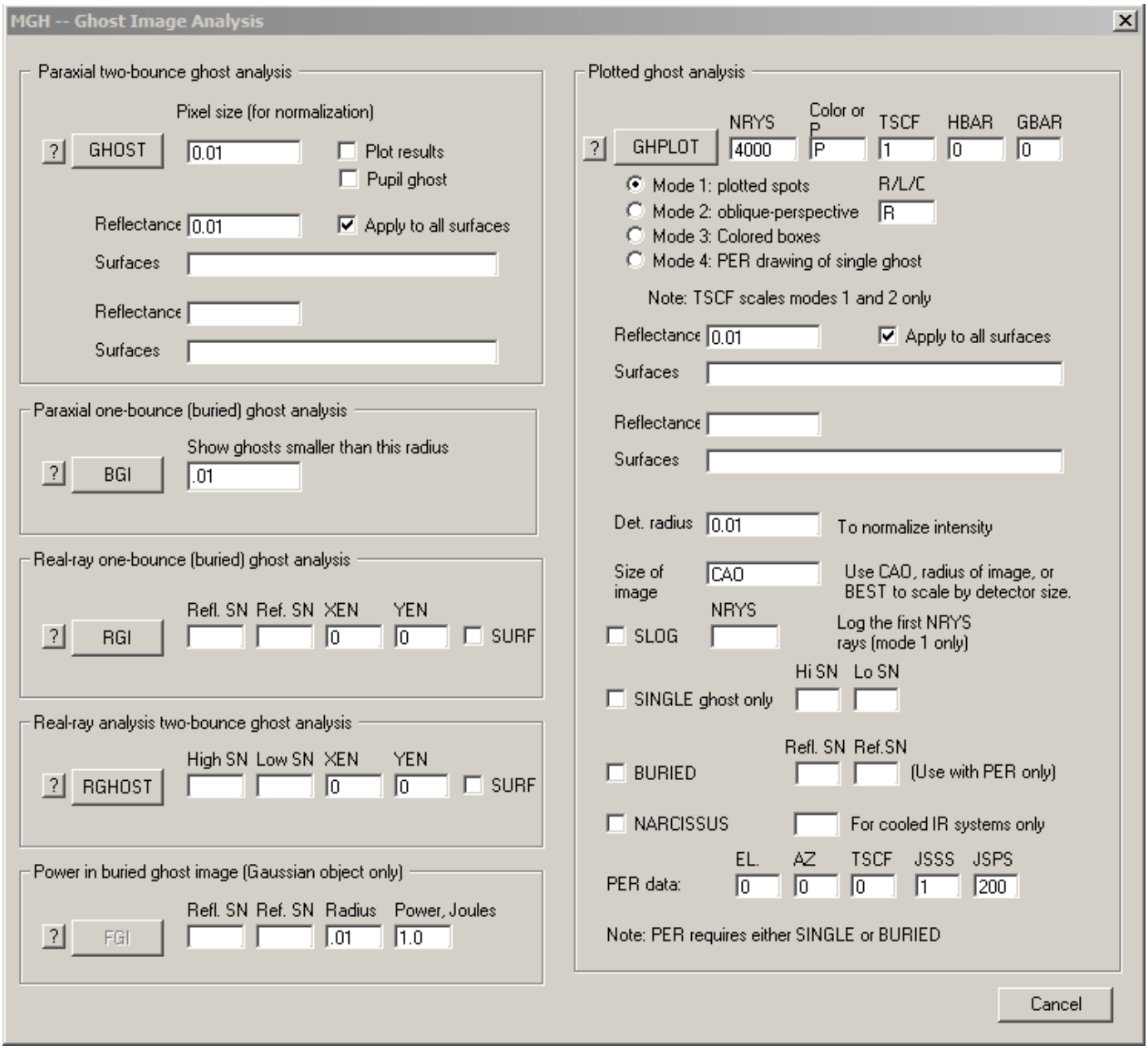
Your lens looks great on paper and the shop did a fine job of building it. But when you test it, you see a horrible ghost image whenever a bright source enters the field. Not a good scenario, but one that happens all too often. The customer will not be pleased.

To prevent this sort of surprise, SYNOPSYS offers a suite of powerful features that you should know about and use when appropriate. They are found in the **MGH** dialog (Menu, GHost image), and with these tools you can find problems such as this early in the design process – and correct them as you go.

Put briefly, a ghost image is a concentration of light at the image arising from two unwanted reflections within the lens system. If you have 3 lenses, there are 15 possible ghosts. With 6 elements you have 66, and so on. That's a lot to keep track of – but don't worry, SYNOPSYS has tools for the job. To see what some of these tools can do, **`FETCH`** the lens 1.RLE, with the ID MIT 1 TO 2 UM LENS. Then look at the PAD display.



It's not obvious that you'll be bothered with ghost images, but then it seldom is. Let's see about that. Open the dialog **`MGH`**.



At the upper left is the **GHOST** button. That feature is used to find ghosts using only paraxial raytracing, and the ghosts it finds of course differ somewhat from those formed by real rays. Nonetheless, the results are usually close enough for you to see where problems will show up. You can assign reflectance coefficients to any or all surfaces in the lens, and the program will take the values into account when it estimates the intensity of each of the ghosts it finds. The dialog opens with a default reflectance of 1%, applied to all lens surfaces. Click the **GHOST** button.

You get two tables of numbers. The first analyzes all combinations of surfaces; a portion of the output is shown below.

```
--- GHOST R 0.01
 ID MIT 1 TO 2 UM LENS

 GHOST IMAGE ANALYSIS

 --- R 0.01 ALL
 --- END
  NO.    GHOST SURF        Ymarg         U'marg         Ychief      INTENSITY
_____________________________________________________________________________
   1      2 -   1        -30.0244        -0.3778         7.3095    1.10930E-11
   2      3 -   1         27.2543        -0.3984         4.6907    1.34627E-11
   3      3 -   2         63.5945        -0.2721         4.1819    2.47264E-12
```

4	4 -	1	-46.5167	-0.2920	4.9249	4.62149E-12
5	4 -	2	-25.1674	-0.3088	6.6272	1.57879E-11
6	4 -	3	-75.6813	-0.4937	4.4156	1.74591E-12
7	5 -	1	-45.8712	-0.2619	4.0455	4.75247E-12
8	5 -	2	-27.0481	-0.2839	6.4039	1.36686E-11
9	5 -	3	-72.6068	-0.4577	2.7558	1.89691E-12
10	5 -	4	-3.4550	-0.3402	6.5304	8.37735E-10
11	6 -	1	0.5515	-0.5074	4.2824	3.28758E-08
12	6 -	2	44.1259	-0.4028	8.4078	5.13585E-12
13	6 -	3	-38.8865	-0.5677	1.4386	6.61305E-12
14	6 -	4	67.9018	-0.0930	9.4364	2.16889E-12
15	6 -	5	66.9185	-0.0241	8.9874	2.23310E-12
16	7 -	1	-26.2150	-0.5336	-37.0598	1.45513E-11
17	7 -	2	17.4775	-0.4677	31.7392	3.27372E-11
18	7 -	3	-71.3906	-0.6925	-107.3067	1.96208E-12

…

Under the heading Ymarg, notice the smallest value, 0.5515, for the combination of surfaces 6 and 1. This tells you that light reflected from surface 6, and then from surface 1, will arrive at the image plane forming a (paraxial) blur of about 1/2 mm in radius. That may be a problem. If your lens is lengthy, it is easier to pick out the problem ghosts by examining the second listing:

CUMULATIVE GHOST DISTRIBUTION
NORMALIZED FOR DETECTOR SEMI-APERTURE 0.0100

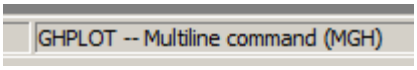
NO.	GHOST INTENS.	ACCUM. INTENS.	SURFACES	
6	1.74591E-12	1.74591E-12	4	3
9	1.89691E-12	3.64282E-12	5	3
18	1.96208E-12	5.60491E-12	7	3
14	2.16889E-12	7.77380E-12	6	4
15	2.23310E-12	1.00069E-11	6	5
3	2.47264E-12	1.24795E-11	3	2
20	3.94955E-12	1.64291E-11	7	5
19	4.15611E-12	2.05852E-11	7	4
4	4.62149E-12	2.52067E-11	4	1
7	4.75247E-12	2.99592E-11	5	1
12	5.13585E-12	3.50950E-11	6	2
13	6.61305E-12	4.17081E-11	6	3
21	6.62606E-12	4.83341E-11	7	6
1	1.10930E-11	5.94271E-11	2	1
2	1.34627E-11	7.28898E-11	3	1
8	1.36686E-11	8.65584E-11	5	2
16	1.45513E-11	1.01110E-10	7	1
5	1.57879E-11	1.16898E-10	4	2
25	2.20749E-11	1.38973E-10	8	4
26	2.25477E-11	1.61520E-10	8	5
17	3.27372E-11	1.94257E-10	7	2
24	5.08281E-11	2.45085E-10	8	3
23	5.72162E-11	3.02302E-10	8	2
28	8.28536E-11	3.85155E-10	8	7
10	8.37735E-10	1.22289E-09	5	4
27	3.67946E-09	4.90235E-09	8	6
22	1.09304E-08	1.58327E-08	8	1
11	3.28758E-08	4.87085E-08	6	1

Here the ghosts are sorted, with the most severe ones at the bottom, and the accumulated intensity is calculated, printed, and summed. Indeed, the cumulative ghost intensity, 4.87E08 is mostly due to that single ghost, which has the intensity 3.29E-9. Now we know where the ghost is coming from. Let's see the effect.

To do this, open the MACro called GHPLOT.MAC. (By this lesson you should know how to use the MACro editor, which you open with the command EE.) Here is that MACro:

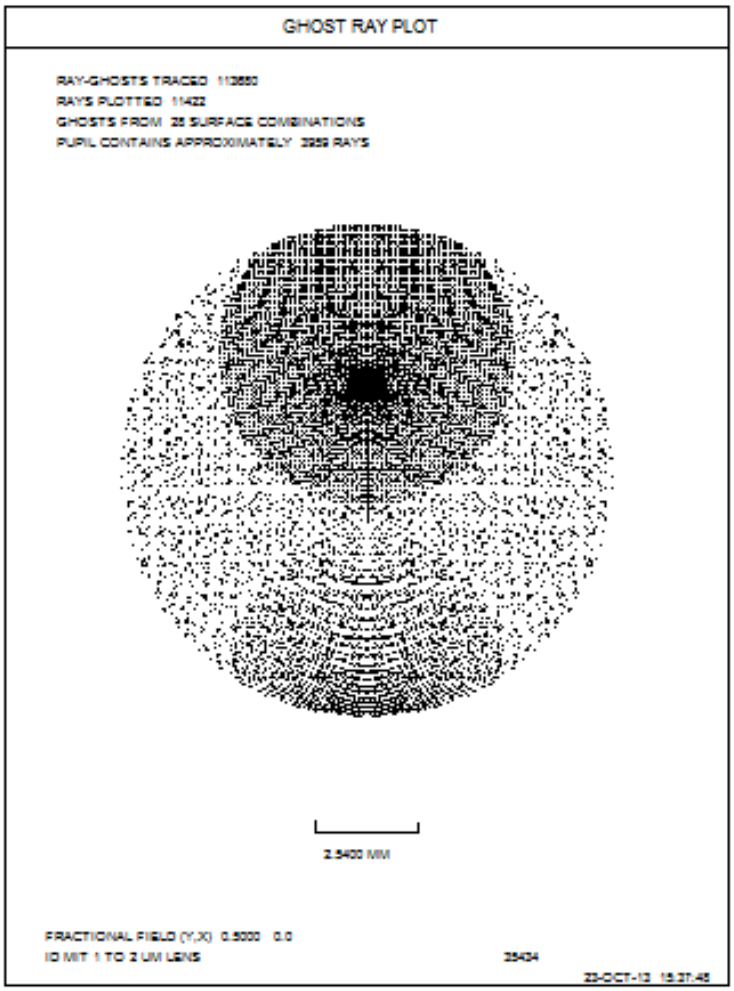
```
; GHPLOT.MAC
; THIS EXAMPLE EXAMINES THE GHOST IMAGE IN A LENS
; IT RUNS GHPLOT IN ALL FOUR MODES.

CCW          ! CLEAN UP FIRST; CLEAR COMMAND WINDOW
KAG          ! AND CLOSE GRAPHICS WINDOWS
FET 1
CHG
CFIX         ; FIX CLEAR APERTURES TO DELETE VIGNETTED GHOSTS
VIG          ; AND TURN ON VIG MODE IF OFF
END

SSS .003       ; SMALL SPOT SIZE HERE

GAW          ; NEED NEW WINDOW FOR EACH PICTURE (GRAPHICS ADD WINDOWS)
GHPLOT 4000 P 10 .5 0 1      ; SELECT MODE 1, INDIVIDUAL RAYS
R .01 ALL     ; THIS IS ALSO THE DEFAULT REFLECTANCE
PLOT

GHPLOT 20000 P 1 .5 0 2 L    ; NOW GET AN OBLIQUE PERSPECTIVE VIEW
DRAD .0004
PLOT

GHPLOT 20000 P 1 .5 0 3 L    ; THIS MAKES COLORED BINS
DRAD .0004
PLOT

GHPLOT 400 P 1 .5 0 4 L           ; AND THIS DRAWS A SINGLE GHOST WITH PER
SINGLE 6 1
PER 0 0 0 1 99
PLOT

GRW          ; RESTORE GRAPHICS OPTION (GRAPHICS REUSE WINDOW)
```

GHPLOT has four modes, and you are encouraged to read about them before we go any further. Since this MACro is already in the editor, simply *select* the characters GHPLOT, and then look at the TrayPrompt[1].

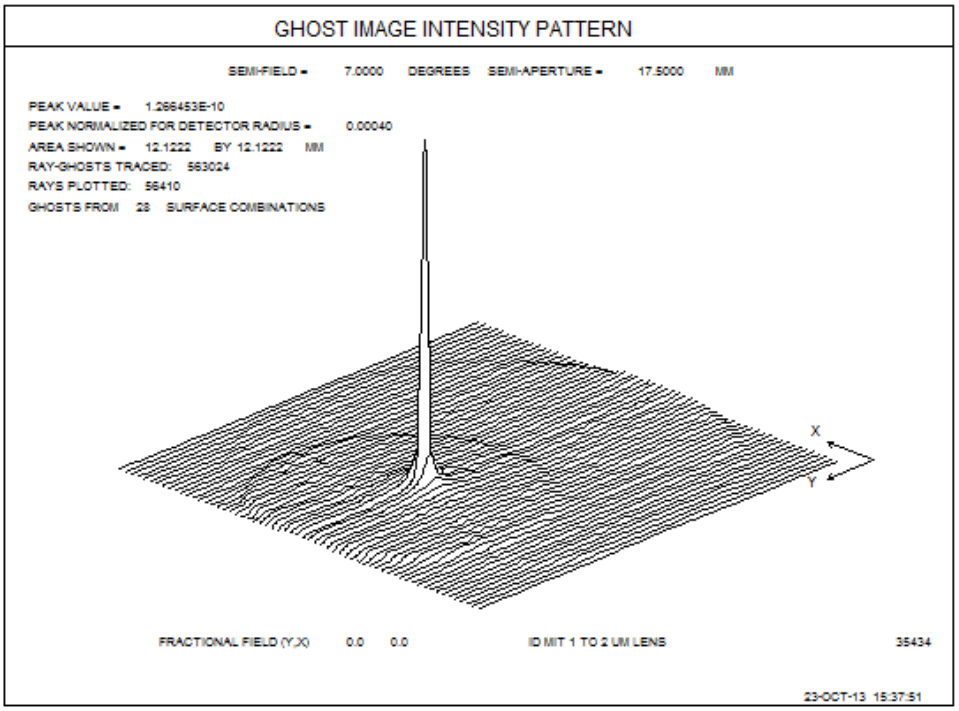


Since this is a multiline command, the prompt cannot show the entire format, but if you press the **F2** key when the prompt is displayed, the help file opens to that section in the index. We will use all four modes in this lesson. The first call to GHPLOT uses mode 1, producing a picture of all the ghost images superimposed for an object point at HBAR = 0.5 at the image plane:

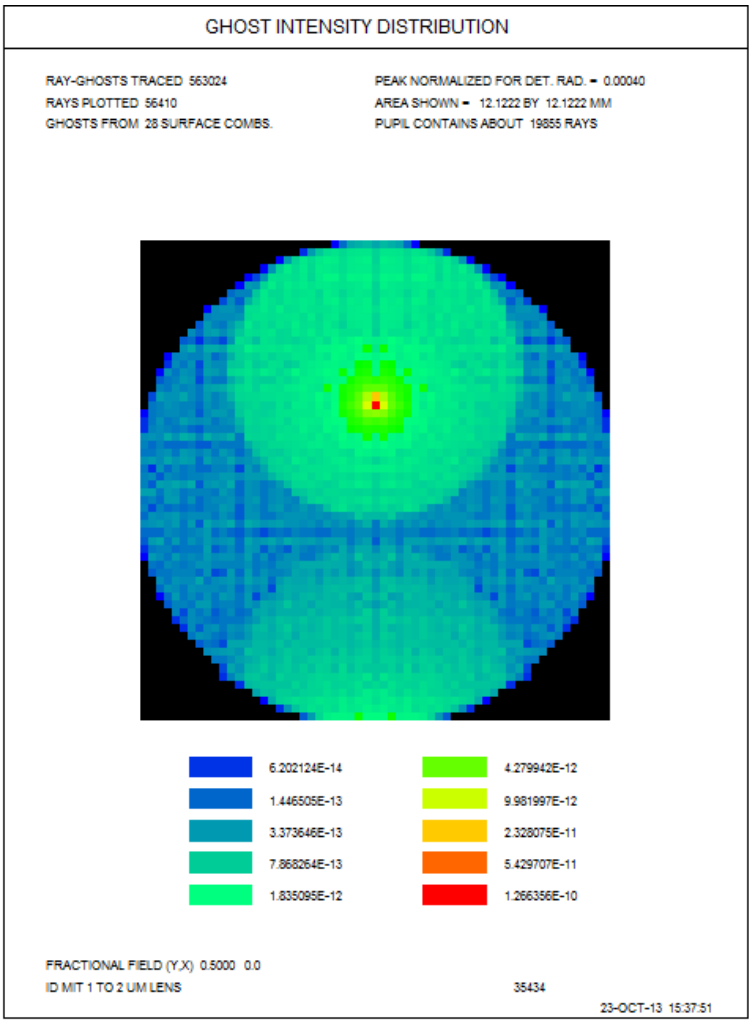
[1] TrayPrompt™ is a trademark of Optical Systems Design, Inc., a Maine, USA corporation.



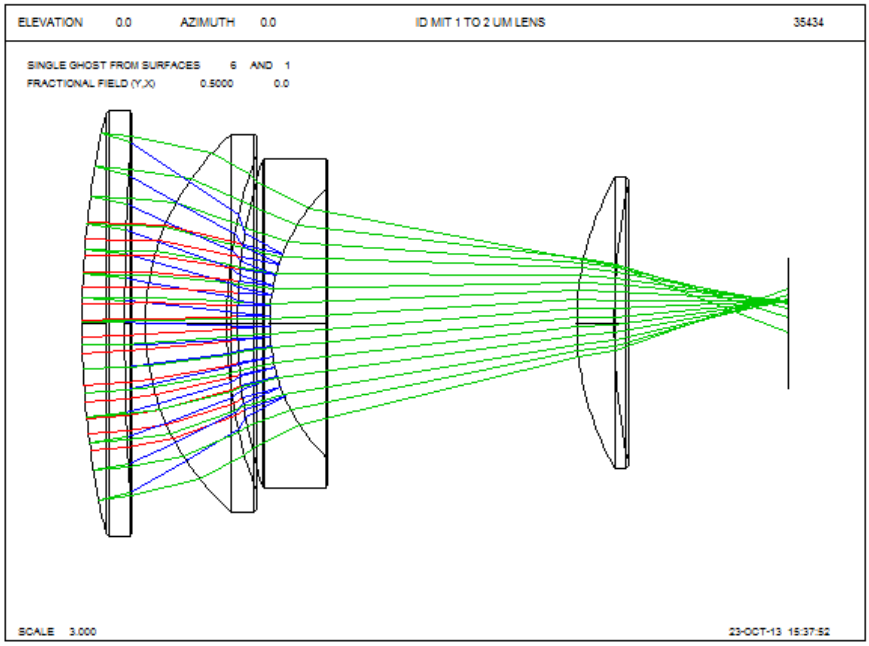
There is indeed a dark blob about halfway up in the field. This is probably the ghost we flagged earlier. The mode-2 analysis shows the same energy distribution as an oblique-perspective plot:



That sharp peak is indeed our ghost. Yet another way to view it is shown in the mode-3 plot:

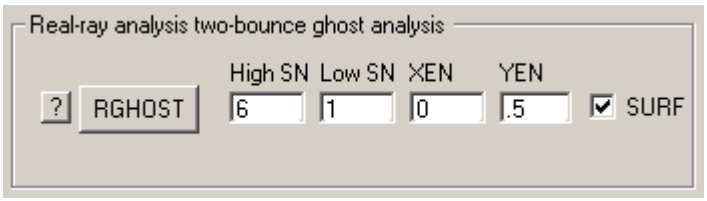


And lastly, the mode-4 plot singles out that particular set of reflections (which we asked for) and draws a tangential fan of rays.



Here, light comes in from the left drawn in red, turns blue after reflecting from surface 6, and then turns green after the second reflection at surface 1. It is indeed almost in focus at the image, but there is a lot of spherical aberration so the ghost is not very sharp.

Looking again at the MGH dialog, you see four more features that we have not used. Let's trace the path of a real ghost ray at zone 0.5. Fill in the boxes as shown and click the RGHOST button.

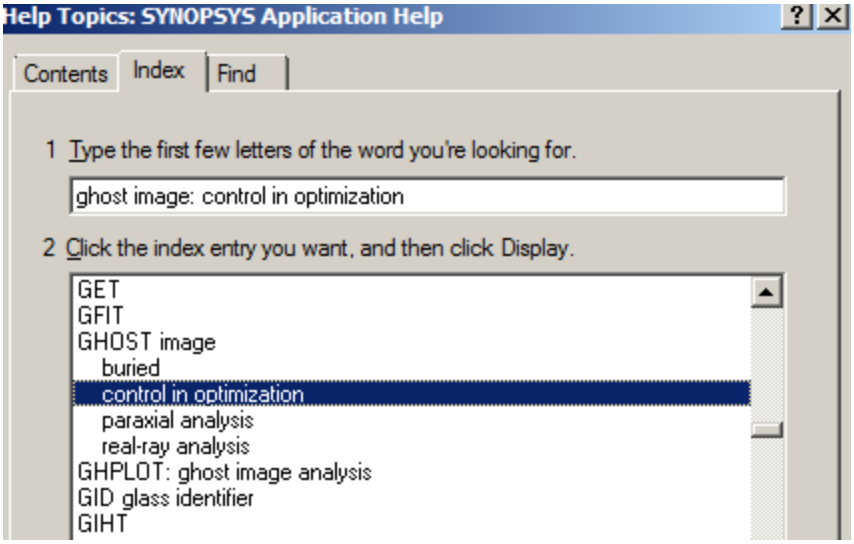


This produces the output

```
--- RGHOST 6 1 0 .5 SURF
                          RAY VECTORS          (X DIR TAN)   (Y DIR TAN)   (INC. ANG.)
 SURF             X              Y              Z             ZZ            HH           UNI
_____________________________________________________________________________________________
  OBJ       0.000000       0.000000       0.000000      0.000000 8.750000E-12
    1       0.000000       8.750000       0.442564      0.000000     -0.056702      5.790967
    2       0.000000       8.540210       0.142402      0.000000     -0.086503      1.334779
    3       0.000000       8.256701       1.510615      0.000000     -0.246653     15.791928
    4       0.000000       6.624679       0.478579      0.000000     -0.384916      5.591649
    5       0.000000       6.274262       0.388953      0.000000     -0.226690     13.957837
 --- RAY REVERSES AFTER NEXT SURFACE ---
    6       0.000000       5.481374      -0.886627      0.000000      0.444814
    5       0.000000       6.994957      -0.483893      0.000000      1.206445
    4       0.000000       7.951450      -0.691073      0.000000      0.498903
    3       0.000000      10.791512      -2.647176      0.000000      0.470102
    2       0.000000      12.783436      -0.319172      0.000000      0.221387
    1       0.000000      13.505397       1.058091      0.000000     -0.095157
    2       0.000000      13.193103       0.339970      0.000000     -0.151262
    3       0.000000      12.414364       3.579028      0.000000     -0.404621
    4       0.000000      10.296378       1.164810      0.000000     -0.674892
    5       0.000000       9.767857       0.947929      0.000000     -0.369535
    6       0.000000       8.241826       2.077523      0.000000     -0.148082
    7       0.000000       4.247415       0.334421      0.000000     -0.153884
    8       0.000000       3.743737       0.107527      0.000000     -0.282387
GHOST REFLECTED FROM SURFACES    1    6 AT SURFACE    9
     X              Y              ZZ             HH
-------------------------------------------------------------
   0.00000       -0.828738         0.00000       -0.282387
```

The ray reflects from surface 6, then again at 1, and proceeds to the image, where its Y-coordinate is -0.829 mm. That may indeed be a serious ghost.

If you catch this problem early in the design process, it is fairly easy to control, however. Type **HELP GHOST**, and select the link that describes controlling the ghost.



This opens a page that describes how to control ghosts.

> **10.3.1.5 Ghost-image control** Next Previous TOC
>
> A ghost image is caused by a reflection from one or more refracting surfaces. SYNOPSYS can evaluate and control two types: The GHOST program can show which combinations of surfaces are responsible for ghost images at the image surface, and BGI can evaluate the properties of a ghost image that is formed at another place within a lens system.
>
> To control the size of the blur at the image from a selected paraxial ghost, the input is
>
> **M TAR WT A PGHOST JREFH JREFL**
> …

Here you see the simple input required to control the ghost. A suitable request in your AANT file might be

```
M 5 0.1 A PGHOST 6 1
```

with the weighting adjusted to balance nicely with your other aberrations. If we achieve this goal, the ghost will be about 1% as intense as before. The target of 5 is somewhat arbitrary; a larger ghost is a weaker ghost, and this is a good guess to start with.

We have found that this procedure usually yields a great improvement in the specified ghost. Often, however, another combination of reflections then produces its own ghost, requiring another evaluation with GHOST and another PGHOST aberration in the merit function. You add them as they show up, until you reach a point where many ghosts are roughly the same intensity. We have never encountered a situation where this intensity was high enough to be a problem. If it were, it would be time to invest in better coatings on the problem surfaces.