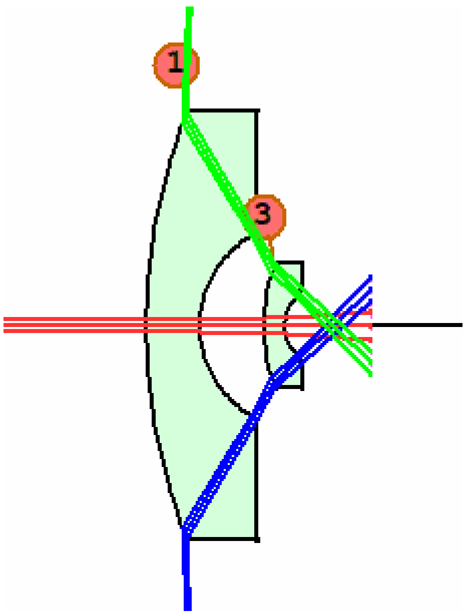
Lesson 41: Designing a very wide-angle lens

We are often asked about designing a wide-angle lens with DSEARCH™. If you enter a wide-angle object specification in the SYSTEM section of the DSEARCH file, it is likely that none of the candidate configurations will work, for the simple reason that no light gets through. DSEARCH can correct for some ray failures, but usually cannot optimize such a system. So what do you do?

There is a rather simple trick that works well in such cases: Rough out a simple front end that converts the beam into one with a smaller angle, and then go from there, declaring that portion with **USE CURRENT**. Here is an example:

We want a lens with a semi-field angle of 92.4 degrees that works at F/2.0. We will make the added elements of plastic, which can be aspheric. First, we have to create a front end that will trace.

We enter a simple system with two lenses and specify object type OBD, which is used for wide angles, declaring a paraxial stop on 5. We start with a moderate angle, say 50 degrees, and then, using the WorkSheet™ sliders, give the elements some negative power and bend them to the right. When that looks good, we increase the OBD field angle, continuing in this manner until we reach the desired angle of 92.4 degrees. Here is that front end:




```
RLE
ID WIDE-ANGLE DESEARCH
WAVL .6562700 .5875600 .4861300
 APS                5
 UNITS MM
 OBD  1.00000E+09   92.4 0.2887  -11.0345861 0 0 0.2887

   0 AIR
   0 CV  1.0000000000000E-09 AIR
   1 CV      0.0356159993000   TH      2.50000000
   1 GLM      1.50000000              55.00000000
   2 CV      0.2018873610000   TH      2.99808431 AIR
   3 CV      0.1145140002814   TH      1.00000000
   3 GLM      1.50000000              55.00000000
   4 CV      0.4600712360000   TH      4.00383115 AIR
   5 CV      0.0000000000000   TH      0.00000000 AIR
 END
```

Our 92.4-degree entering beam exits at a reasonable angle. Now we can create our DSEARCH input MACro.

```
CORE 14
ON 98
TIME
DSEARCH 2 QUIET
USE CURRENT 5 ALL

GOALS
ELEMENTS 5
FNUM 2 1
BACK 5 SET
STOP MIDDLE
STOP FREE
ASPHERIC 3 5 6 7 8 9 10 11 12 13 14
FOV 0 .2 .4 .6 .8 1
NGRID 6
SNAP 10
RT 0.5
RSTART 50
PLASTIC 5 7 9 11 13
ANNEAL 50 10 Q 40
NPASS 50
! QUICK 20 30
END
SPECIAL AANT
ACC 10 1 1
ACA 55 1 10
ASC 85 1 1
LUL 90 .1 1 A TOTL
END

GO
TIME
```

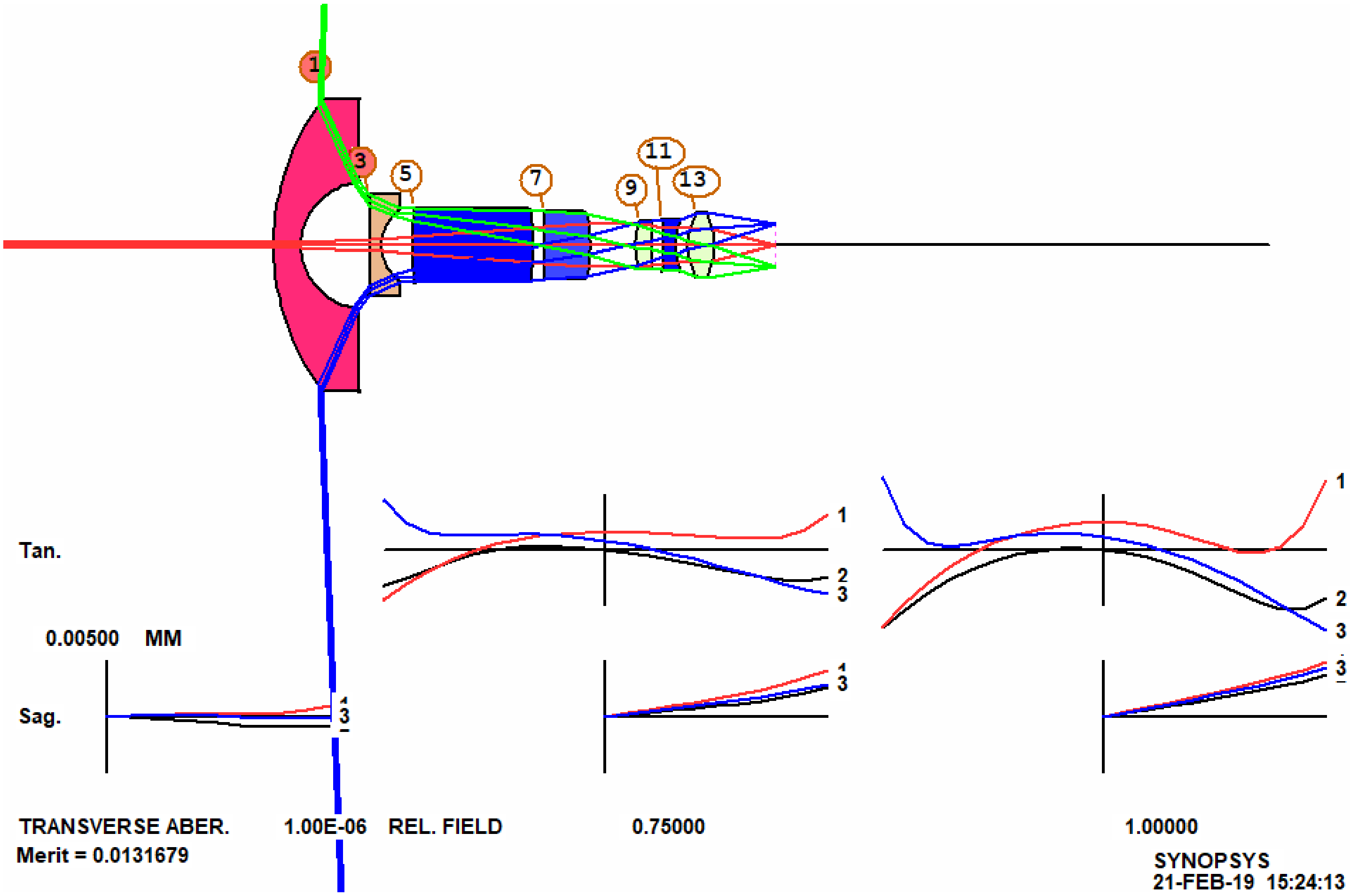
In this file, we have specified a back-focus distance of 5 mm, fixed with the **SET** directive. DSEARCH lets you manage that distance in three ways: If you just give a distance, such as **BACK 5**, the program adds a YMT solve at the end and includes a target in the AANT file to control the resulting value. If you add a weighting factor, such as **BACK 5 100**, that weight is applied to the target. The third way is to request an exact value, in this case with **BACK 5 SET**. Now the program will simply set the back-focus distance to the entered value, 5 mm in this case, and will *not* add a YMT solve. This is often a good choice for difficult designs, especially when the other options return systems with a virtual image.

We request a maximum element thickness of 10 mm and an upper limit on the total length of 90 mm, to keep things reasonable. Also, we restrict ray intercept angles to no more than 55 degrees. Otherwise, for steep angles like this, one can get grazing-incidence rays at full field, which are impractical because of coating concerns. The ASC monitor is there to keep surface slopes no greater than 85 degrees. Any steeper and you run into manufacturing and coating problems.

Note that we are *not* using the QUICK option in this case. That is a powerful tool for simpler jobs, but this one is not so simple, and we need the power of the full optimization on each candidate system. We commented out that line above, to emphasize the point.

A final note: We gave a weight to the **FNUM** request in the above input. If we did not, the program would control the F/number with a UMC solve, and the resulting curvature would likely be so steep that no light would get through. Again, for difficult designs like this, we have to steer things a bit. With the weight added on the FNUM line, the program treats the final curvature as a variable and controls the F/number in the AANT file instead of with a curvature solve.

Okay, our input is prepared, so we run this DSEARCH file. In about two minutes we see the results:



DSEARCH made a drawing of the 10 best designs it found, and most of them are actually quite good.

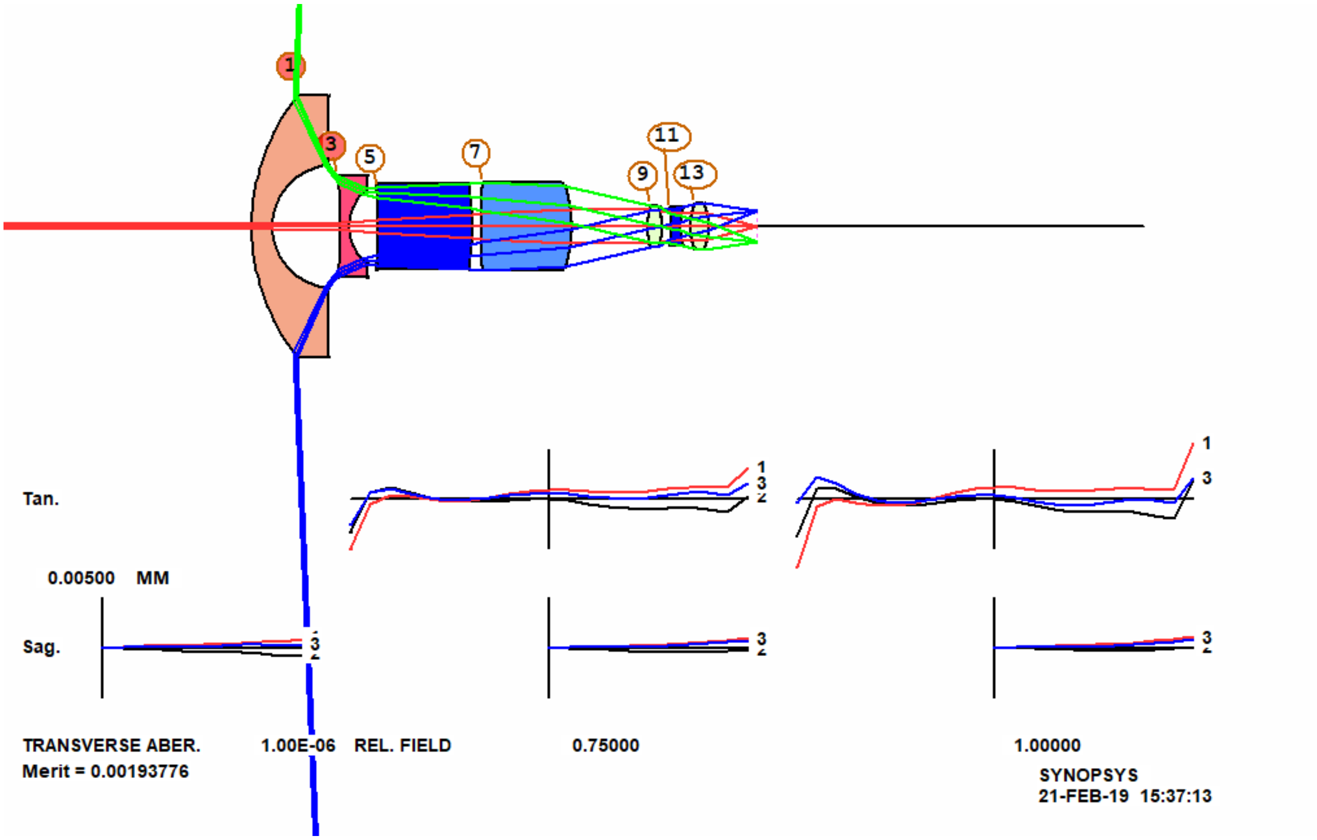
Okay, we are well on our way, but we need to refine the design somewhat. We run the optimization MACro that DSEARCH has made for us, and the lens improves.

Now we have to check the quality over the field. In PAD, we click the Scan button  in the PAD toolbar, and see the implied stop, which is close to surface 10, is not well filled at all fields. Well, what can you expect in a system with a field this wide and a paraxial pupil? We have to control that.

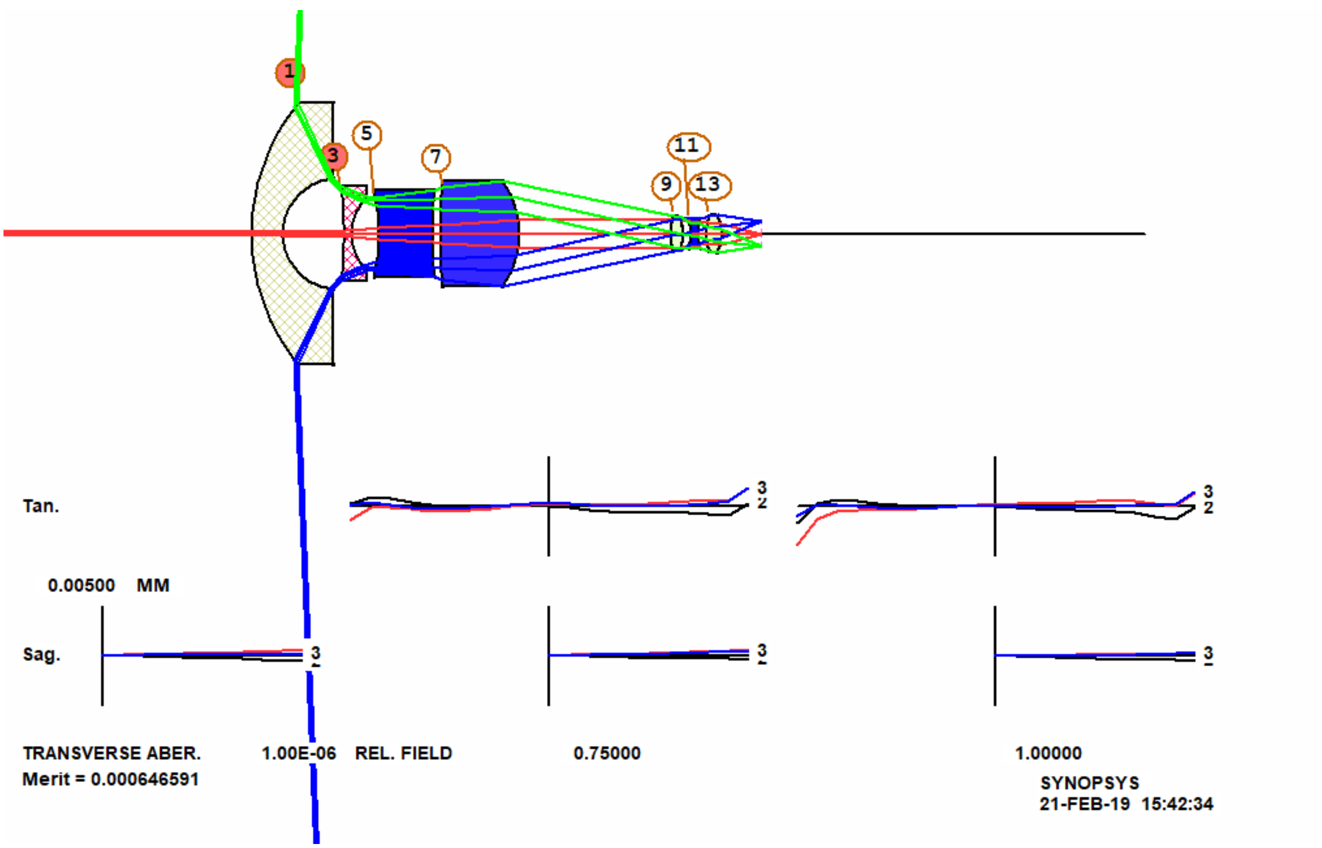
The lens only has an *implied* pupil at the moment, as a result of our varying the quantity YP0. This gets us close to where the stop really wants to be, but now we have to actually put it there. In the WS edit pane, enter

```
APS -10
```

to put a real stop on surface 10. Then we delete the variable **`VY 0 YP1`** from the PANT file, optimize and anneal.

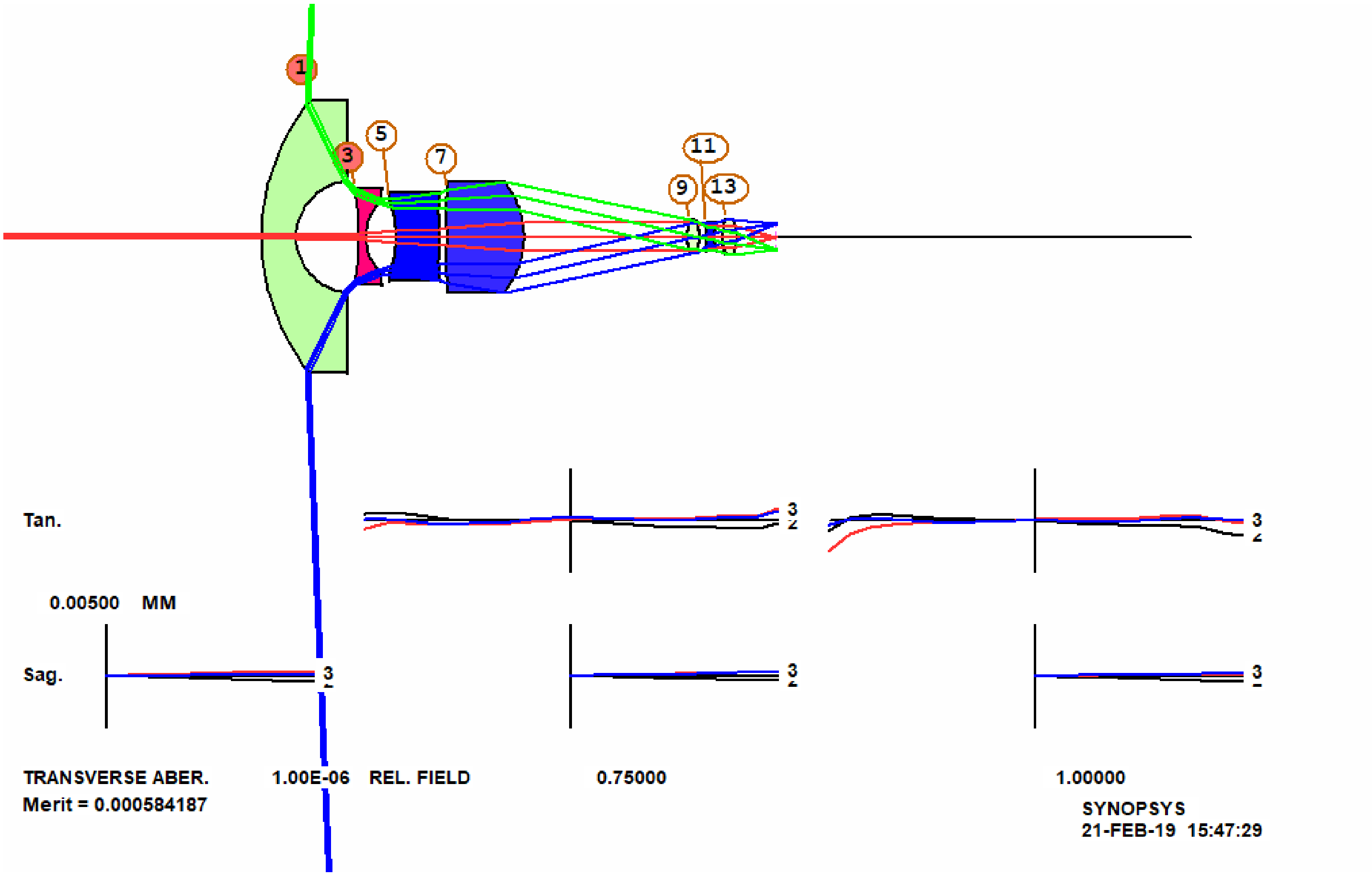


This is a very promising design, so let's insert real materials. Open the **MRG** dialog, select the U catalog (which will match only plastic elements), QUIET, SORT, and click OK. The lens now has real plastics.

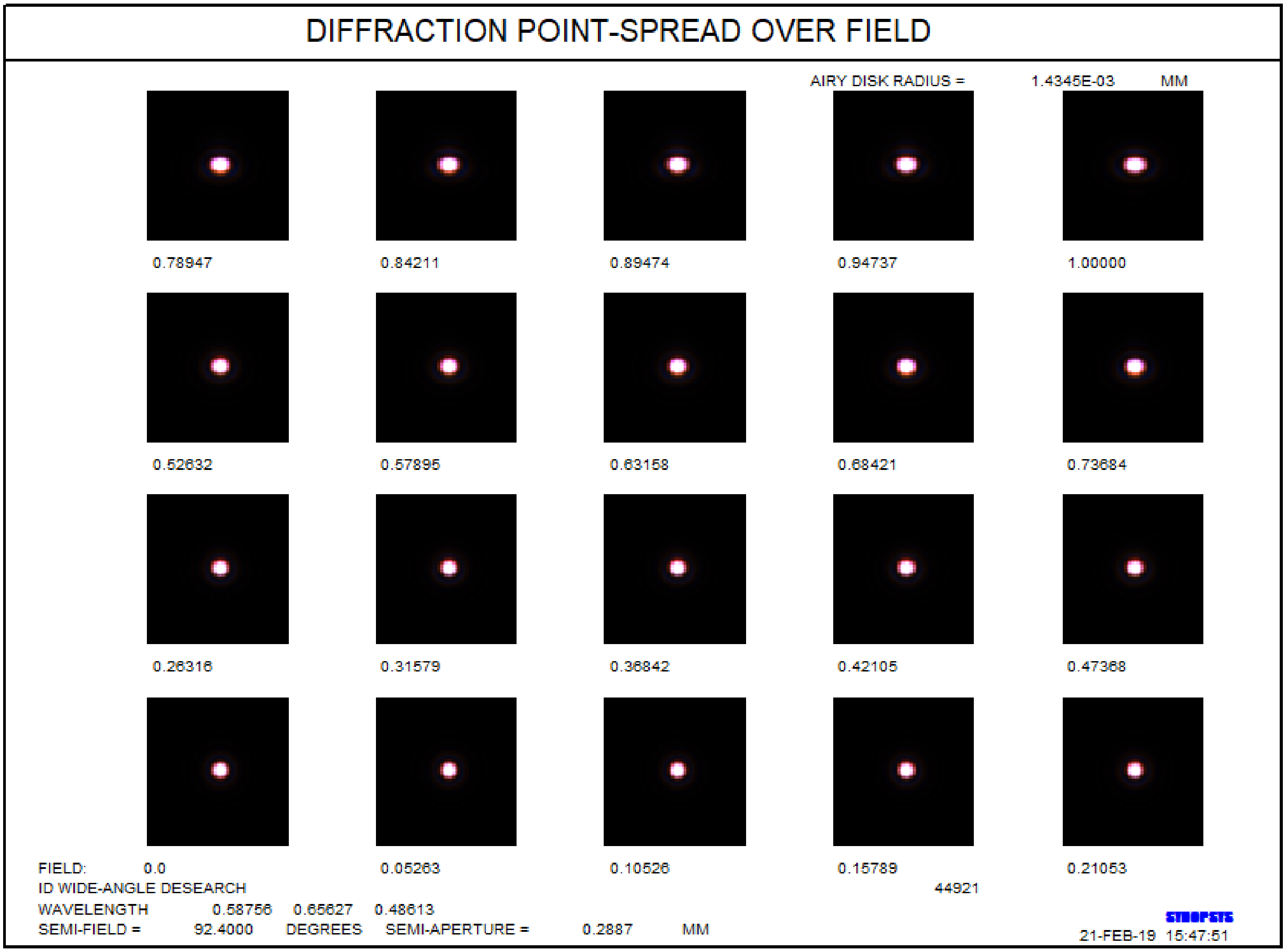


We are almost done. The picture above shows the PAD display setting which fills GLM elements with a cross-hatch pattern, showing that the first two elements are not yet matched to real glasses.

Now run **MRG** again, this time selecting the Ohara catalog. The program now matches those elements, which are glass, not plastic. The design comes back just as good as before, shown below.



How well did we do? Let's look at the diffraction pattern over the field. Go to the **MPF** dialog, select Show visual appearance, and click Execute. The result is nearly perfect over the whole field.



For those who may want to evaluate this lens further, the RLE file is below. You can copy these lines and paste them into the EE editor.

```
RLE
ID WIDE-ANGLE DESEARCH                            44921
ID1 DSEARCH CASE WAS 0000000000000000000001101      13
 FNAME 'DSEARCH06.RLE                                      '
 MERIT    0.584187E-03
 LOG     44921
 WAVL .6562700 .5875600 .4861300
 APS                -10
 UNITS MM
 OBD  1.00000E+09   92.40000153 0.2887  -17.2566408 0 0 0.2887

   0 AIR
   0 CV  1.0000000000000E-09 AIR
   1 CV      0.0352438335795   TH      4.48434853
   1 N1 1.82896003 N2 1.83478459 N3 1.84849295
   1 CTE   0.620000E-05
   1 GTB O    'S-LAH55V        '
   2 CV      0.1375497211862   TH      8.08932062 AIR
   3 CV     -0.0238328156059   TH      1.00000000
   3 N1 1.61505461 N2 1.61801777 N3 1.62481031
   3 CTE   0.101000E-04
   3 GTB O    'S-PHM52         '
   4 CV      0.1402843170760   TH      3.84886615 AIR
   5 RAD   -17.8857821811566   TH      5.65497496
```

```
  5 CC      5.03168294
  5 N1 1.62500787 N2 1.63247281 N3 1.65207563
  5 DNDT -1.100E-04 -1.100E-04 -1.100E-04 4.00000E-01 7.00000E-01 9.00000E-01
  5 CTE   0.690000E-04
  5 GTB U    'AL-6263           '
  5 DC1  0.00000000E+00 -1.86093355E-04 -5.49254912E-06  0.00000000E+00  0.00000000E+00
 5 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 5 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 5 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
  5 PLASTIC
  6 RAD    -35.1266227788697   TH      1.00000000 AIR
  6 CC    -13.59627575
  6 DC1  0.00000000E+00  7.03653778E-04 -4.86373248E-06  0.00000000E+00  0.00000000E+00
 6 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 6 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 6 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
  7 RAD    -25.7991681851016   TH     10.01179729
  7 CC     -3.63258849
  7 N1 1.56269979 N2 1.56743991 N3 1.57900003
  7 CTE   0.660000E-04
  7 GTB U    'SAN               '
  7 DC1  0.00000000E+00  8.05690517E-04 -5.68265355E-06  0.00000000E+00  0.00000000E+00
 7 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 7 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 7 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
  7 PLASTIC
  8 RAD    -10.2990877365687   TH     21.20305917 AIR
  8 CC     -0.63845393
  8 DC1  0.00000000E+00  5.57190639E-06  5.35006434E-08  0.00000000E+00  0.00000000E+00
 8 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 8 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 8 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
  9 RAD      6.9939984729416   TH      1.47827577
  9 CC     -1.26738540
  9 N1 1.52289510 N2 1.52565759 N3 1.53222386
  9 DNDT -1.100E-04 -1.100E-04 -1.100E-04 4.30000E-01 5.80000E-01 7.80000E-01
  9 CTE   0.600000E-04
  9 GTB U    'ZEON480R          '
  9 DC1  0.00000000E+00 -6.12059103E-04  1.00979216E-05  0.00000000E+00  0.00000000E+00
 9 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 9 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 9 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
  9 PLASTIC
 10 RAD    -11.6064531699523   TH      1.00000000 AIR
 10 CC     -3.12369636
 10 DC1  0.00000000E+00 -4.72298296E-04  1.11815203E-05  0.00000000E+00  0.00000000E+00
10 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
10 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
10 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 11 RAD    -25.2911417125612   TH      1.00000000
 11 CC     97.59749792
 11 N1 1.64225416 N2 1.65063034 N3 1.67223994
 11 CTE   0.630000E-04
 11 GTB U    'OKP4RX50          '
 11 DC1  0.00000000E+00 -3.31779879E-03  1.30009165E-04  0.00000000E+00  0.00000000E+00
11 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
11 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
11 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 11 PLASTIC
 12 RAD      4.5765024675393   TH      1.00000000 AIR
 12 CC     -4.13583208
 12 DC1  0.00000000E+00 -1.73450179E-03 -1.80280362E-04  0.00000000E+00  0.00000000E+00
12 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
12 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
12 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 13 RAD      4.7368527067791   TH      1.90883343
 13 CC     -1.57470512
```

```
 13 N1 1.52289510 N2 1.52565759 N3 1.53222386
 13 DNDT -1.100E-04 -1.100E-04 -1.100E-04 4.30000E-01 5.80000E-01 7.80000E-01
 13 CTE   0.600000E-04
 13 GTB U    'ZEON480R        '
 13 DC1  0.00000000E+00 -1.80380415E-03 -2.75491946E-06  0.00000000E+00  0.00000000E+00
13 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
13 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
13 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 13 PLASTIC
 14 RAD     -5.6610605778815   TH      5.00000000 AIR
 14 CC     -0.92742860
 14 DC1  0.00000000E+00 -3.57699860E-04  5.25201770E-05  0.00000000E+00  0.00000000E+00
14 DC2  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
14 DC3  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
14 DC4  0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
 15 CV      0.0000000000000   TH      0.00000000 AIR
END
```

Let me add some words of wisdom. This kind of design is tricky, and if you are a new user of SYNOPSYS, and things don't go exactly right, you will not know what to do. Note that we did not use a curvature or thickness solve in this exercise, since a common problem with very wide-angle lenses is trying to avoid ray failures. While using solves makes perfect sense mathematically, they can cause just this kind of problem with this kind of lens. Also, we did not change to a real pupil until the design was well along. The real-pupil search is robust but not infallible, and with these steep ray angles and power-series aspherics, it is easy to get to a configuration where there is no solution to the search. All that can be avoided by using the implied pupil until the design is in good shape.

This example started with a front end we created by manipulating sliders in the WorkSheet™, and those values were essentially random, since there was no optimization involved in that process. With a different front end, the result could be quite different, and it might well be worth the extra effort, now that we have a good design, to copy the top section from the final lens, with the optimized first two elements, and then paste those lines into the original DSEARCH input file and run it once more. Then you start with a much better front end, and you might get even better results than before. This is a trick you should keep up your sleeve.

Lastly, do not hesitate to investigate more than just the top lens returned by DSEARCH. The top one, in this case, turned out to be an excellent lens, but that does not happen all the time. That's why DSEARCH returns more than just one.