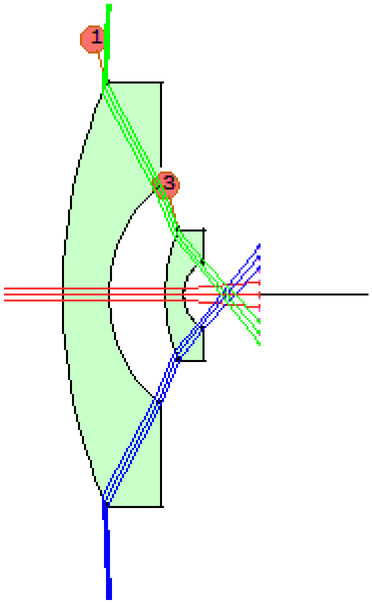
Lesson 41: Designing a very wide-angle lens

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      0.1318873610000   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 16
DSEARCH 2 QUIET
USE CURRENT 5 ALL

GOALS
ELEMENTS 5
FNUM 2 1
BACK 10 SET
STOP MIDDLE
STOP FREE
ASPH Q
ASPHERIC 3 5 6 7 8 9 10 11 12 13 14
FOV .2 .4 .6 .8 1
DELAY OFF
NGRID 6
SNAP 10
PLASTIC 5 7 9 11 13
!QUICK 30 40
ANNEAL 50 10 Q
NPASS 50
END
SPECIAL AANT
ACC 10 1 1
ACA 70 1 10
LUL 90 .1 1 A TOTL
END

GO
```

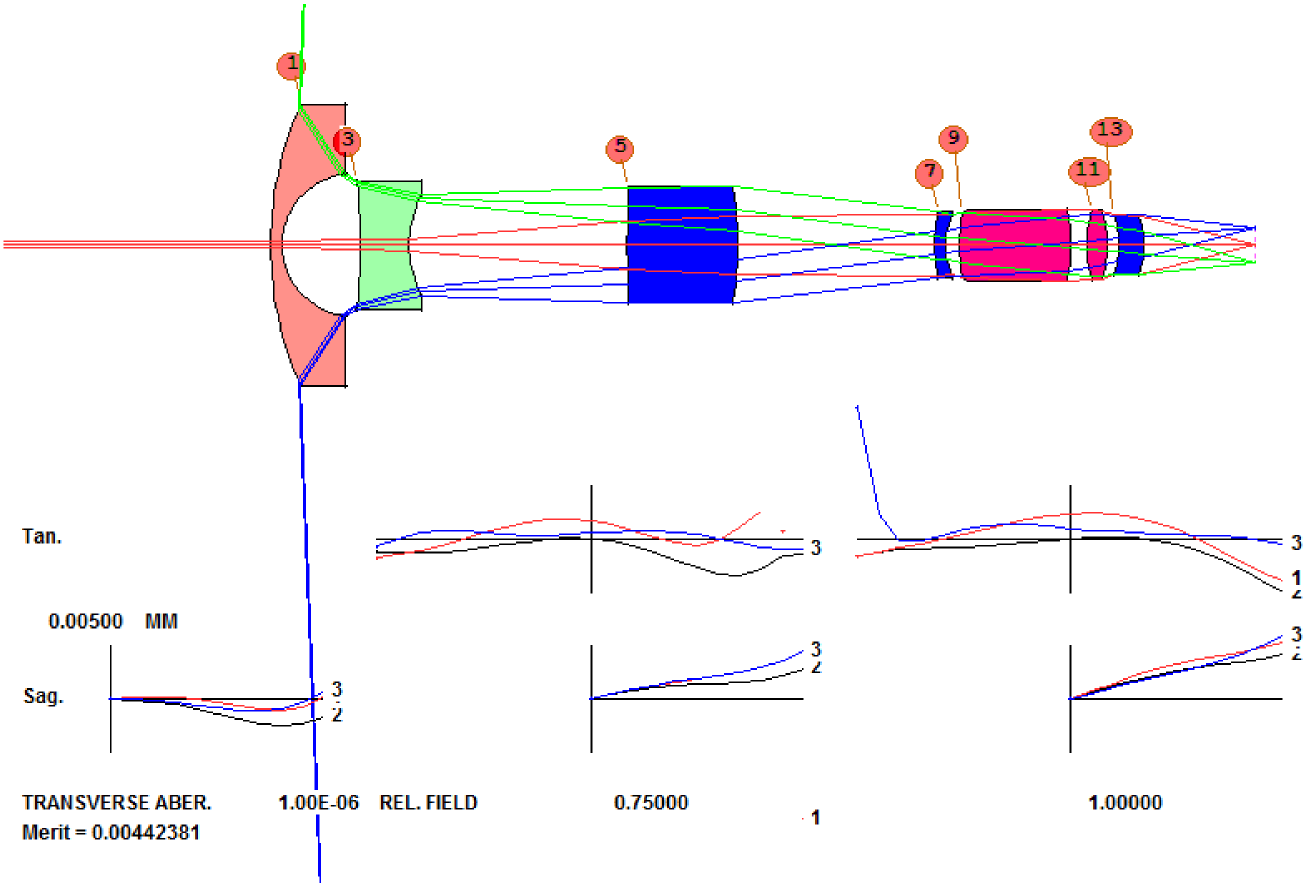
In this file, we have specified a back-focus distance of 10 mm, fixed with the **SET** directive. DSEARCH lets you manage that distance in three ways: If you just give a distance, such as **BACK 10**, the program adds a YMT solve at the end and includes a target in the AANT file to control the resulting value. If you add a weighting factor, such as **BACK 10 100**, that weight is applied to the target. The third way is to request an exact value, in this case with **BACK 10 SET**. Now the program will simply set the back-focus distance to the entered value, 10 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 70 degrees. Otherwise, for steep angles like this, one can get grazing-incidence rays at full field, which are impractical because of coating concerns.

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.

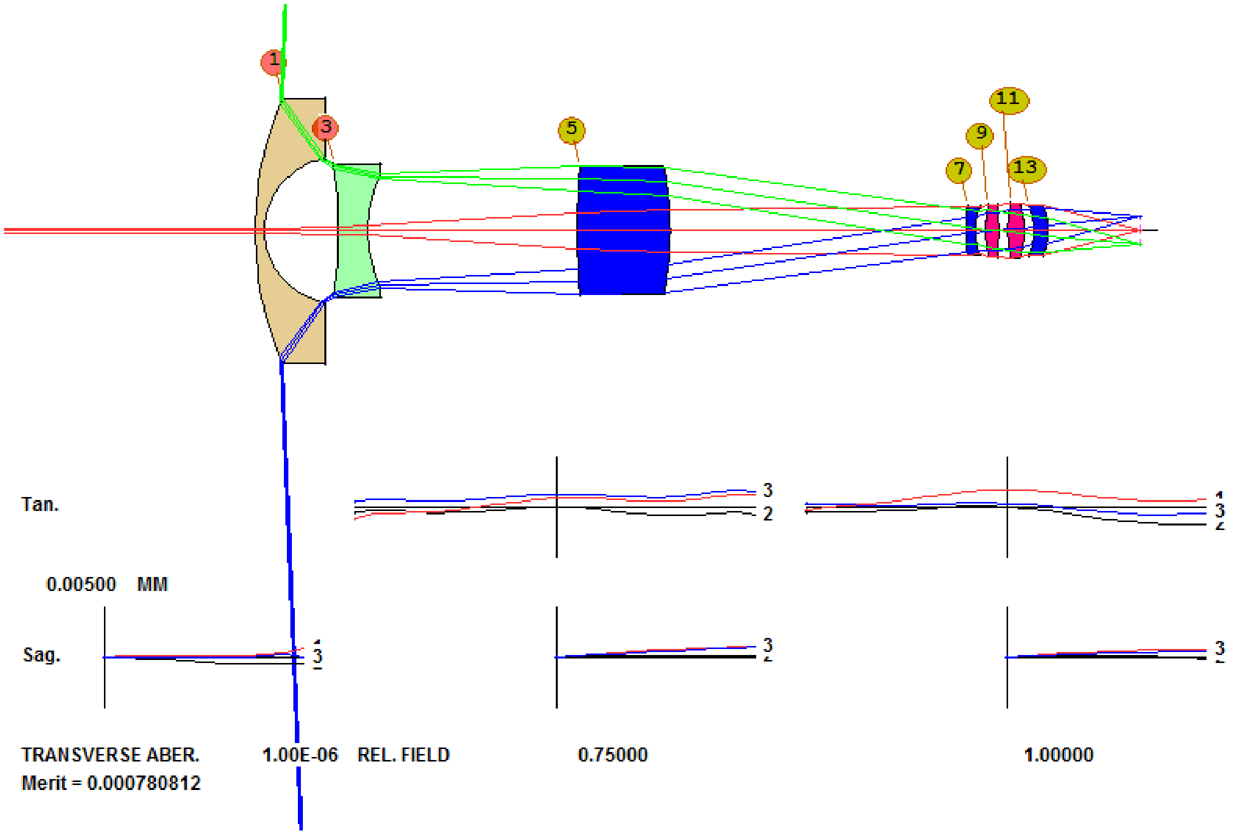
Okay, we are well on our way, but we need to refine the design somewhat. We run the optimization MACro that DSEARCH has made for us, and the lens changes very little.

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, we 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.

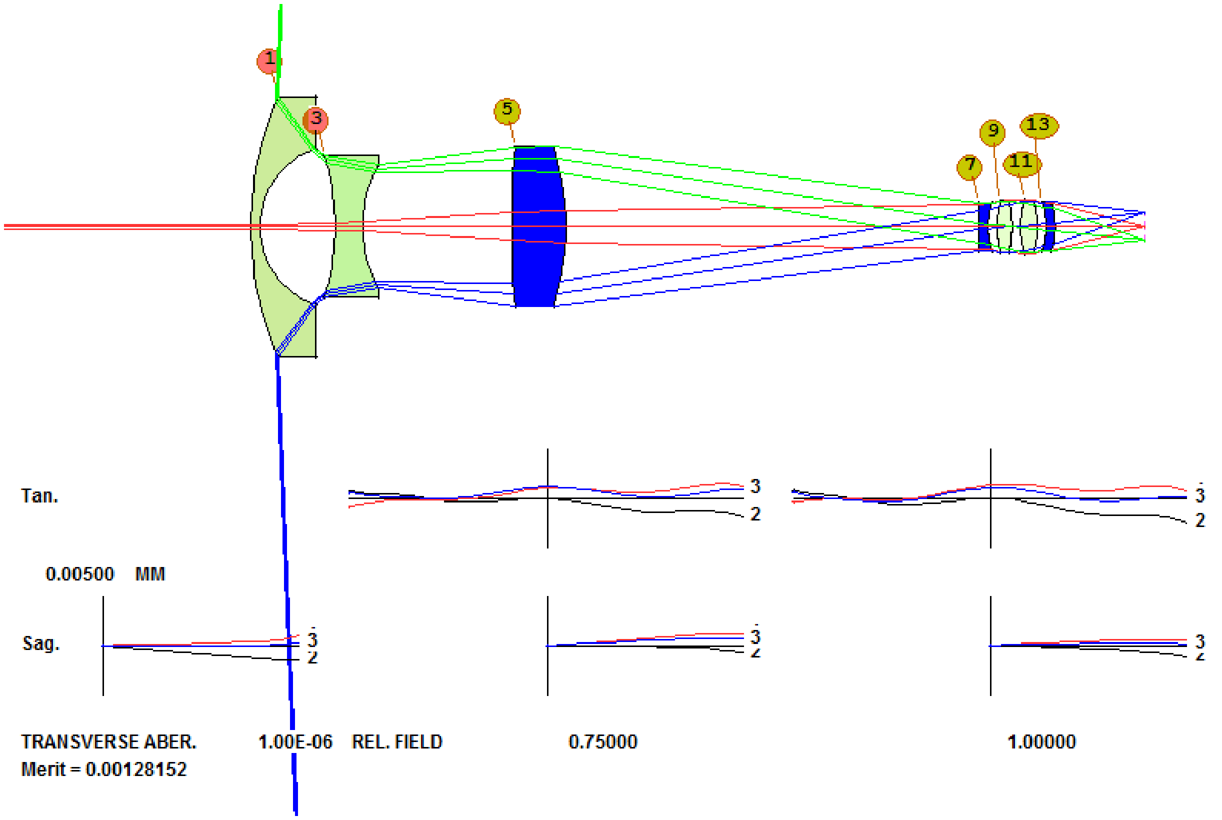


Fig. 5. Lens with real plastics replacing the glass models on the last five elements.

We are almost done. We are going to continue optimizing the lens, and we don't want our plastics to be replaced with new model glasses, so we delete all the VY sn GLM lines from the PANT file and replace them with a single line:

```
VLIST GLM ALL.
```

That will only vary those materials that are currently glass models, on elements one and two. Optimize and anneal once more.

Now we run `MRG` again, this time selecting the Ohara catalog. The program now matches the first two elements, which are glass, not plastic. The design comes back just as good as before, shown in Fig. 6. (L41L1)

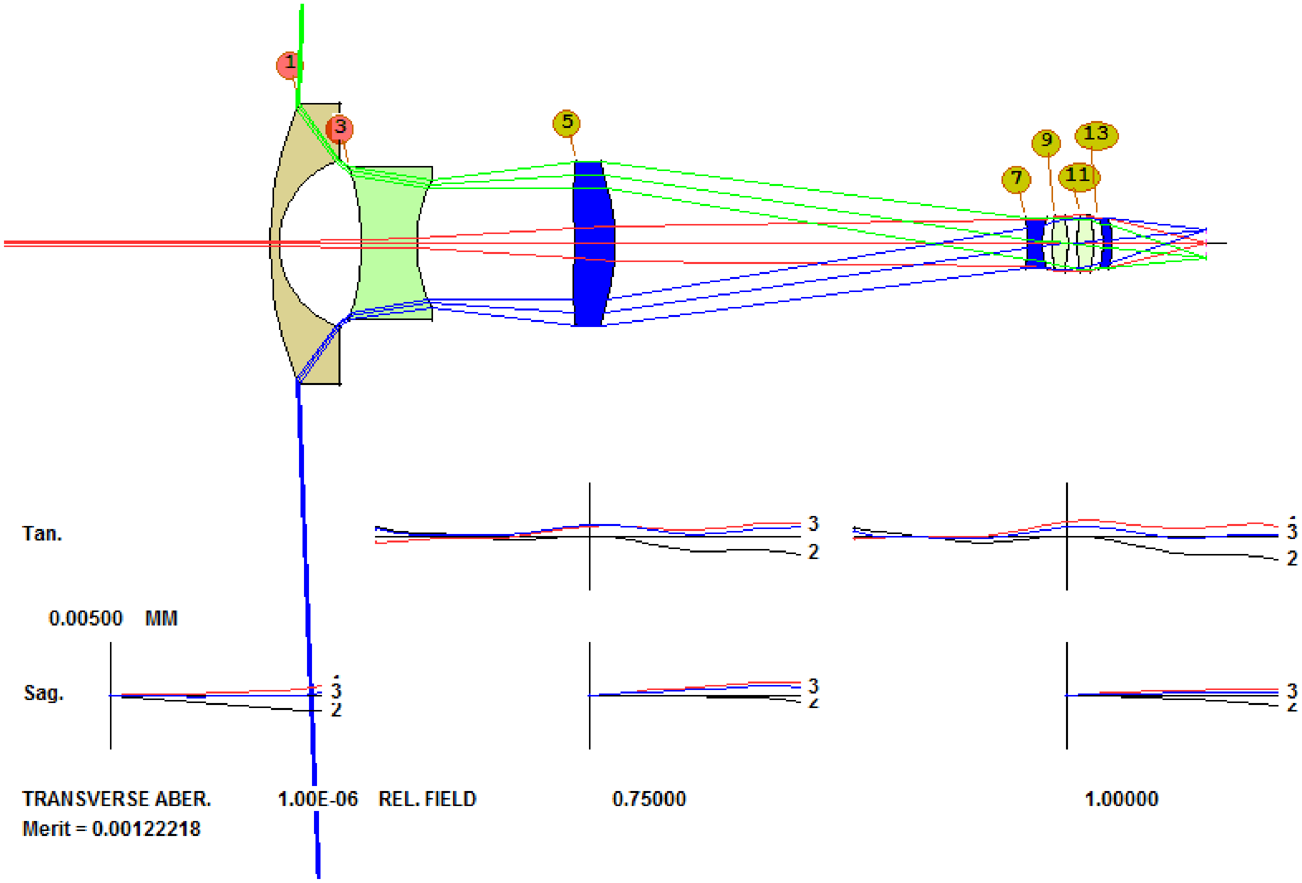


Fig. 6. Lens with all real materials.

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, in Fig. 8, is nearly perfect over the whole field.

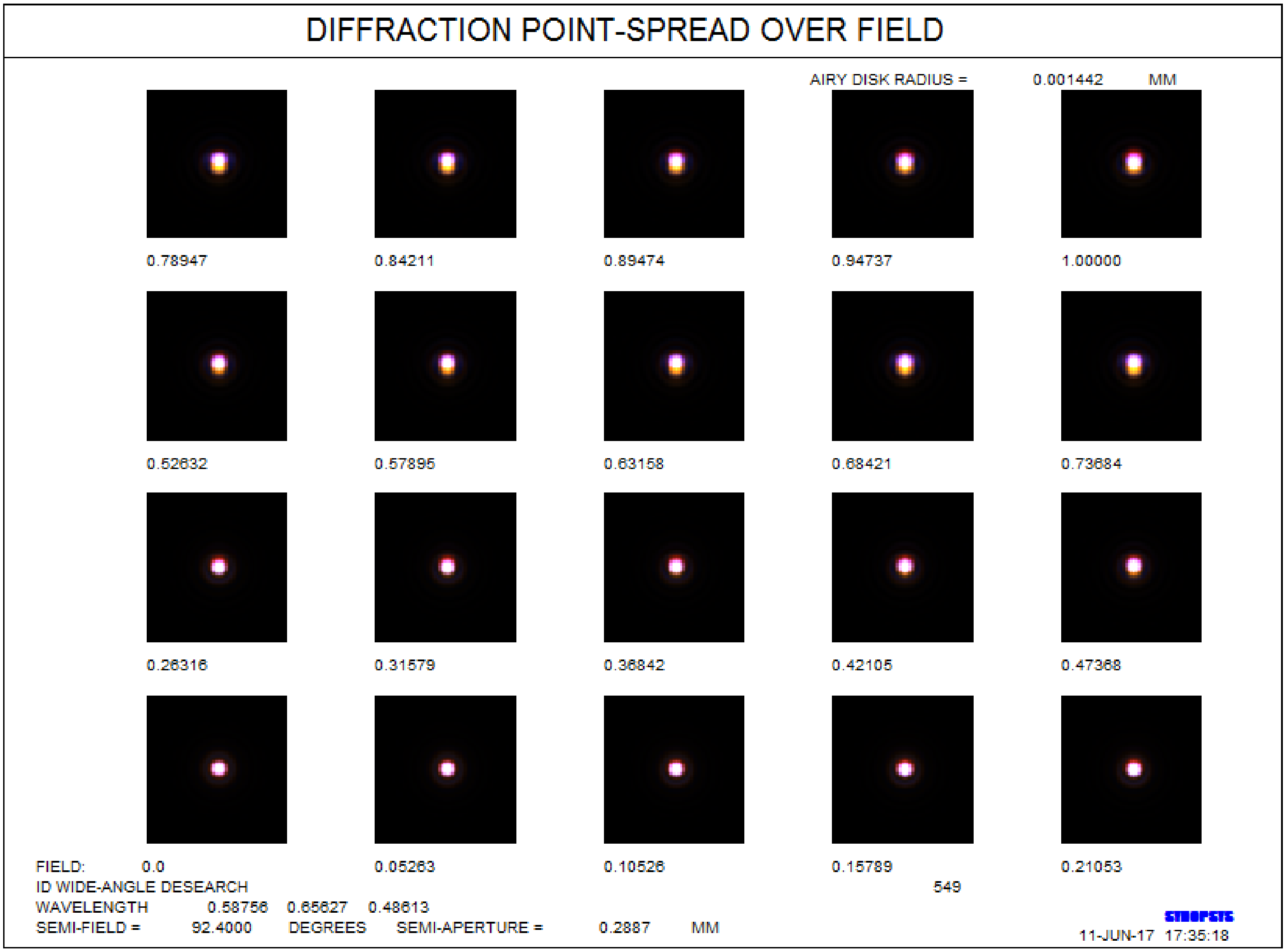


Fig. 8. Diffraction PSF over the field.

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                    549
ID1 DSEARCH CASE WAS 0000000000000000000001111     15
 WAVL .6562700 .5875600 .4861300
 APS             -10
 UNITS MM
 OBD  1.00000E+09   92.40000153 0.2887  -15.8713919 0 0 0.2887

   0 AIR
   0 CV  1.0000000000000E-09 AIR
   1 CV      0.0260937958778   TH      1.00000000
   1 N1 1.81072491 N2 1.81597447 N3 1.82822278
   1 CTE   0.630000E-05
   1 GTB O    'S-LAH59         '
   2 CV      0.1062185691313   TH      8.73634084 AIR
   3 CV     -0.0381411162195   TH      5.91174196
   3 N1 1.82896003 N2 1.83478459 N3 1.84849295
   3 CTE   0.620000E-05
   3 GTB O    'S-LAH55V        '
   4 CV      0.0660034452801   TH     16.85831989 AIR
   5 RAD   -138.0968858112222   TH      4.37718093
   5 CC    100.00000000
```

```
  5 N1 1.64225416 N2 1.65063034 N3 1.67223994
  5 CTE   0.630000E-04
  5 GTB U    'OKP4RX50        '
  5 DC1  0.00000000E+00 7.30200857E-05 1.48416975E-07 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    -21.0605738757054   TH     44.03095789 AIR
  6 CC     -4.75816695
  6 DC1  0.00000000E+00-6.94211792E-06 3.43604999E-07 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   -111.0507956868741   TH      1.67384895
  7 CC   -100.00000000
  7 N1 1.64225416 N2 1.65063034 N3 1.67223994
  7 CTE   0.630000E-04
  7 GTB U    'OKP4RX50        '
  7 DC1  0.00000000E+00-1.94604199E-03 5.49833735E-05 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      6.7304260208507   TH      1.00000000 AIR
  8 CC     -0.58536337
  8 DC1  0.00000000E+00-2.59873419E-03 9.92318034E-05 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      9.7697110081571   TH      1.75562117
  9 CC     -3.39966178
  9 N1 1.50724931 N2 1.50995136 N3 1.51625020
  9 DNDT -1.100E-04 -1.100E-04 -1.100E-04 4.30000E-01 5.80000E-01 7.80000E-01
  9 CTE   0.900000E-04
  9 GTB U    'ZEON330R        '
  9 DC1  0.00000000E+00-9.94688980E-04 1.07499451E-04 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     -8.8072667951121   TH      1.00000000 AIR
 10 CC     -4.25736209
 10 DC1  0.00000000E+00 5.98624949E-04 5.28052568E-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     23.2403610905735   TH      1.72858896
 11 CC      1.69037601
 11 N1 1.50724931 N2 1.50995136 N3 1.51625020
 11 DNDT -1.100E-04 -1.100E-04 -1.100E-04 4.30000E-01 5.80000E-01 7.80000E-01
 11 CTE   0.900000E-04
 11 GTB U    'ZEON330R        '
 11 DC1  0.00000000E+00 2.10417649E-03-3.35758216E-05 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    -11.1049150737322   TH      1.00000000 AIR
 12 CC     -0.19799751
 12 DC1  0.00000000E+00-2.14632707E-04 1.93285361E-05 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    -10.1118316301289   TH      1.00000000
 13 CC     -0.64163783
 13 N1 1.64225416 N2 1.65063034 N3 1.67223994
```

```
 13 CTE   0.630000E-04
 13 GTB U    'OKP4RX50        '
 13 DC1  0.00000000E+00-1.84686149E-03 6.79336881E-05 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     -9.0418834379157   TH     10.00000000 AIR
 14 CC     -0.05459002
 14 DC1  0.00000000E+00-9.65748548E-04 5.96199181E-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 essentially finished. The real-pupil search is robust but not infallible, and with this kind of steep ray angle and with power-series aspherics, it is very 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.

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 best, but that does not happen all the time. That's why DSEARCH returns more than just one lens.