

Lesson 26: Putting it All Together

In this lesson we will undertake a rather difficult lens design task, one that will demonstrate some of the many powerful features that you have learned about in previous lessons. (You will need a license to run this example, since it requires more than 12 surfaces and requires saving lens files.) As you read each of the paragraphs below, be sure to look up any topics you are not yet familiar with in the help file so you understand what the arguments mean and what other possibilities exist.

This lens must work over the wavelength range of 0.38 to 0.9 microns – which is a challenge right off the bat. In addition, we want the lens to work at a speed of F/0.714. That's also not too easy to do. Here are the requirements:

1. Object at infinity, 0.8 degree semi-field, 1.26 mm semi-aperture.
2. Spectral range 0.38 to 0.9 microns.
3. F/number 0.714
4. Total track length not more than 45 mm.
5. Good distortion correction.
6. Telecentric at image.
7. No feathered edges, center thicknesses not over 8 mm.

We guess that this job will require perhaps 10 elements, but want to get there gradually. We set up the input for DSEARCH, asking for eight elements. That will give us some potential configurations, and we can increase the complexity as needed once we see how things are going. Since the spectral range is so wide, we elect to specify five wavelengths instead of the usual three in order to avoid large focus errors at in-between wavelengths.

```
CORE 14
DSEARCH 3 QUIET
```

```
SYSTEM
ID EXAMPLE WIDE-SPECTRUM FAST LENS
UNI MM
OBB 0 0.8 1.26
WA1 0.9 0.77 0.64 0.51 0.38
CORDER 3 1 5
END
```

```
GOALS
ELEMENTS 8
FNUM 0.7143 100
BACK 0 0
TOTL 0 0
STOP FREE
COLORS M
RSTART 10
THSTART .25
ASTART 0.1
RT 0.7
OPD
QUICK 50 50
ANNEAL 200 20 Q
END
```

```

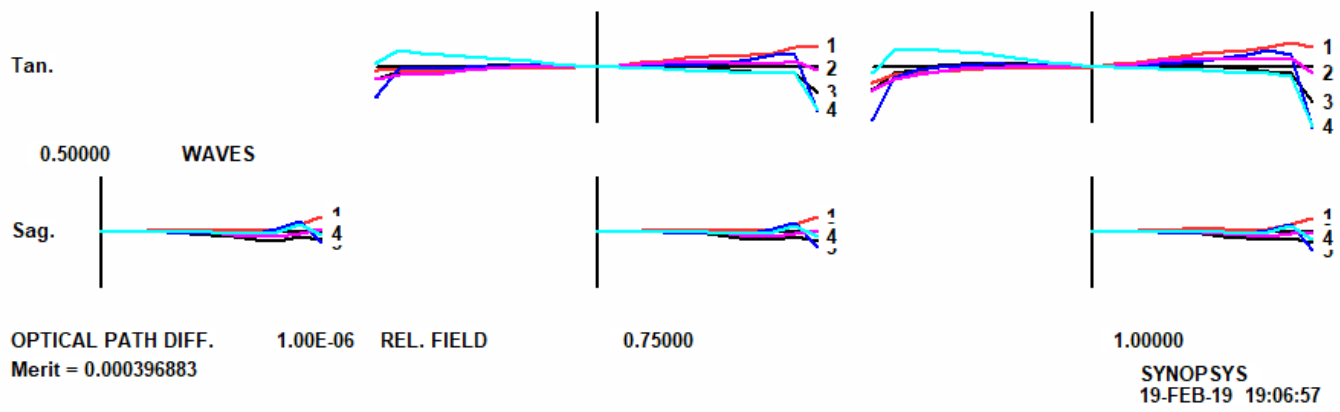
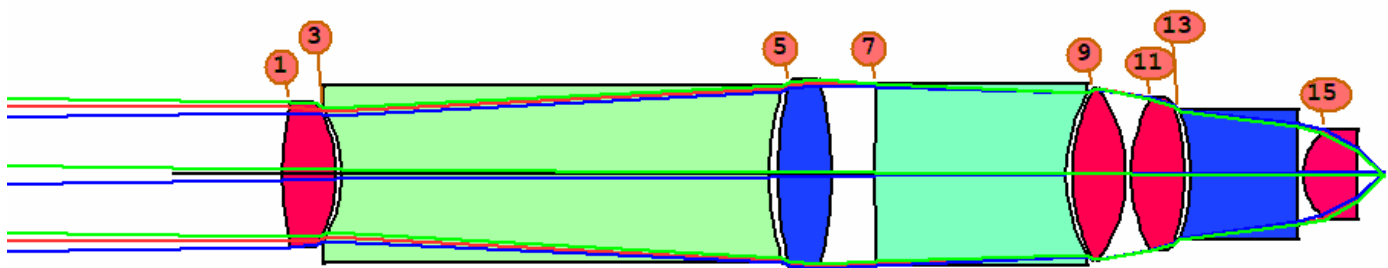
SPECIAL PANT
SLIMIT 100 0.1           ! SMALL ELEMENTS; CAN BE CLOSE TOGETHER
END

SPECIAL AANT
AEC .1 1 .05            ! edge monitor
ACM .1 1 .05            ! minimum element TH
ACC 8 1 0.5             ! maximum TH
ACA 70 1 1              ! avoid critical-angle refraction
LUL 45 1 1 A TOTL      ! limit track length
A BACK
M 0.5 1 A BACK          ! want image clearance of 0.5mm
M 0 1 A P YA 1          ! control distortion
S GIHT
M 0 1 A P HH 1         ! and make telecentric
END

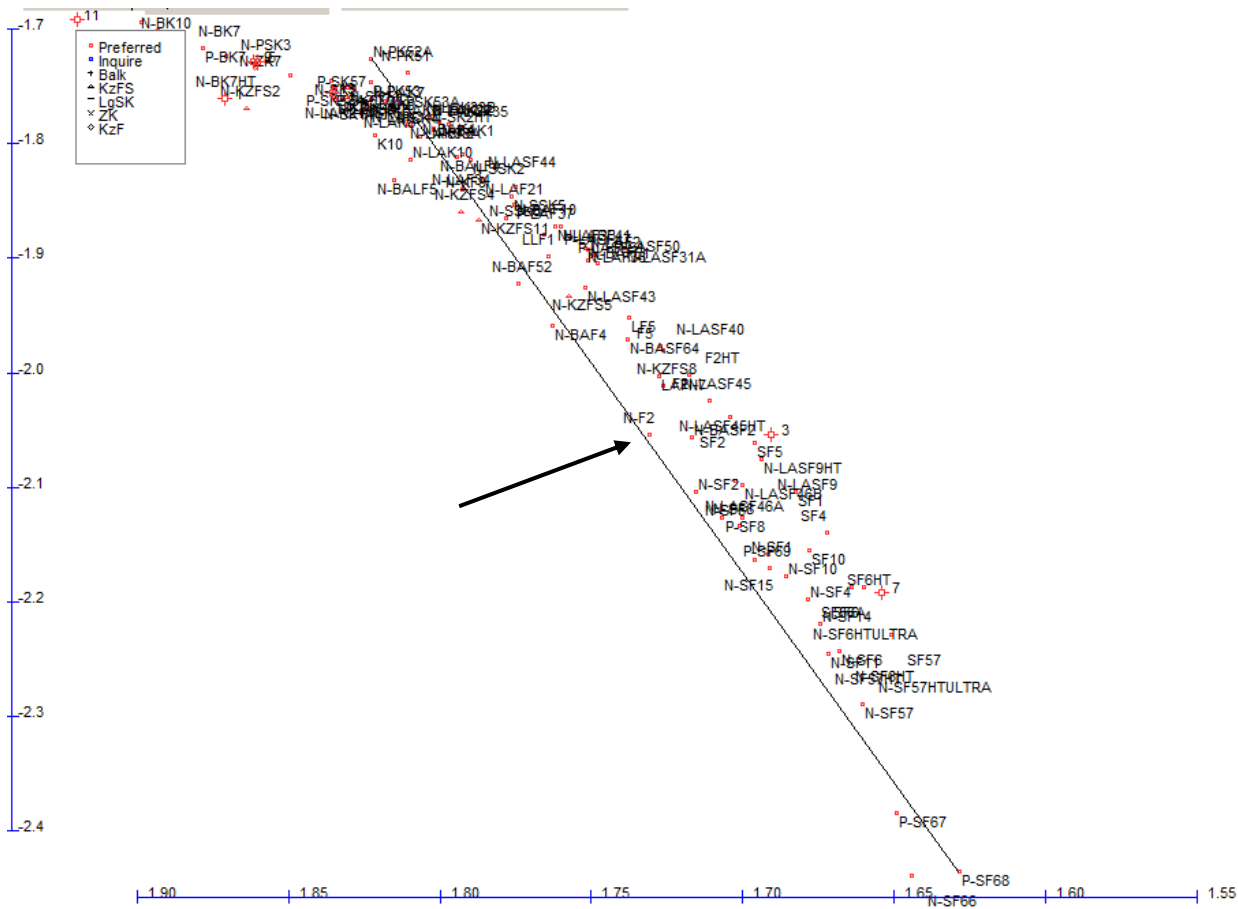
GO

```

Run this file, and in about a minute you get a nice starting point. DSEARCH has created an optimization MACro, and after running it and then annealing for a few cycles we get this design:



Since color correction is going to be a challenge, the next step is to find some glasses that have the potential to make a “superachromat”. Open the glass map with the command **MGT**, select the Schott catalog, click the Graph button, and select the bottom option, to **plot P* vs. P****. We need three glasses that lie on a long line. <Ctrl> click the glass P-SF68, which defines the bottom of the line, and then <Shift> click the glass N-PK52A, defining the top.



See the glass N-F2? It's near the center of the line. That gives us three types, but we don't know which glass to assign to which element yet. Never fear: GSEARCH can tell us.

We next create two files. The first is a normal optimization file. Using the MACro that DSEARCH has nicely created for us, we just edit it a little: remove the GLM variables and request 40 passes. We also request that the optimization program run the automatic ray-failure fixing routine if any of the combinations will not trace initially. (And well they might; large changes to the index of refraction send rays in a different direction, which can cause failures.)

```

PANT
SLIM 100 0.1
VY 0 YP1           ! let the program find the best stop position
VLIST RD ALL
VLIST TH ALL
END
AANT P
M 0.140000E+01 0.100000E+03 A CONST 1.0 / DIV FNUM
GSR 0.500000 1.000000 4 M 0.000000
GNR 0.500000 1.000000 4 M 0.500000
GNR 0.500000 1.000000 4 M 1.000000
AEC .1 1 .05
ACM .1 1 .05
ACC 8 1 0.5
ACA 70 1
LUL 45 1 1 A TOTL
A BACK
M 0.5 1 A BACK
M 0 1 A P YA 1
S GIHT

```

```

M 0 1 A P H H 1
END
SNAP 10
SYNOPSIS 40 0 FIX 10

```

Save this file with the name GSOPT.MAC, and then create a second MACro to tell GSEARCH what we want it to do.

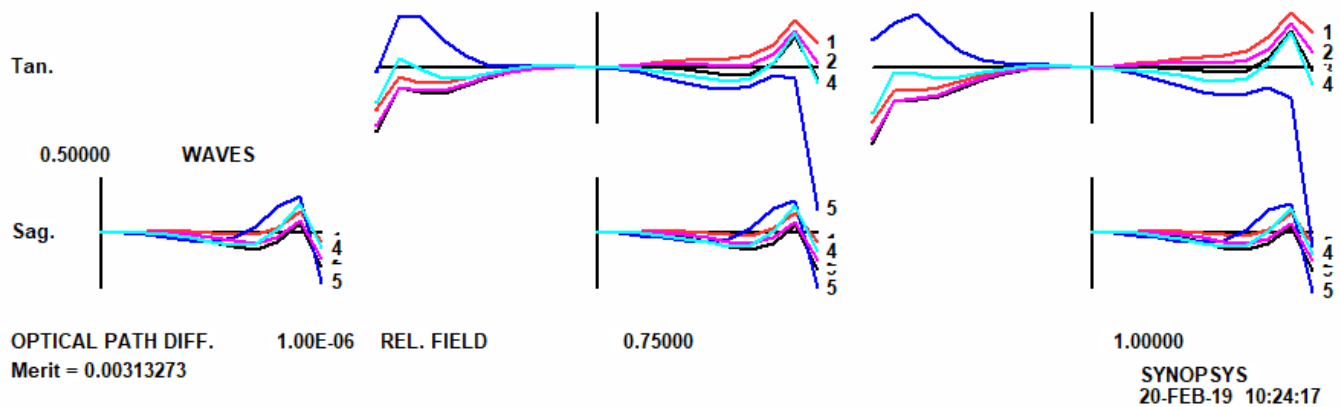
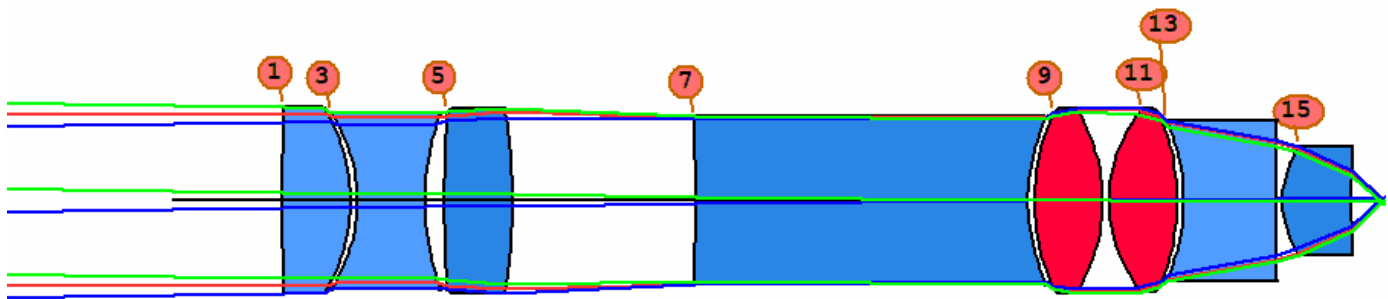
```

GSEARCH 3 QUIET LOG
SURF
1 3 5 7 9 11 13 15
END
NAMES
S N-PK52A
S N-F2
S P-SF68
END
DELAY OFF
USE 3           ! only allow cases that use all three glass types
GO

```

Then run this file.

On our 8-core PC this runs for about 23 minutes, producing this design:



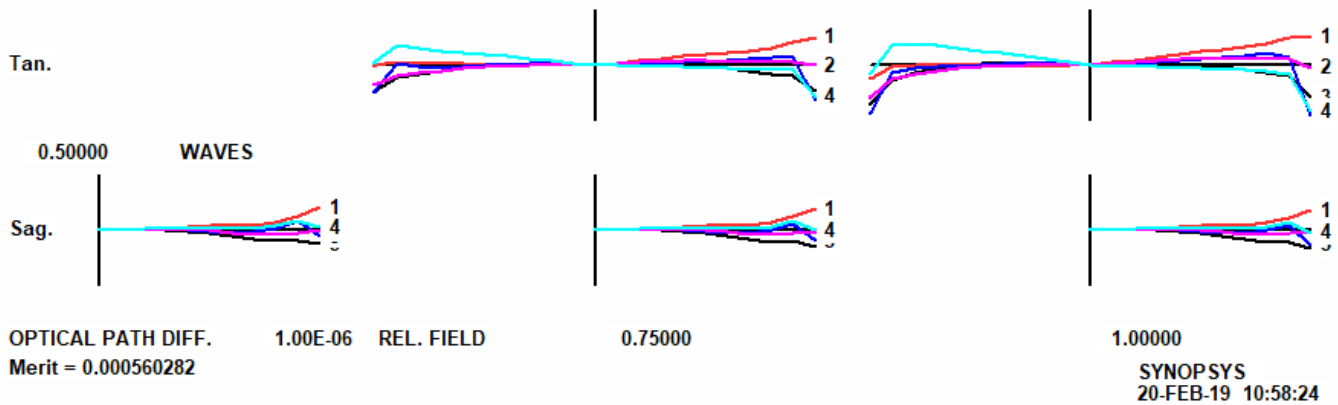
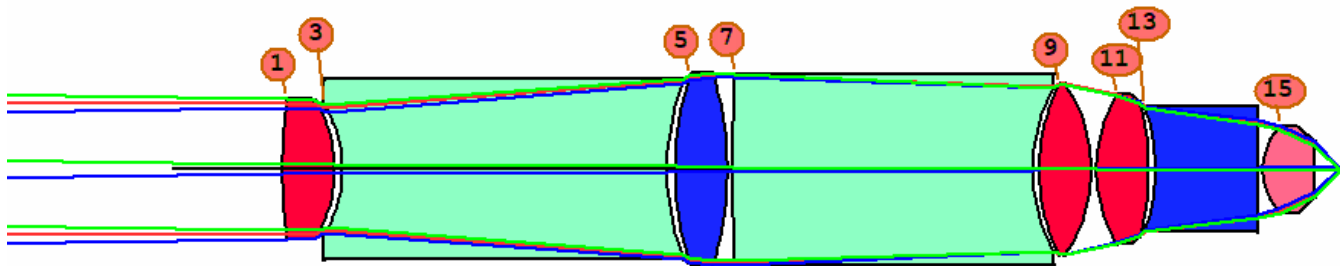
This is getting close – but let's try something else. The theory of the superachromat applies strictly to thin lenses, and these are not thin. Go back to the result from DSEARCH, and this time ask GSEARCH to find its own glasses, not too far from the present ones, from the Schott catalog. Change the GSEARCH MACro to

```

GSEARCH 3 QUIET LOG
SURF
1 3 5 7 9 11 13 15
END
NEAREST 3 P
S
END
DELAY OFF
GO

```

and run it again. The result is even better, shown below after some more optimization and annealing. Then try it with other glass catalogs too. Some may be better, and some will be worse, depending on which glasses are available in which parts of the glass map.



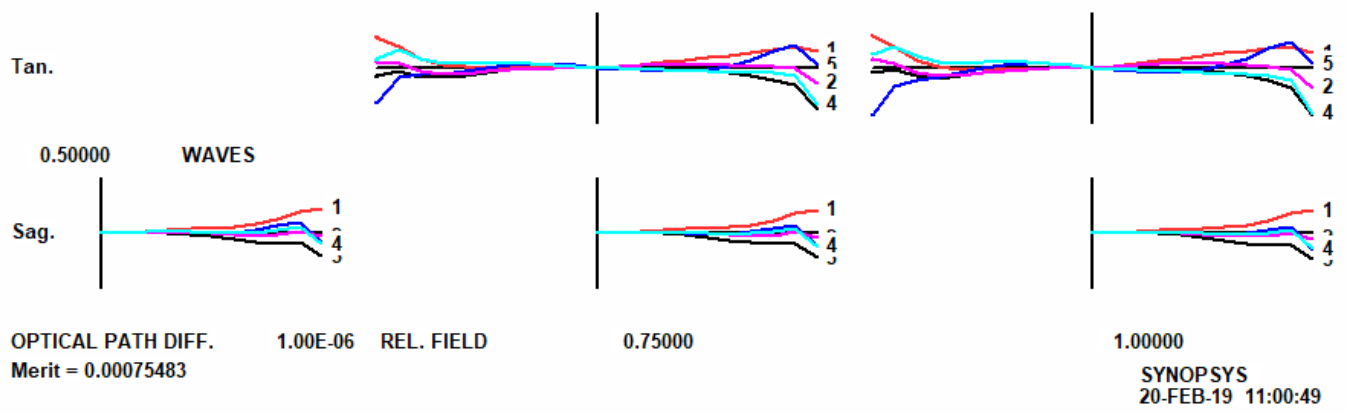
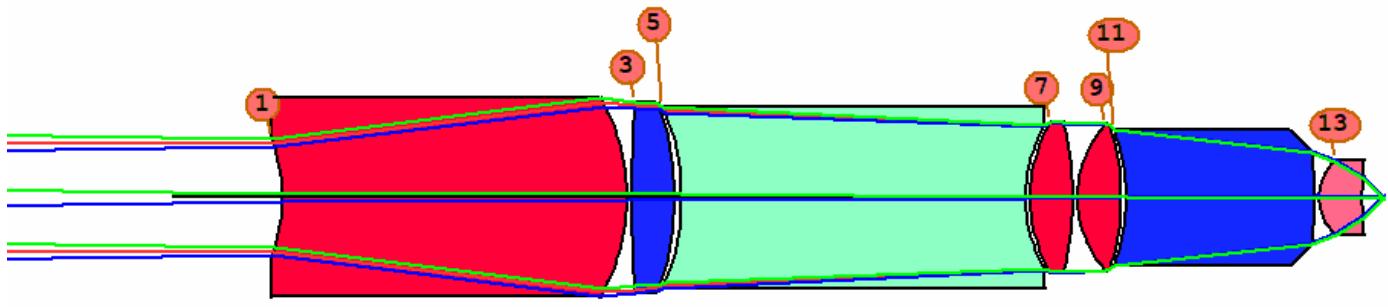
This lens is essentially perfect. But we instinctively ask, Can we do it with fewer elements? It's easy to find out with the Automatic Element Deletion feature. Add a new line at the top of the optimization MACro:

```

AED 3 QUIET 1 16

```

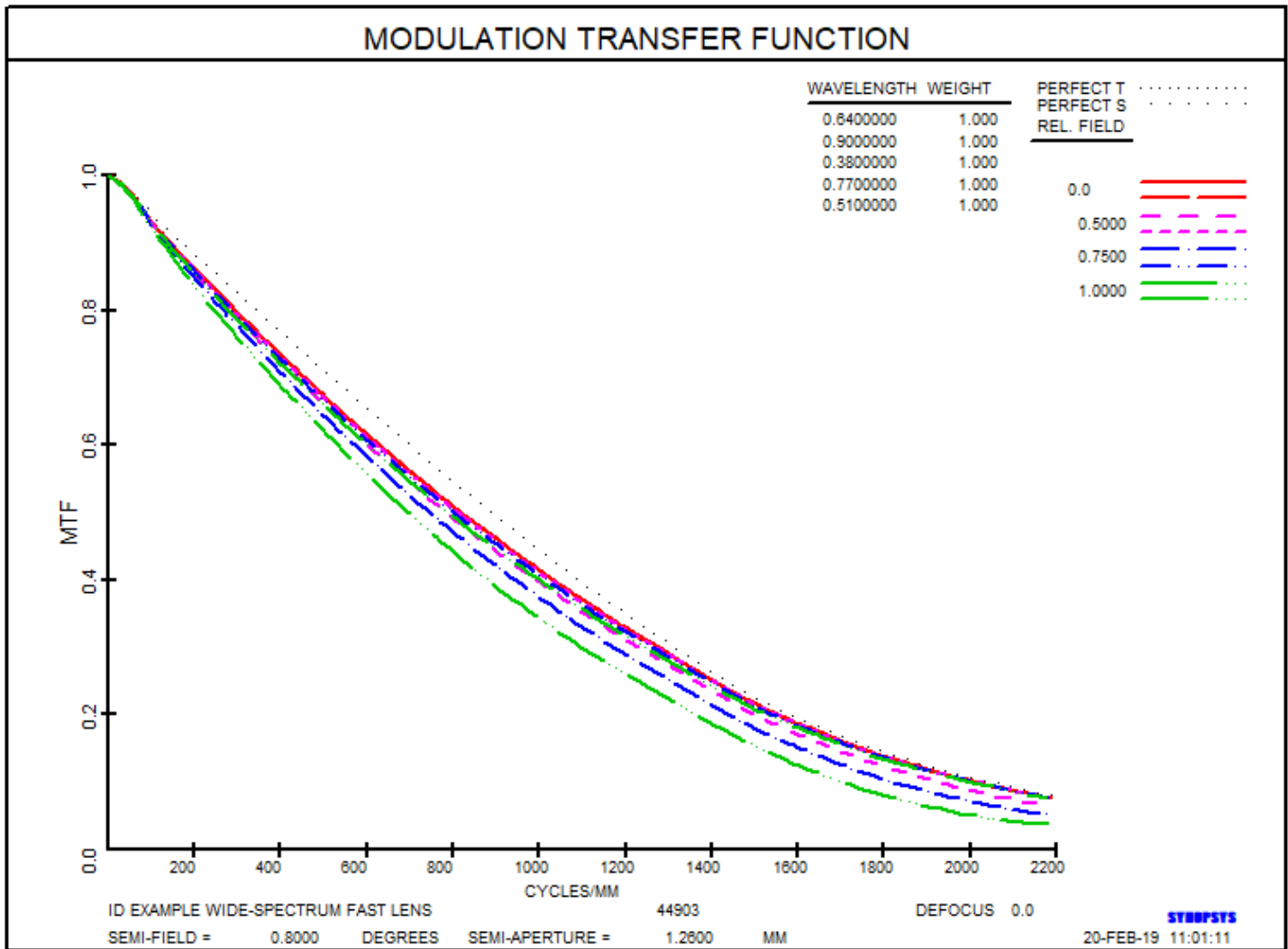
and run it again. The program detects that you can remove element 2. Accept the suggestion (which deletes that element), remove the AED line from the MACro, and reoptimize and anneal. Now you get this:



Again, nearly perfect – and requiring only seven elements! Let's see what the MTF looks like over the field.

```

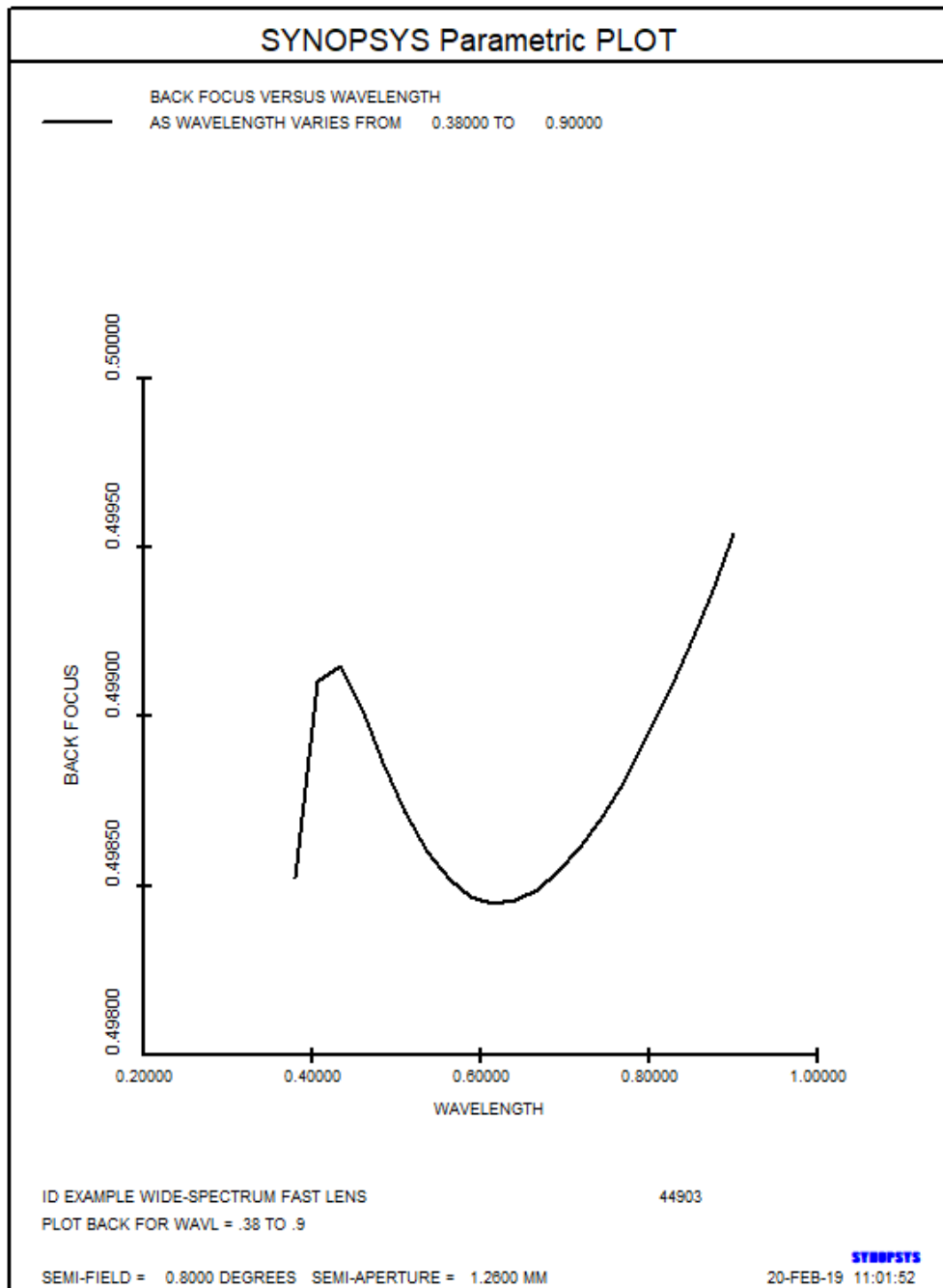
FCO 0
MFF
ICOL M
HBAR 0 .5 .75 1
GBAR 0
PLOT
  
```



Can't get much better than that.

Are we done? Let's see how stable the back focus position is as a function of wavelength. Enter the AI sentence

PLOT BACK FOR WAVL = .38 TO .9



Indeed! The paraxial focus position varies by only about 1.0 μm over this wide range. Yes, this is an excellent lens! Before you actually make the lens, it would be a good idea to move the stop to surface 6 – but that is enough for this lesson. You see how easily SYNOPSIS handles this challenging problem.

There are other things we could have tried. What if the results were not good enough with seven elements? Well, then you could try the Automatic Element Insertion feature, adding the line

AEI 3 1 14 ONLY 100 1 10 50

to the top of the MACRO. That will add a cemented element on each side of all the current lenses in sequence and then come back with the combination that worked best. With these tools you can go either way. If you also want to try airspaced elements, change ONLY to CEMENT. Then they will be tested as well.

What happens if we select a different line on the P*-P** diagram? That would give us three different glasses to try. You never know what might work even better than this until you try it.

When you have so many powerful tools, it is interesting and often rewarding to explore other combinations of them.

In case you want to investigate the properties of our excellent lens, here is the RLE file:

```
RLE
ID EXAMPLE WIDE-SPECTRUM FAST LENS          44903
ID1 DSEARCH CASE WAS 00000000000000010000000    128
FNAME 'DSEARCH07.RLE
MERIT  0.754830E-03
LOG    44903
WA1 .9000000 .7700000 .6400000 .5100000 .3800000
CORDER  3  1  5  2  4
WT1 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000
APS      1
UNITS MM
OBB  0.000000    0.80000    1.26000    -0.08813    0.00000    0.00000    1.26000
 0 AIR
 1 RAD    -3.5623167882117    TH    8.01111049
 1 N1 1.49128809 N2 1.49299454 N3 1.49554375 N4 1.50001997 N5 1.50986013
 1 CTE  0.130100E-04
 1 GTB S  'N-PK52A
 2 RAD    -4.5942849596626    TH    0.10002926 AIR
 3 RAD    25.6070000687597    TH    1.00000000
 3 N1 1.81773053 N2 1.82556414 N3 1.83857962 N4 1.86440502 N5 1.93631495
 3 CTE  0.846000E-05
 3 GTB S  'N-SF57
 4 RAD    -6.5263729215189    TH    0.17094028 AIR
 5 RAD    -5.2448377442769    TH    8.01055126
 5 N1 1.81464113 N2 1.82010927 N3 1.82880226 N4 1.84513149 N5 1.88540100
 5 CTE  0.584000E-05
 5 GTB S  'N-LASF40
 6 RAD    3.5002311356565    TH    0.10000000 AIR
 7 RAD    3.5068618849739    TH    1.00000111
 7 N1 1.49128809 N2 1.49299454 N3 1.49554375 N4 1.50001997 N5 1.50986013
 7 CTE  0.130100E-04
 7 GTB S  'N-PK52A
 8 RAD    -6.5549018440878    TH    0.10000000 AIR
 9 RAD    2.5626337946951    TH    1.01726614
 9 N1 1.49128809 N2 1.49299454 N3 1.49554375 N4 1.50001997 N5 1.50986013
 9 CTE  0.130100E-04
 9 GTB S  'N-PK52A
10 RAD    -5.3106315674462    TH    0.12296476 AIR
11 RAD    -4.4024424380658    TH    4.38416192
11 N1 1.88762683 N2 1.89708892 N3 1.91293610 N4 1.94491007 N5 2.03856725
11 CTE  0.590000E-05
11 GTB S  'N-SF66
12 RAD    -6.9738653956615    TH    0.10000000 AIR
13 RAD    1.2115604130491    TH    1.00007973
13 N1 1.61070031 N2 1.61361653 N3 1.61792847 N4 1.62548336 N5 1.64228892
13 CTE  0.630000E-05
13 GTB S  'N-SK16
14 RAD    2.6131402057036    TH    0.49845489 AIR
14 TH    0.49845489
14 YMT    0.00000000
15 CV    0.0000000000000    TH    0.00000000 AIR
END
```

Do you think you could have found this design as quickly with a different lens design program? We don't think so. Try it and let us know how long it took, if it succeeded at all.