

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
```

```

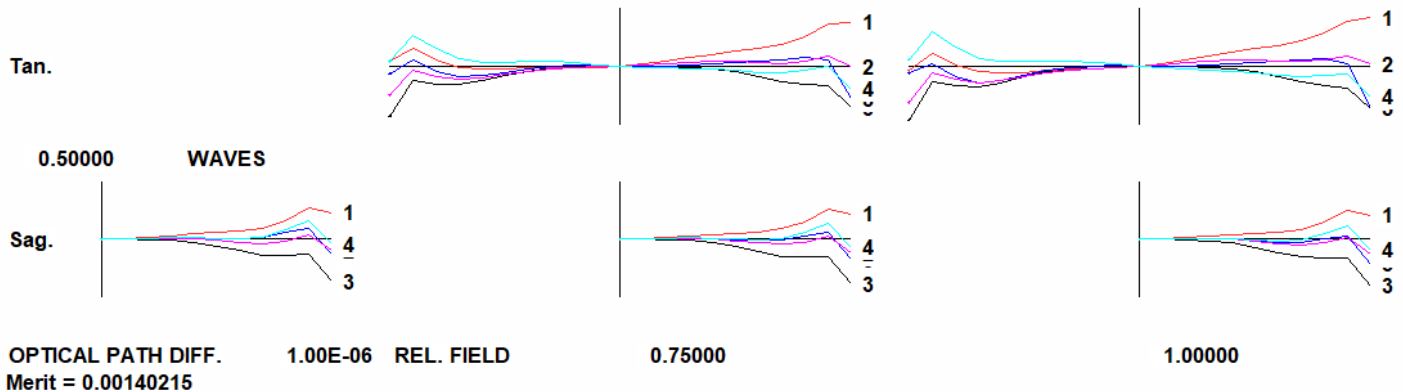
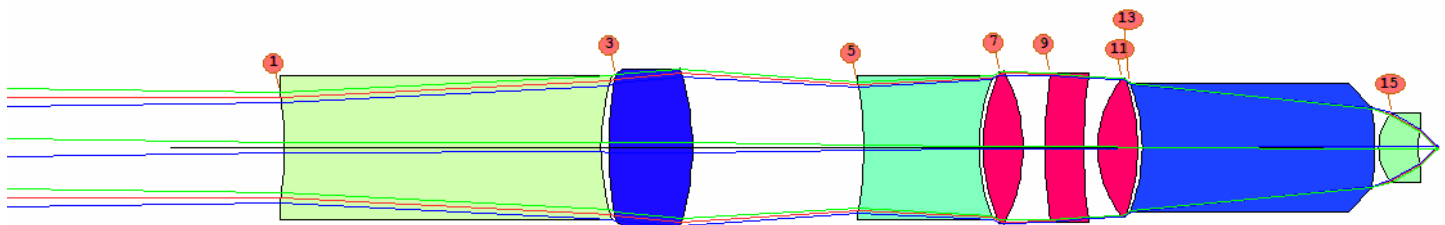
SPECIAL PANT
SLIMIT 100 0.1          ! SMALL ELEMENTS; CAN BE CLOSE TOGETHER
END

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

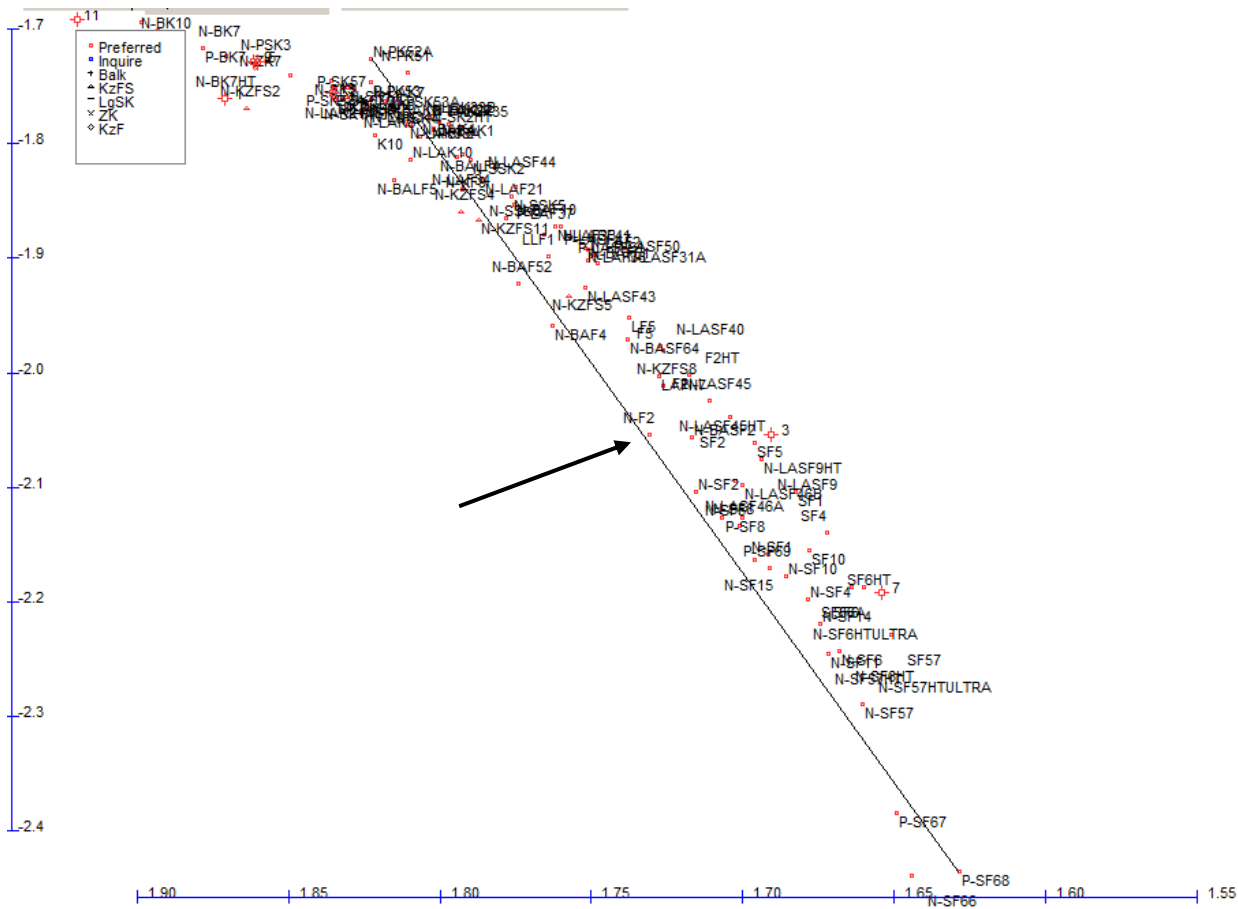
```

GO

We run this file, and in less than a minute get a nice starting point. DSEARCH has created an optimization MACro for us, 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”. We 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. We <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
GSR 0.500000 1.000000 4 M 0.500000
GSR 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 30

```

We save this file with the name GSOPT.MAC, and then create a second MACro to tell GSEARCH what we want it to do. (L26M3)

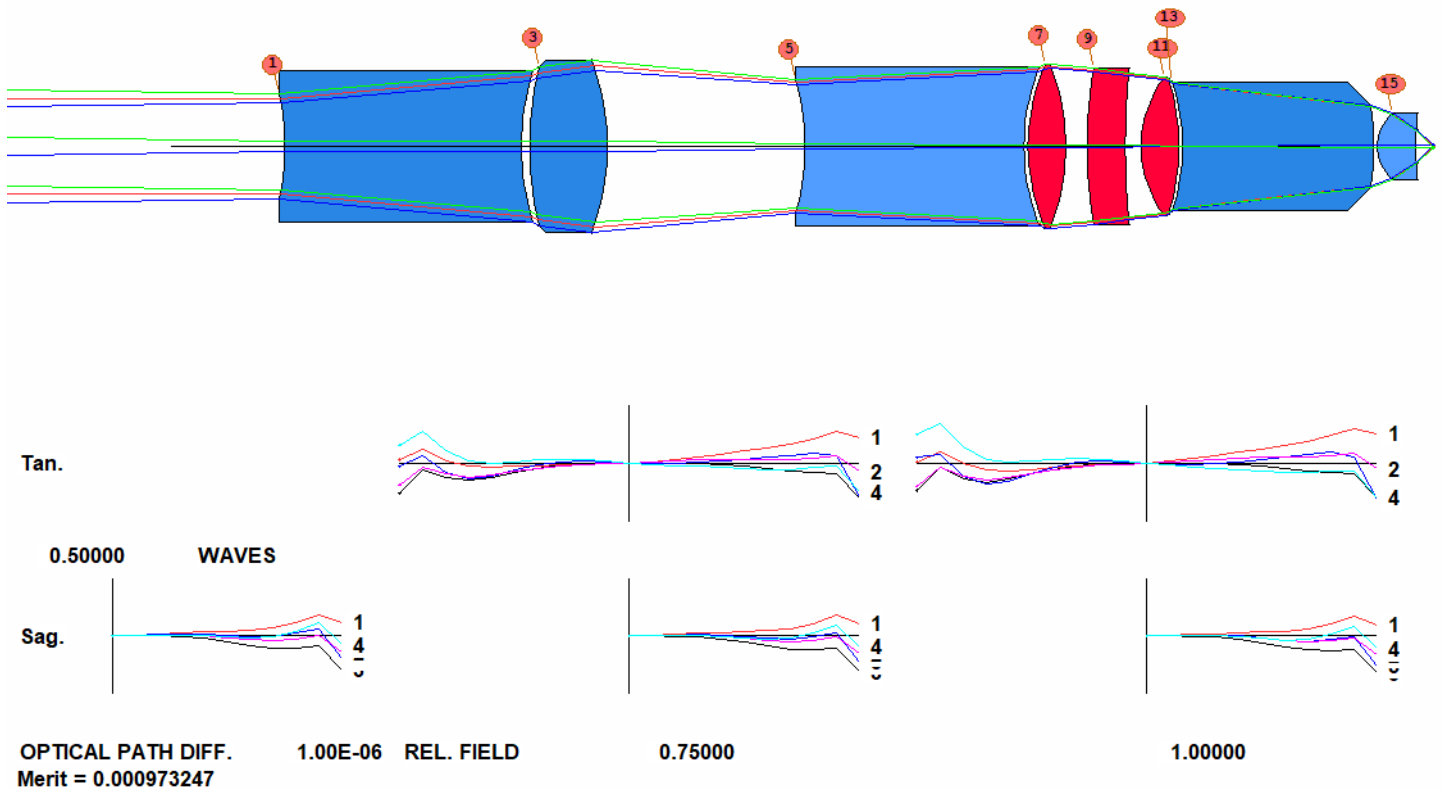
```

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
USE 3           ! only allow cases that use all three glass types
GO

```

Then we run this file.

On our 8-core PC this runs for about 40 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

```

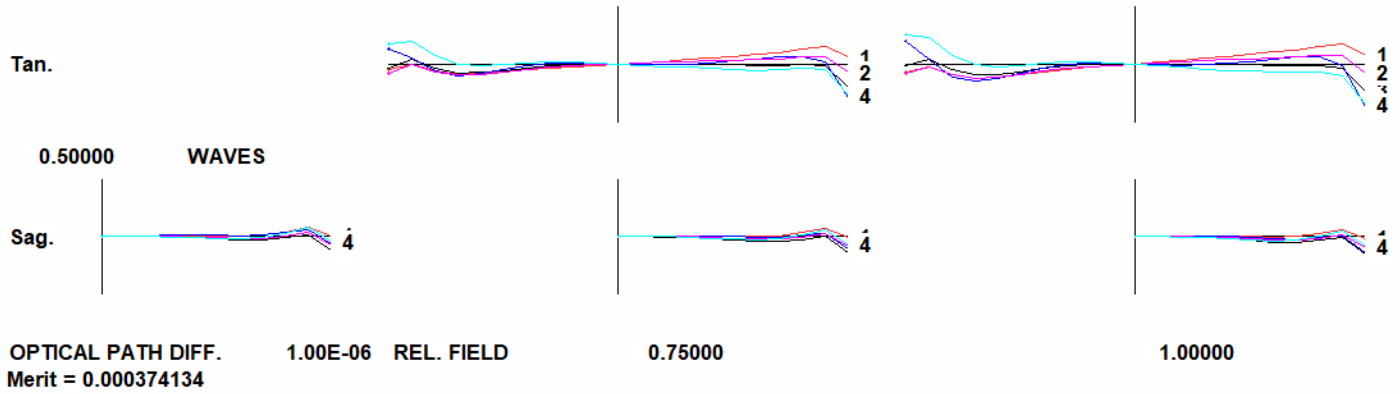
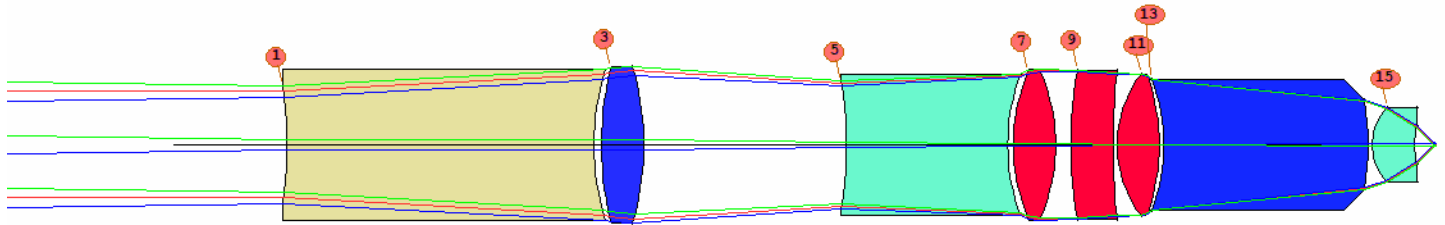
```

NEAREST 3 P
S
END

GO

```

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



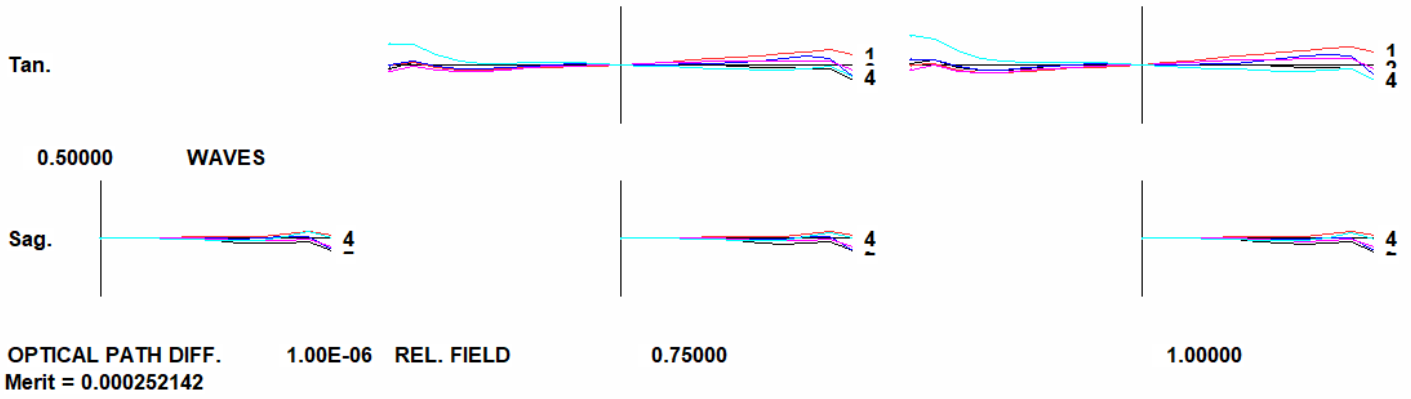
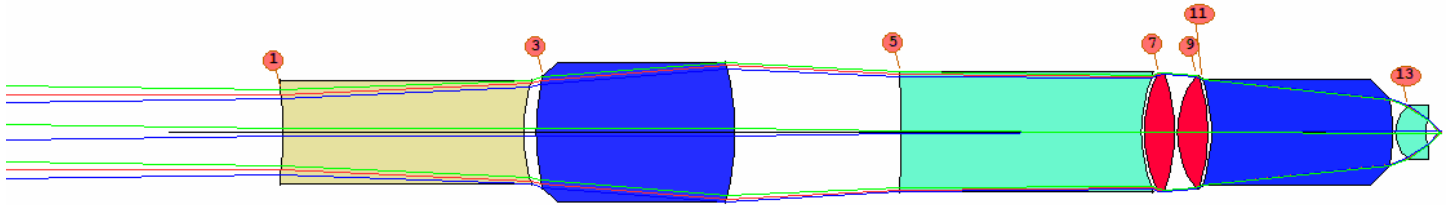
This lens is essentially perfect. But we instinctively ask, Can we do it with fewer elements? It's easy to find out with the Automatic Element Deletion feature. Add a new line at the top of the optimization MACro:

```

AED 3 QUIET 1 16

```

and run it again. The program detects that you can remove element 5. Accept the suggestion (which deletes that element), remove the AED line from the MACro, and reoptimize and anneal. Now you get this:



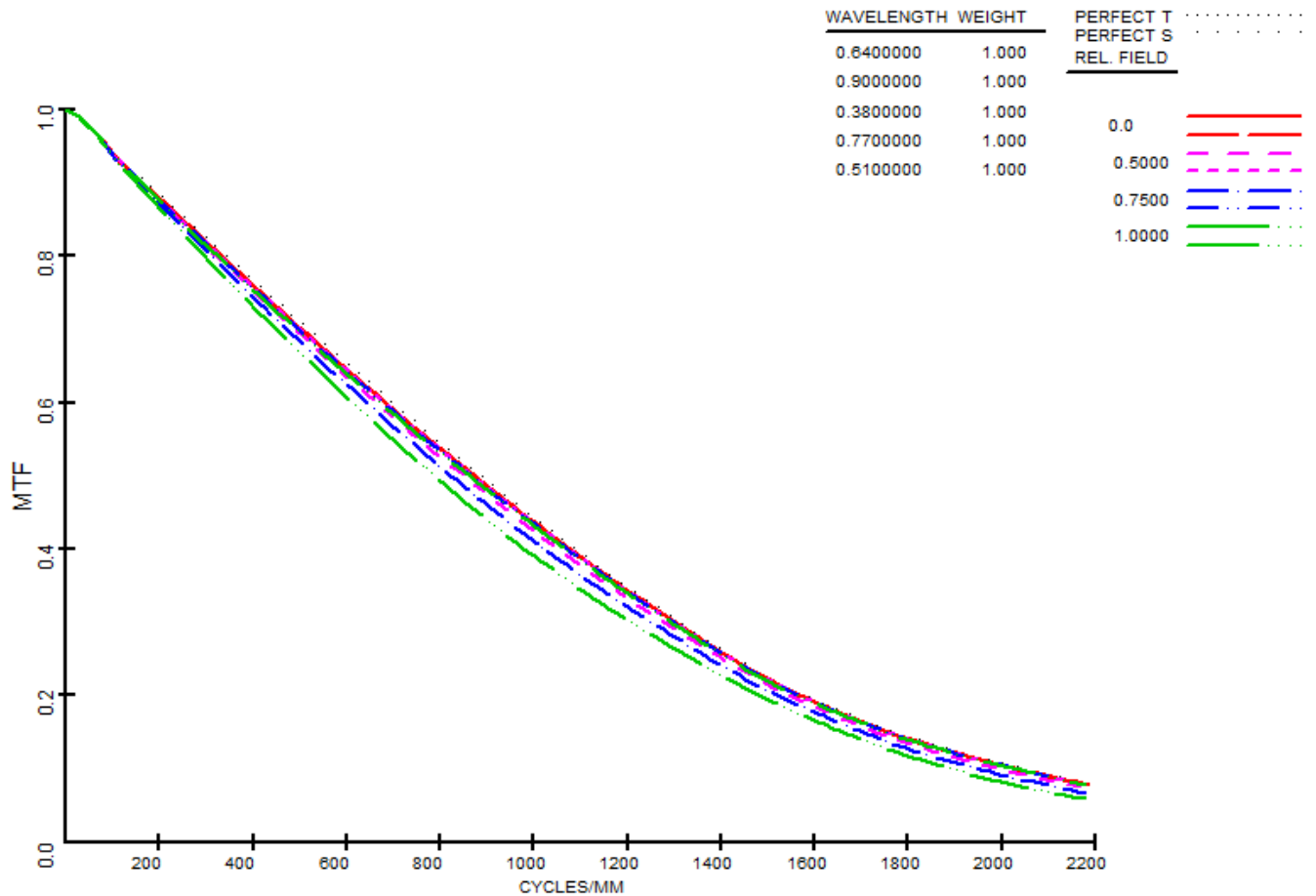
Again, nearly perfect – and requiring only seven elements! Let's see what the MTF looks like over the field.

```

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

```

MODULATION TRANSFER FUNCTION



ID EXAMPLE WIDE-SPECTRUM FAST LENS

50760

DEFOCUS 0.0

SEMI-FIELD = 0.8000 DEGREES SEMI-APERTURE = 1.2600 MM

20-AUG-17 12:41:19

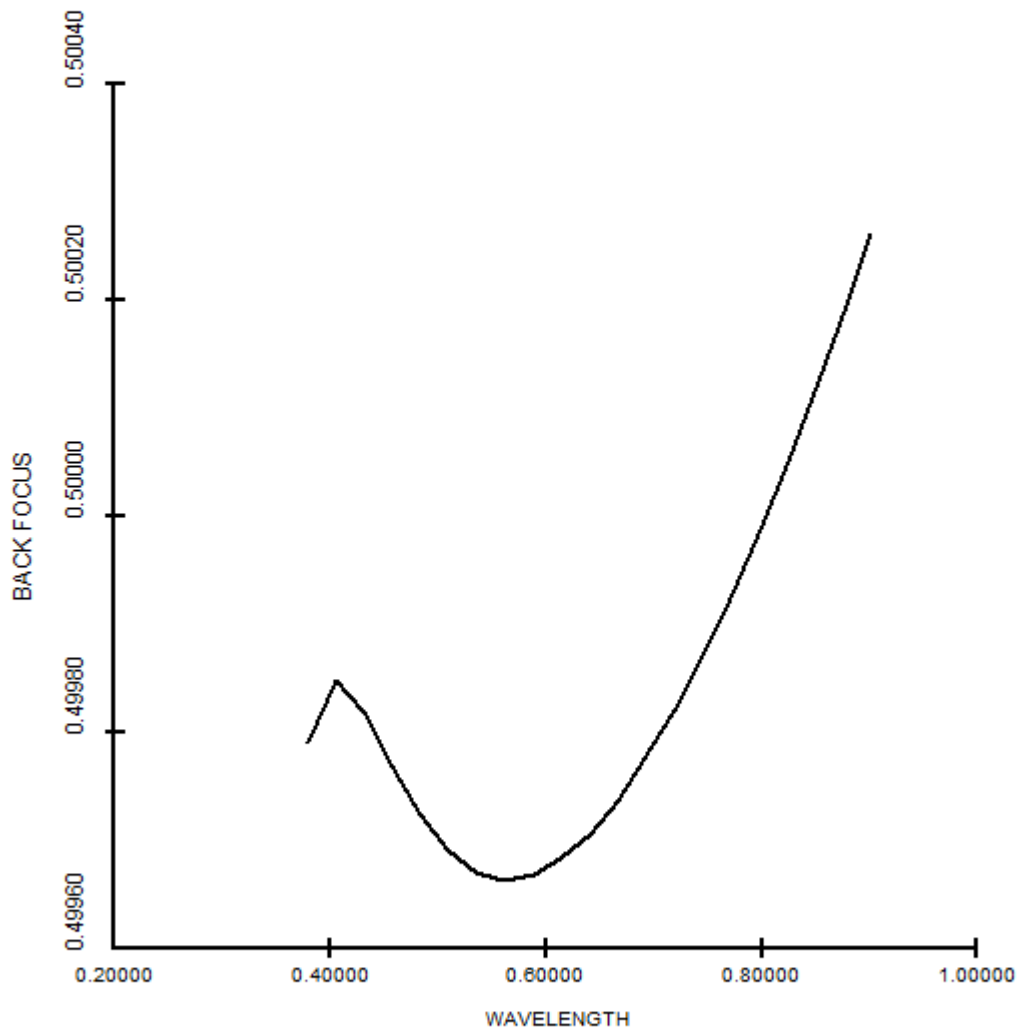
Can't get much better than that.

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

SYNOPTSYS Parametric PLOT

BACK FOCUS VERSUS WAVELENGTH
AS WAVELENGTH VARIES FROM 0.38 TO 0.90



ID EXAMPLE WIDE-SPECTRUM FAST LENS
PLOT BACK FOR WAVL = .38 TO .9

50760

SEMI-FIELD = 0.8000 DEGREES SEMI-APERTURE = 1.2600 MM

SYNOPTSYS
20-AUG-17 12:41:57

Indeed! The paraxial focus position varies by only about 0.6 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 5 – but that is enough for this lesson. You see how easily SYNOPTSYS 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          50760
ID1 DSEARCH CASE WAS 000000000000000001011101    93
FNAME 'DSEARCH07.RLE
MERIT  0.252142E-03
LOG    50760
WA1 .9000000 .7700000 .6400000 .5100000 .3800000
CORDER  3  1  5  2  4
WT1 1.00000 1.00000 1.00000 1.00000 1.00000
APS          1
UNITS MM
OBB  0.000000    0.80000    1.26000    -0.14478    0.00000    0.00000    1.26000
 0 AIR
 1 RAD    -12.3575888493127  TH      8.00349843
 1 N1 1.70683888 N2 1.71075605 N3 1.71661866 N4 1.72704962 N5 1.75095371
 1 CTE  0.568000E-05
 1 GTB S  'N-LAK10
 2 RAD     5.6036307276255  TH      0.42904026 AIR
 3 RAD     8.4130780171013  TH      6.59790611
 3 N1 1.73259261 N2 1.73873215 N3 1.74890937 N4 1.76882390 N5 1.82136771
 3 CTE  0.800000E-05
 3 GTB S  'SF4
 4 RAD    -9.1818032305934  TH      5.54967141 AIR
 5 RAD    -56.1367087651872  TH      8.00224863
 5 N1 1.87928012 N2 1.88604915 N3 1.89699697 N4 1.91801250 N5 1.97244514
 5 GTB S  'N-LASF46B
 6 RAD     4.8482482223468  TH      0.10000000 AIR
 7 RAD     4.3440291976542  TH      1.00000148
 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    -5.7980974504808  TH      0.10000000 AIR
 9 RAD     3.1580916229850  TH      1.00865373
 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    -6.1466379437070  TH      0.12251679 AIR
11 RAD    -5.2492188361156  TH      6.03606534
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    -7.8896787646760  TH      0.10004337 AIR
13 RAD     1.1618206771614  TH      1.00000000
13 N1 1.87928012 N2 1.88604915 N3 1.89699697 N4 1.91801250 N5 1.97244514
13 GTB S  'N-LASF46B
14 RAD     1.0699320226013  TH      0.49970566 AIR
14 TH      0.49970566
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.