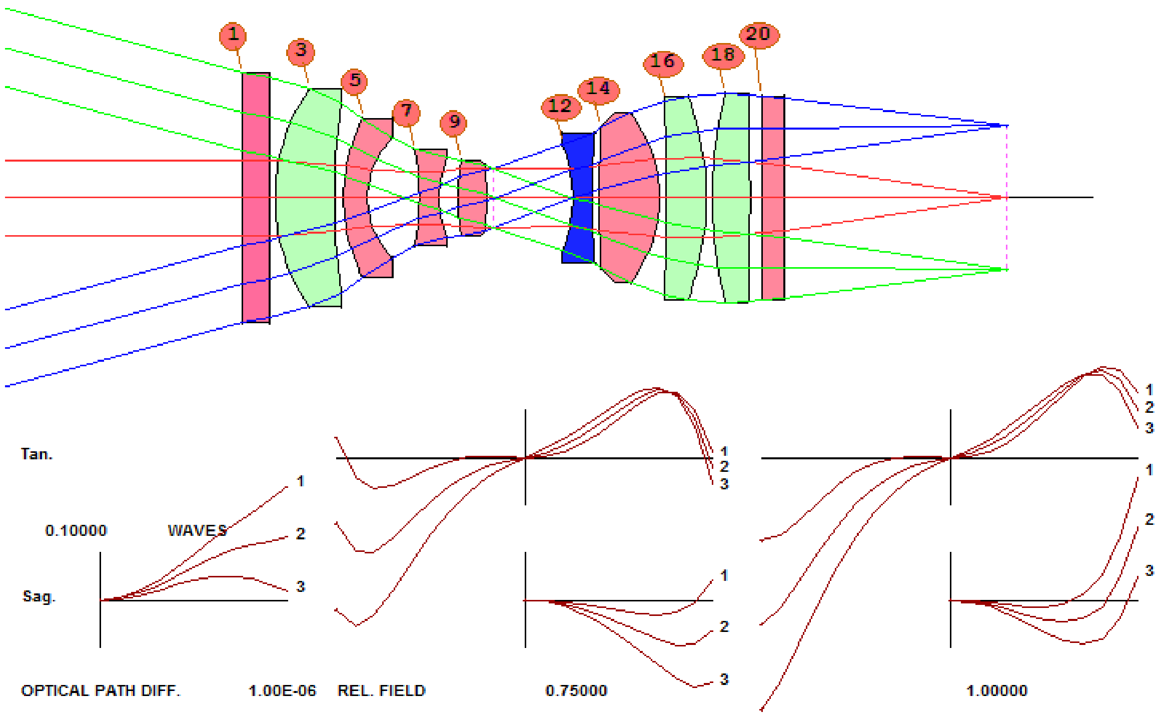
Lesson 5: Improving a lens designed on another program

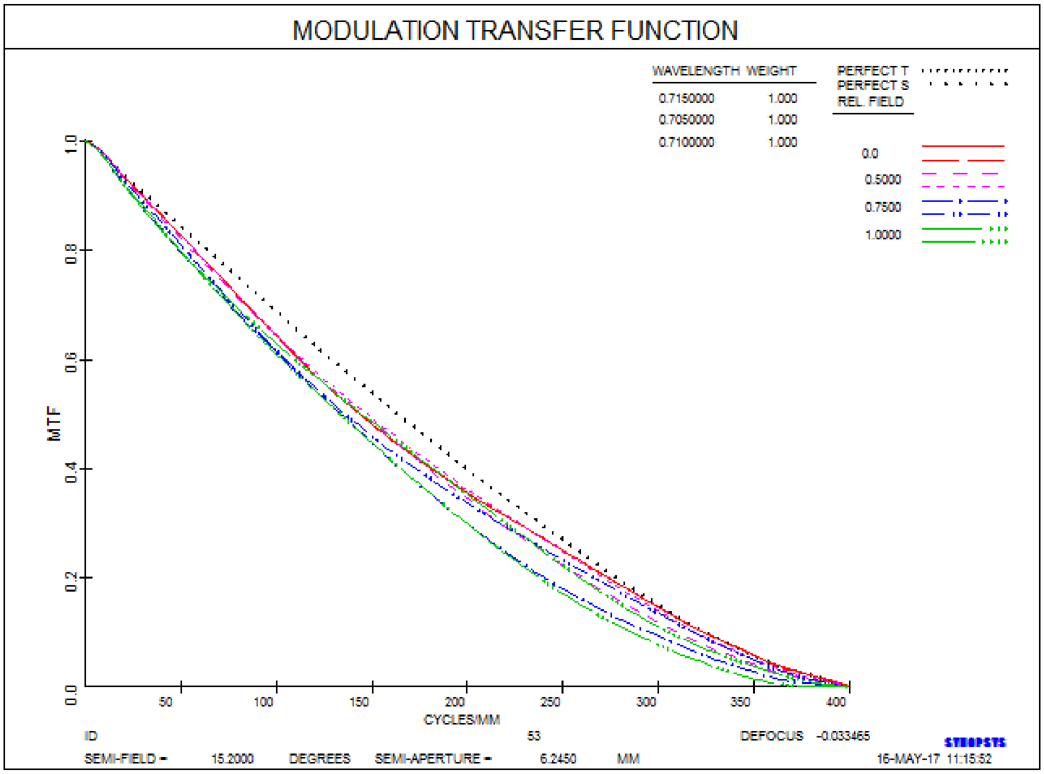
In this lesson we start with a lens designed on a different program and apply some of the newest tools to see if we can improve its performance.

Here is the starting lens, along with MTF curves at three field points. (Type **MMF**, select the Multicolor option, then click Execute.) (The picture below has switch 85 turned on, showing IR wavelengths in red.)




```
RLE
ID EXAMPLE LENS                                   53
 WAVL .7150000 .7100000 .7050000
 CORDER    1    3    2
 APS                -11
 TEMPERATURE        30.00000
 WAP                   3
 GTZ
 UNITS MM
 OBB   0.000000     15.20000      6.24500     -13.54114       0.00000       0.00000
6.24500
   0 AIR
   1 CV       0.0000000000000    TH       4.50000000
   1 N1 1.45505601 N2 1.45516542 N3 1.45527657
   1 DNDT  1.090E-05  9.960E-06  9.700E-06 3.65000E-01 5.46000E-01 6.44000E-01
   1 CTE   0.500000E-06
   1 GTB U    'FUSILICA           '
   2 CV       0.0000000000000    TH       1.00000000 AIR
   3 RAD      31.3000000000000    TH       9.80000000
   3 N1 1.73585988 N2 1.73610163 N3 1.73634814
   3 CTE   0.806000E-05
   3 GTB S    'N-LAF2             '
   4 RAD     111.9000000000000    TH       1.50000000 AIR
   5 RAD      28.2100000000000    TH       4.00000000
   5 N1 1.51269554 N2 1.51282313 N3 1.51295285
```

```
  5 CTE   0.710000E-05
  5 GTB S    'N-BK7            '
  6 RAD     14.2600000000000   TH      8.50000000 AIR
  7 RAD    -46.1600000000000   TH      3.40000000
  7 N1 1.51269554 N2 1.51282313 N3 1.51295285
  7 CTE   0.710000E-05
  7 GTB S    'N-BK7            '
  8 RAD     19.3000000000000   TH      3.00000000 AIR
  9 RAD     28.1400000000000   TH      4.80000000
  9 N1 1.51269554 N2 1.51282313 N3 1.51295285
  9 CTE   0.710000E-05
  9 GTB S    'N-BK7            '
 10 RAD    -47.0000000000000   TH      1.00000000 AIR
 11 CAO      4.90993000       0.00000000       0.00000000
 11 CV      0.0000000000000   TH     13.20000000 AIR
 12 RAD    -24.2000000000000   TH      3.20000000
 12 N1 1.83018573 N2 1.83066058 N3 1.83114590
 12 CTE   0.846000E-05
 12 GTB S    'N-SF57           '
 13 RAD    150.0000000000000   TH      1.20000000 AIR
 14 RAD    269.0000000000000   TH     10.00000000
 14 N1 1.51269554 N2 1.51282313 N3 1.51295285
 14 CTE   0.710000E-05
 14 GTB S    'N-BK7            '
 15 RAD    -22.6200000000000   TH      1.00000000 AIR
 16 RAD  -1000.0000000000000   TH      6.70000000
 16 N1 1.73585988 N2 1.73610163 N3 1.73634814
 16 CTE   0.806000E-05
 16 GTB S    'N-LAF2           '
 17 RAD    -48.1100000000000   TH      1.00000000 AIR
 18 RAD     70.1900000000000   TH      6.20000000
 18 N1 1.73585988 N2 1.73610163 N3 1.73634814
 18 CTE   0.806000E-05
 18 GTB S    'N-LAF2           '
 19 RAD   -725.0000000000000   TH      2.00000000 AIR
 20 CV      0.0000000000000   TH      3.60000000
 20 N1 1.51269554 N2 1.51282313 N3 1.51295285
 20 CTE   0.710000E-05
 20 GTB S    'N-BK7            '
 21 CV      0.0000000000000   TH     36.90500000 AIR
 22 CV      0.0000000000000   TH      0.00000000 AIR
END
```



This lens operates in the near IR at a speed of F/3.5, and must be telecentric, have low distortion, and be diffraction limited. At first look, this design is not bad, with less than ¼ wave of aberration.

Maximum distortion over the field is just over ½ micron, and the maximum departure from telecentricity is about 0.01 radians. Not bad at all – but if we can improve the baseline performance, that will give us more leeway for tolerances, so it's worth a try.

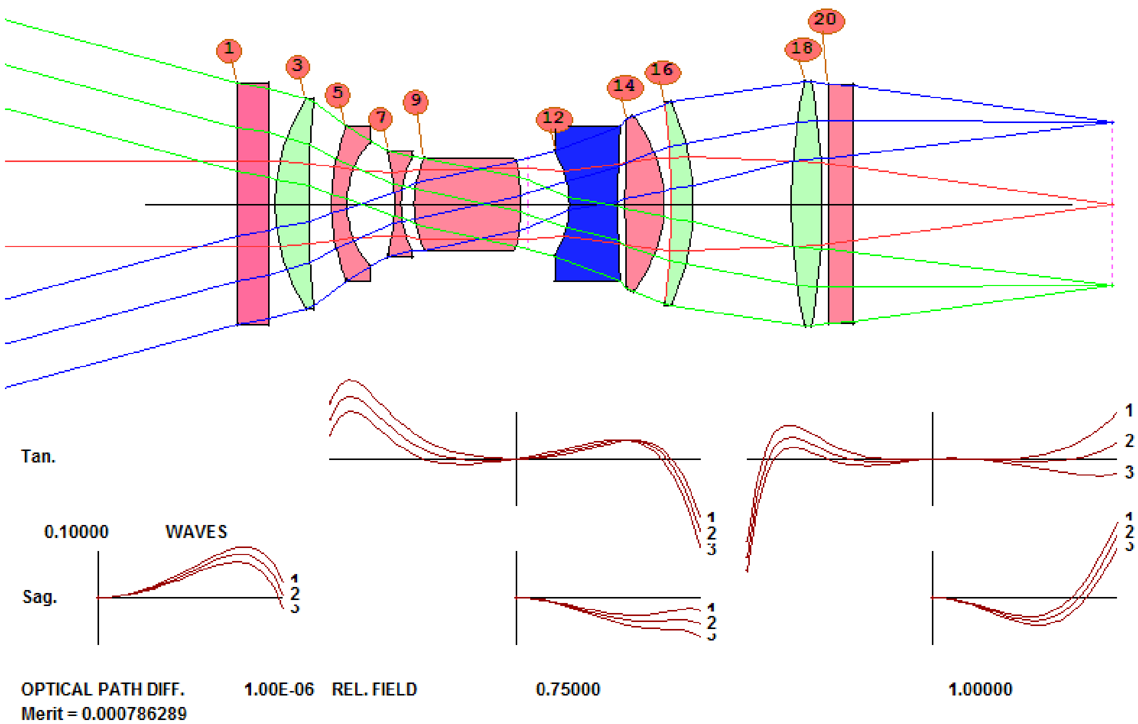
The lens at the moment uses the WAP 3 pupil, so we first make some system changes. Then we optimize. Here is our MACro:

```
CHG
WAP 1                ! keep entering beam diameter constant over field
19 UMC -0.14286      ! maintain F/number
CFREE                ! remove the clear aperture at the stop
END

PANT
VY 0 YP1             ! let the program find the best stop location
VLIST RAD ALL        ! all radii will change except 19 and the flat windows
VLIST TH ALL EXCEPT 1 LB2      ! and all thicknesses except 1 and 20
END

AANT
AEC                  ! monitor feathered edges
ACC                  ! and keep thicknesses less than 25.4 mm
M 89.6 1 A TOTL      ! keep total lens length constant
M 0 50 A GIHT        ! control distortion at full field
S P YA 1

M 0 50 A GIHT        ! and at half field
DIV CONST 2
```

```
S P YA .5

M 0 20 A P HH .7   ! control telecentricity at 0.7 field

GSO 0 0.1 5 M 0    ! correct OPDs of ray grids at three fields
GNO 0 0.05 4 M .7
GNO 0 0.05 4 M 1
END

SNAP         ! get snapshot every iteration
SYNO 30      ! optimize for 30 cycles.
```

(The simplest way to create this set of ray-grid aberrations is with the **Ready Made Raysets** button in the MACro editor. In this case we selected set number 8, which creates both transverse and OPD targets, and then elected to delete the transverse targets and increase the weighting of the OPD targets at full field. The Bare-bones **Rayset** dialog can also do it, with more options then available.)

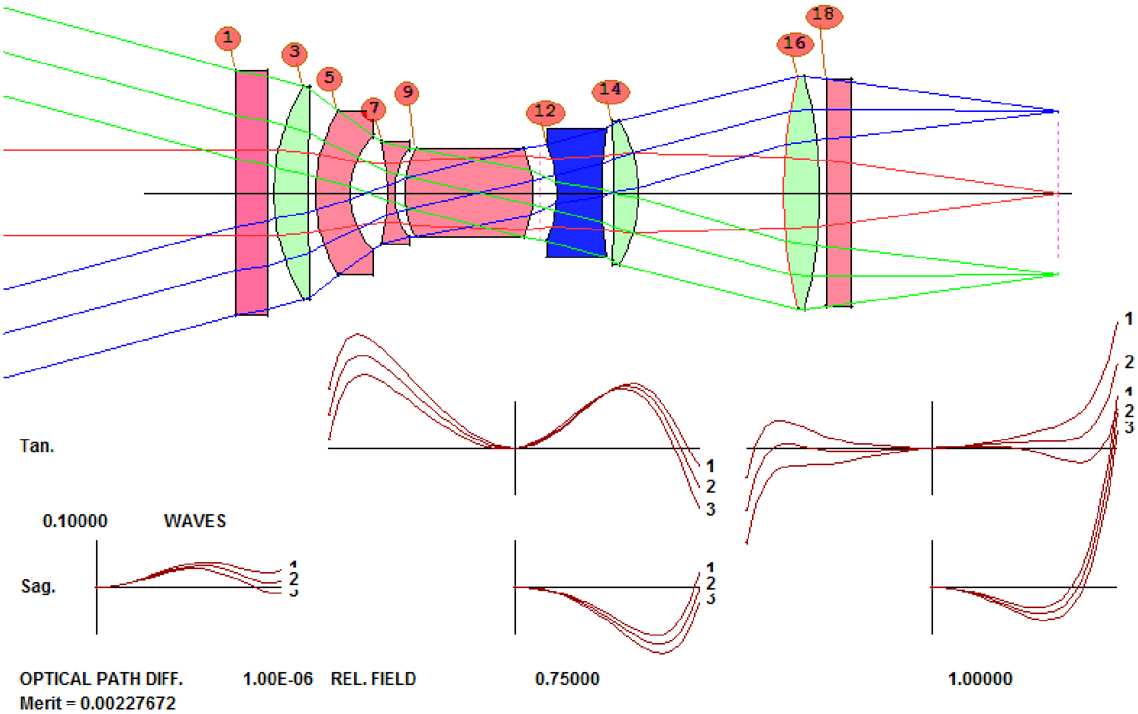
We optimize with this file and then anneal for a few cycles. The lens is improved somewhat.



Now let's apply some powerful tools. First, we run the **Automatic Element Deletion** feature. This finds the element that can be removed with least degradation to the merit function. To do so, we simply add the line

```
AED 3 Q 3 19       ! find which element to delete between surfaces 3 and 19.
```

to the MACro *before the PANT command* and reoptimize. The program reports that the lens at surface 14 can be removed. We allow it to remove that element and then optimize and anneal some more (after commenting out the AED line so we don't remove yet another element and removing the CHG file at the top).



The lens is not quite as good as before, as expected, but still not bad. Now we will use the **Automatic Element Insertion** feature to see if going back to the previous number of elements gives us results better than the original lens.

To do this, we change the AED line to

```
AEI 3 3 17 0      ! insert one element between surfaces 3 and 17.
```

and run the MACro once more. (If you have a multicore PC, you should also add the line

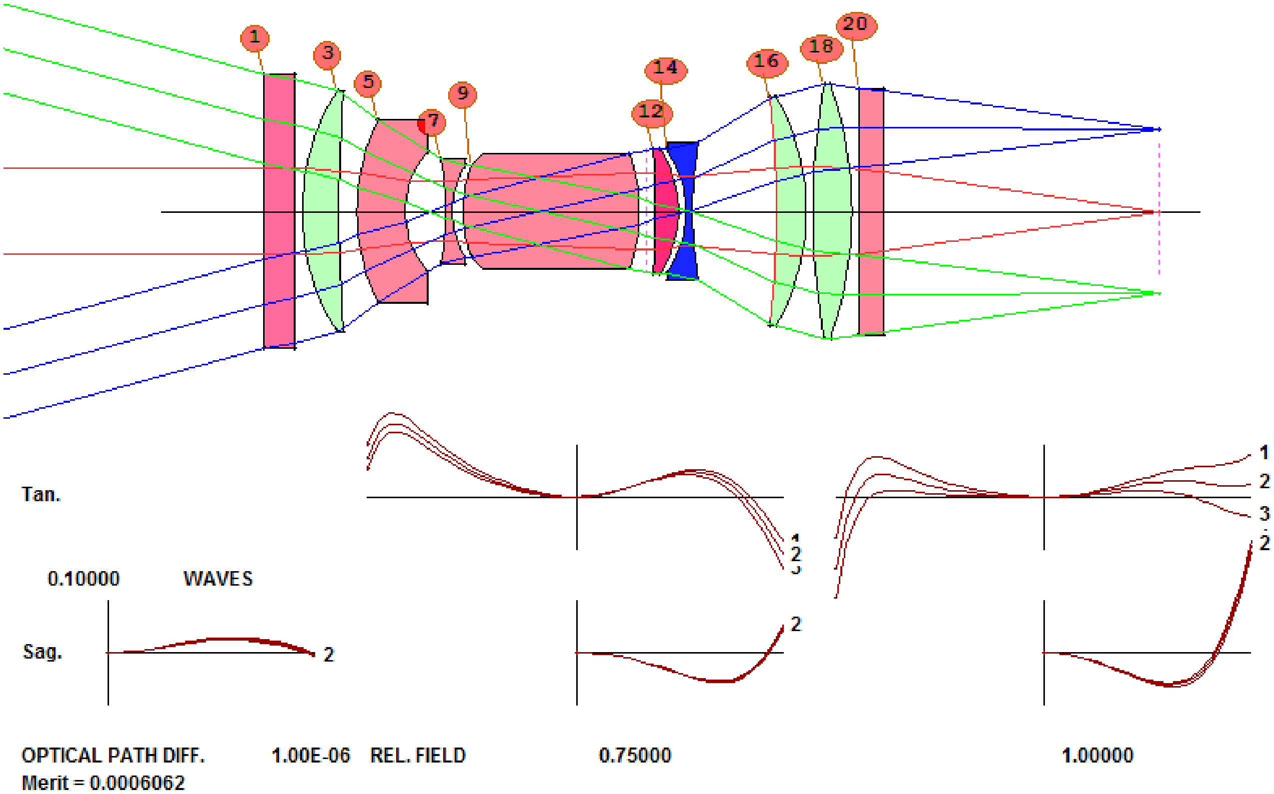
```
CORE nb
```

at the top of your MACro, where nb is the number of cores. This will run AEI nb times faster.)

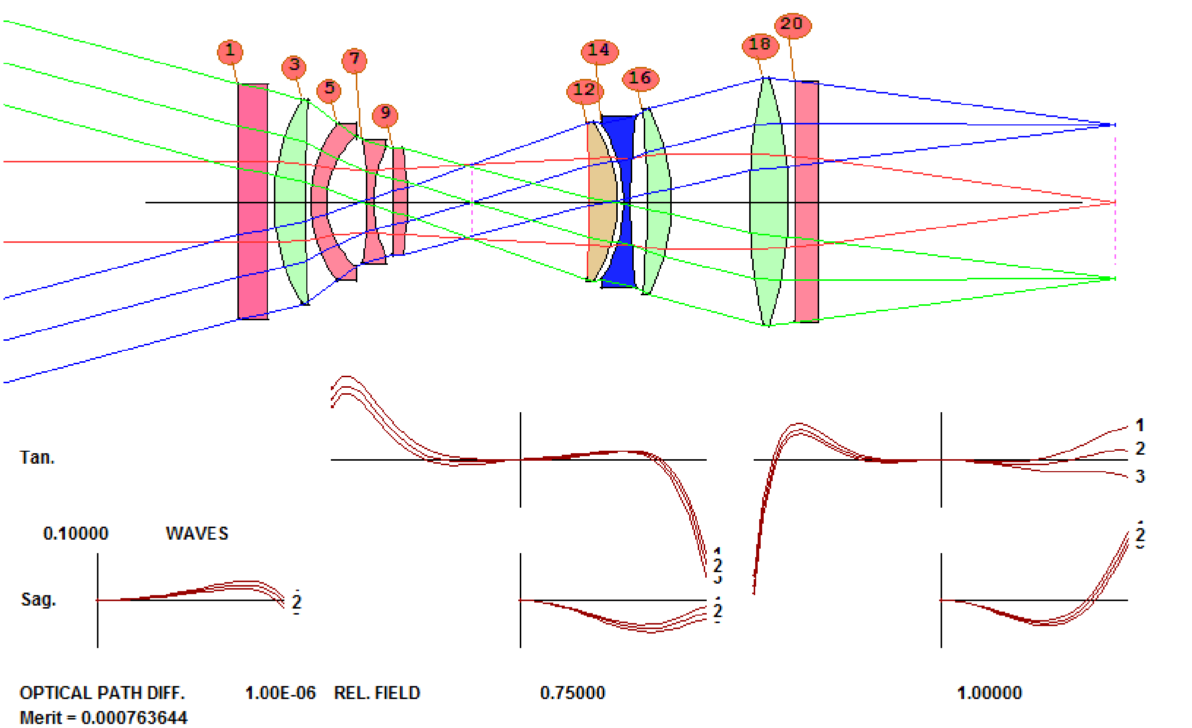
The program has inserted an element before surface 12. We add a new variable

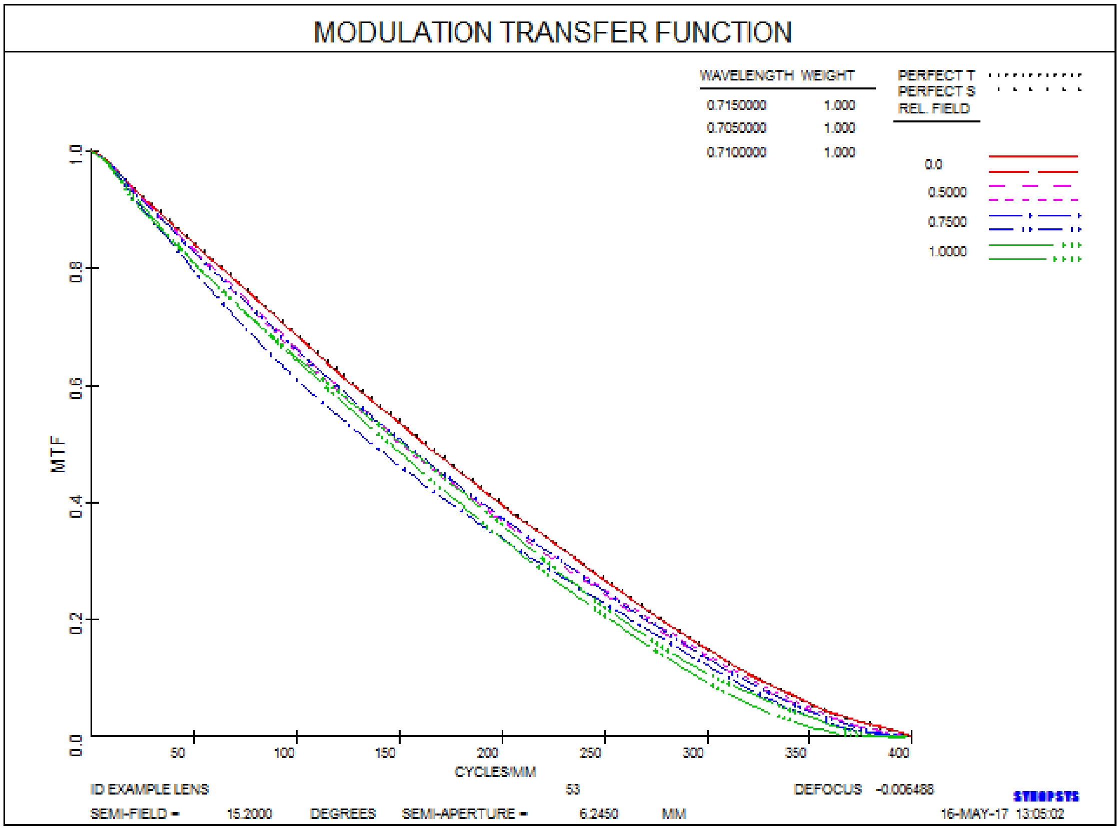
```
VY 12 GLM
```

to the PANT file, so the glass model on the new element can vary, comment out the AEI line, reoptimize and anneal this version.



Very interesting! The program has moved the stop location *inside* the lens at 9. We could cut a groove in that element, if the lens has a fixed aperture, and get superb performance – but if not, we assign a real stop to surface 11, remove the variable for YP1, and reoptimize once again. This works almost as well, giving us this lens:






```
RLE
ID EXAMPLE LENS                                    141
 WAVL .7150000 .7100000 .7050000
 CORDER    1    3    2
 APS                -11
 TEMPERATURE        30.00000
 WAP                   1
 GTZ
 UNITS MM
 OBB  0.000000     15.20000      6.24500     -11.63722      0.00000      0.00000
6.24500
   0 AIR
   1 CV       0.0000000000000    TH       4.50000000
   1 N1 1.45505601 N2 1.45516542 N3 1.45527657
   1 DNDT  1.090E-05  9.960E-06  9.700E-06 3.65000E-01 5.46000E-01 6.44000E-01
   1 CTE   0.500000E-06
   1 GTB U    'FUSILICA         '
   2 CV       0.0000000000000    TH       1.00000000 AIR
   3 RAD      31.7420365099046    TH       4.89311077
   3 N1 1.73585988 N2 1.73610163 N3 1.73634814
   3 CTE   0.806000E-05
   3 GTB S    'N-LAF2           '
   4 RAD     205.8474850968830    TH       6.35592001 AIR
   5 RAD      31.8551157618315    TH       1.39568729
   5 N1 1.51269554 N2 1.51282313 N3 1.51295285
   5 CTE   0.710000E-05
   5 GTB S    'N-BK7            '
   6 RAD      12.9057883346246    TH       7.19477052 AIR
   7 RAD     -23.8475364230033    TH       1.00000000
   7 N1 1.51269554 N2 1.51282313 N3 1.51295285
   7 CTE   0.710000E-05
   7 GTB S    'N-BK7            '
```

```
   8 RAD     18.0286949741191   TH      1.24241640 AIR
   9 RAD     21.7606620988429   TH     11.21030691
   9 N1 1.51269554 N2 1.51282313 N3 1.51295285
   9 CTE   0.710000E-05
   9 GTB S    'N-BK7          '
  10 RAD    -27.0144706600627   TH      1.00000000 AIR
  11 CV      0.0000000000000   TH     15.36917292 AIR
  12 RAD   -221.0555600124851   TH      3.83402160
  12 GLM      1.73264979           52.69907560
  13 RAD    -18.9307423606996   TH      1.00000000 AIR
  14 RAD    -18.3189387535143   TH      1.00000790
  14 N1 1.83018573 N2 1.83066058 N3 1.83114590
  14 CTE   0.846000E-05
  14 GTB S    'N-SF57         '
  15 RAD     77.6676600402005   TH      8.59463594 AIR
  16 RAD    -98.5742040515266   TH      3.91807638
  16 N1 1.73585988 N2 1.73610163 N3 1.73634814
  16 CTE   0.806000E-05
  16 GTB S    'N-LAF2         '
  17 RAD    -31.6148606190401   TH      5.55657931 AIR
  18 RAD     90.9510179315515   TH      5.93527419
  18 N1 1.73585988 N2 1.73610163 N3 1.73634814
  18 CTE   0.806000E-05
  18 GTB S    'N-LAF2         '
  19 RAD    -60.9109375555036   TH      1.00003786 AIR
  19 CV     -0.01641741
  19 UMC    -0.14286000
  20 CV      0.0000000000000   TH      3.60000000
  20 N1 1.51269554 N2 1.51282313 N3 1.51295285
  20 CTE   0.710000E-05
  20 GTB S    'N-BK7          '
  21 RAD -1.1487695061324E+17   TH     43.52197472 AIR
  21 CV  -8.70496644E-18
  21 UMC    -0.14286000
  22 CV      0.0000000000000   TH      0.00000000 AIR
 END
```

Yes, this exercise was definitely worth doing! The program has removed the original lens element at 14 and replaced it with a new lens at 12. Maximum distortion is now about ¼ micron (half of the original), and departure from telecentricity is now less than 0.0048. We then replaced the model glass at 12 with the glass used on surface 3 and reoptimized with little loss of quality. (When you do these lessons yourself, you may get slightly different results, due to the randomness of the annealing stage.)