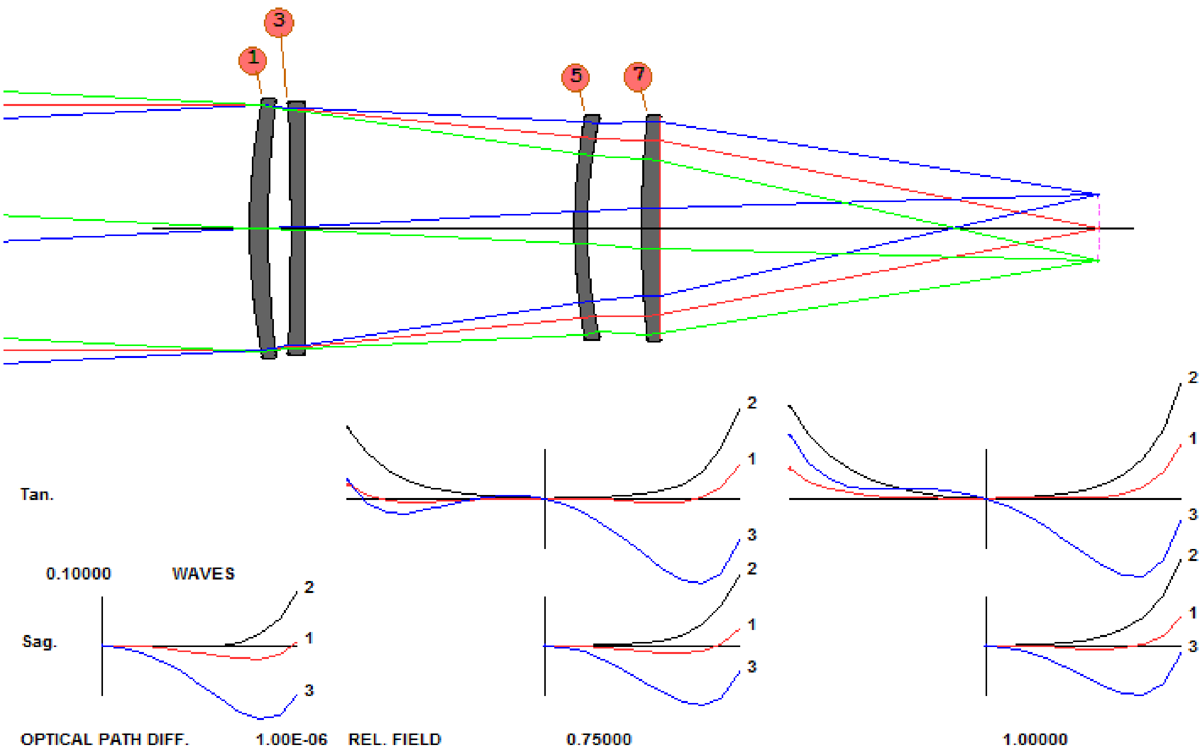
# Lesson 35: Athermalizing an Infrared Telescope

In this lesson we will examine what happens to the image of a mid-infrared telescope as the temperature changes. We start with lens below.




This is lens X11 in the example files, and we have adjusted the last airspace to improve the focus. Here is the RLE file for this example:

```
RLE
ID FOUR ELEMENT INFRARED OBJECTIVE
 WAVL 4.000000 3.250000 2.500000
 APS                  1
 UNITS MM
 OBB  0.000000    3.00000   30.00000    0.00000    0.00000    0.00000   30.00000
 MARGIN       1.270000
 BEVEL       0.254001
   0 AIR
   1 RAD    163.0500000000000   TH      4.50000000
   1 N1 3.42403414 N2 3.42836910 N3 3.43782376
   1 DNDT  1.336E-04  1.336E-04  1.336E-04 1.40000E+00 7.50000E+00 1.60000E+01
   1 CTE   0.255000E-05
   1 GTB U    'SILICON          '
   1 EFILE EX1    31.417334    31.417334    31.671335     0.000000
   1 EFILE EX2    31.014427    31.417334     0.000000
   2 RAD    255.4500000000000   TH      5.55000000 AIR
   2 AIR
   2 EFILE EX1    31.014427    31.417334    31.671335
   3 RAD   -721.5000000000000   TH      3.60000000
   3 N1 4.02415626 N2 4.03741119 N3 4.06419029
   3 DNDT  4.100E-04  4.100E-04  4.100E-04 2.05000E+00 1.10000E+01 2.20000E+01
   3 CTE   0.550000E-05
   3 GTB U    'GE               '
   3 EFILE EX1    30.633643    30.633643    30.887644     0.000000
   3 EFILE EX2    30.633643    30.633643     0.000000
```

```
   4 RAD  -1590.0000000000000   TH     65.70000000 AIR
   4 AIR
   4 EFILE EX1    30.633643    30.633643    30.887644
   5 RAD    145.5000000000000   TH      3.15000000
   5 N1 4.02415626 N2 4.03741119 N3 4.06419029
   5 DNDT  4.100E-04  4.100E-04  4.100E-04 2.05000E+00 1.10000E+01 2.20000E+01
   5 CTE   0.550000E-05
   5 GTB U    'GE             '
   5 EFILE EX1    27.236976    27.236976    27.490977     0.000000
   5 EFILE EX2    26.712556    27.236976     0.000000
   6 RAD    120.4500000000000   TH     13.20000000 AIR
   6 AIR
   6 EFILE EX1    26.712556    27.236976    27.490977
   7 RAD    255.0000000000000   TH      4.50000000
   7 N1 3.42403414 N2 3.42836910 N3 3.43782376
   7 DNDT  1.336E-04  1.336E-04  1.336E-04 1.40000E+00 7.50000E+00 1.60000E+01
   7 CTE   0.255000E-05
   7 GTB U    'SILICON        '
   7 EFILE EX1    27.355510    27.355510    27.609511     0.000000
   7 EFILE EX2    27.165926    27.355510     0.000000
   8 RAD   2025.0000000000000   TH    107.272545 AIR
   8 AIR
   8 EFILE EX1    27.165926    27.355510    27.609511
   9 RAD   -405.0000000000000   TH      0.00000000 AIR
   9 AIR
 END
```

Let us assume this lens must stay in focus over the temperature range of 20 to 100 C.  What does is do now?  To find out, we run the THERM program, first testing to see if all required coefficients are present.

```
SYNOPSYS AI>THERM TEST

WARNING -- NO DEFAULT CTE HAS BEEN ASSIGNED TO AIRSPACES
ALL GLASSES IN THIS LENS HAVE BEEN ASSIGNED THERMAL-INDEX COEFFICIENTS
SYNOPSYS AI>
```

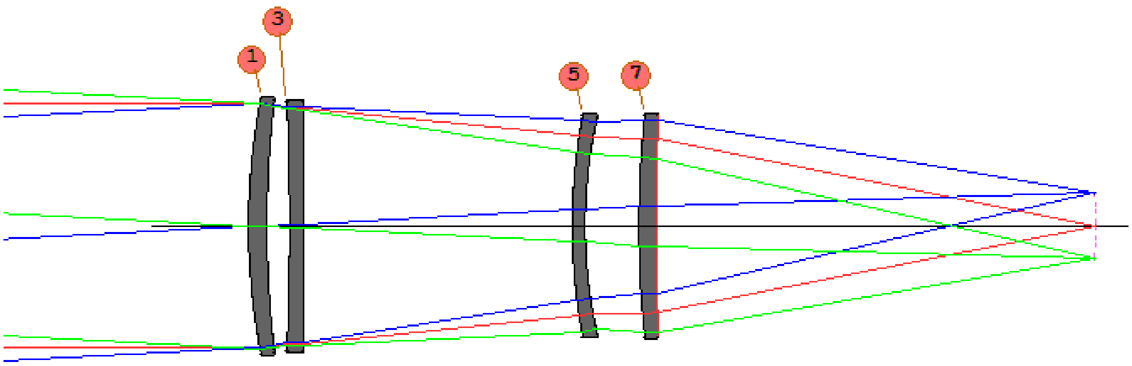
Indeed, this lens was never assigned a coefficient for the airspaces.  We fix that with a CHG file, assigning the coefficient of aluminum type 6061:

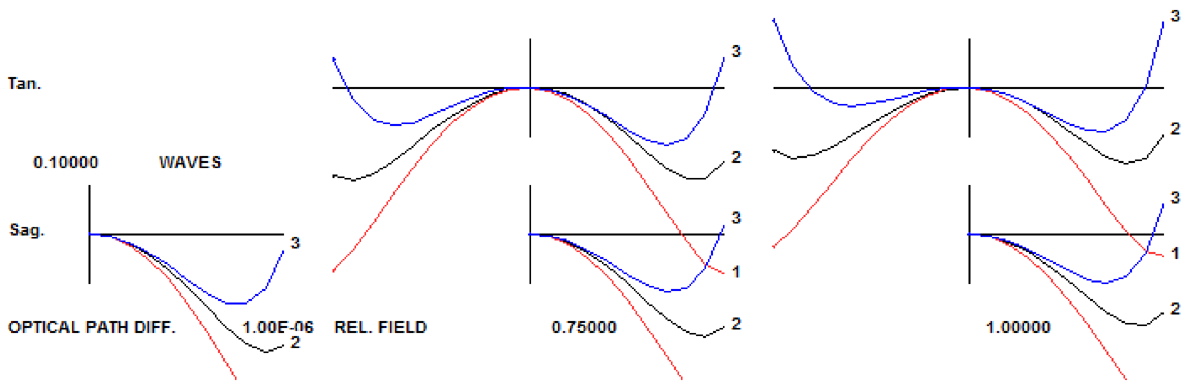
```
CHG
ALPHA A6061
END
```

Now we can activate thermal shadowing.  We create and run a new MACro:

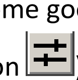
```
THERM
ATS 100 2
END
```

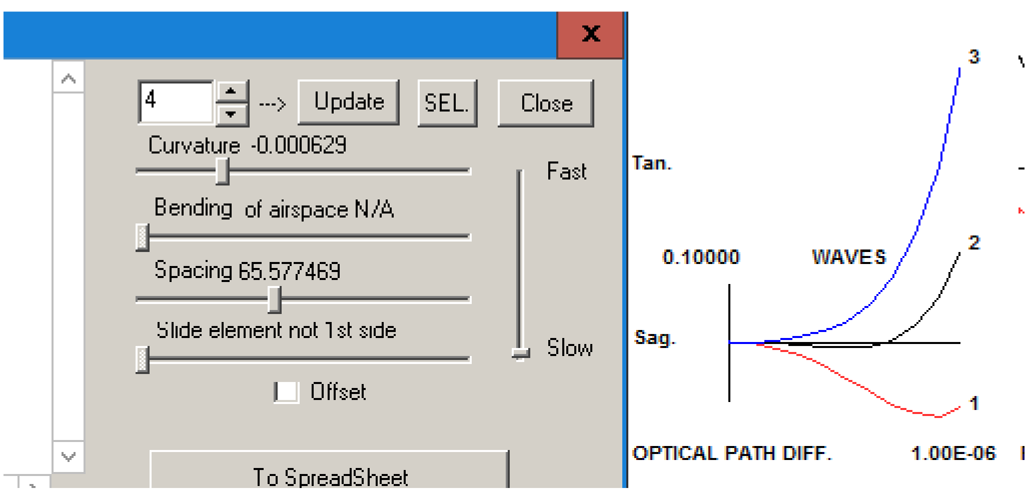
This puts a copy of the lens in configuration 2, with all parameters altered as required by the change in temperature from the default 20 to 100 degrees.  Here is what ACON 2 looks like now:



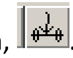

Ouch! The lens is out of focus. We have to correct that.

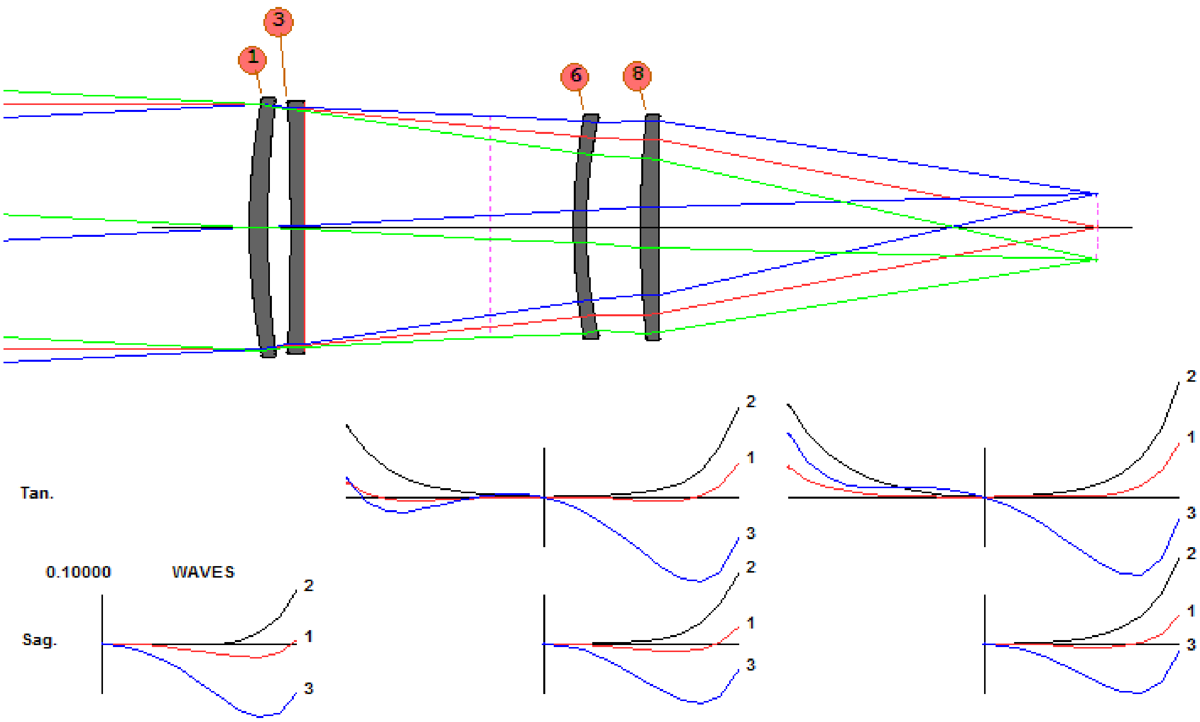
Here's an easy way to tell where an axial shift of an element might do some good. First, make a checkpoint in ACON 2, by clicking the button . Now open the WorkSheet (click on the button ), and then click on surface 4 in the PAD display. We suspect that a change of the following airspace might alter the focus position. To be practical, the required motion must be quite small, so slide the speed slider closer to the bottom, and then slide the Spacing slider to the right, as shown.




Indeed, the image comes back nearly in focus, and the motion was quite small, from 65.7 to 65.577. We're getting close.

Now we have to figure out a way to make element 3 move in that way with temperature. One trick that sometimes works is to design the cell with an outer sleeve that extends from surface 4 to the right, past the next elements, and then with an inner sleeve that comes back partway and holds those elements. If the outer sleeve is made of aluminum and the inner one of plastic, the net motion of element 3 will be less than it would be with an all-aluminum cell.

Go back to ACON 1 again, with the WorkSheet still open, make a checkpoint, and click the Add Surface button, . Now click on the axis in the lens drawing in between surfaces 4 and 5. A dummy surface is inserted.




Now we must tell the program that the expansion coefficient from 5 to 6 is different from the default aluminum. Close WS and make a new THERM file:

```
THERM
COE 1 STYRENE
TCHANGE 1
5
ATS 100 2
END
```

We run this, and ACON 2 has indeed changed. The trick now is to find the length of the outer and inner sleeves that will best compensate as we wish. For this task we use the optimization program. Here is our MACro:

```
ACON 1
PANT
VY 4 TH 1000 -1000
VY 5 TH 1000 -1000
END

AANT
ACON 1
M 0 1 A DELF
M 8.103249 1 A P YA 1

GSO 0.5 5.332000 3 M 0
GNO 0.5 1 3 M 0.5
```

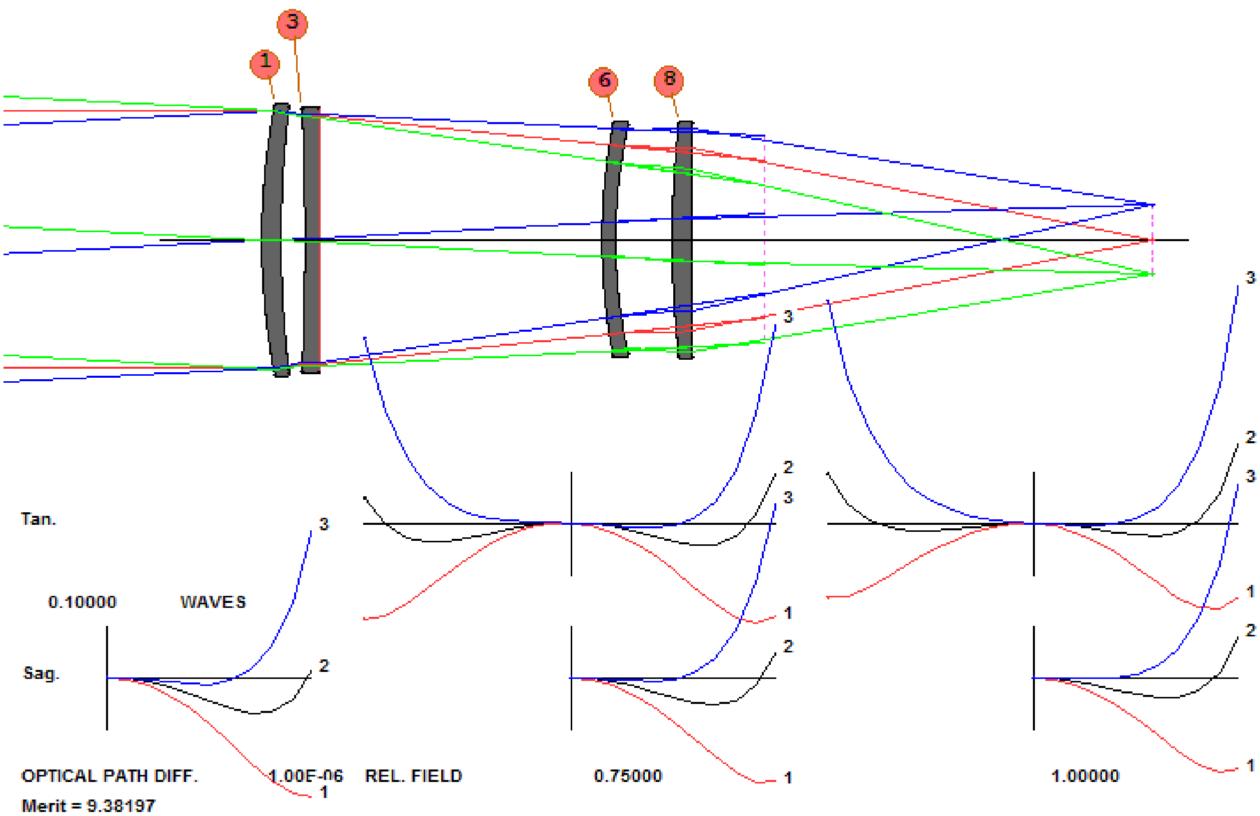
```
GNO 0.5 1 3 M 1.0

ACON 2
M 0 1 A DELF

GSO 0.5 5.332000 3 M 0
GNO 0.5 1 3 M 0.5
GNO 0.5 1 3 M 1.0
END

SNAP
SYNO 20 MULTI
```

This will attempt to keep the system in focus at both temperatures and try to hold image quality at the same time. We run this, and now the lens in ACON 2 is better than before:




There is some image degradation, but within reason, and the focus remains where it should even with the change in temperature. Note the position of surface 5 now. That tells you where the two sleeves must extend to and where they should connect. Athermalization does not have to be difficult.

Some comments are in order. We have entered explicit limits for the TH variables since the program will not let a positive TH become negative otherwise. To keep the magnification constant, we added a target for the YA of the chief ray. (Some changes can alter this, and we have to be careful.) We have not implemented the options to account for whether the cells hold the lenses on the right or left side of an element, because for this example the expansion is applied in the right place by default. Yes, sometimes athermalization is indeed more complicated, and you are referred to the User's Manual for a complete description of the options you have available with this powerful feature for more demanding tasks.