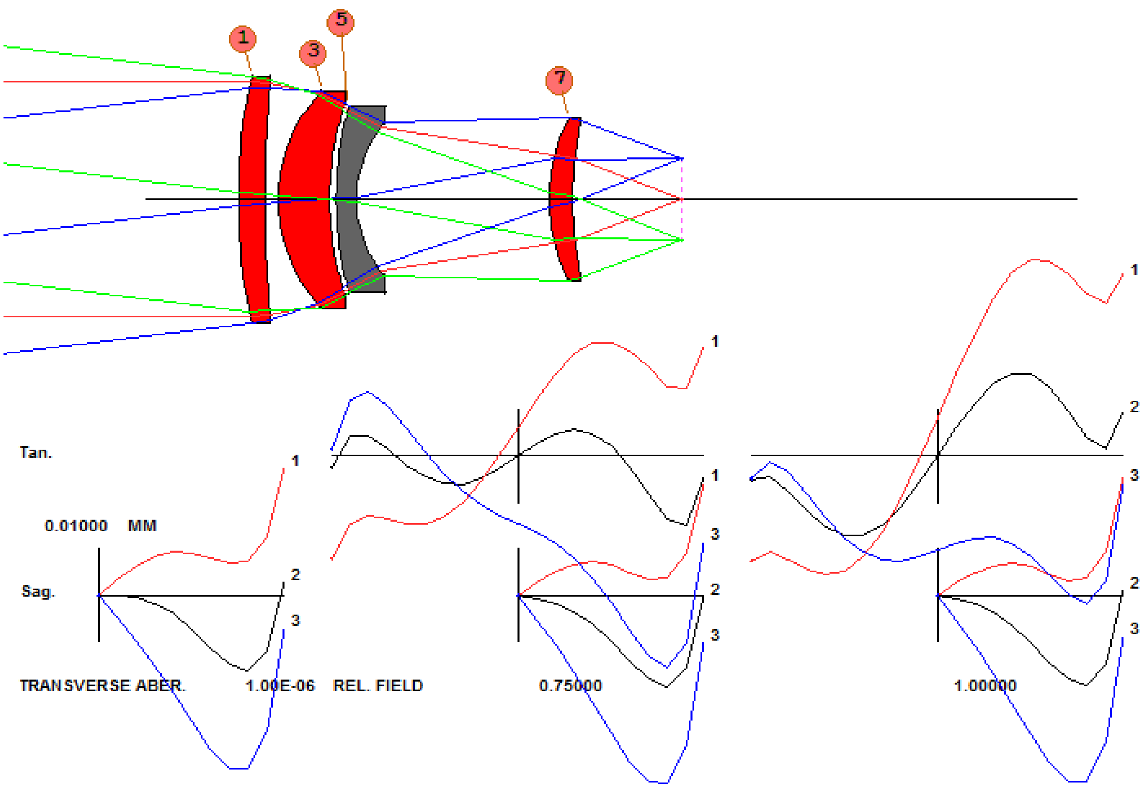
Lesson 10: Near-IR Lens Example

Lesson 8 showed how to design an apochromatic objective for use in the visible spectrum. Now we will design one for the near infrared over the wavelength range from 1.06 to 1.97 um.

The challenge when designing a lens for the infrared is finding optical materials that are useful over the spectral range and whose cost and chemical properties are attractive. The task in this lesson is to redesign an existing lens, replacing some undesirable materials with ordinary optical glass. The reference system is bundled as 1.RLE, with the ID MIT 1 TO 2 UM LENS. You can FETCH that lens and examine its performance. Set the scale of the Fans curves to 0.01 mm.

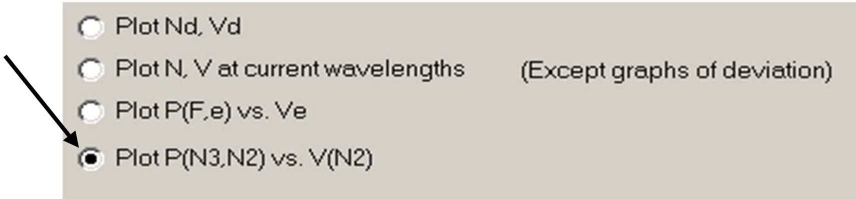


That lens has three elements of ZNS and one of AS2S3, making four elements in all. Those names refer to zinc sulphide and arsenic trisulphide glass, and we would like to avoid those materials if possible. The first-order properties we need to match are as follows (dimensions are in mm):

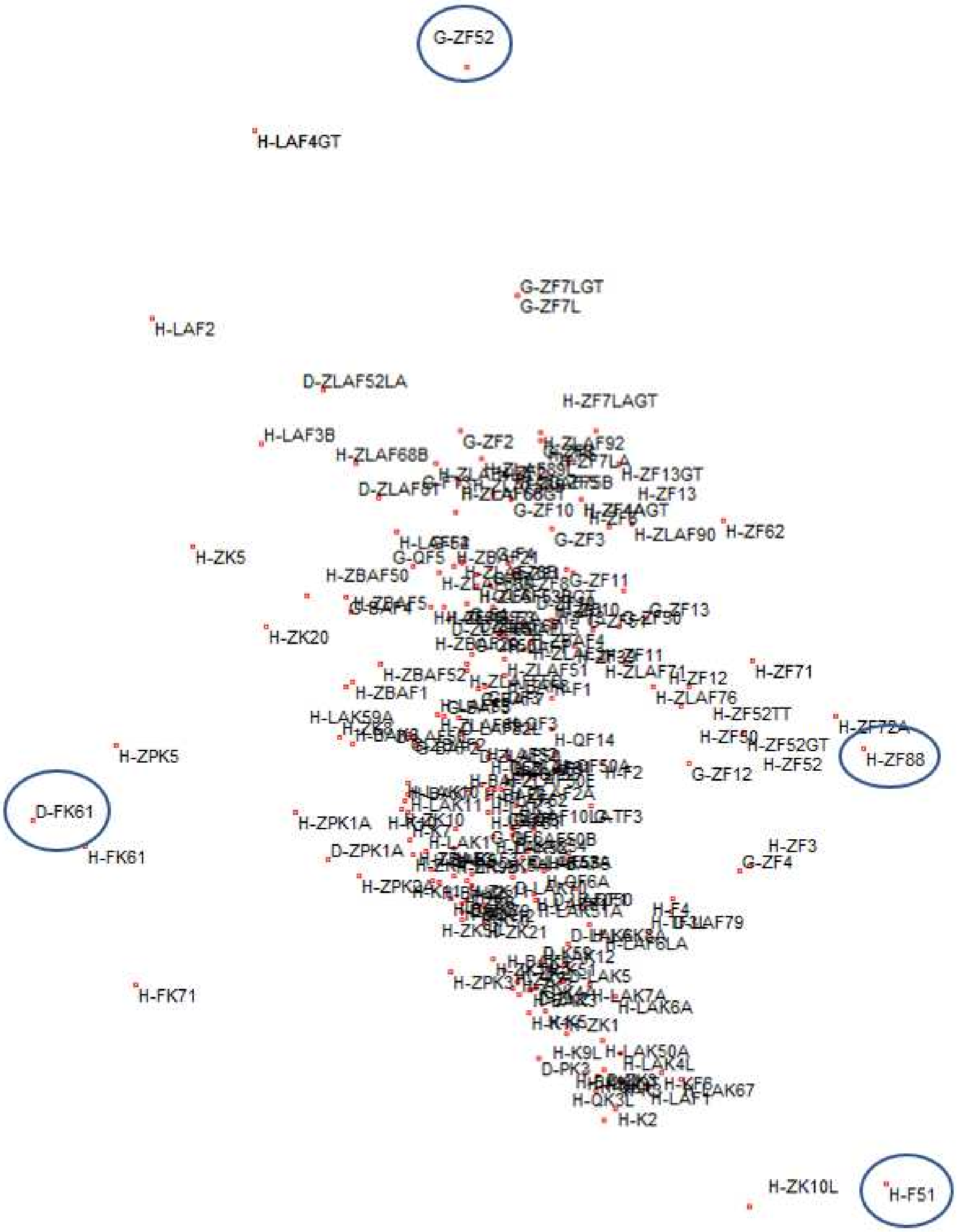
- Entering beam radius 17.5
- Chief-ray angle 0.935 degrees
- Back focus distance 16.3
- Cell length 50

The Plan of Action

Rather than try to change the materials in the present lens, all of which have an index greater than 2.0, let us start from scratch. For this we will use the design search program. But first we have to be somewhat choosy: if we just run **DSEARCH** and let it find model glasses, it will not come back with any of the unusual glasses that make a big difference in the NIR. (The model represents an *average* of all glasses.) So we have to steer it. Open the glass table display (**MGT**), select the Guangming table, and then click the Graph button and select the option shown.



The data are now off the screen, so click in the display and zoom out with the mouse wheel until you see a collection of red dots. Then pan with the right mouse button to center things and zoom in. Click the Full Name button. You should see the display below.

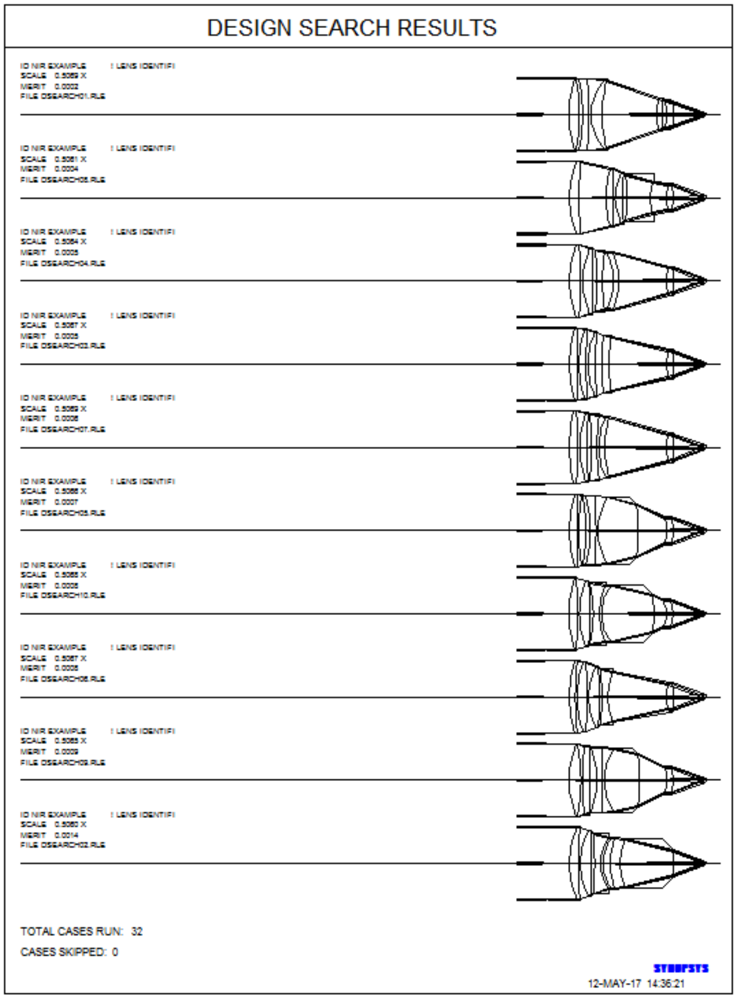


Write down the four glass names circled: D-FK61, G-ZF52, H-ZH88, and H-F51. Those definitely do not behave the same as all the others. We will direct DSEARCH to only use two of them, and later use all four for a comprehensive glass search.

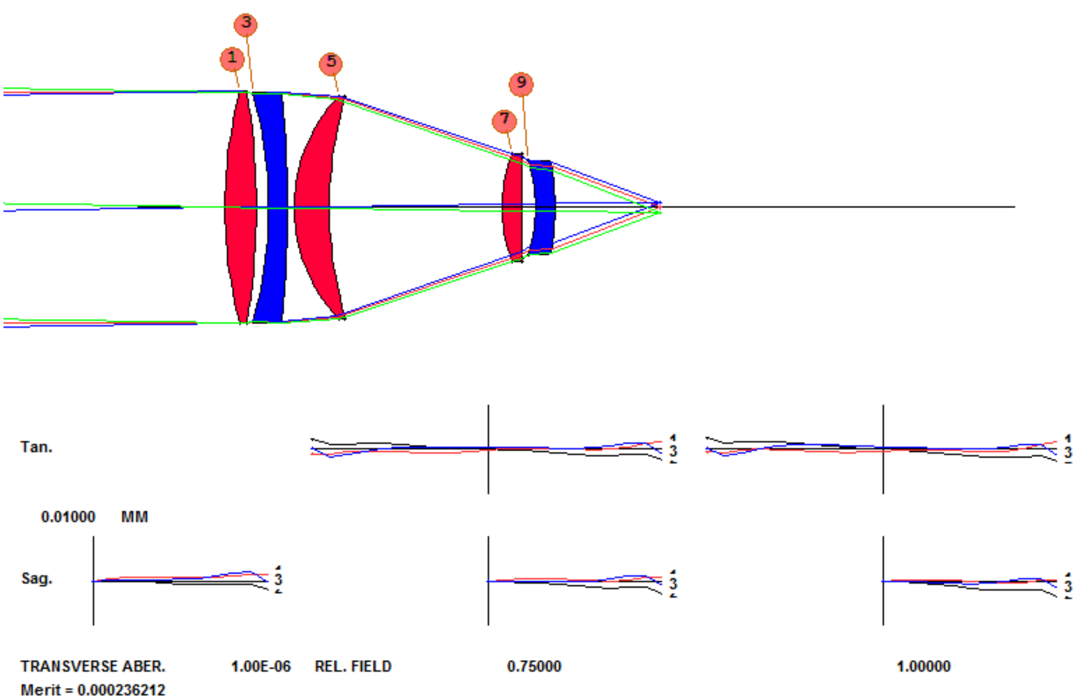
Here is our DSEARCH input:

```
CORE 16
PROJ
DSEARCH 3  QUIET       ! the best lens will show up in library location 3 (and also in PAD)
 SYSTEM                 ! system requirements follow
 ID NIR EXAMPLE         ! lens identification
 OBB 0 .935 17.5        ! specify the object
 WAVL 1.97 1.53 1.06    ! and the wavelength range
 UNITS MM
 END

 GOALS              ! here we set the goals
 ELEMENTS 5         ! since glass has a lower index, we'll ask for 5.
 FNUM 1.428
 BACK 16 .1
 TOTL 50 .1
 STOP FIRST         ! there seems to be no reason to let the stop position vary
 STOP FIX           ! so we put it in front and keep it there
 NPASS 100
 ANNEAL 200 20
 RSTART 300       ! a useful starting radius,
 TSTART 1         ! and this thickness on each element to start with
 QUICK 60 90
FOV 0 .5 1
FWT 2 1 1
GLASS POS          ! positive elements will use this glass type
G D-FK61
GLASS NEG         ! and negative this type.
G H-ZF88
END

 SPECIAL      ! here we give requirements that are not defaults
 ACM 3 .1 1   ! auto edge control (AEC) and center thickness control (ACC) are defaults
 ACA          ! but we add to these ACM, so thicknesses do not get too thin, ACA,
 ASC          ! so rays do not approach the critical angle, and ASC so surfaces do not
 END          ! get too close to the hemisphere point.

 GO           ! this starts the process.
PROJ
```

In less than a minute, the process produces a picture of the 10 best configurations it found.



We now have a very good 5-element lens, but it has only the two glass types we specified. It's time to do a more comprehensive search.



Look at the MACro DSEARCH_OPT .MAC, which DSEARCH has conveniently constructed for us and should be open in a new editor window.

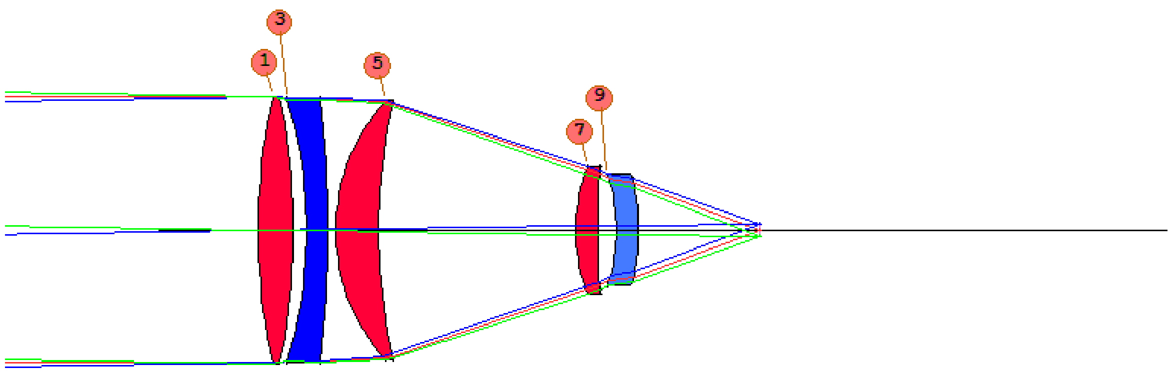
```
PANT
VLIST RD ALL
VLIST TH ALL
END
AANT P
AEC
ACC
GSR     0.000000     2.000000      4  M     0.000000
GNR     0.000000     1.000000      4  M     0.500000
GNR     0.000000     1.000000      4  M     1.000000
M   0.160000E+02  0.100000E+00 A BACK
M   0.500000E+02  0.100000E+00 A TOTL
 ACM 3 .1 1    ! AUTO EDGE CONTROL (AEC) AND CENTER THICKNESS CONTROL (ACC) ARE DEFAULTS
 ACA           ! BUT WE ADD TO THESE ACM, SO THICKNESSES DO NOT GET TOO THIN, ACA,
 ASC           ! SO RAYS DO NOT APPROACH THE CRITICAL ANGLE, AND ASC SO SURFACES DO NOT
END
SNAP/DAMP 1
SYNOPSYS  100
```

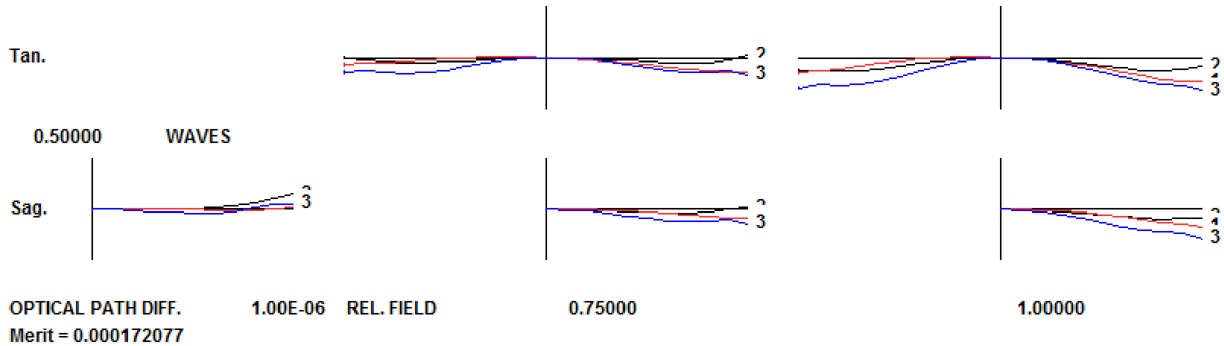
Save this MACro with the name NIR_OPT.MAC. This is the optimization MACro that will be run over and over when we execute **GSEARCH**, which will determine which glass should go on which elements.
Now make a new MACro (type **AEE** to open a new editor, and type the data below)

.

```
CORE 16

GSEARCH 3 QUIET LOG

SURF
1 3 5 7 9
END

OFILE 'NIR_OPT.MAC'
NAMES
G G-ZF52
G D-FK61
G H-ZF88
G H-F51

END
USE 2
GO
```

The lens has improved even more. The performance is now just over 0.2 waves of aberration everywhere.





It looks like we have a solution! There is almost no primary or secondary chromatic aberration. We have succeeded in replacing the undesirable materials with ordinary glass, and the performance became much better than the original at the same time.

Mission accomplished! Here is a SPEC listing of the final lens:

```
SYNOPSYS>SPE


ID NIR EXAMPLE
ID1 DSEARCH CASE WAS 0000000000000000000010110     22
LENS SPECIFICATIONS:

SYSTEM SPECIFICATIONS
------------------------------------------------------------------------------
OBJECT DISTANCE     (TH0)         INFINITE  FOCAL LENGTH       (FOCL)      49.9800
OBJECT HEIGHT      (YPP0)         INFINITE  PARAXIAL FOCAL POINT           15.9992
MARG RAY HEIGHT    (YMP1)          17.5000  IMAGE DISTANCE     (BACK)      15.9992
MARG RAY ANGLE     (UMP0)           0.0000  CELL LENGTH        (TOTL)      50.0025
CHIEF RAY HEIGHT   (YPP1)           0.0000  F/NUMBER           (FNUM)       1.4280
CHIEF RAY ANGLE    (UPP0)           0.9350  GAUSSIAN IMAGE HT(GIHT)         0.8157
ENTR PUPIL SEMI-APERTURE           17.5000  EXIT PUPIL SEMI-APERTURE       24.7688
ENTR PUPIL LOCATION                 0.0000  EXIT PUPIL LOCATION           -54.7406

WAVL (uM) 1.970000 1.530000 1.060000
WEIGHTS   1.000000 1.000000 1.000000
COLOR ORDER    2    1    3
UNITS                                MM
APERTURE STOP SURFACE (APS)           1     SEMI-APERTURE    17.53054
FOCAL MODE                           ON
MAGNIFICATION              -4.99800E-11
POLARIZATION AND COATINGS ARE IGNORED.
SURFACE DATA
------------------------------------------------------------------------------
SURF          RADIUS       THICKNESS    MEDIUM              INDEX       V-NUMBER
------------------------------------------------------------------------------
```

```
  0        INFINITE       INFINITE   AIR
  1        83.04964        4.55863   D-FK61          1.48647     78.02 GUANGMIN
  2       -90.13577        1.76097   AIR
  3       -61.20988        2.89016   H-ZF88          1.87811     26.89 GUANGMIN
  4      -136.80545        1.00000   AIR
  5        26.01458        5.71573   D-FK61          1.48647     78.02 GUANGMIN
  6        83.59388       25.92496   AIR
  7        24.21580        2.91205   D-FK61          1.48647     78.02 GUANGMIN
  8       117.43058        2.36412   AIR
  9       -24.23661        2.87587   H-F51           1.60755     25.46 GUANGMIN
 10       -40.27187S      15.99923S  AIR
IMG        INFINITE

 KEY TO SYMBOLS
 ______________
 A  SURFACE HAS TILTS AND DECENTERS    B  TAG ON SURFACE
 G  SURFACE IS IN GLOBAL COORDINATES   L  SURFACE IS IN LOCAL COORDINATES
 O  SPECIAL SURFACE TYPE               P  ITEM IS SUBJECT TO PICKUP
 S  ITEM IS SUBJECT TO SOLVE           M  SURFACE HAS MELT INDEX DATA
 T  ITEM IS TARGET OF A PICKUP
 THIS LENS HAS NO SPECIAL SURFACE TYPES
 THIS LENS HAS NO TILTS OR DECENTERS
 SYNOPSYS>
```

If these lenses are okay mechanically, the problem is solved.

Except ... what is the transmission at 1.97 microns? Type **`FIND TRANS IN COLOR 1`**. It comes back 98.18%. (Coatings are ignored here because the lens is not in polarization mode.) Very good!

But what if the value had come back too low? Well, then go back to the glass map and display the absorption at 1.97 microns – and select glasses with shorter data bars. Lens design is all about tradeoffs, after all, and with these tools one can get the best one rather easily.