SYNOPSYS™ Starting Guide with *Ui-Plus*

SYNOPSYS™ *(SYNthesis of OPtical SYStems)*

Lens Design Software

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www.osdoptics.com

info@osdoptics.com

SYNOPSYS™ is a trade name used by Optical Systems Design commercially since 1981.

Table of Content

Other Tutorials, Videos, and Optical Design books:

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- 5-Element DSEARCH (Video)
- Ray Failure Fix (Video)
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- ‘**Lens Design. Automatic and quasi-autonomous computational methods and techniques’,** by Don Dilworth, https://osdoptics.com/resources/books/

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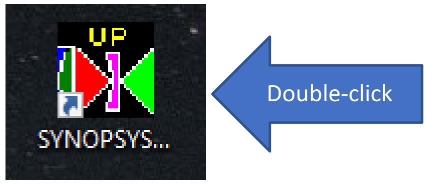
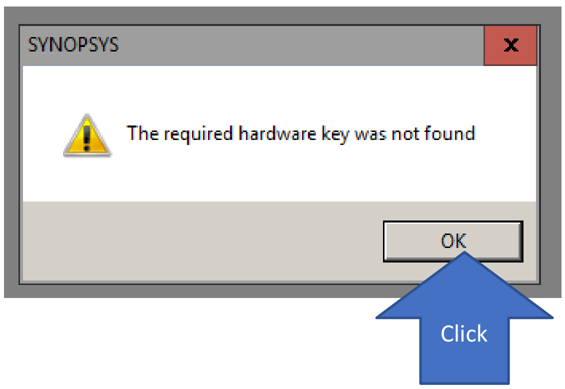
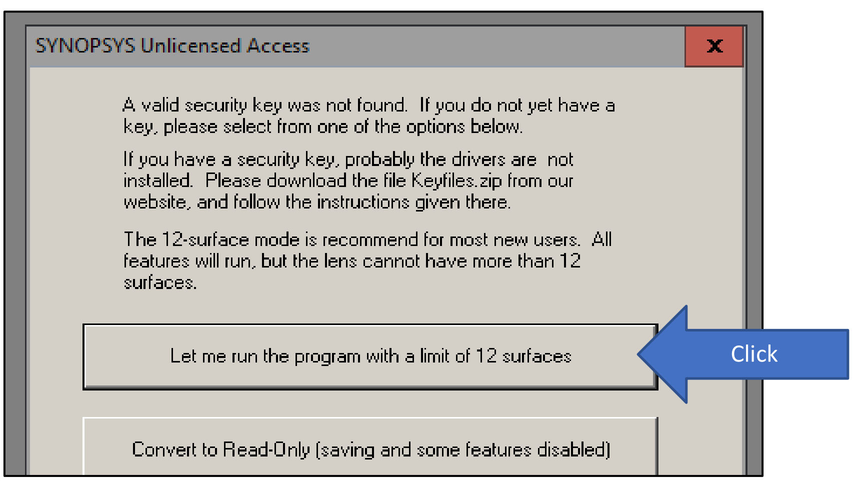
Basic Concepts

Start SYNOPSYS™ Ui-Plus by double clicking the shortcut icon on your desktop:



If you are running the trial version and do not yet have a license, you get the following messages. Just click through them as shown below:

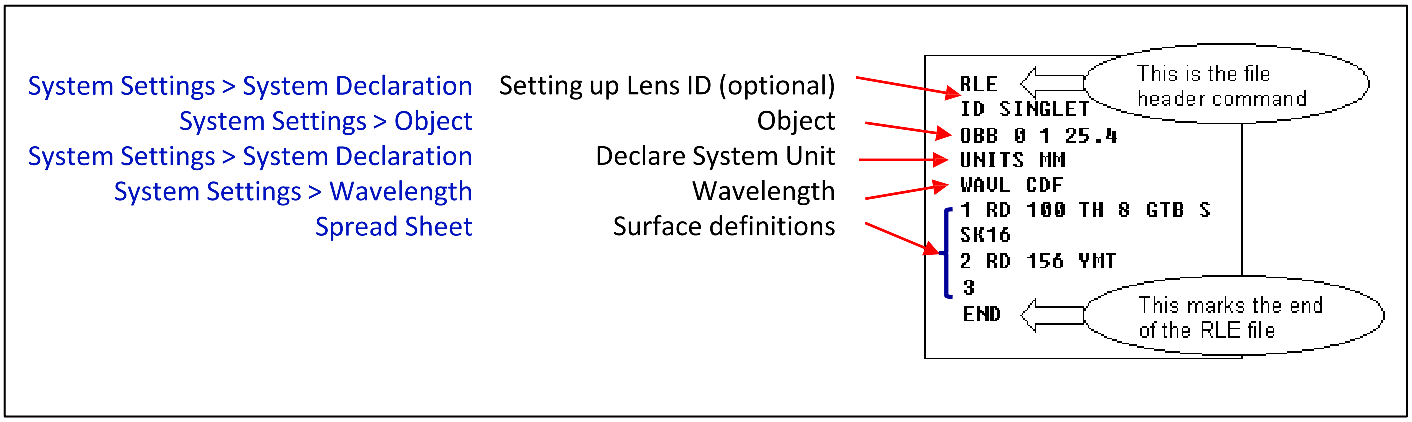




In SYNOPSYS™ , there are two important file types: lens data file (.RLE) and macro file(.MAC).

1. Lens Data file (.RLE): The specifications for a lens are entered into SYNOPSYS™ by means of a data file of the structure shown below and is saved as a .RLE file.

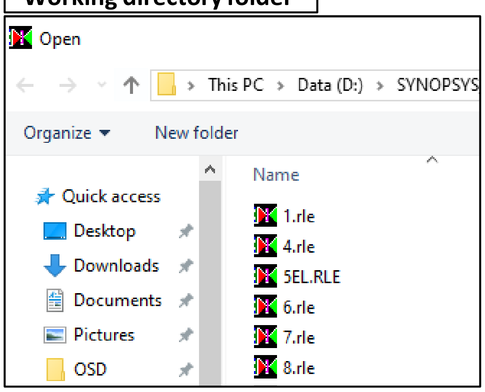
In the illustration below, the RLE script is shown at the right. The corresponding Menu items and Spread Sheet you can use to implement the commands are shown at the left.



For more information on the System Settings Menu, see the section 'System Settings Menu' in the User Manual for User Interface Plus. For the Spread Sheet, see the section 'Spread Sheet' in the same Manual. For the lens data input command scripts, refer to **User Manual 3.0 Lens Data Input**.

You can save the .RLE file in the working directory folder or the Lens Library:

Working directory folder



Lens Library

CONTENTS OF THE LENS LIBRARY

LOCATION	LENS ID
1	ID MIT 1 TO 2 UM LENS
2	ID RAYZOOM A
3	*** EMPTY LOCATION ***
4	ID RELAY FLAT
5	*** EMPTY LOCATION ***
6	ID TRIPLET START
7	ID KOSO LENS 1:1
8	ID IATTEL EYEPIECE
9	ID START FROM FLAT
10	ID NEW LENS

Lens Libraray:

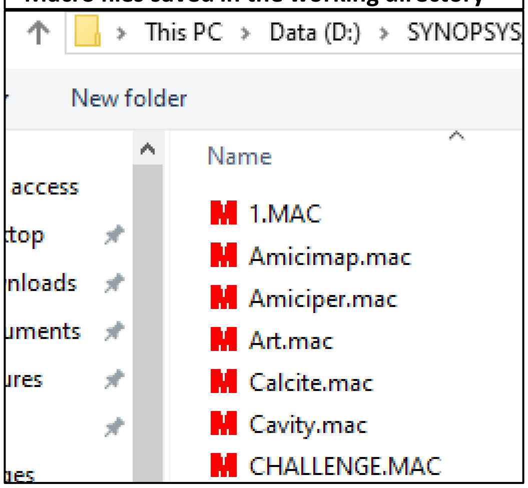
We mostly save and launch files directly from the working directory. However, the Lens Library is an alternative file storage space for up to 10 lenses. This is a practical place to store lenses under active development since some of the features of SYNOPSYS™ can read these data and their flexibility is thereby enhanced (See **User Manual 3.7.1 The Lens Library**). The 10 locations associated with the lens library are displayed when you first launch SYNOPSYS™. Also, the lens that you are working on is automatically saved into location 10 of the Lens Library.

2. Macro (.mac): MACros are sequences of SYNOPSYS™ commands or AI sentences, entered in the Macro Editor window and usually saved to disk. Macros reside in your working directory only.

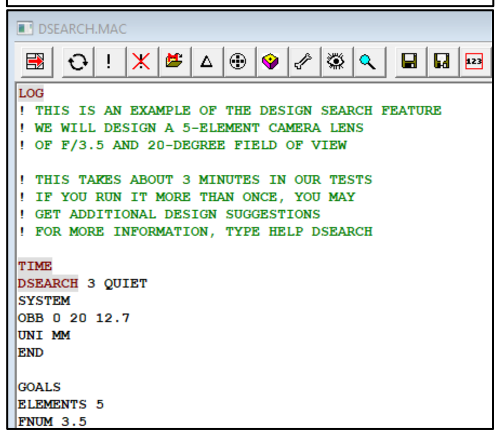
You can have any number of MACro editor windows open at the same time. Much of the work you do in SYNOPSYS™ will require several lines of input, and it is much easier to accomplish what you want if you prepare a MACro first. Then you can easily rerun or edit the MACro if necessary, and save it to disk for use at another time.

Macro files are mostly used for specific analysis such optimization and automatic search. You can also incorporate the lens data construct in the macro but we recommend not to do so because we may need to run the optimization multiple times. If you put your initial lens definition in the same macro, you may run the risk that the initial lens system will be launched and replace the newer version of the lens system that has been optimized.

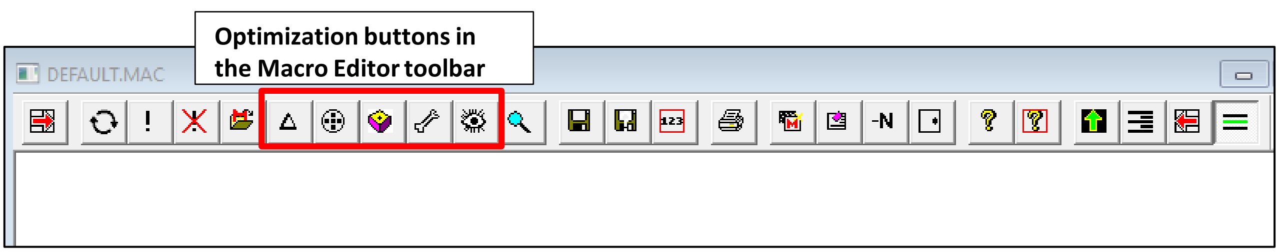
Macro files saved in the working directory



A snippet of the Macro file in the Macro Editor

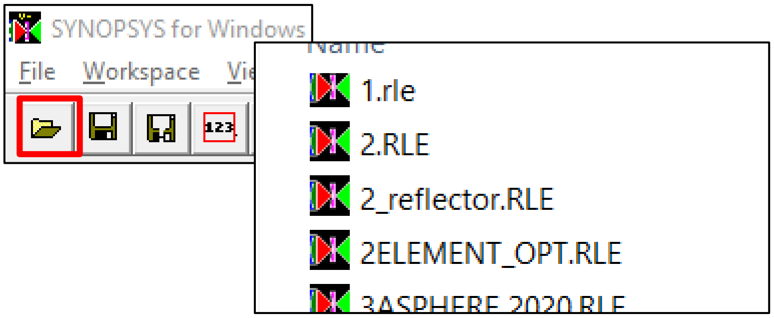


The macro editor toolbar not only provide access to standard functionalities such as saving, opening, and printing the macro files. It also has a set of buttons that are built in for setting up and editing your optimization macro easily. For more details of the macro toolbar and the SYNOPSYS™ commands to launch, open, and run the macro files, refer **to** APPENDIX: Macro files.



1. Launching an existing Lens Data File (.RLE) from the working directory

There are different ways to launch a lens data file (.rle). Here we will introduce the most basic operation: use the 'Open a File' button from the top Toolbar:



You can also use the command FETCH filename to open an existing lens data file:

SYNOPSYS AI>FETCH SINGLET

Once the file is launched, SYNOPSYS™ will automatically execute the paraxial raytrace (PXT) and Lens Specifications (SPEC, **User Manual 4.1**) analysis for the Lens Data file and present the paraxial characteristic of the lens system, as well as its specifications (SPEC), in the Command Output Window.

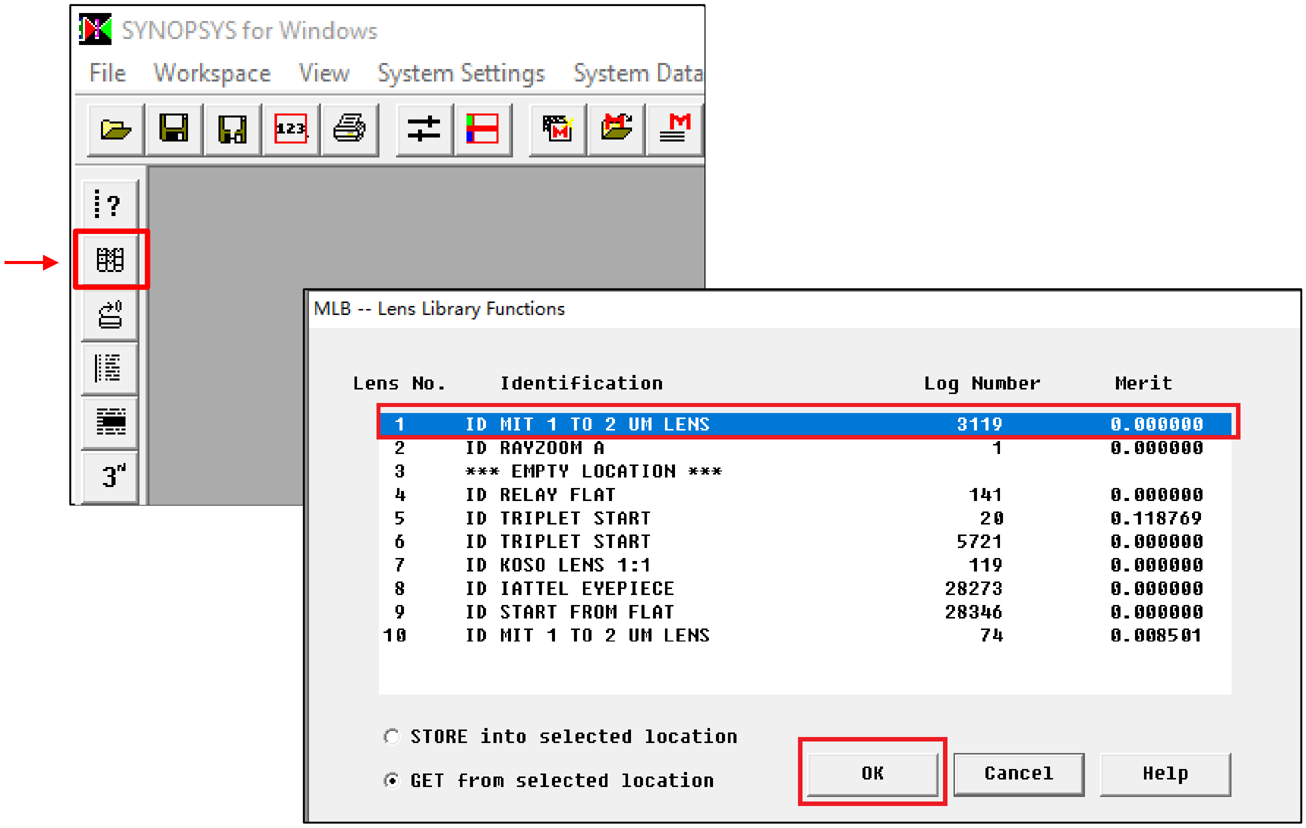
Paraxial raytrace (PXT) result

System specifications (SPEC)

```
SYNOPSYS>         GIHT        FOCL        FNUM        BACK        TOTL
     8.53727  97.58144     3.84179    95.91907     5.00000     0.00000

ID EXAMPLE SINGLET                         168         08-SEP-19   13:02:03
LENS SPECIFICATIONS:

SYSTEM SPECIFICATIONS

OBJECT DISTANCE     (TH0)        INFINITE  FOCAL LENGTH       (FOCL)      97.5814
OBJECT HEIGHT      (YPP0)        INFINITE  PARAXIAL FOCAL POINT           95.9191
MARG RAY HEIGHT    (YMP1)         12.7000  IMAGE DISTANCE     (BACK)      95.9191
MARG RAY ANGLE     (UMP0)          0.0000  CELL LENGTH        (TOTL)       5.0000
CHIEF RAY HEIGHT   (YPP1)          0.0000  F/NUMBER           (FNUM)       3.8418
CHIEF RAY ANGLE    (UPP0)          5.0000  GAUSSIAN IMAGE HT (GIHT)        8.5373
ENTR PUPIL SEMI-APERTURE          12.7000  EXIT PUPIL SEMI-APERTURE       12.9201
ENTR PUPIL LOCATION                0.0000  EXIT PUPIL LOCATION            -3.3536

WAVL (uM)  .6562700 .5875600 .4861300
WEIGHTS    1.000000 1.000000 1.000000
COLOR ORDER      2       1       3
UNITS                             MM
APERTURE STOP SURFACE (APS)        1    SEMI-APERTURE     12.77165
FOCAL MODE                        ON
MAGNIFICATION               -9.75814E-11
GLASS INDEX FROM SCHOTT OR OHARA ADJUSTED FOR SYSTEM TEMPERATURE
SYSTEM TEMPERATURE =    20.00 DEGREES C
POLARIZATION AND COATINGS ARE IGNORED.
SURFACE DATA

SURF         RADIUS       THICKNESS   MEDIUM            INDEX       V-NUMBER

  0         INFINITE       INFINITE   AIR
  1        100.00000        5.00000   N-BK7           1.51679      64.17 SCHOTT
  2       -100.00000       95.91907S  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
```

2. Launching an existing Lens Data File (.RLE) from the Lens Library

As mentioned before, the Lens Library is an alternative file storage space for up to 10 lenses. To get a Lens Data file from the Lens Library, one can use the Lens Library menu button to select the Lens Data File in the Lens Library dialogue:

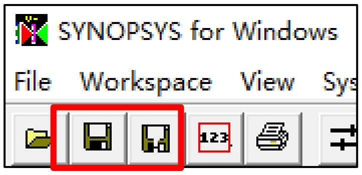


Or you can use the command GET. The example shown below will be the Lens Data file in Library slot 1:

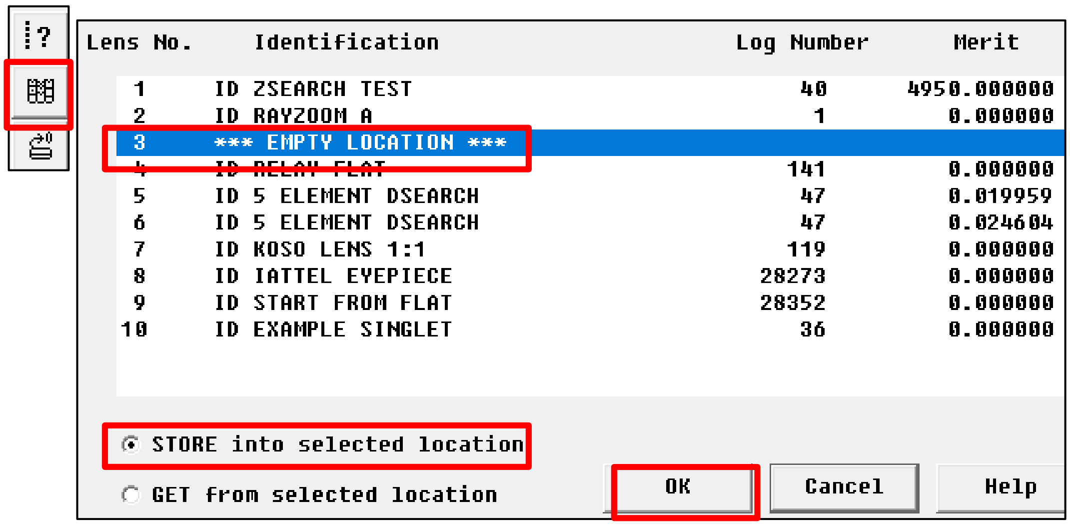
GET 1

3. Saving your Lens File

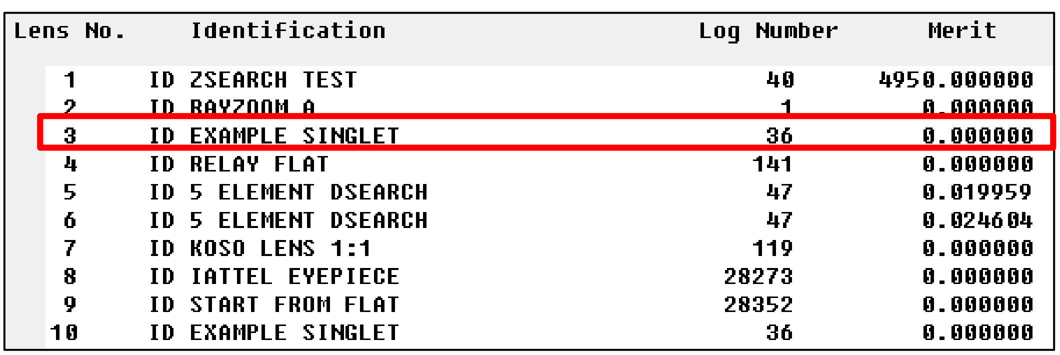
To save a file into the working directory, you can click the 'save' or 'save as' button .



Or, you can Store the file into the Lens Library by clicking the 'Lens Library' button at the side Toolbar. Then select a location (for example, 3) to store the lens in the library and then click OK.

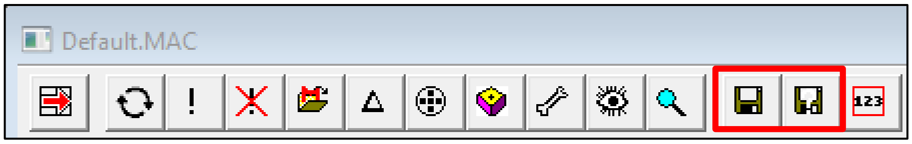


The lens (Example Singlet) is stored in location 3 of the lens library:



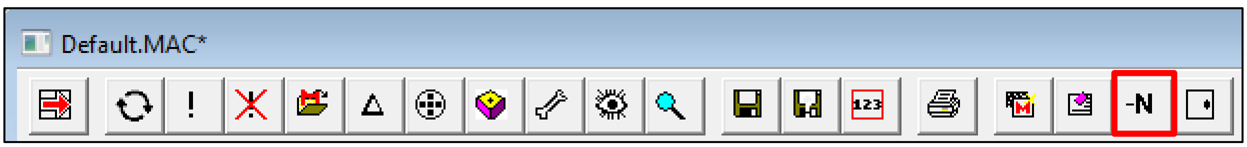
4. Saving your Macros

To save your Macro, you can use the 'save' or 'save as' buttons in the Macro Editor:



When you click the run button in the Macro Editor, SYNOPSYS™ will automatically save your macro under the same name shown at the upper left corner of the macro editor (which is Default.MAC for any unsaved or unnamed macro that you are working on). Do the followings before you click run, if you don't want to overwrite your current macro:

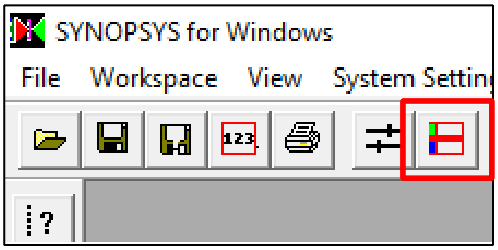
1. Save your current macro by clicking the 'save' or 'save as' button at the macro editor (or same buttons at the Command Window top toolbar) with the filename of your choice
2. Then you can save the work-in-progress macro under a different filename before making changes so that the new changes will be saved into the new filename when you click 'run'.
3. Another way to do this is to change the name at the current macro editor window back to the Default.MAC by clicking the 'Rename Default.MAC' button before running it.



For more information on the Macro Editor toolbar and other commands, see APPENDIX: Macro Files.

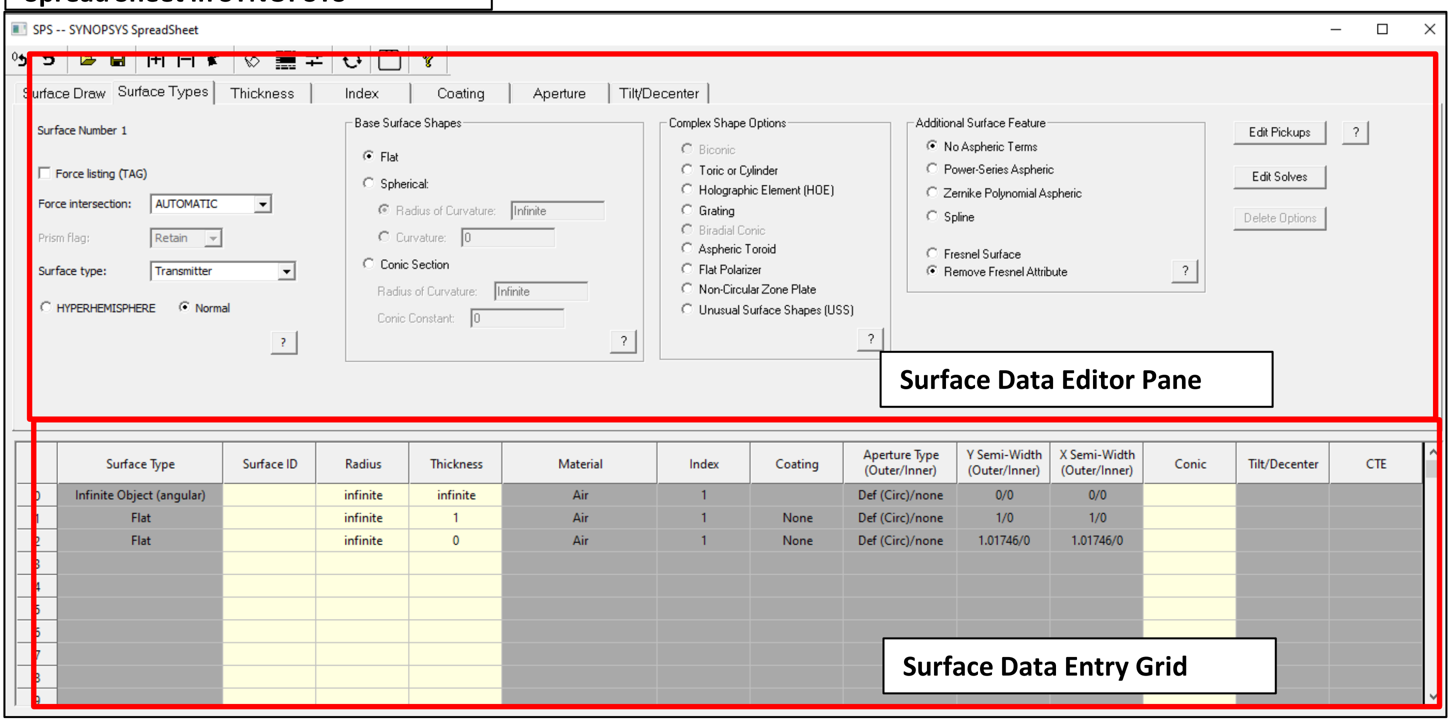
Editing Lens Data with Spread Sheet

Click at the Spread Sheet button in the SYNOPSYS™ main toolbar to open it. You can then enter the data directly in the Data Entry Grid or using the Surface Data Editor Tabs. The columns in yellow can be edited directly. The other columns can be edited via the Surface Data Editors. For more information, see the Spread Sheet section in the User Manual for User Interface Plus.



Note: You can also access the Spread Sheet by typing SPS in the Command Window:
SYNOPSYS AI> SPS

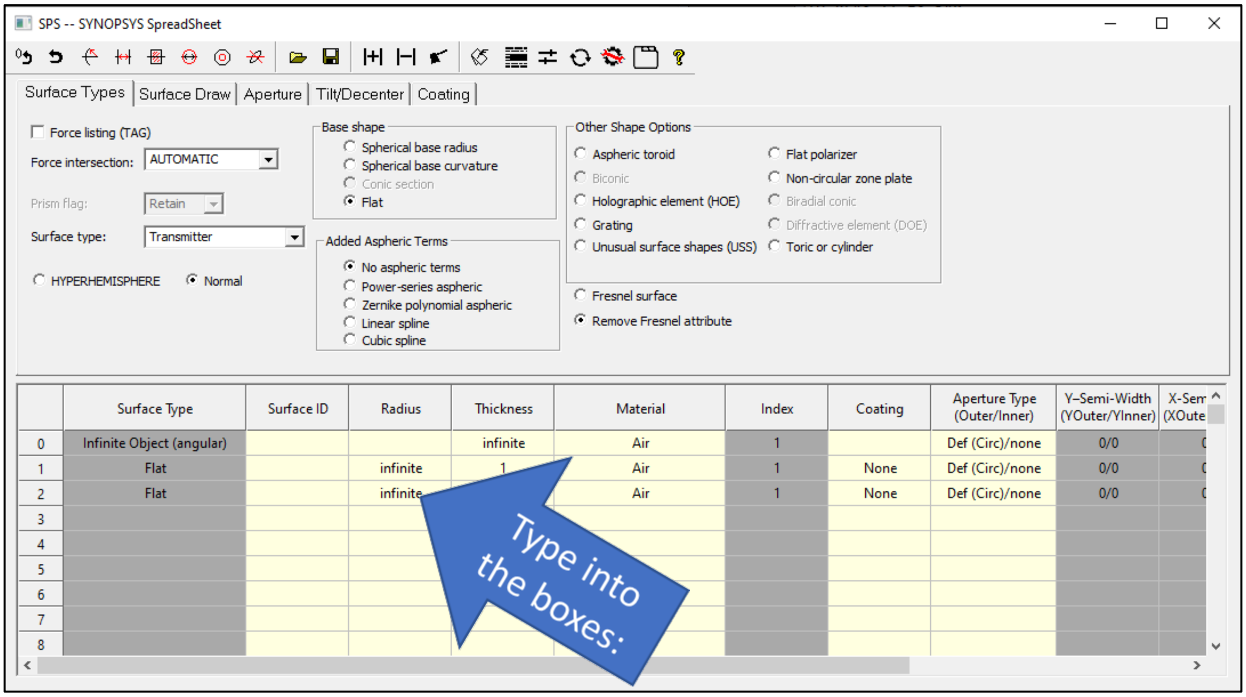
Spread Sheet in SYNOPSYS™



For example, you can enter the lens surface data directly into the Data Entry Grid of the Spread Sheet to define a singlet with the following characteristics:

Surface 1. Radius of Curvature: 50, Thickness: 5

Surface 2. Radius of Curvature: -50



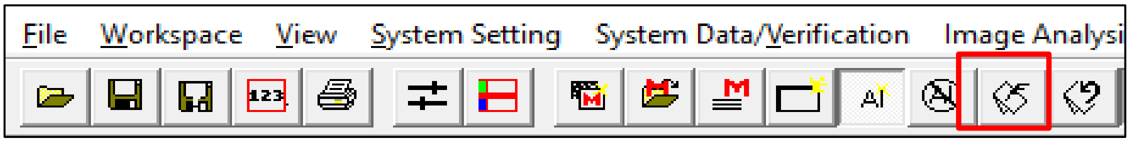
	Surface Type	Surface ID	Radius	Thickness
0	Infinite Object (angular)			infinite
1	Spherical		50	5
2	Spherical		-50	0

So far, two surfaces exist (plus surface 0 for the object.)

System visualization

1. SketchPad™, Graphic View of Lens System and Characteristics

To view the lens layout and its characteristics, click the SketchPad button in the Command Window Top Toolbar to open the SketchPad™.

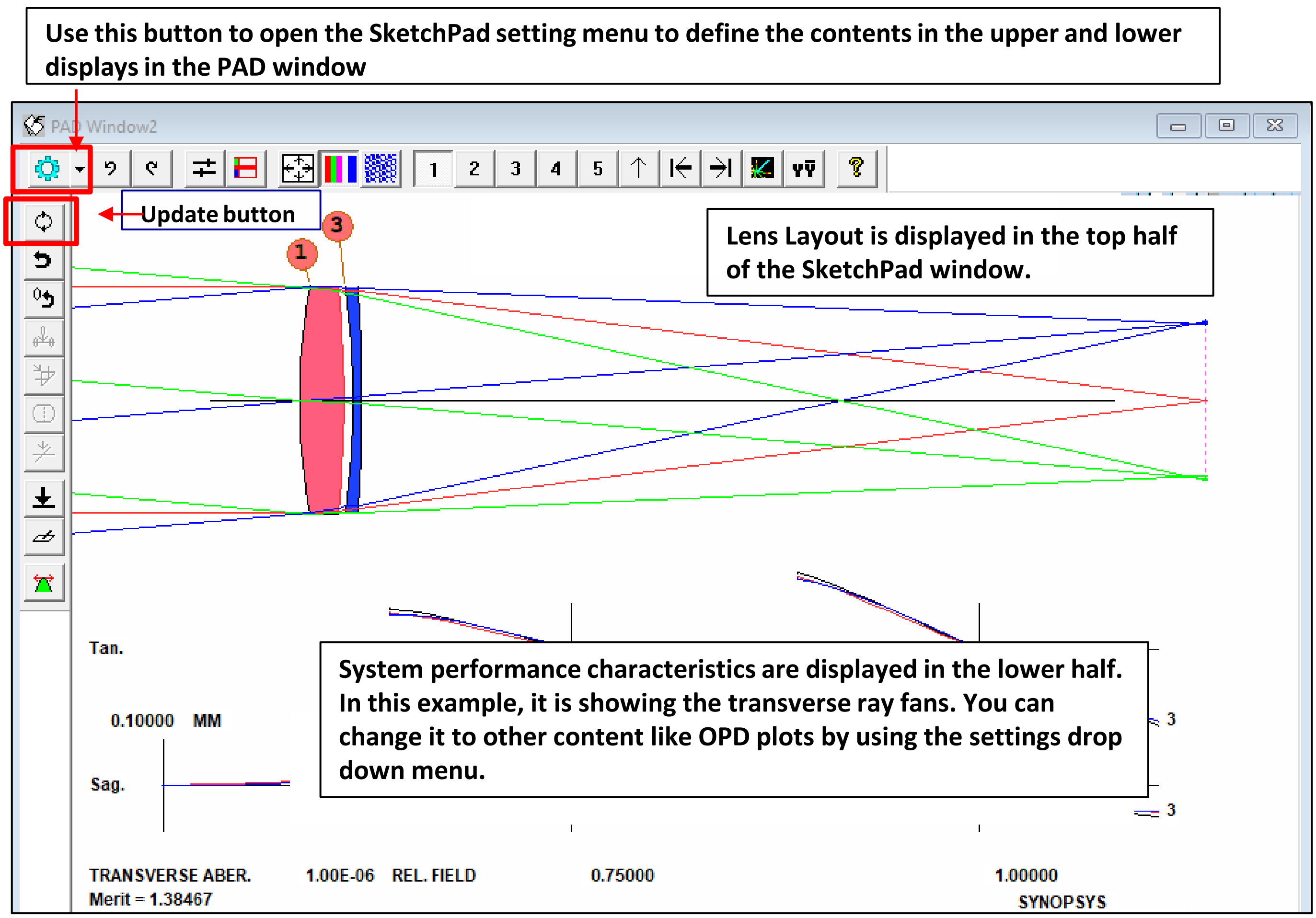


Sometimes if the PAD window doesn't open, click at the 'Pad Default' button to the right of the Pad button to restore it.

The SketchPad™ is the primary graphical interface for SYNOPSYS™. You can use it to:

- View the lens and the image in many formats.
- Watch the lens change as you optimize
- Watch the image change as you alter the lens with the WorkSheet™ (WS).

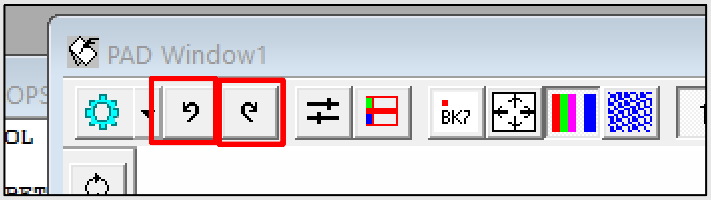
The SketchPAD feature is a graphics window that can show either one or two displays simultaneously. It is typically used to view the lens drawing and a display of image quality at the same time. This is an interactive window that you can open, fill with your choice of display formats, and then update at any time with the update button to see the current lens and its image characteristic displayed in the chosen format. It is also updated whenever you GET or FETCH a lens, and during optimization if you have entered the **SNAPSHOT** command.

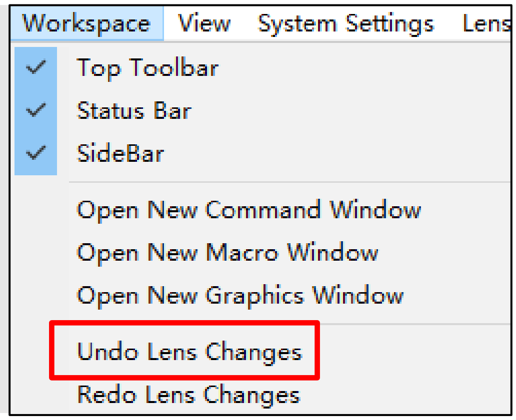


Note:

Go to the 'Ui-Plus Workspace Overview' section in the 'User Manual for Ui-Plus' to read more about the SketchPad toolbars. Or see User Manual 13.3.

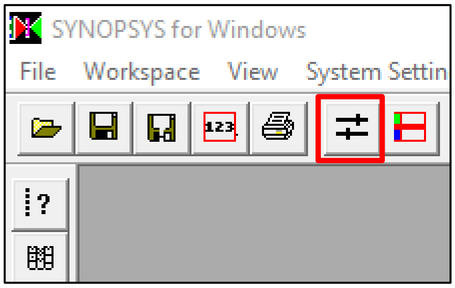
Hint: You can use the 'undo' and 'redo' buttons in the SketchPad toolbar to undo or redo changes you made to the lens.   Or you can access these features via the Workspace menu.





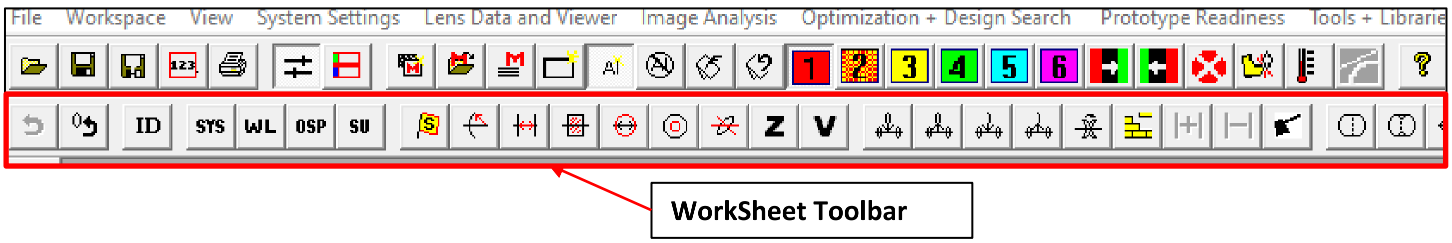
2. WorkSheet™ (WS)

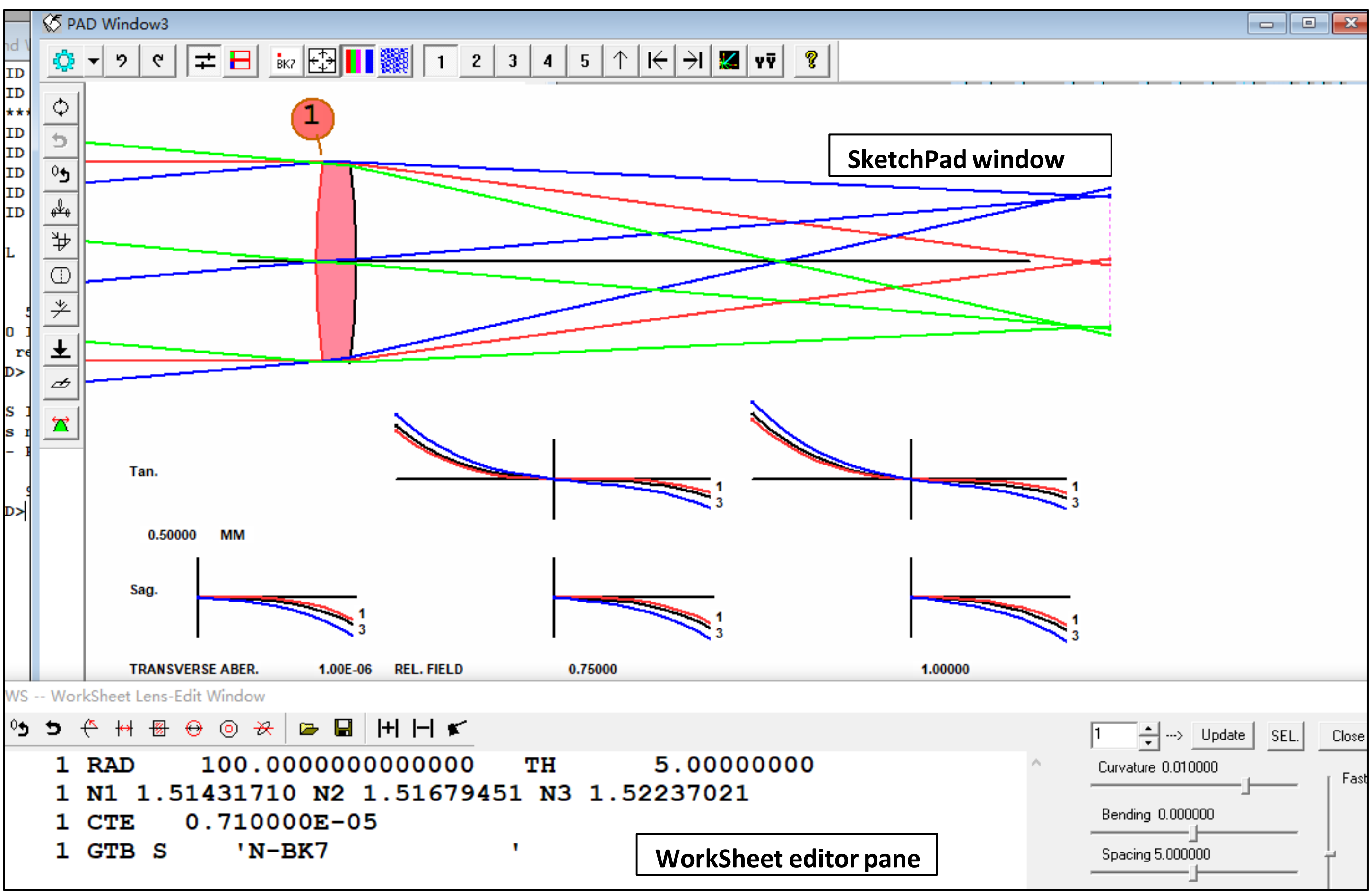
In this section, we introduce another important system visualization and editing tool in SYNOPSYS™: the WorkSheet (WS). To access it, click at the WorkSheet button in the SYNOPSYS™ Top Toolbar:



You can also use enter the WS command to open it:
SYNOPSYS AI>WS

When you open the WorkSheet in SYNOPSYS™ , it will automatically open the SketchPad and the WorkSheet toolbar will appear underneath the SYNOPSYS™ main toolbar. For more information on the WorkSheet Toolbar, see 'WorkSheet Toolbar' in the 'Ui-Plus Workspace Overview' in the User Manual for Ui-Plus.

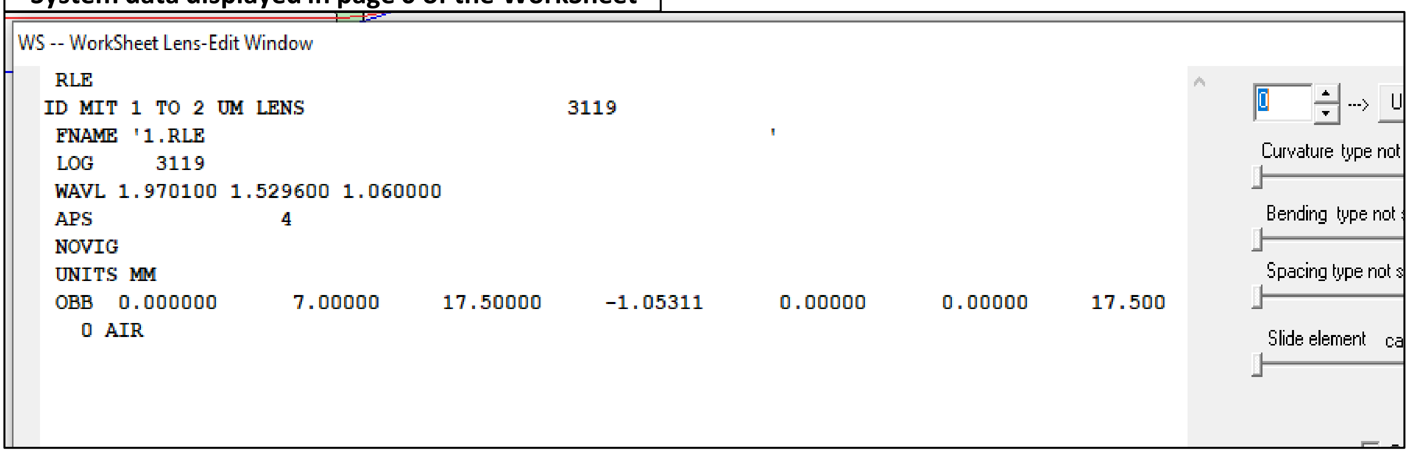




The Worksheet Editor displays the parameters of a selected surface in RLE format, which you may edit. It is a very versatile construct in SYNOPSYS™ . There are a lot of design functions built into the WorkSheet and made available via the WorkSheet toolbar:

- It is an integrative platform to work with SketchPad to give you instant feedback as you alter the lens in a variety of ways.
- You can use the WS toolbar to manipulate the lens system such as inserting and removing surfaces, folding mirrors and elements, flipping an element or mirror around, or creating a checkpoint to which you can later revert with the Undo button.
- The Worksheet also shows an edit window that displays the parameters of a selected surface in RLE format, which you may edit. You can use the 'up' and 'down' arrows next to the surface number to go to other surfaces. Surface 0 is reserved for the display of systemdata. You may enter anything in this window to change the lens system (for example, change the radius of curvature of a surface). When you click on the Update button, the changes are applied to the lens and the PAD display is updated.
- In addition, four slider bars are provided with which you may alter any parameter in the RLE file, including the curvature, bending, and thickness of a surface, or slide an element along the axis – all the while monitoring the effects with the PAD display. You can even select a data item in the edit window – not otherwise assigned to a slider – and vary it with the top slider after clicking on the SEL button.

System data displayed in page 0 of the WorkSheet



Hands-on Exercises

Exercise 1: Working with a Singlet

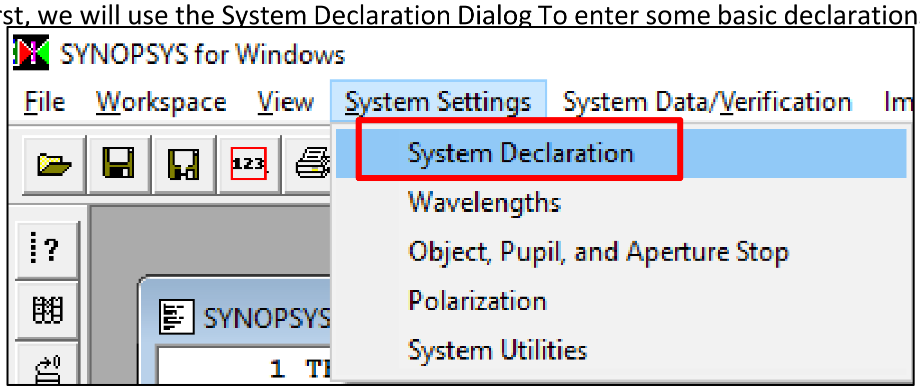
Now let us use a simple singlet example to demonstrate

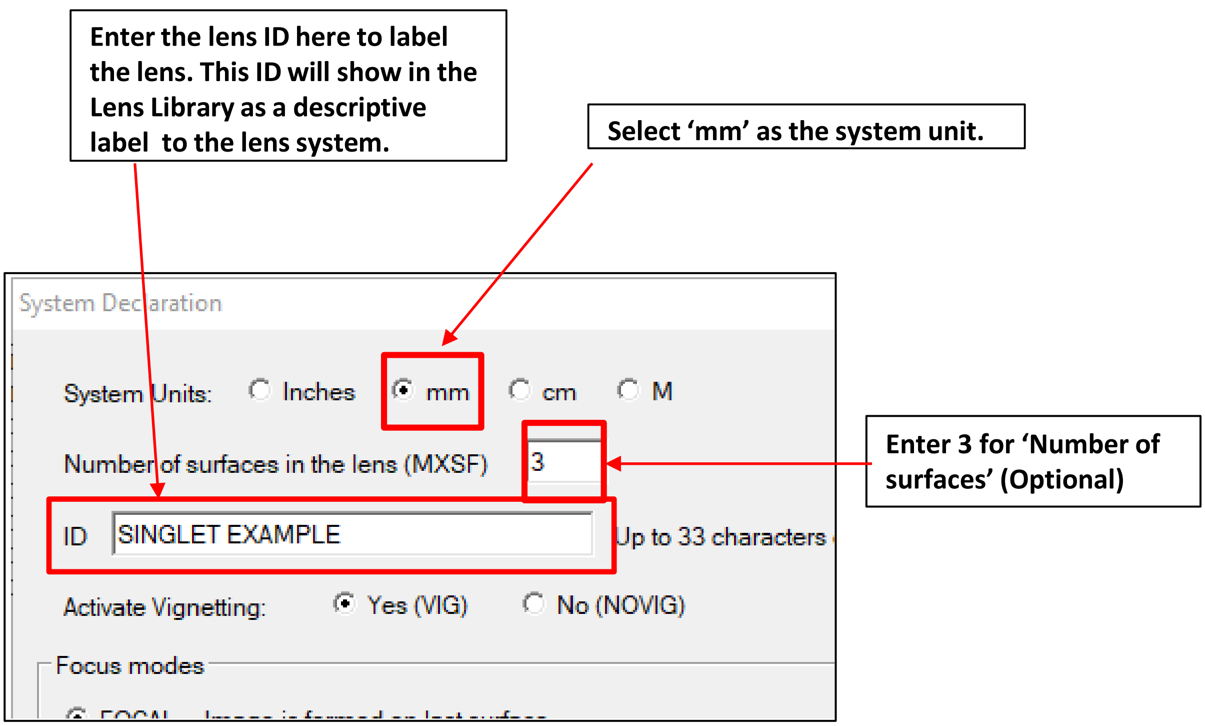
- How to create a lens data file in SYNOPSYS™
- How to do optimization in SYNOPSYS™
- How to improve the singlet system by adding an element

Now we demonstrate how to enter system data to define the object, wavelengths for your design, system units, aperture stop, …etc. This will be done through several dialogs in the System Settings Menu that allows you to input data relating to the system set-up such as object definition, system unit, types of pupils, wavelengths, and everything that is not unique to a single surface.

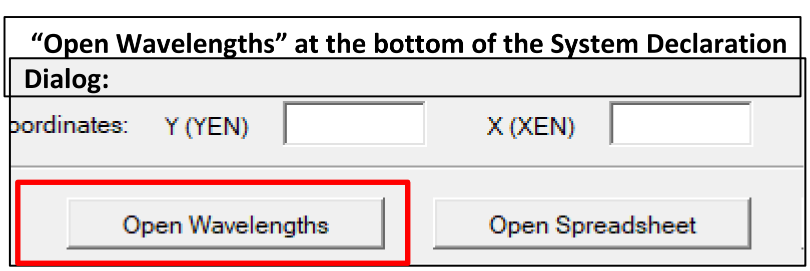
System Declaration:

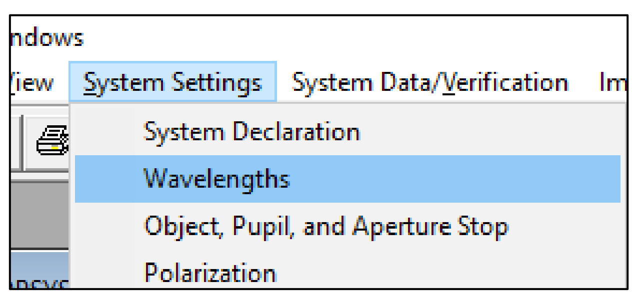
First, we will use the System Declaration Dialog To enter some basic declarations:





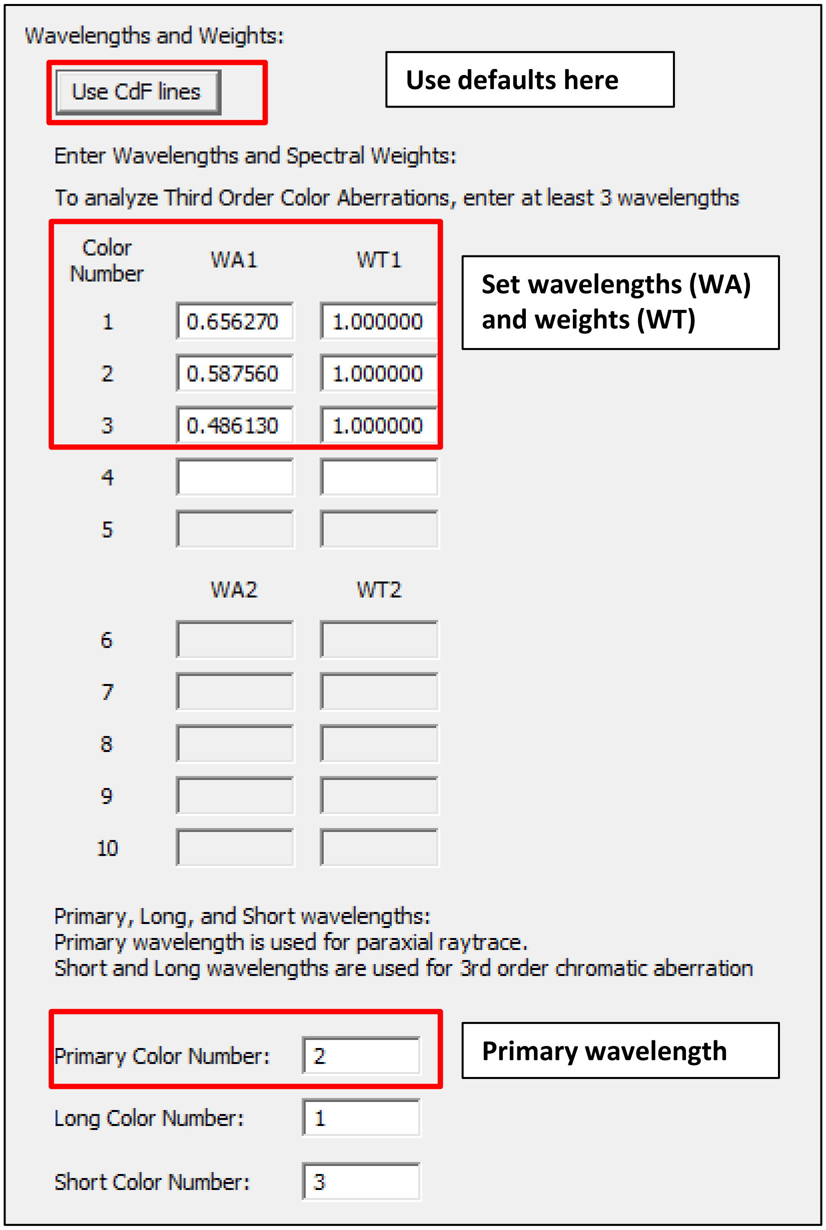
To adjust the wavelengths, click "Open Wavelengths" at the bottom of the System Declaration Dialog. You can also select the Wavelengths Dialog from the Systems Settings dropdown:



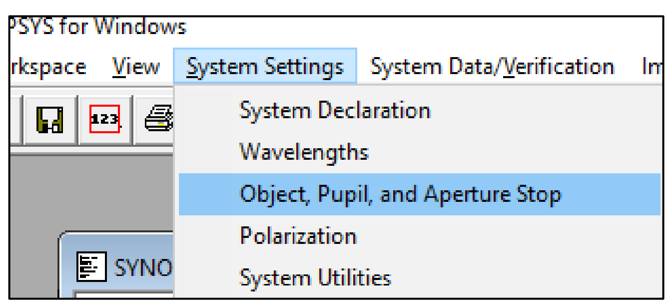


Wavelengths Dialog

Wavelength data can be set on this window. Advanced options are available, but for now let's use the default CdF lines and default uniform spectral weights.

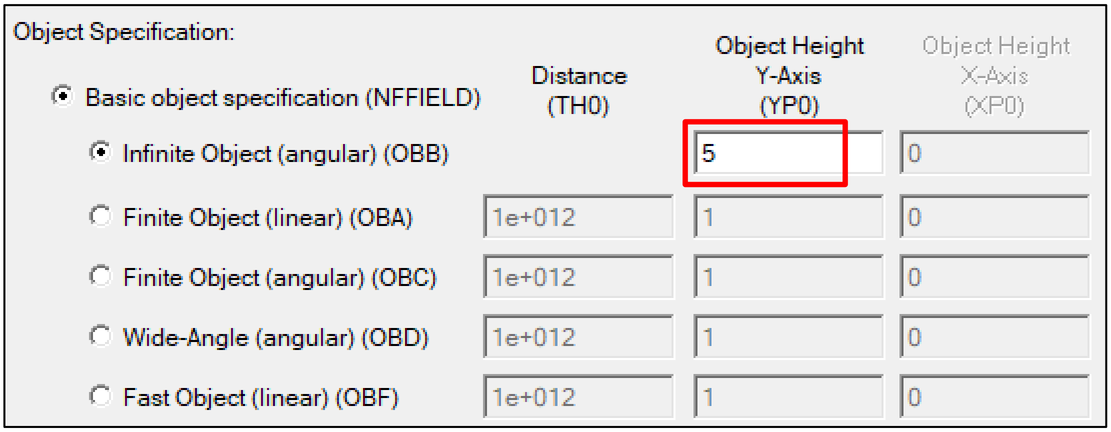


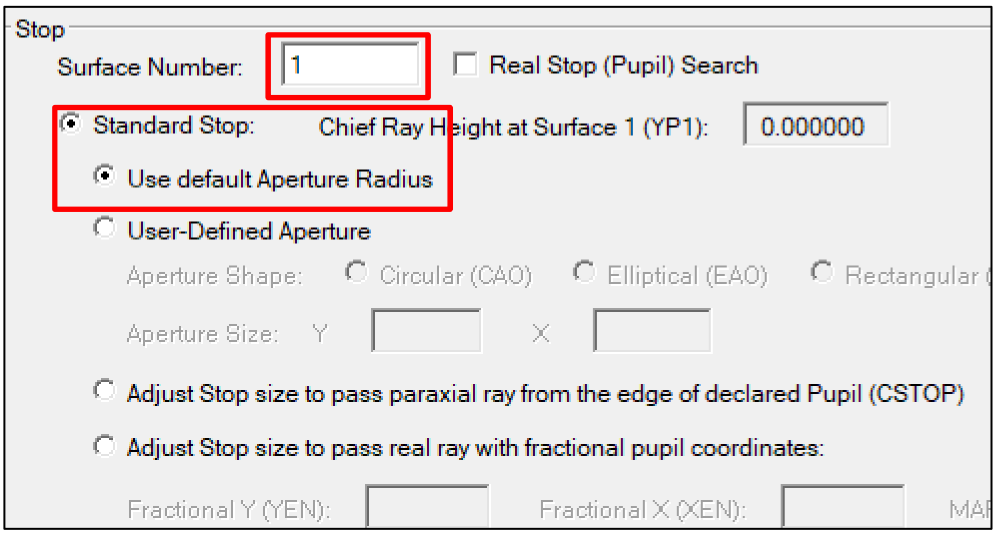
The next step is to define the object, pupil, and stop for the system. To enter the last general system parameters, click on "Open Object/Pupil/Stop" at the bottom of the Wavelength Dialog. Or you can select 'Object, Pupil, and Aperture Stop' under the System Settings dropdown.

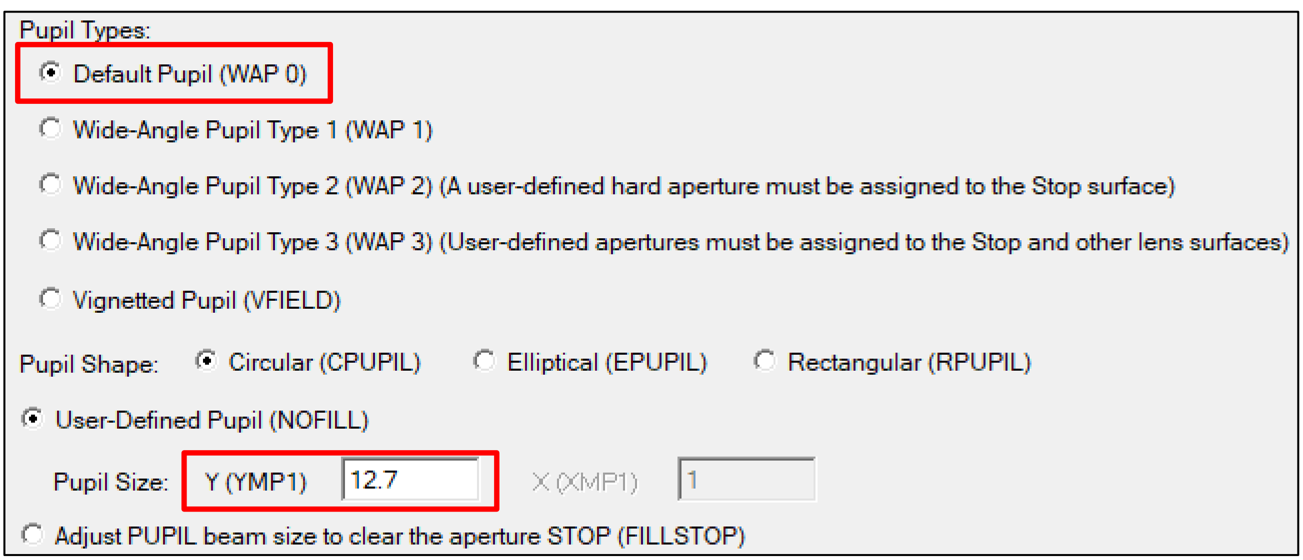


Object, Stop, and Pupil

In the ‘Object, Stop, and Pupil’ dialog, first define an infinite object type (OBB) with height of 5. Set the stop on the first surface with a default soft clear aperture. The Pupil Radius is declared to 12.7 and we will use the simple default pupil. For more information, see ‘Object, Stop, and Pupil’ in the System Settings Menu of the User Manual for Ui-Plus.





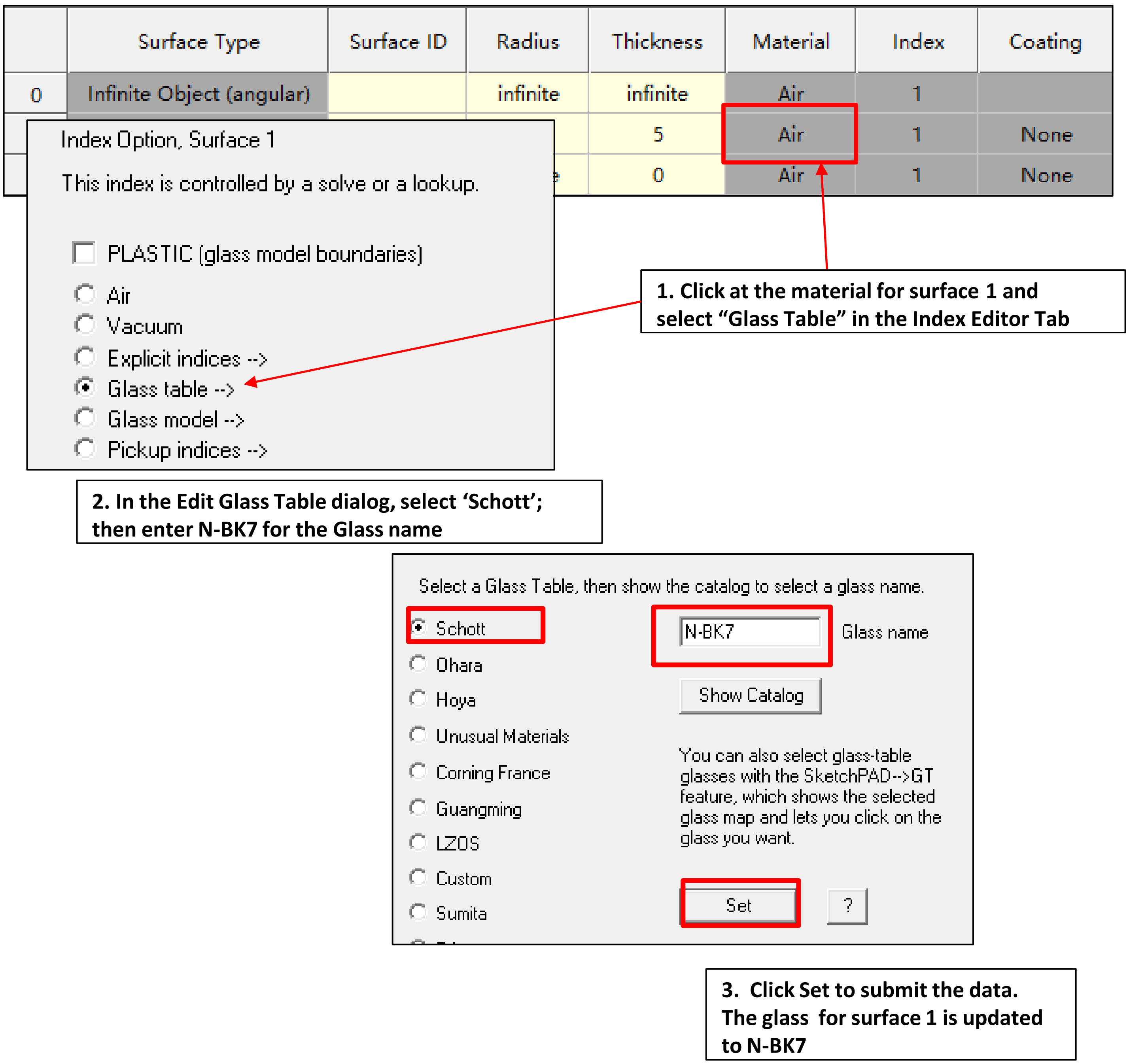


Surface Data

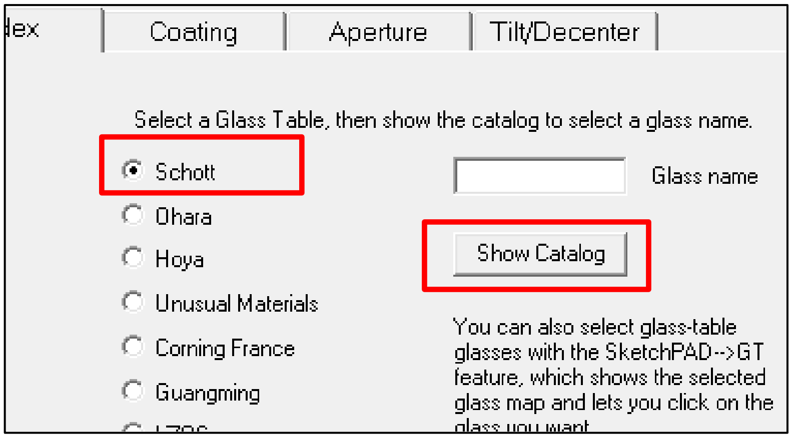
Now, we will enter the surface data using the Spread Sheet. For surface 1, enter 5 for Thickness and 100 for Radius of Curvature.

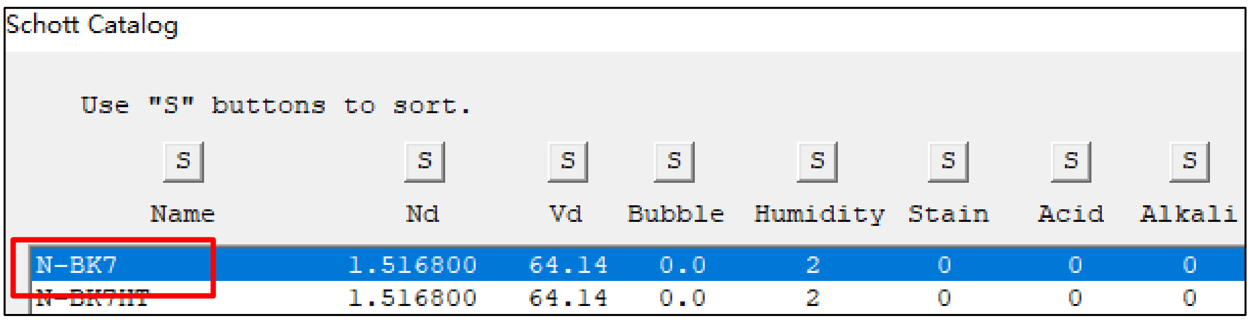
	Surface Type	Surface ID	Radius	Thickness	Material	Index	Coating
0	Infinite Object (angular)		infinite	infinite	Air	1	
1	Spherical		100	5	Air	1	None
2	Flat		infinite	0	Air	1	None

Click at the Material or Index cell of surface 1 to activate the Index Editor. Select Glass Table, then Schott catalog and enter the glass name N-BK7 in the Glass Name box.. If you don't know the glass name you want to use, you can click 'Show Catalog' button to browse and select N-BK7 from the list. Click 'OK' to close the catalog listing window. Then click 'Set' to set up the Material for surface 1.



If you don't know the glass name you want to use, you can click 'Show Catalog' button to browse and select N-BK7 from the list. Click 'OK' to close the catalog listing window. Then click 'Set' to set up the Material for surface 1.





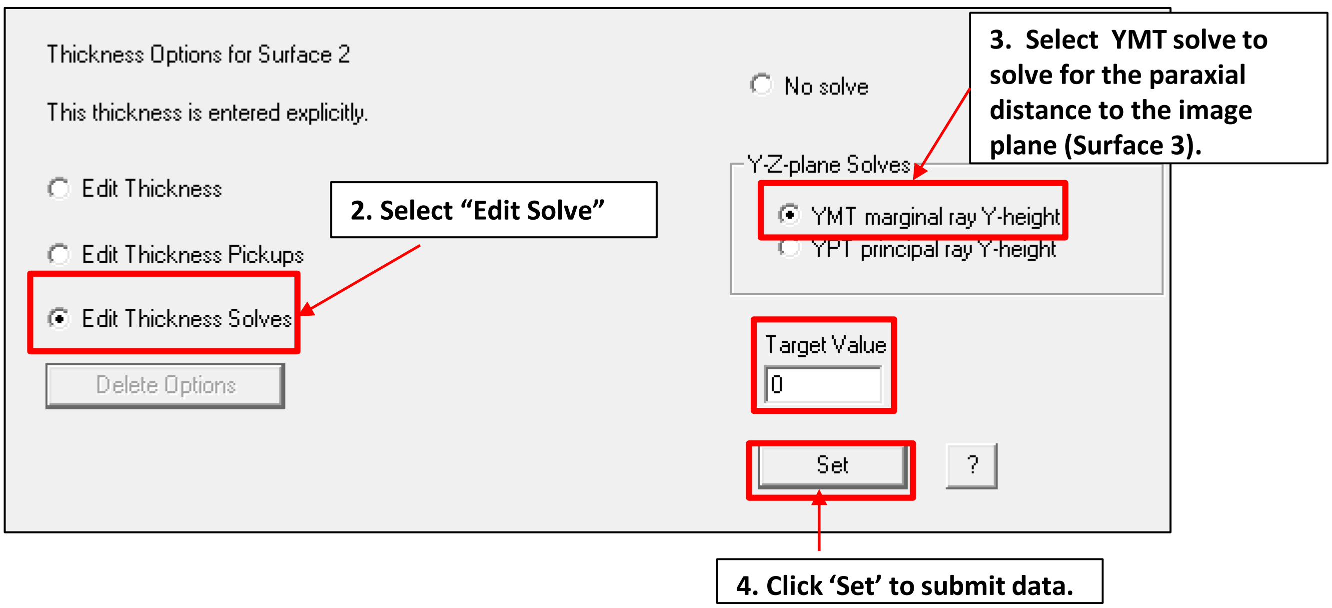
For surface 2 ,enter -100 for Radius of Curvature.

	Surface Type	Surface ID	Radius	Thickness	Material	Index
0	Infinite Object (angular)		infinite	infinite	Air	1
1	Spherical		100	5	N-BK7	1.51679
2	Spherical		-100	0	Air	1

Now we will define the Thickness for surface 2m which is also the back-focus distance for the singlet. To do so, we will add a Thickness solve at surface 2 to place the image plane at the paraxial focus.

1. Click at the cell under Thickness column at surface 2 to activate the Thickness Editor.

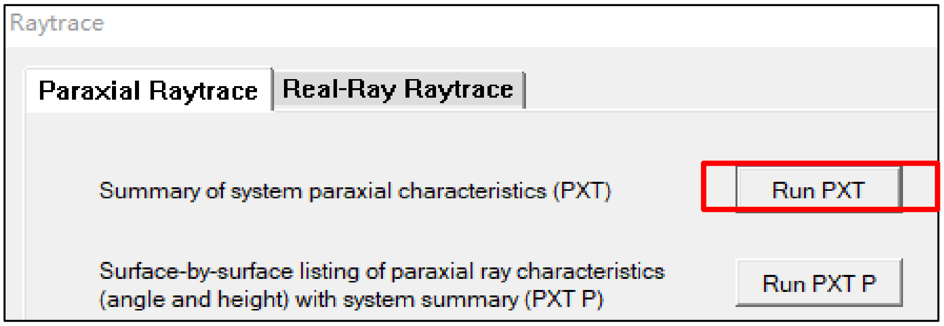
	Surface Type	Surface ID	Radius	Thickness	Material
0	Infinite Object (angular)		infinite	infinite	Air
1	Spherical		100	5	N-BK7
2	Spherical		-100	0	Air
3	Flat		infinite	0	Air
4					
5					



When we select the 'YMT, marginal ray Y-height' solve, SYNOPSYS™ finds the thickness (T) such that the height (Y) of the marginal paraxial ray (M) will be the requested Target value (zero) at the next surface. In other words, surface 3 will be at the paraxial focus. This is an example of paraxial solve. With the thickness solve in place, the distance between the back surface of the singlet and the image plane is set to be 95.9191.

	Surface Type	Surface ID	Radius	Thickness	Material	Index
0	Infinite Object (angular)		infinite	infinite	Air	1
1	Spherical		100	5	N-BK7	1.51679
2	Spherical		-100	95.9190677	Air	1
3	Flat		infinite	0	Air	1

Click at the Save button at the Top Toolbar and save the system as 'EX1_singlet.rle'. We will use it later.
To examine the first order characteristics of the system, in the 'Raytrace ' dialog of the Image Analysis Menu, click 'Run PXT'.

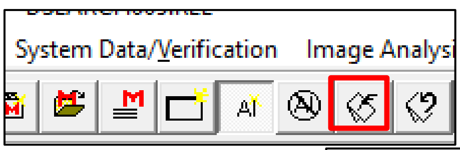


paraxial characteristic of the lens system

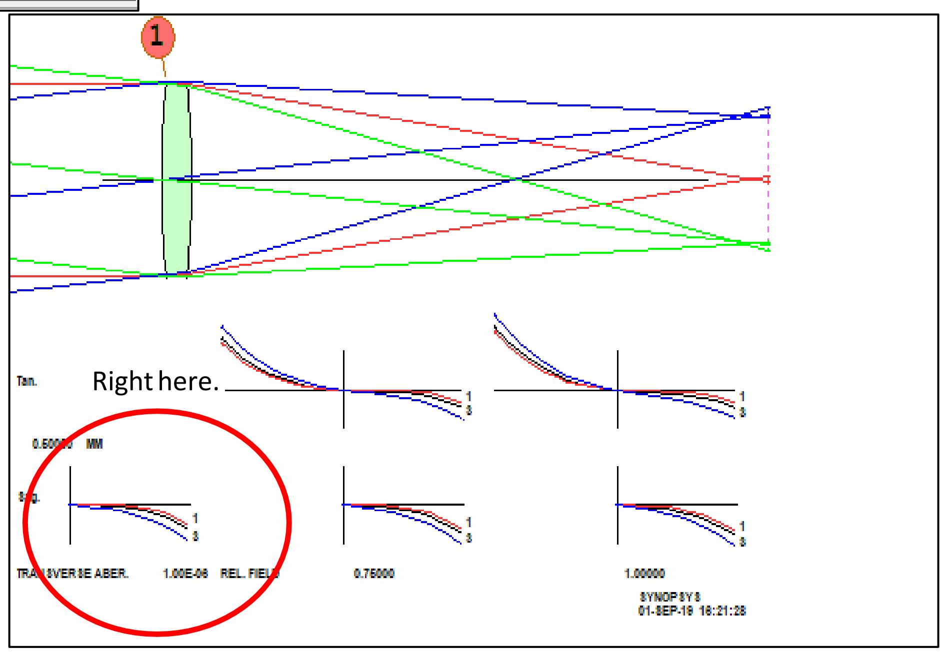
SYNOPSYS AI> --- PXT

GIHT	FOCL	FNUM	BACK	TOTL	DELF
8.53727	97.58144	3.84179	95.91907	5.00000	0.00000

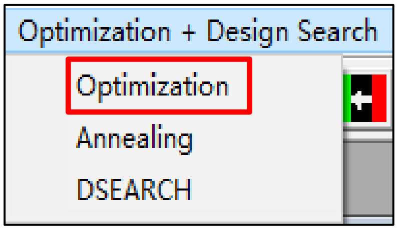
To view the lens layout and rayfans, click the SketchPad button in the Command Window Top Toolbar to open the SketchPad™.

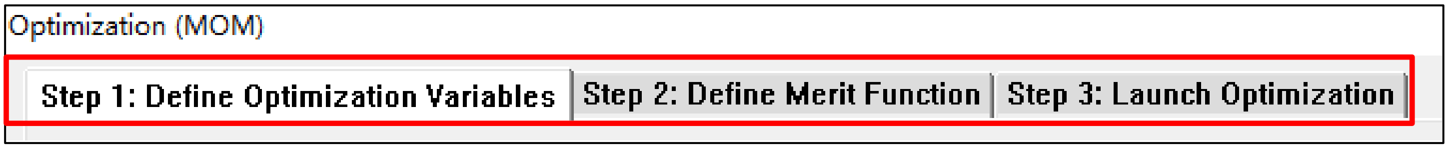


There are uncorrected spherical aberration (SA3) and primary axial color (PAC) as shown at the on-axis ray fans.



We will demonstrate how to create an optimization macro to optimize the singlet using the Optimization Dialog in the "Optimization + Design Search" Menu:

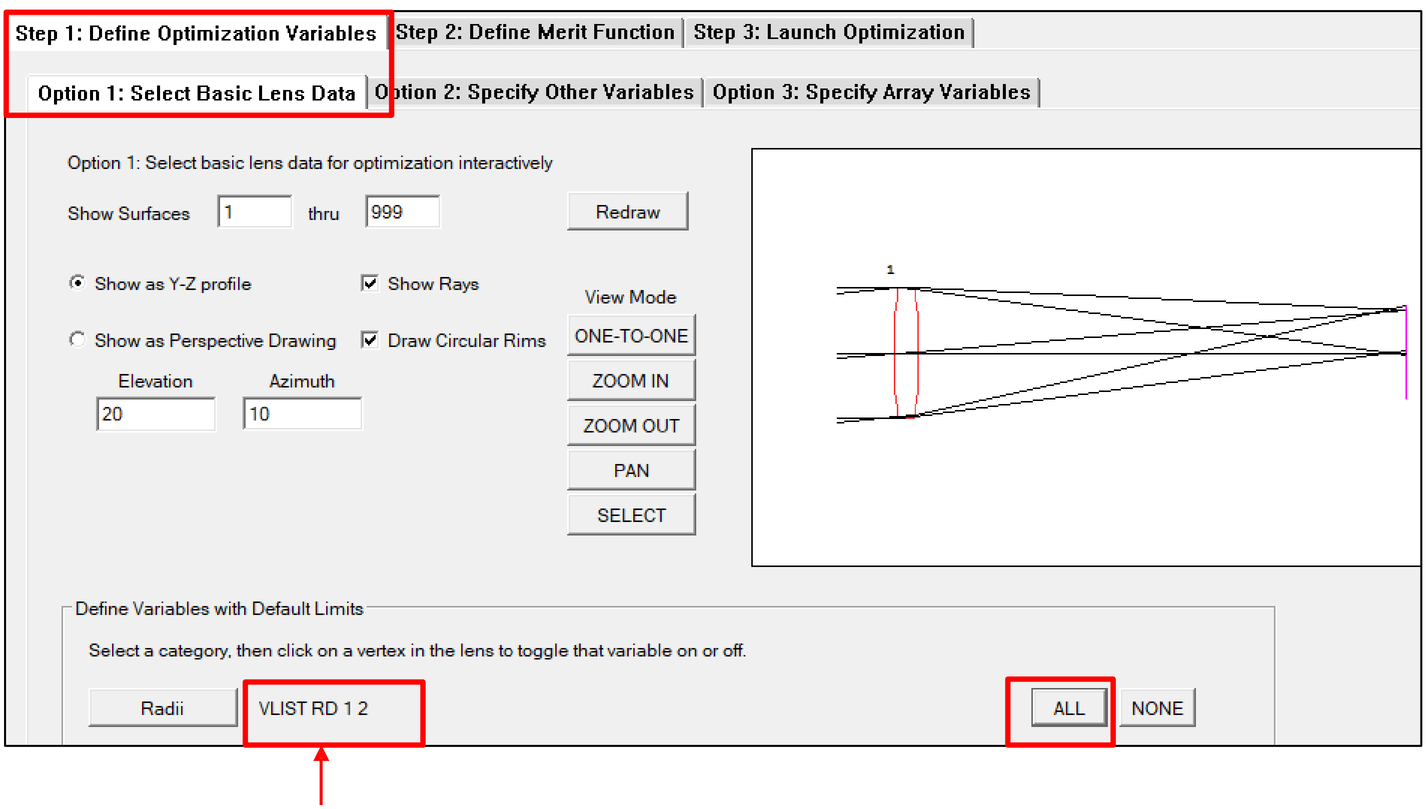




There are three steps in generating the optimization macro:
Step 1 : Define optimization variables into the parameter input module (PANT...END);
Step 2 : Define Merit Function aberration into the aberration input module (AANT...END).
Step 3 : Launch Optimization will add the **SNAPSHOT** (SNAP for short) command to show the update system in the SketchPad and add the **SYNOPSYS** command to start the optimization iterations.

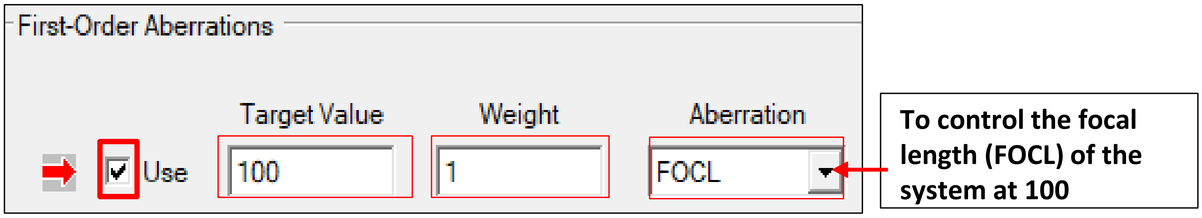
Step 1. Optimization Variables:

First activate the 'Define Optimization Variables' tab. Select Option 1 to select basic lens data as the optimization variables. In this dialog, You will see an interactive lens layout window at the left which you can use to select what parameters at which surface to be included as the optimization variables (For more information, see the 'Select Basic Lens Data' section in the Optimization Menu of the User Manual for Ui-Plus for more details) . For this example, we will just select all Radii by clicking at the 'ALL' button of Radii selection.

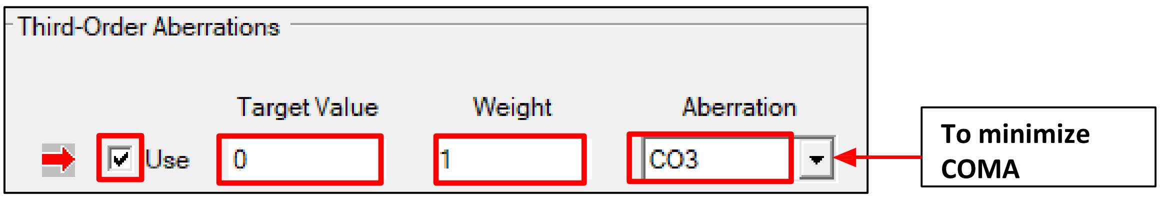


Optimization variables: varying the radii on surface 1 and 2

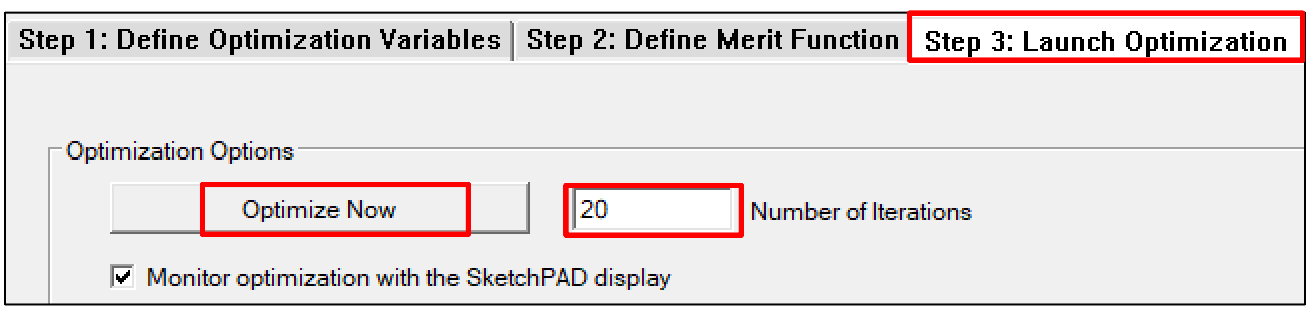
Step 2. Define Merit Function:
Open the 'Define Merit Function' dialog. Then select 'Option 5' to set controls for the system focal length and COMA.
In the 'First-Order Aberrations' block, click at the 'Use' checkbox to activate the input line. Then enter 100 for the Target Value, 1 for Weight, and in the Aberration dropdown menu select FOCL (Focal Length) as the control term.



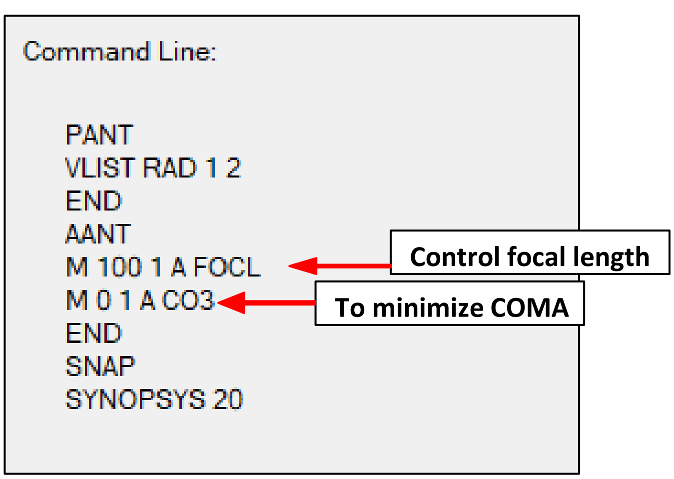
In the 'Third-Order Aberrations' block, click at the 'Use' checkbox to activate the input line. Then enter 0 for the Target Value, 1 for Weight, and in the Aberration dropdown menu select CO3 (Third order COMA) as the control term.



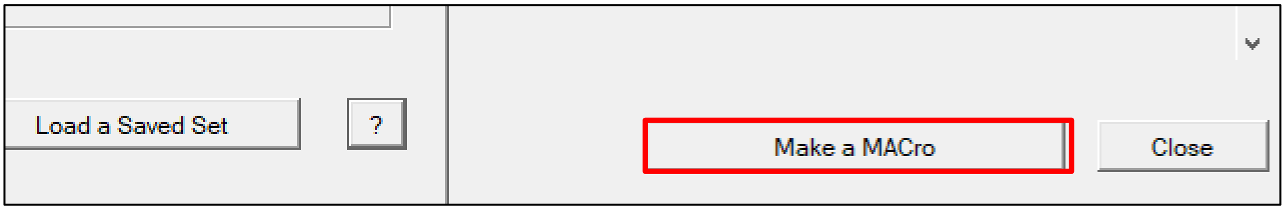
Step 3. Launch Optimization:
In the Launch Optimization dialog, enter '20' for the Number of Iteration. You can Click the 'Optimize Now' button to start optimization without saving the optimization macro. Usually, we would like to create the optimization macro by clicking at the 'Make a MACro' button at the lower right corner of the dialog.

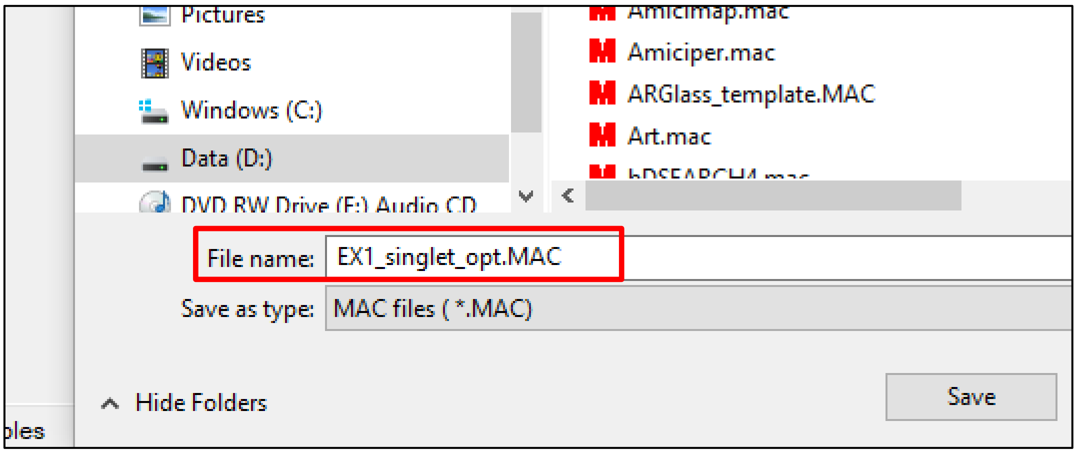


This is the list of commands that goes into the optimization macro and appears in the right pane of the Optimization dialog.

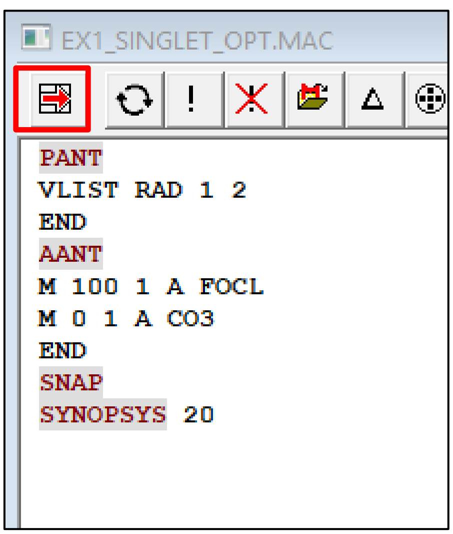


To create the optimization macro, You can click at the Make a MACro button and enter filename (for example, EX1_singlet_opt.mac) to save it:





After you save the macro, it will open automatically in the SYNOPSYS™ workspace. To execute the macro, click the run button at the top toolbar:



Now let's look at the print-out in the Command Window after running the optimization macro:

```
Iteration No.       1
Present merit function   5.918844E+00
Damping factor         5.000000E-01

Iteration No.       2
Present merit function   2.761606E-01

Iteration No.       3
Present merit function   3.697975E-05

Iteration No.       4
Present merit function   4.572332E-06

Iteration No.       5
Present merit function   1.268009E-09


Improvement in the merit function is below threshold value.
The KICK or ANNEAL function may further improve the lens.

Final merit function     7.499139E-22

 Improvement in the merit function is below threshold value.
 The KICK or ANNEAL function may further improve the lens.

Lens number    10 ID EXAMPLE SINGLET
 SYNOPSYS AI>
```

After five passes, the merit function is close to zero.

Also note that the current lens file is saved in location 10 in the Lens Library with the lens ID 'Example Singlet' declared in the RLE file.

Type the command FINAL to read the resulting individual aberrations and its relative impact on merit function:

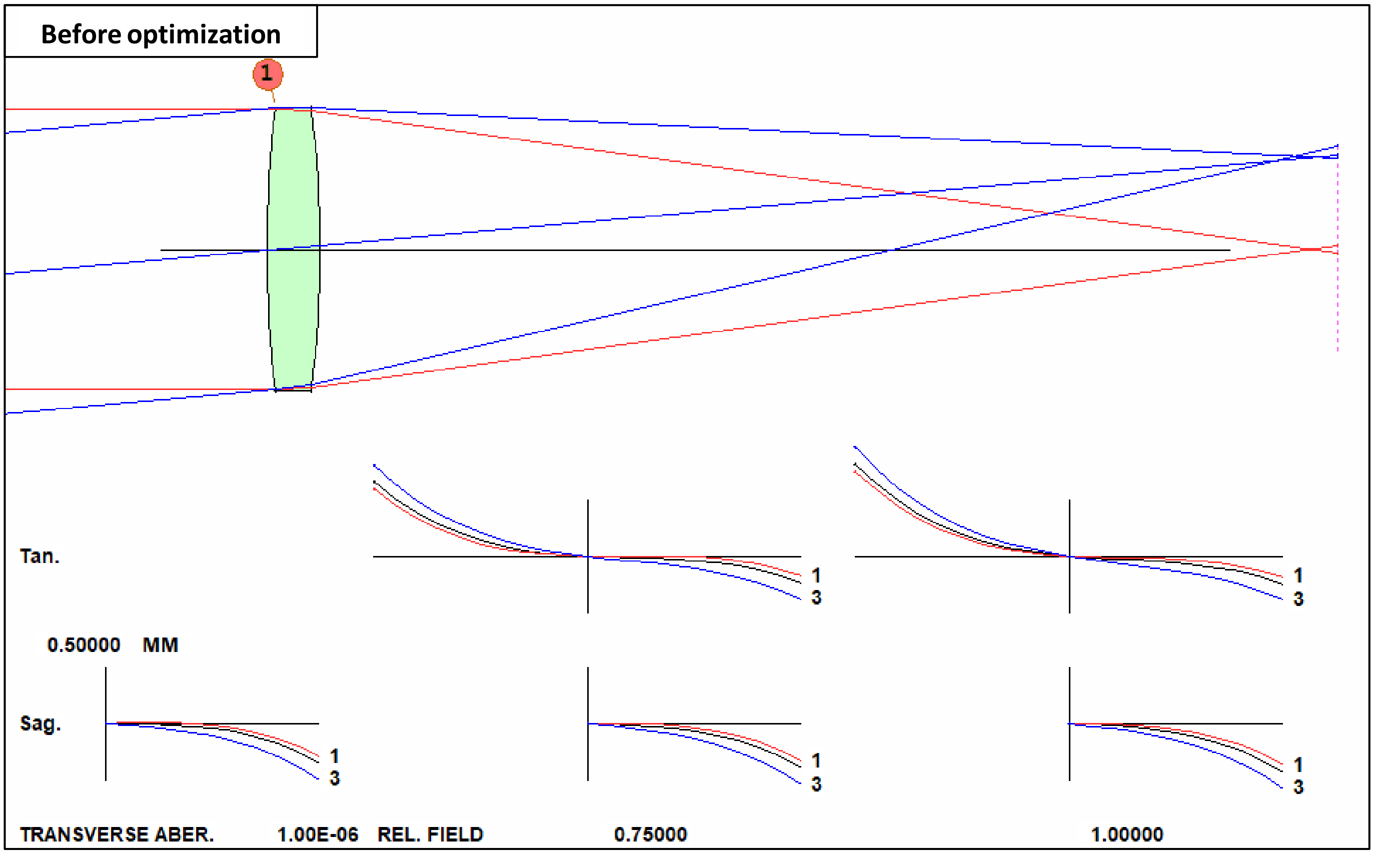
```
SYNOPSYS AI>FINAL

 ABERRATION LIST
        NAME          TARGET          WEIGHT          RAW VAL.   FINAL ERROR    R. EFFECT

      1               100.0000000      1.0000000        100.0000    0.273701E-10    0.998945
       A    FOCL

      2                 0.0000000      1.0000000      -8.8948E-13  -0.889483E-12    0.001055
       A    CO3
 SYNOPSYS AI>
```

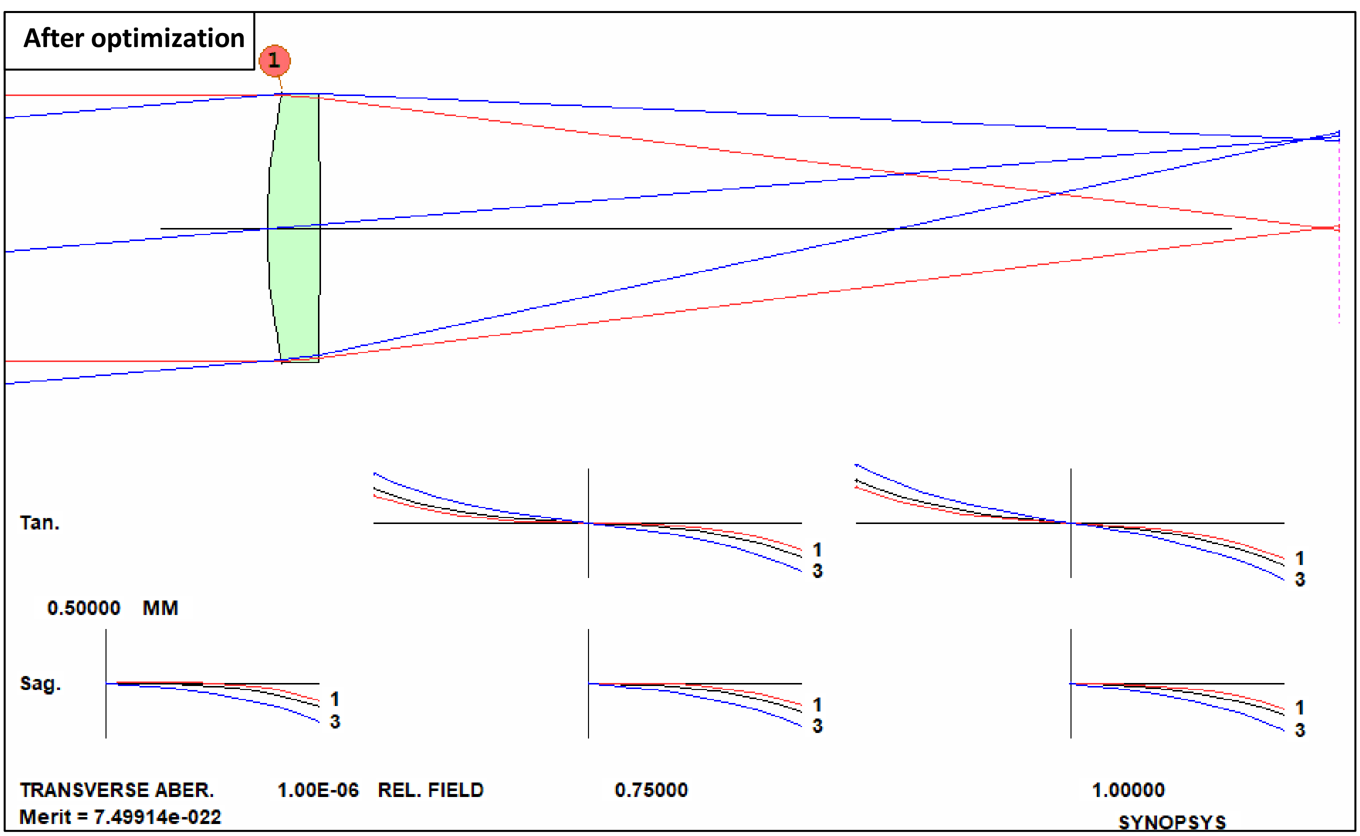
Focal length is on target

The COMA term is *almost* zero.

Both targets have been met exactly.

Note: for more information about the command FINAL, please refer to User Menu 10.9. This command is quite important because it tells you which factors in the system are the major hindrances in reaching the optimization goal as specified by the directives in the meritfunction.


Before optimization
1
Tan.
1
3
1
3
0.50000 MM
Sag.
1
3
1
3
1
3
TRANSVERSE ABER. 1.00E-06 REL. FIELD 0.75000 1.00000


After optimization
1
Tan.
1
3
1
3
0.50000 MM
Sag.
1
3
1
3
1
3
TRANSVERSE ABER. 1.00E-06 REL. FIELD 0.75000 1.00000
Merit = 7.49914e-022
SYNOPSYS

Ex1.2 Improve the Singlet by Adding an Element

Now that you have seen a simple optimization, we'll show how to improve the singlet by adding an element.

For a singlet, there are 6 regular parameters (degrees of freedom) available for design or optimization: 2 radii, 1 thickness, 2 from material (index n and V number), and 1 APS position.

If we want to improve the optimized singlet further, we can increase the degree of freedoms to the system by,

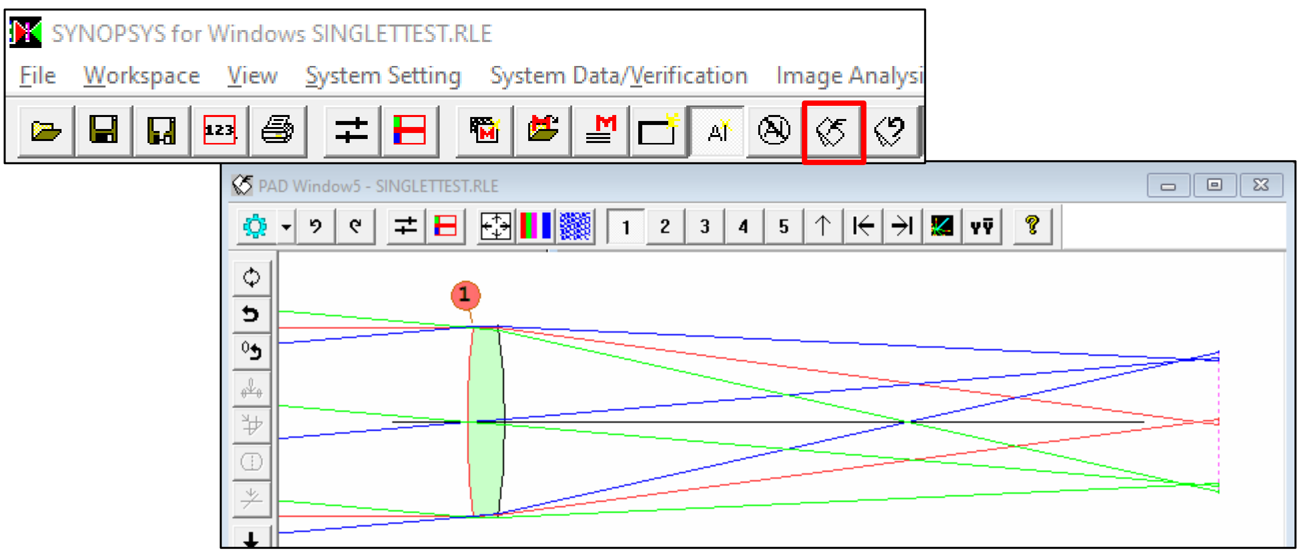
- Adding more components;
- Adding parameters to lens shape: aspheres, DOE, HOE;
- Adding parameters to lens material: gradient index lens;

Changing PARAMETERS (CONSTRAINTS) in an optical system is the way of meeting design specifications.

In this section, we will show how to improve a singlet by:

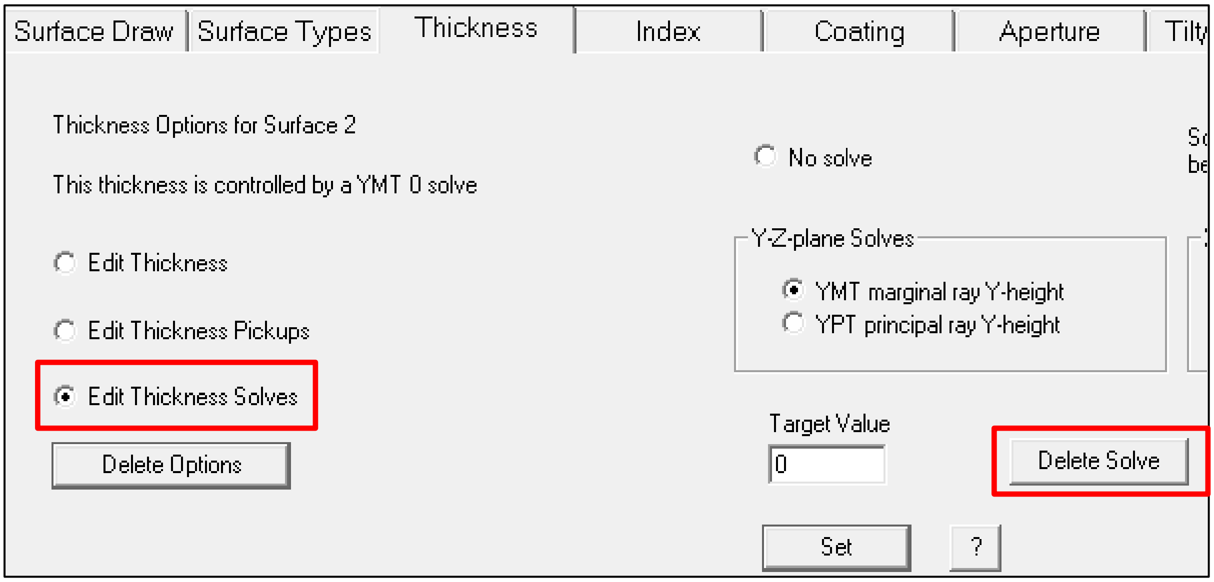
- Adding a second element in the Spread Sheet.
- Creating a merit function using the Ready-made Merit Functions in SYNOPSYS™.
- Re-optimizing on the new system.

First, let's get back to the original singlet. We will open the lens file, EX1_singlet.rle, from your working directory by Using the Open file button in the top Toolbar. Then click the PAD button in the Top Toolbar to launch SketchPad and examine the lens system.



Now we will demonstrate how to insert an element into the current lens system by using the 'Insert Surface button' in the SpreadSheet (SPS) toolbar.

Before adding more surfaces, we will first remove the Thickness solve at surface 2 of the singlet. Click at the Thickness cell of surface 2 to activate the Thickness Editor. Select 'Edit Thickness Solves', then click at the 'Delete Solve' button to delete it.



	Surface Type	Surface ID	Radius	Thickness	Material	Index	Co
0	Infinite Object (angular)		infinite	infinite	Air	1	
1	Spherical		100	5	N-BK7	1.51679	N
2	Spherical		-100	95.9190677	Air	1	N
3	Flat		infinite	0	Air	1	N

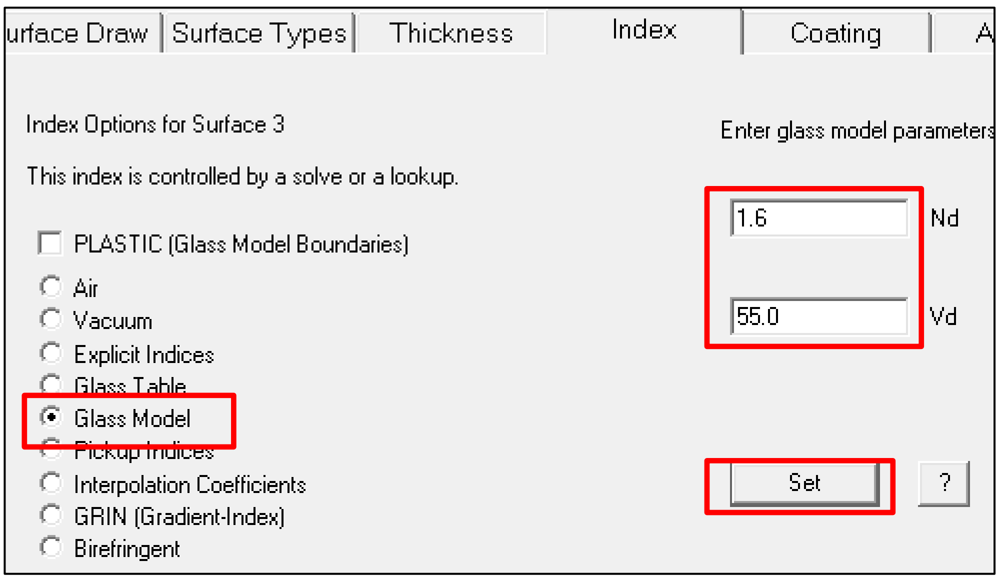
Click at the line number of surface 3 or just anywhere in the same row to select the row. Then click 'insert surface' button twice in the Spread Sheet toolbar to add two surfaces to the system. Or you can just start editing new surfaces after surface 3.

	Surface Type	Surface ID	Radius	Thickness	Material	Index	Coating
0	Infinite Object (angular)		infinite	infinite	Air	1	
1	Spherical		100	5	N-BK7	1.51679	None
2	Spherical		-100	95.9190677	Air	1	None
3	Flat		infinite	0	Air	1	None
4	Flat		infinite	0	Air	1	None
5	Flat		infinite	0	Air	1	None

At surface 2, enter 2 for Thickness. Then enter 1 for Thickness at surface 3. You can enter other values as long as the Thickness 2 is small to keep the two elements close to each other to mimic a doublet.

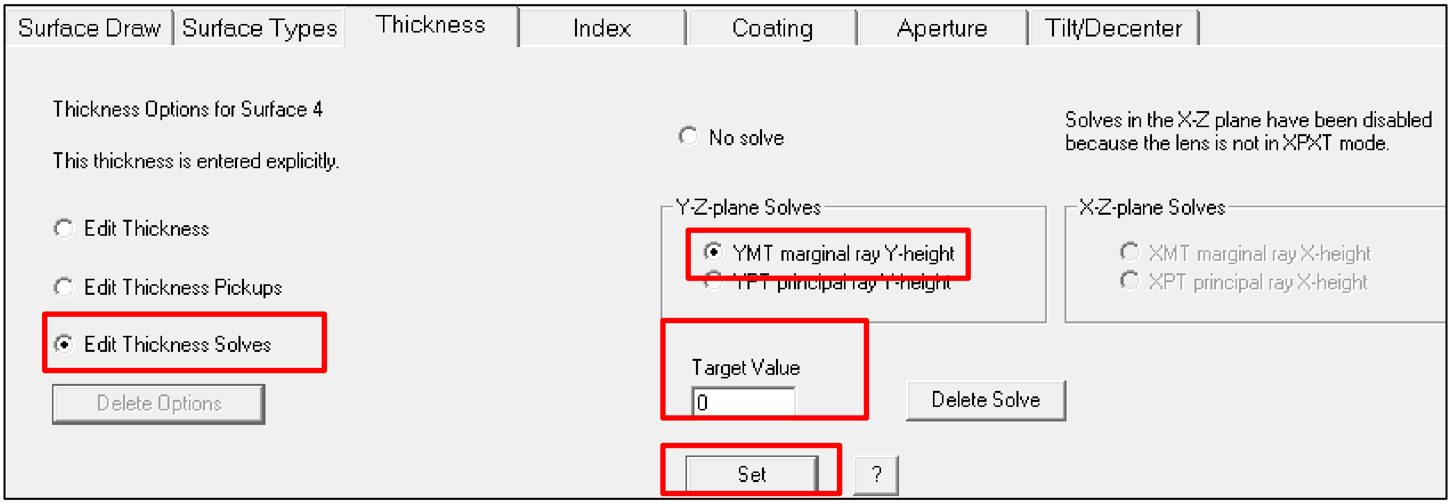
	Surface Type	Surface ID	Radius	Thickness	Material	Index	Coating	Aperture Type (Outer/Inner)
0	Infinite Object (angular)		infinite	infinite	Air	1		Def (Circ)/none
1	Spherical		100	5	N-BK7	1.51679	None	Def (Circ)/none
2	Spherical		-100	2	Air	1	None	Def (Circ)/none
3	Flat		infinite	1	Air	1	None	Def (Circ)/none

Click at the Material or Index cell of surface 3 to activate the Index Editor Tab. Select Glass Model. Enter 1.6 for Nd (refractive index) and 55.0 for Vd (Abbe number), which corresponds to a generic glass at the center of the glass map. Then click 'Set' to set up the GLM Material for surface 3.



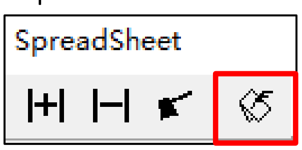
	Surface Type	Surface ID	Radius	Thickness	Material	Index	Coating
0	Infinite Object (angular)		infinite	infinite	Air	1	
1	Spherical		100	5	N-BK7	1.51679	None
2	Spherical		-100	2	Air	1	None
3	Flat		infinite	1	GLM	1.6	None
4	Flat		infinite	0	Air	1	None

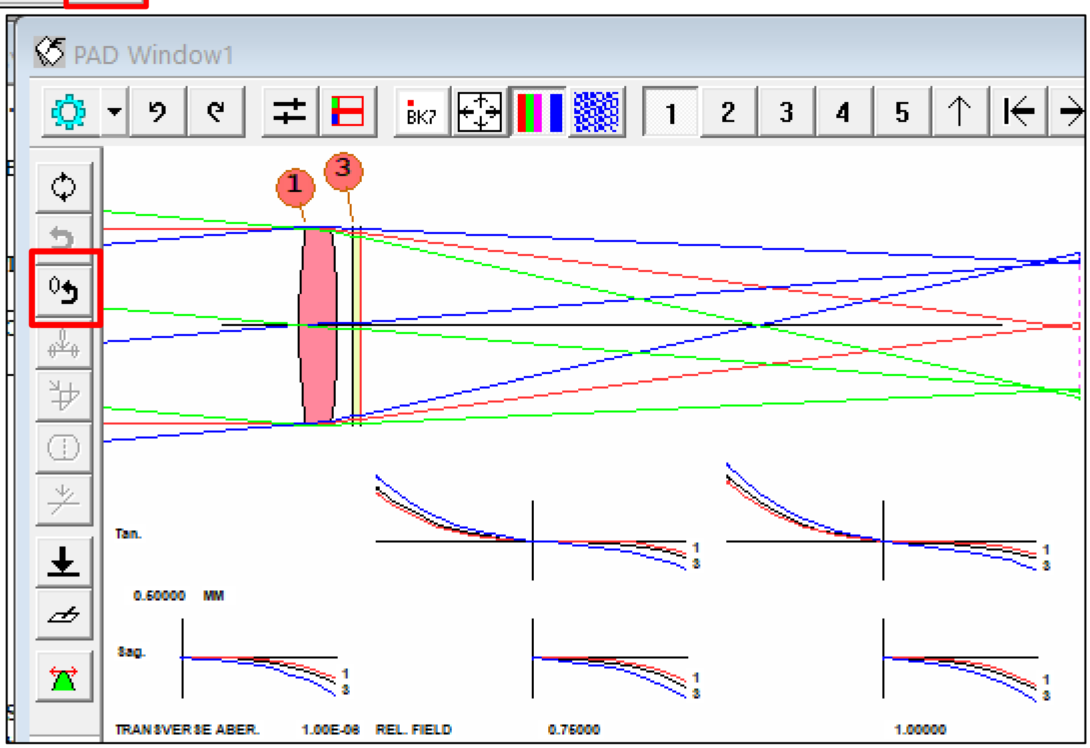
Click at the Thickness cell of surface 4 to activate the Thickness Tab. Select Edit Thickness Solves and then YMT solve with a Target ray height of zero. Then click 'Set' to set up the thickness solve for surface 4.



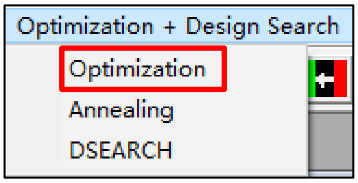
	Surface Type	Surface ID	Radius	Thickness	Material	Index	Coating	Aperture Type (Outer/Inner)	Y Semi-Width (Outer/Inner)	X Semi-Width (Outer/Inner)
0	Infinite Object (angular)		infinite	infinite	Air	1		Def (Circ)/none	0/0	0/0
1	Spherical		100	5	N-BK7	1.51679	None	Def (Circ)/none	12.7716/0	12.7716/0
2	Spherical		-100	2	Air	1	None	Def (Circ)/none	12.8162/0	12.8162/0
3	Flat		infinite	1	GLM	1.6	None	Def (Circ)/none	12.6839/0	12.6839/0
4	Flat		infinite	93.2940677	Air	1	None	Def (Circ)/none	12.6547/0	12.6547/0
5	Flat		infinite	0	Air	1	None	Def (Circ)/none	9.35798/0	9.35798/0

Click the SketchPad button in the Spread Sheet toolbar to open the SketchPad™ to examine the system layout. Click the Checkpoint button in the SketchPad to keep a copy of the current system before running the optimization.

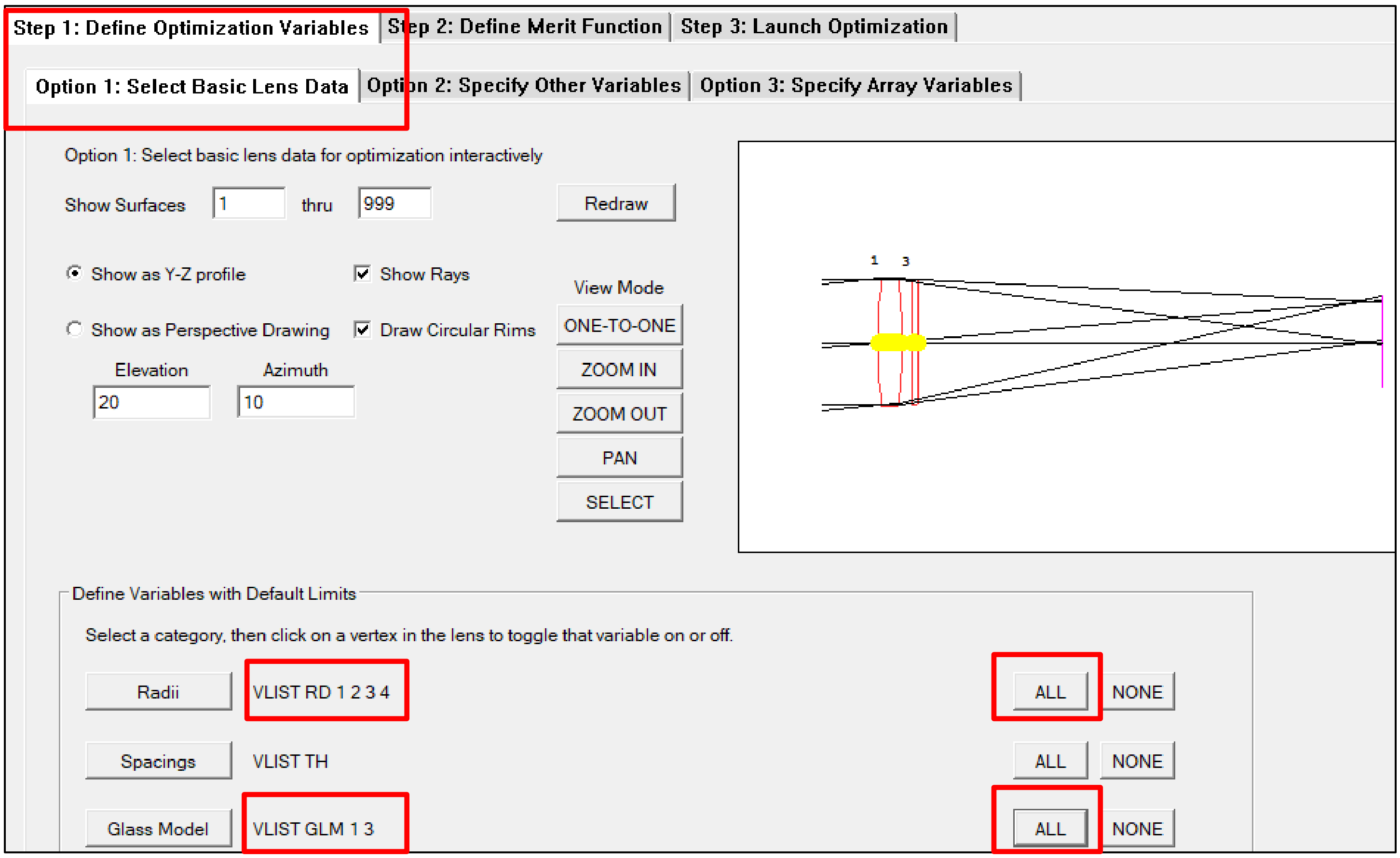




The next step is to create an optimization macro for this system. Open the 'Optimization' Dialog:

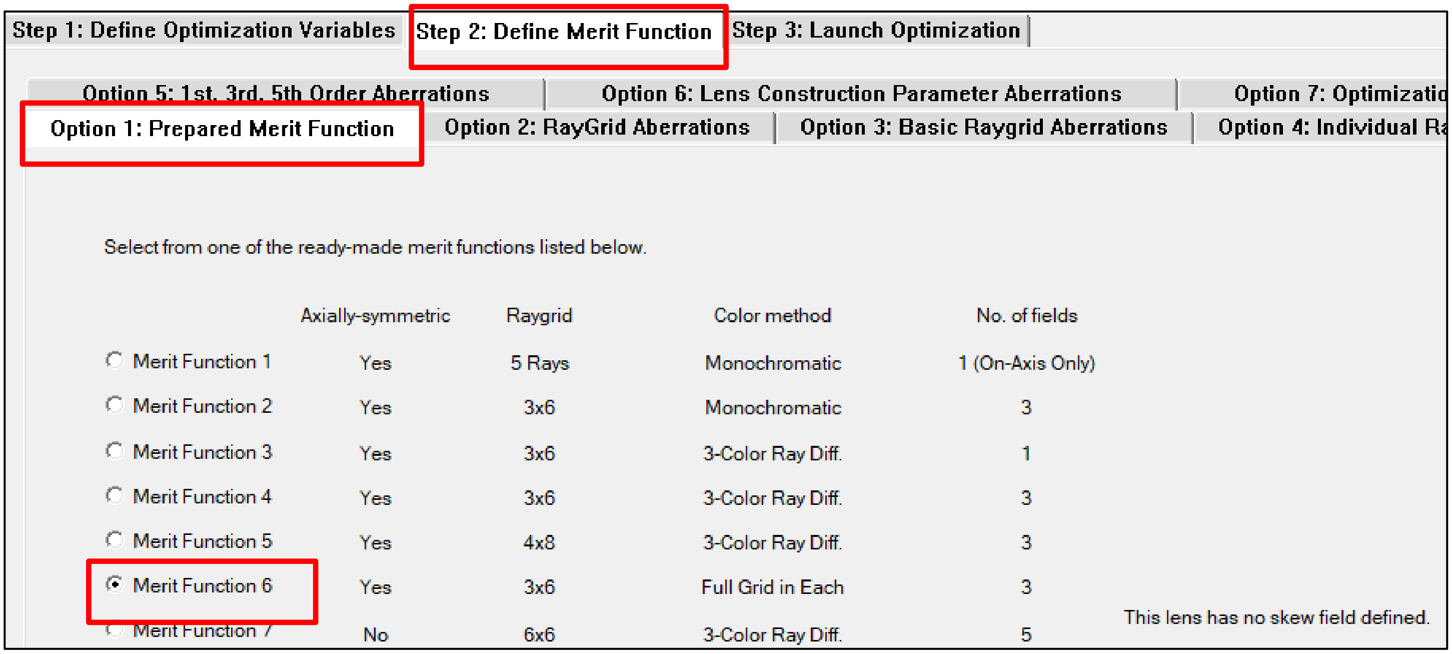


Step 1 Optimization Variables:
Again, we will use the Option 1 in the Define Optimization Variables Dialog to define the optimization variables by selecting All Radii and All Glass Model to declare all the Glass Models and Radii on all surfaces as variables to be varied in the optimization process.

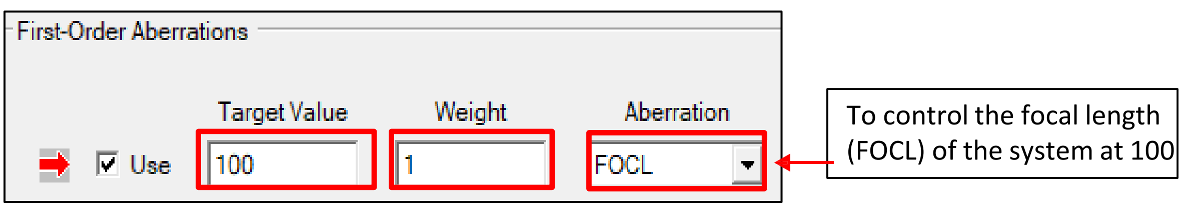


Step 2 Define Merit Function:

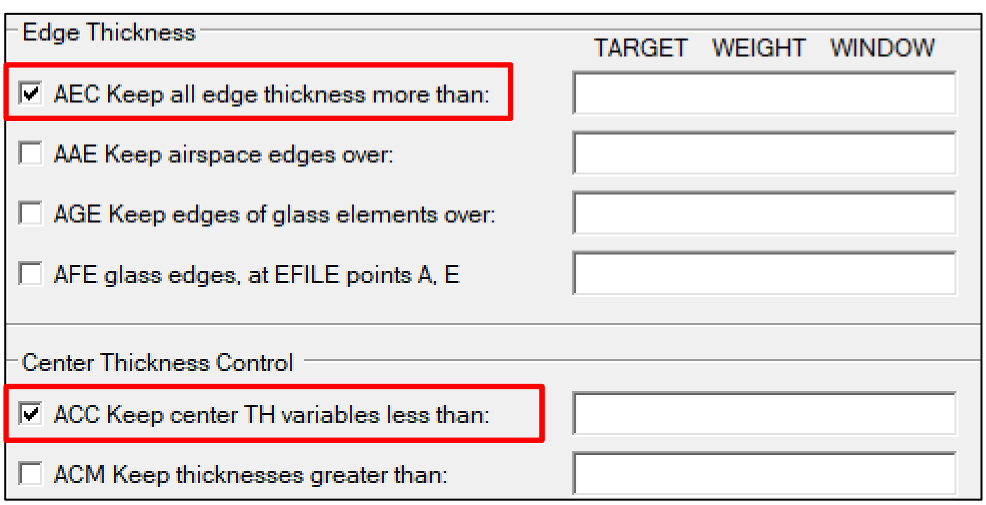
Select Option 1 (Prepared Merit Function dialog) and then ‘Merit Function 6’. Merit Function 6 defines a set of raygrid to minimize the transverse ray aberrations. For more details, see the Prepared Merit Function section of the Optimization menu in the User Manual for Ui-Plus. You can also find a discussion of the Ready-made Merit Function in ‘APPENDIX: Optimization Introduction’ of this guide.



Next, we will open the dialog for option 5 (1st, 3rd, 5th Order Aberrations) dialog. In the ‘First-Order Aberrations’ block, click at the ‘Use’ checkbox to activate the input line. Then enter 100 for the Target Value, 1 for Weight, and in the Aberration dropdown menu select FOCL (Focal Length) as the control term.

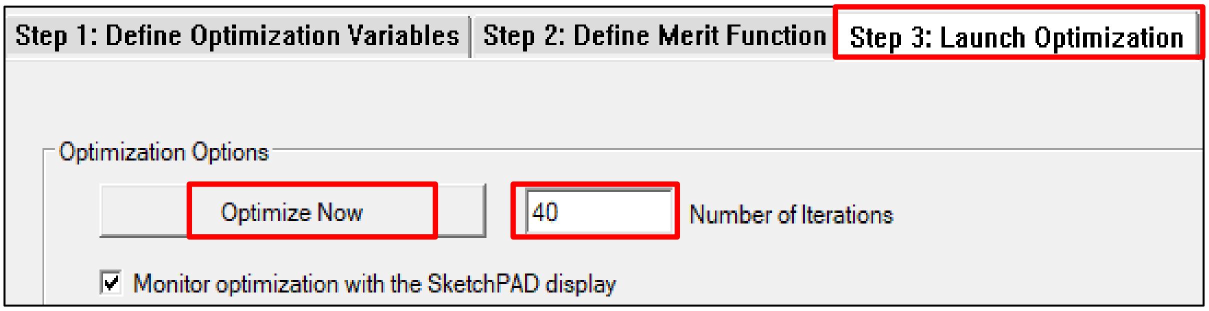


Lastly, we will add two optimization monitors to control the system. For more details, see the Prepared Optimization Monitor section of the Optimization menu in the User Manual for Ui-Plus. We will select ‘AEC’ to set a lower bound to all the edge thickness (default is 1mm) and ‘ACC’ to keep an upper bound to the center thickness (default is 25.4mm).

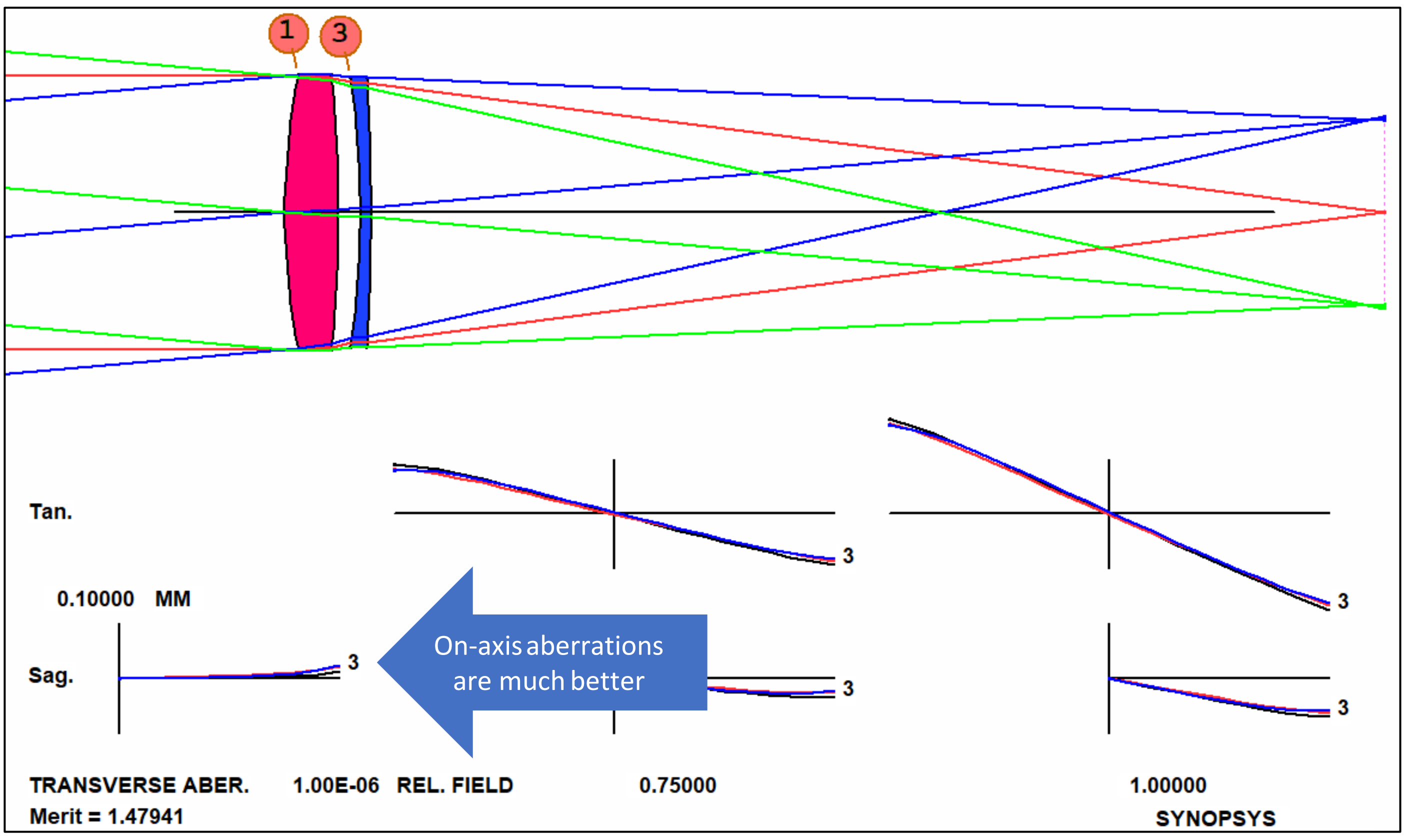


Step 3 Launch Optimization

Enter 40 for Number of Iterations. Then either click at the Optimize Now to run the optimization or click at the Make a MACro button to create a macro file.



This is the system after optimization:



But the lens still has astigmatism and field curvature, which you cannot correct with a doublet.

This is the list of commands that goes into the optimization macro and appears in the right pane of the Optimization dialog.

```
Command Line:

    PANT
    VLIST RAD 1 2 3 4
    VLIST GLM 1 3
    END
    AANT
    AEC
    ACC
    GSR .5 10 5 M 0
    GNR .5 2 3 M .7
    GNR .5 1 3 M 1
    M 100 1 A FOCL
    END
    SNAP
    SYNOPSYS 40
```

Commands inserted by Merit Function 6:

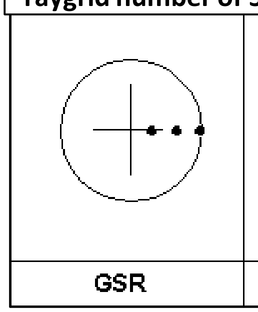
- ray-grid definitions (on-axis GSR, GNR at 0.7 field and full field). These ray grids are often used as a good starting merit function. For more sophisticated control, you can specify individual rays.

Below is a brief explanation to the GSR and GNR commands. For more details, see the Prepared Raygrid Aberrations section of the Optimization menu in the User Manual for Ui-Plus. You can also find a discussion of the Raygrid Aberrations in ‘APPENDIX: Optimization Introduction’ of this guide.

```
GSR .5 10 5 M 0
```

- Generate 1D sagittal rays,
- With RT (pupil weighting factor) .5
- Weighting factor to merit function = 10
- With a ray grid number of 5
- For all the color (multiple color) in the system
- For on-axis field (field 0)

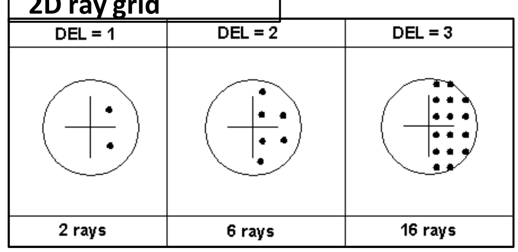
1D Sagital ray grid with raygrid number of 3




```
GNR .5 2 3 M .7
GNR .5 1 3 M 1
```

- Generate 2D raysets,
- With RT (pupil weighting factor) .5
- Weighting factor to merit function weight 2 for 0.7 field, first line weight 1 for edge field. 2nd line
- Ray grid number of 3
- For all the color (multiple color) in the system
- For 0.7 field and the edge

2D ray grid



Exercise 2: A Five Element System Design

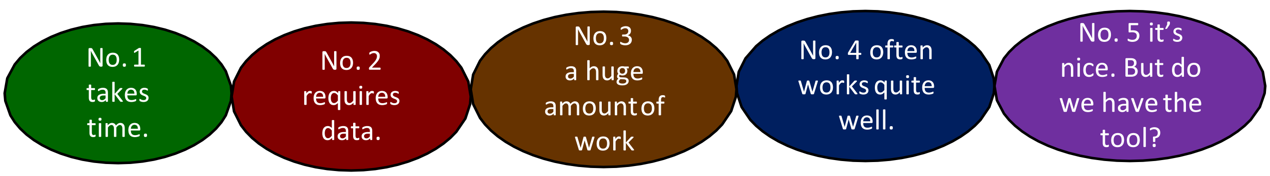
Example 2: A Five Element System Design

Now we'll do a more complex design:

- Five elements
- FOCL 150 mm
- F/3.5
- Semi field 14 degrees
- BACK focus distance 16 mm
- TOTL length 250 mm.
- Visible light
- Aperture diameter = 150/3.5, so paraxial marginal ray height at the first element (YMP1) is 21.42 mm.

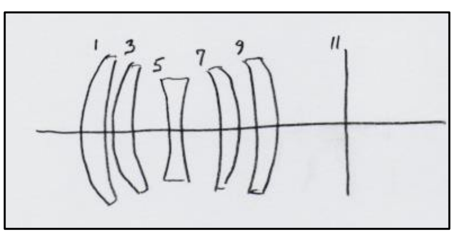
How does one approach this kind of problem? Some possible approaches:

1. Search a patent database
2. Look in your file of previous designs
3. Do a third-order design by hand
4. Play it by ear
5. Let the computer do the work.



Let's say we'll start with option 4: enter lens data based on intuition.

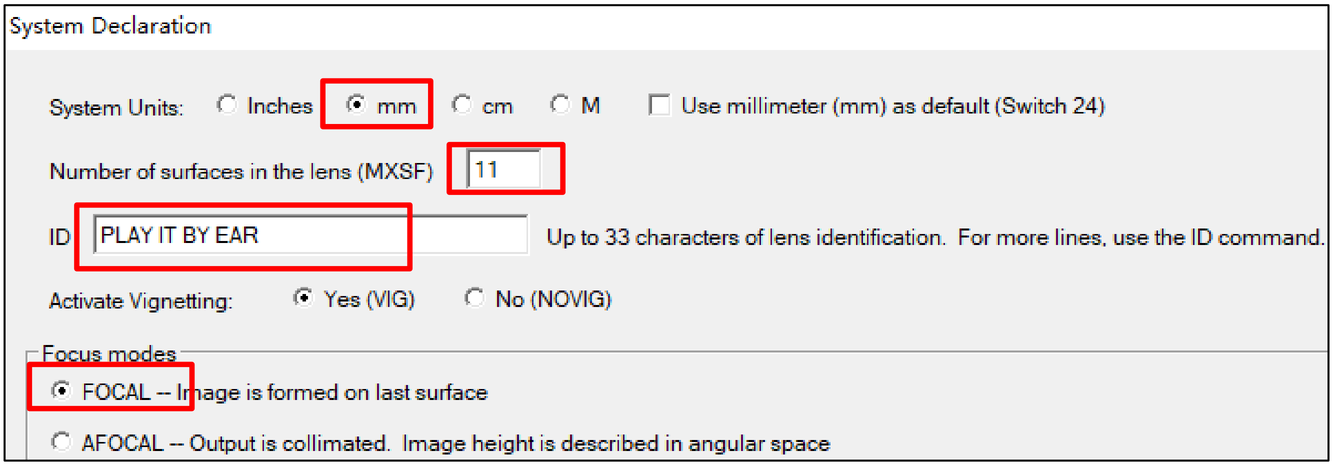
- First, a sketch:



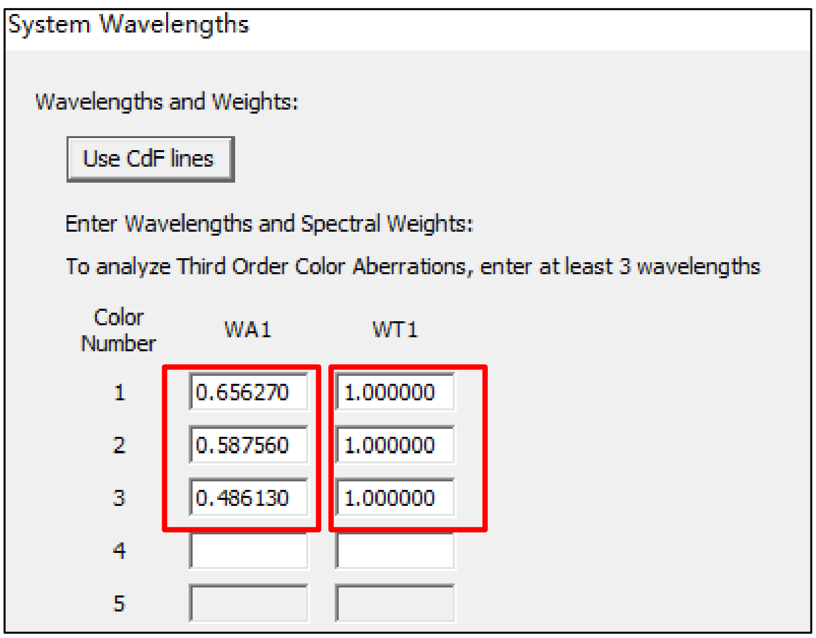
- Then *Guess* values for radii, thickness, and glass index.

We start setting up the system parameters using the System Settings Menu:

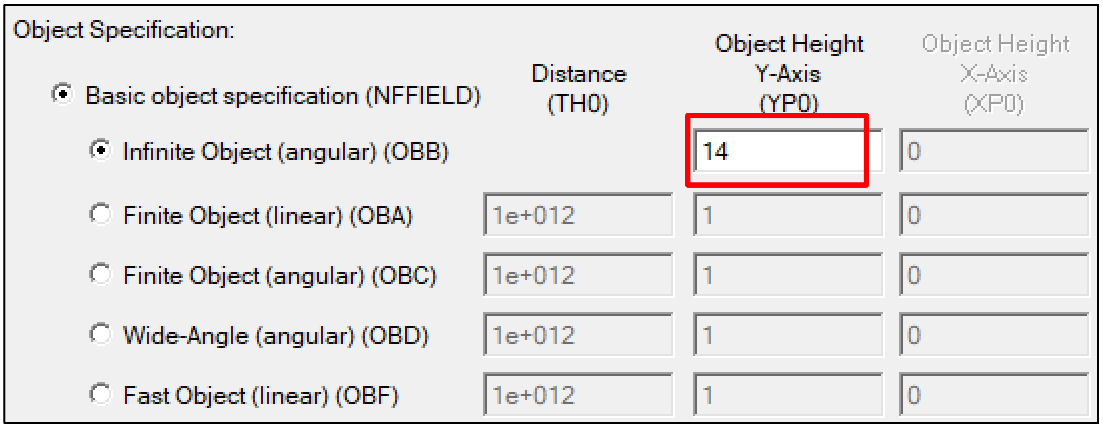
In the System Declaration Dialog of System Settings Menu, select 'mm' for the System Units and enter 11 for 'Number of surface'. Enter the string 'PLAY IT BY EAR ' for the optional Lens ID. Make sure the FOCAL mode is selected.

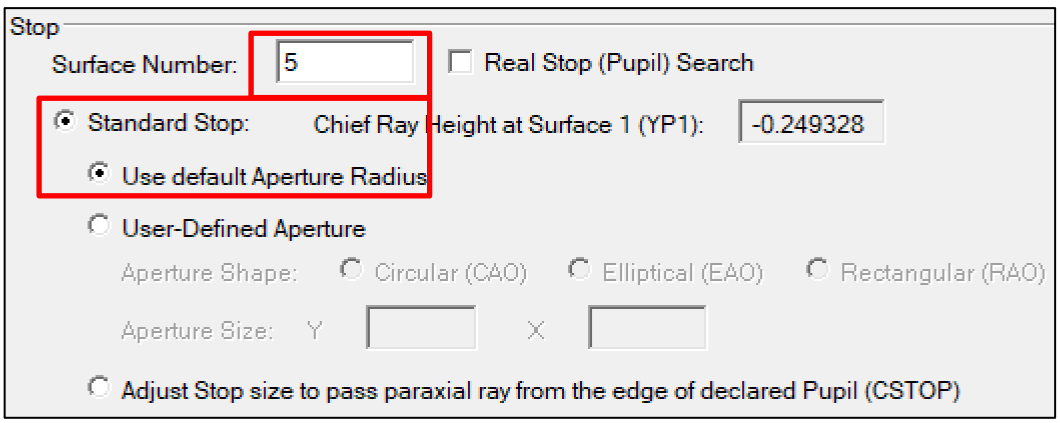


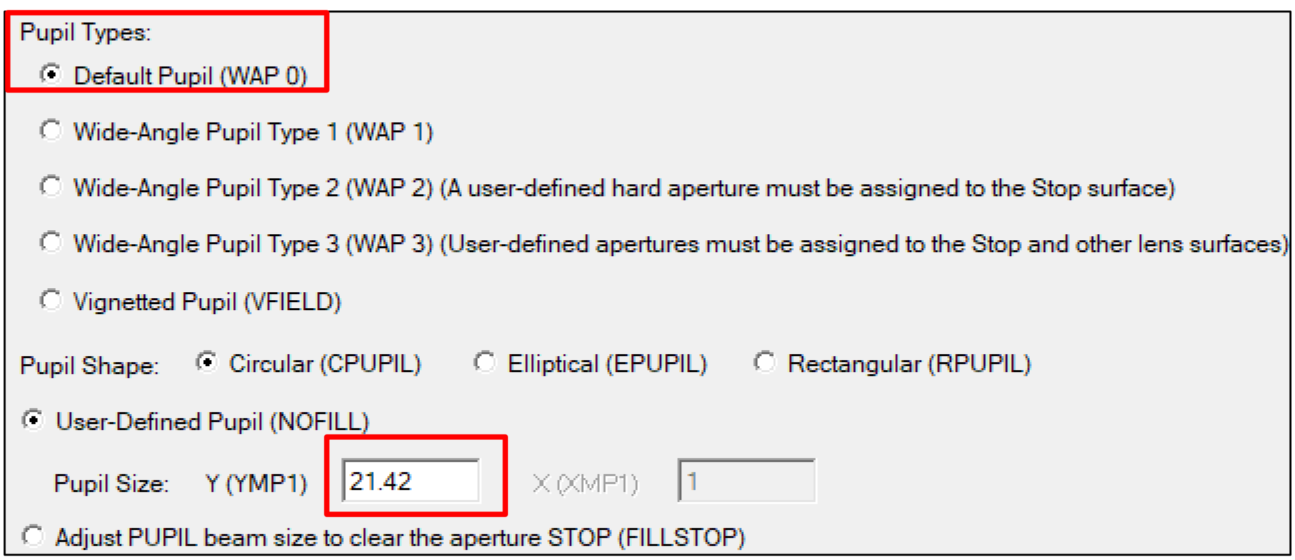
In the Wavelength dialog (System Settings menu), accept the default visible wavelengths and spectral weights.



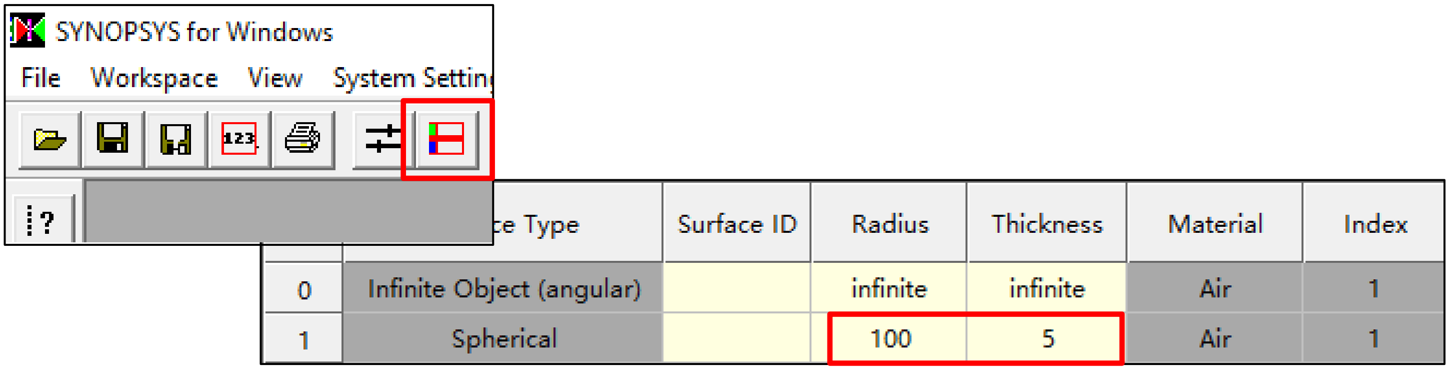
We will use the 'Object, Stop, and Pupil' dialog of the System Settings Menu to define the object, stop, and pupil characteristics of the system. First define an infinite object type (OBB) with height of 14. Set the stop on the fifth surface. The Pupil Radius is declared to 21.42 and accept the simple default pupil. For more details, refer to the 'Object, Stop, and Pupil' section of the System Settings Menu in the User Manual for Ui-Plus.



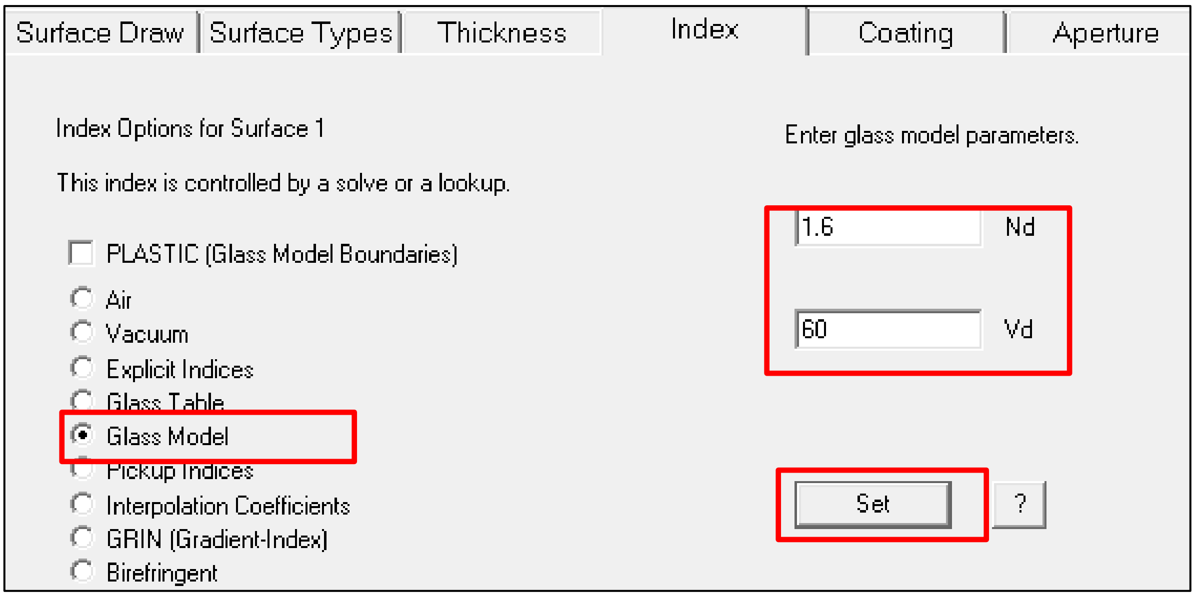


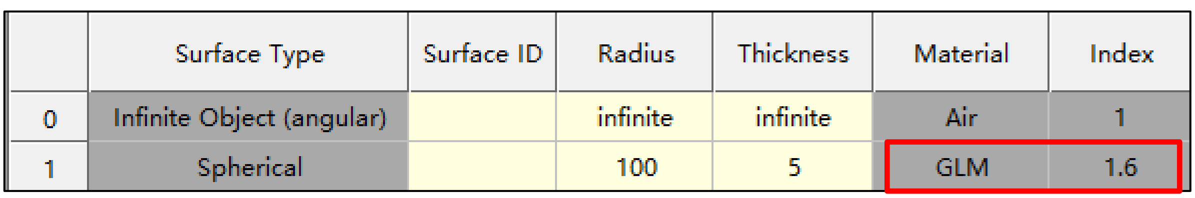


Next, we will enter the surface data using the Spread Sheet. Click at the Spread Sheet button in the Top Toolbar to open the Spread Sheet. For surface 1, enter 100 for surface Radius of Curvature and 5 for Thickness.



Click at the Material or Index cell to activate the Index Editor. Select Glass Model, enter 1.6 for Nd and 60 for Vd. Then click 'Set' to set up the Material for surface 1.





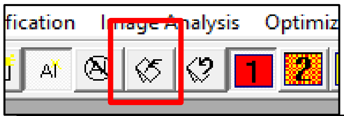
	Surface Type	Surface ID	Radius	Thickness	Material	Index
0	Infinite Object (angular)		infinite	infinite	Air	1
1	Spherical		100	5	GLM	1.6

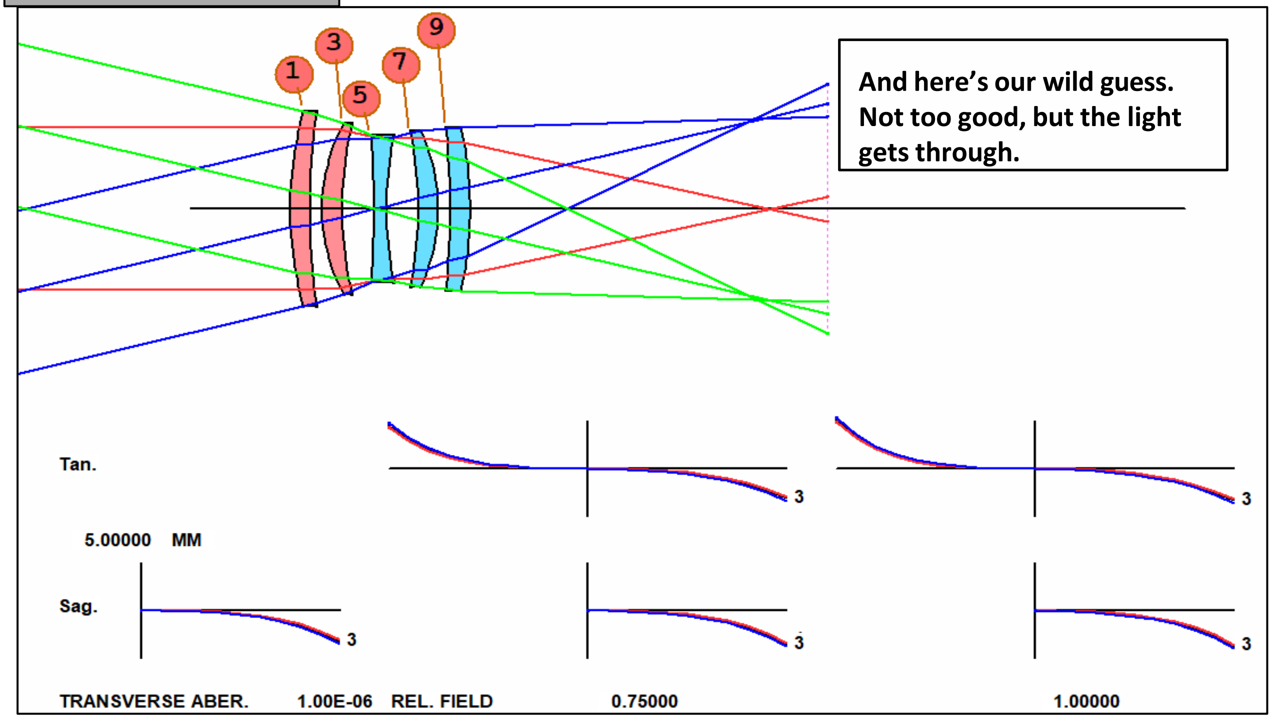
Follow the same steps to enter the following parameters for surfaces 2 to 10.
For surface 2:
Radius of Curvature: 200
Thickness: 3
Material: Air
For surface 3:
Radius of Curvature: 50
Thickness: 5
Material: Glass Model, with 1.6 for Nd (index) and 60 for Vd (V-number)
For surface 4:
Radius of Curvature: 100
Thickness: 8
Material: Air

For surface 5:
Radius of Curvature: -200
Thickness: 3
Material: Glass Model, with 1.6 for Nd (index) and 40 for Vd (V-number)
For surface 6:
Radius of Curvature: 100
Thickness: 8
Material: Air
For surface 7:
Radius of Curvature: -100
Thickness: 5
Material: Glass Model, with 1.6 for Nd (index) and 40 for Vd (V-number)
For surface 8:
Radius of Curvature: -50
Thickness: 3
Material: Air
For surface 9:
Radius of Curvature: -200
Thickness: 5
Material: Glass Model, with 1.6 for Nd (index) and 40 for Vd (V-number)
For surface 10:
Radius of Curvature: -100
Thickness: YMT solve with target ray height of 0
Material: Air

	Surface Type	Surface ID	Radius	Thickness	Material	Index
0	Infinite Object (angular)		infinite	infinite	Air	1
1	Spherical		100	5	GLM	1.6
2	Spherical		200	3	Air	1
3	Spherical		50	5	GLM	1.6
4	Spherical		100	8	Air	1
5	Spherical		-200	3	GLM	1.6
6	Spherical		100	8	Air	1
7	Spherical		-100	5	GLM	1.6
8	Spherical		-50	3	Air	1
9	Spherical		-200	5	GLM	1.6
10	Spherical		-100	89.1326653	Air	1
11	Flat		infinite	0	Air	1

Click the SketchPad button to view the system layout:



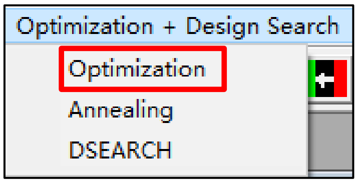


The command script describing this system is shown below:

```
RLE
ID PLAY IT BY EAR                   47
 LOG      47
 WAVL .6562700 .5875600 .4861300
 APS           5
 UNITS MM
 OBB  0.0000000  14.0000000  21.4200000  -4.96944821498     0.0000000   0.0000000  21.4200000
   0 AIR
   1 RAD    100.0000000000000   TH      5.00000000
   1 GLM      1.600000000          60.000000000
   2 RAD    200.0000000000000   TH      3.00000000 AIR
   3 RAD     50.0000000000000   TH      5.00000000
   3 GLM      1.600000000          60.000000000
   4 RAD    100.0000000000000   TH      8.00000000 AIR
   5 RAD   -200.0000000000000   TH      3.00000000
   5 GLM      1.600000000          40.000000000
   6 RAD    100.0000000000000   TH      8.00000000 AIR
   7 RAD   -100.0000000000000   TH      5.00000000
   7 GLM      1.600000000          40.000000000
   8 RAD    -50.0000000000000   TH      3.00000000 AIR
   9 RAD   -200.0000000000000   TH      5.00000000
   9 GLM      1.600000000          40.000000000
  10 RAD   -100.0000000000000   TH     89.13266528 AIR
  10 TH      89.13266528
  10 YMT      0.00000000
  11 CV      0.0000000000000   TH      0.00000000 AIR
 END
```

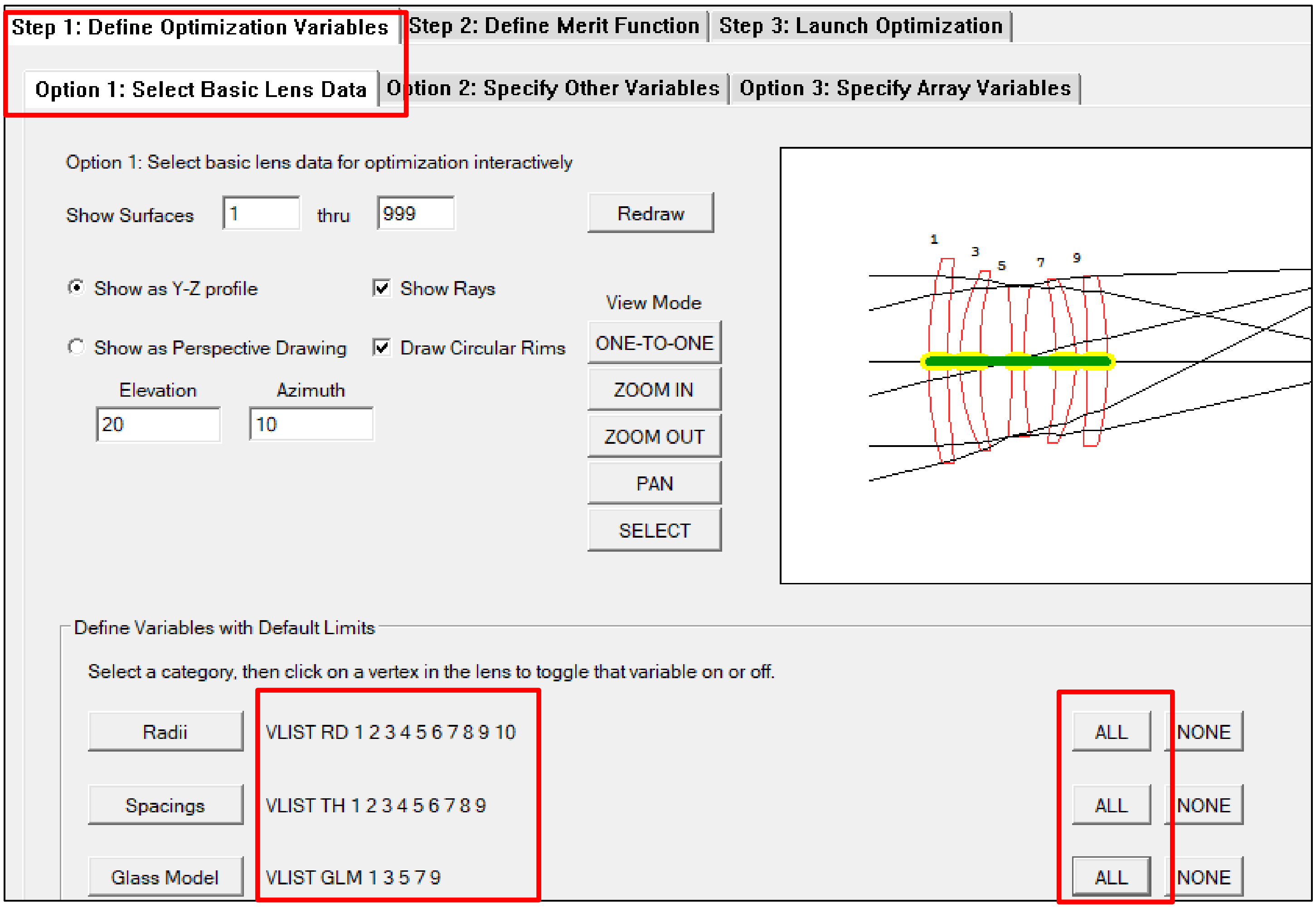
Optimization

Now we will optimize the system. Open the 'Optimization' of the Optimization + Design Search Menu to set up a Marco.



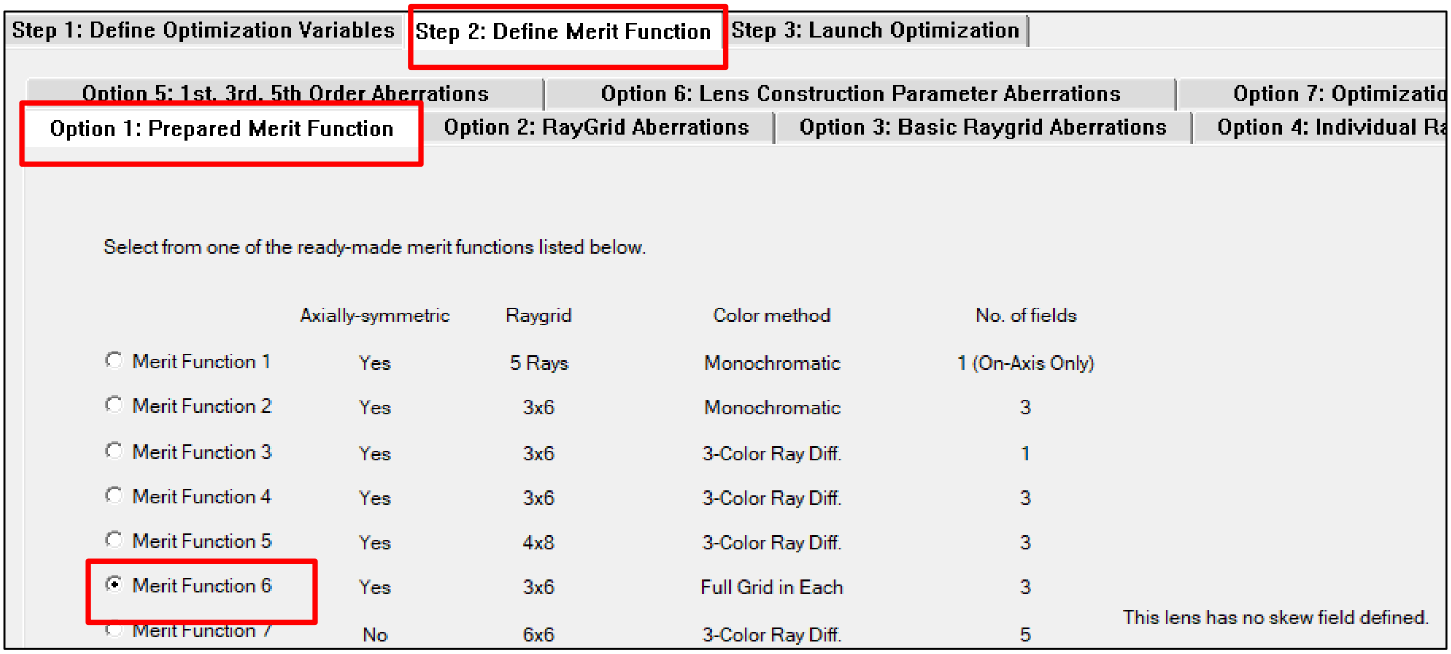
Step 1 Optimization Variables:

We will use the Option 1 in the Define Optimization Variables Dialog to define the optimization variables by selecting All Radii, All Spacings, and All Glass Model to declare the optimization variables.



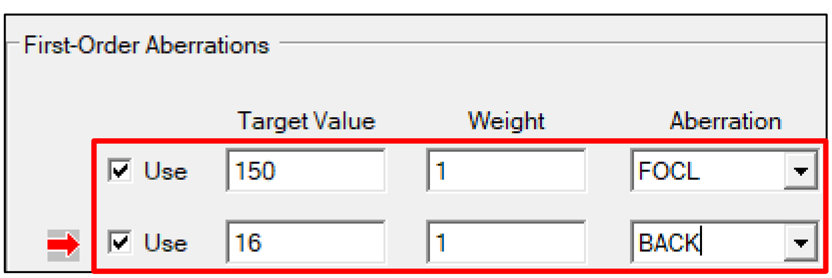
Step 2 Define Merit Function:

Select Option 1 (Prepared Merit Function dialog) and then ‘Merit Function 6’. Merit Function 6 defines a set of raygrid to minimize the transverse ray aberrations. For more details, see the Prepared Merit Function section of the Optimization menu in the User Manual for Ui-Plus. You can also find a discussion of the Ready-made Merit Function in ‘APPENDIX: Optimization Introduction’ of this guide.

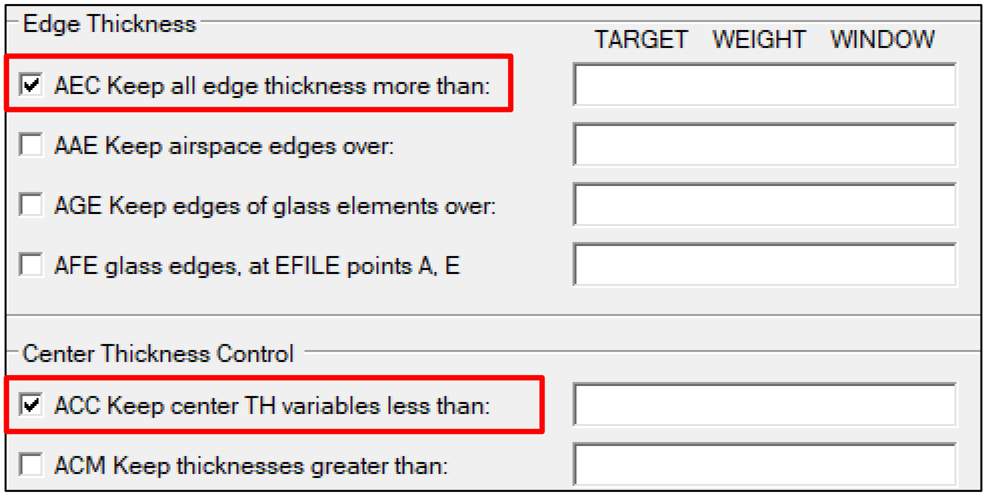


Next, we will open the dialog for option 5 (1st, 3rd, 5th Order Aberrations). In the ‘First-Order Aberrations’ block, click at the ‘Use’ checkbox to activate the input line.

- Enter 100 for the Target Value, 1 for Weight, and in the Aberration dropdown menu select FOCL (Focal Length) as the control term.
- Enter 16 for the Target Value, 1 for Weight, and in the Aberration dropdown menu select BACK (BACK Focal Length) as the control term.

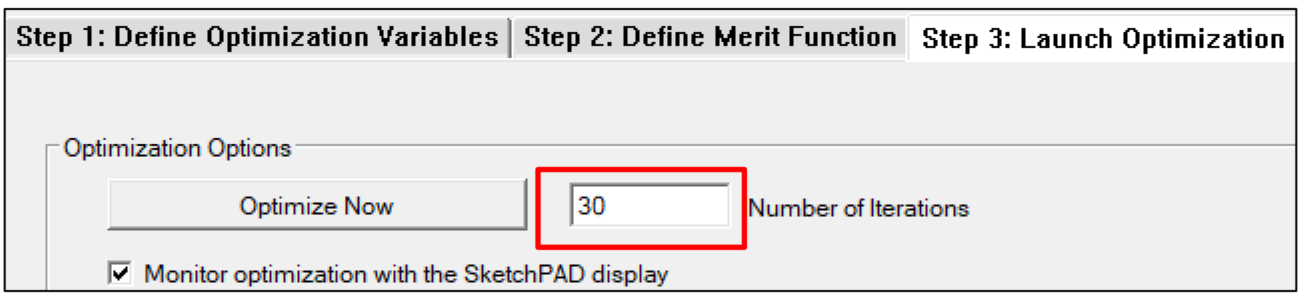


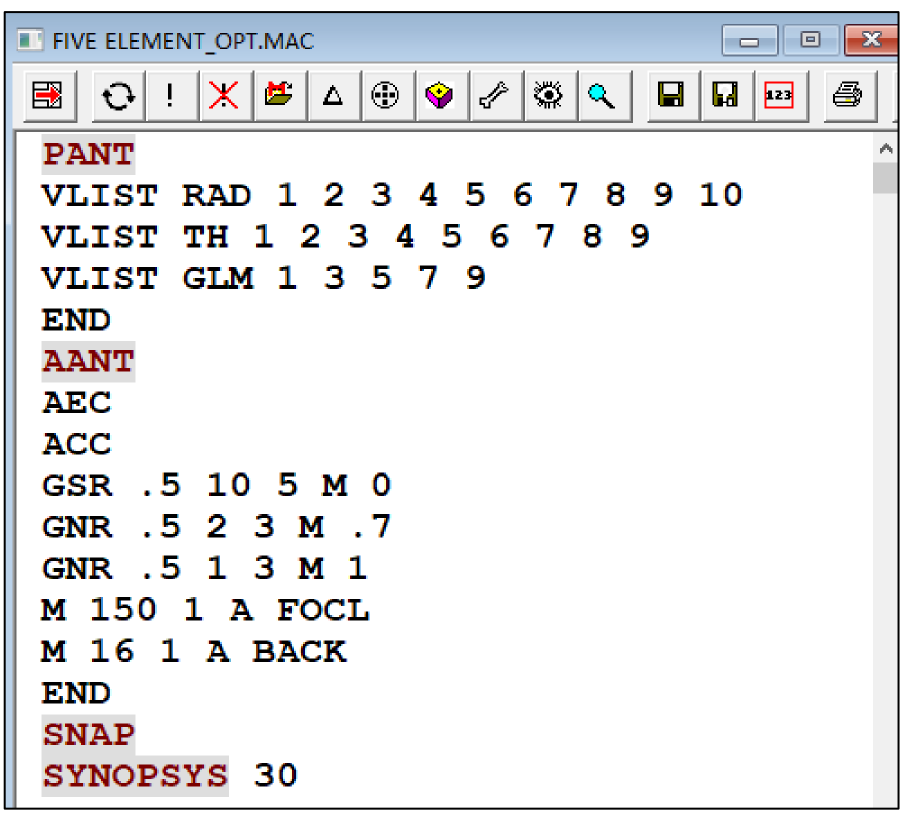
Lastly, we will add two optimization monitors to control the system. For more details, see the Prepared Optimization Monitor section of the Optimization menu in the User Manual for Ui-Plus. We will select 'AEC' to set a lower bound to all the edge thickness (default is 1mm) and 'ACC' to keep an upper bound to the center thickness (default is 25.4mm).



Step 3 Launch Optimization

Enter 30 for Number of Iterations. Then click at the 'Make a MACro' button to save as a Marco with the filename 'five element_opt'.

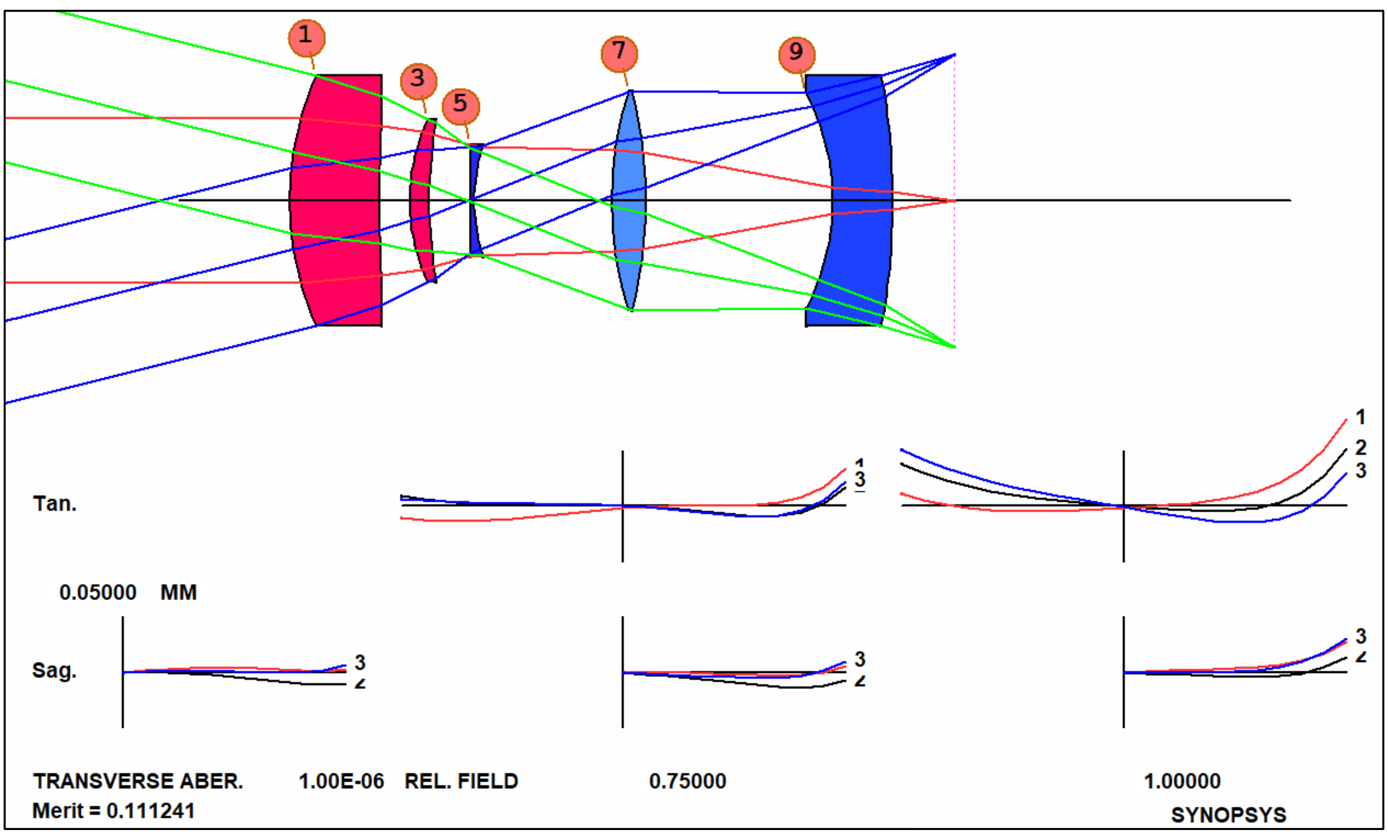




Next, we want to add a control to keep the total length (between the vertices of the first and last surfaces) not larger than 250. We will do this by enter the command line 'LUL 250 1 1 A TOTL' to the Macro file as shown below. See 'APPENDIX: Optimization introduction' for an explanation to the LUL command.

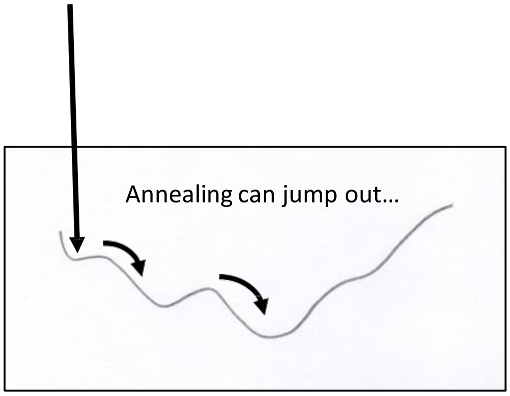
```
PANT
VLIST RAD 1 2 3 4 5 6 7 8 9 10
VLIST TH 1 2 3 4 5 6 7 8 9
VLIST GLM 1 3 5 7 9
END
AANT
AEC
ACC
GSR .5 10 5 M 0
GNR .5 2 3 M .7
GNR .5 1 3 M 1
M 150 1 A FOCL
M 16 1 A BACK
LUL 250 1 1 A TOTL
END
SNAP
SYNOPSYS 30
```

Run the MACro, and the lens is much improved.



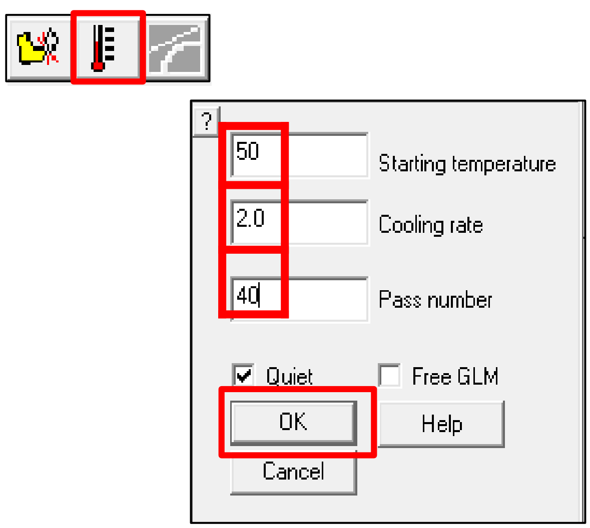
Annealing

Now, let's see how Annealing impact the lens. During the optimization process, Lenses often get stuck in a local minimum. Annealing can help the system jump out of the local minimum and go on to find the lower one. When the lens is annealed, the program makes a series of small random changes to the design variables and reoptimizes, over and over.

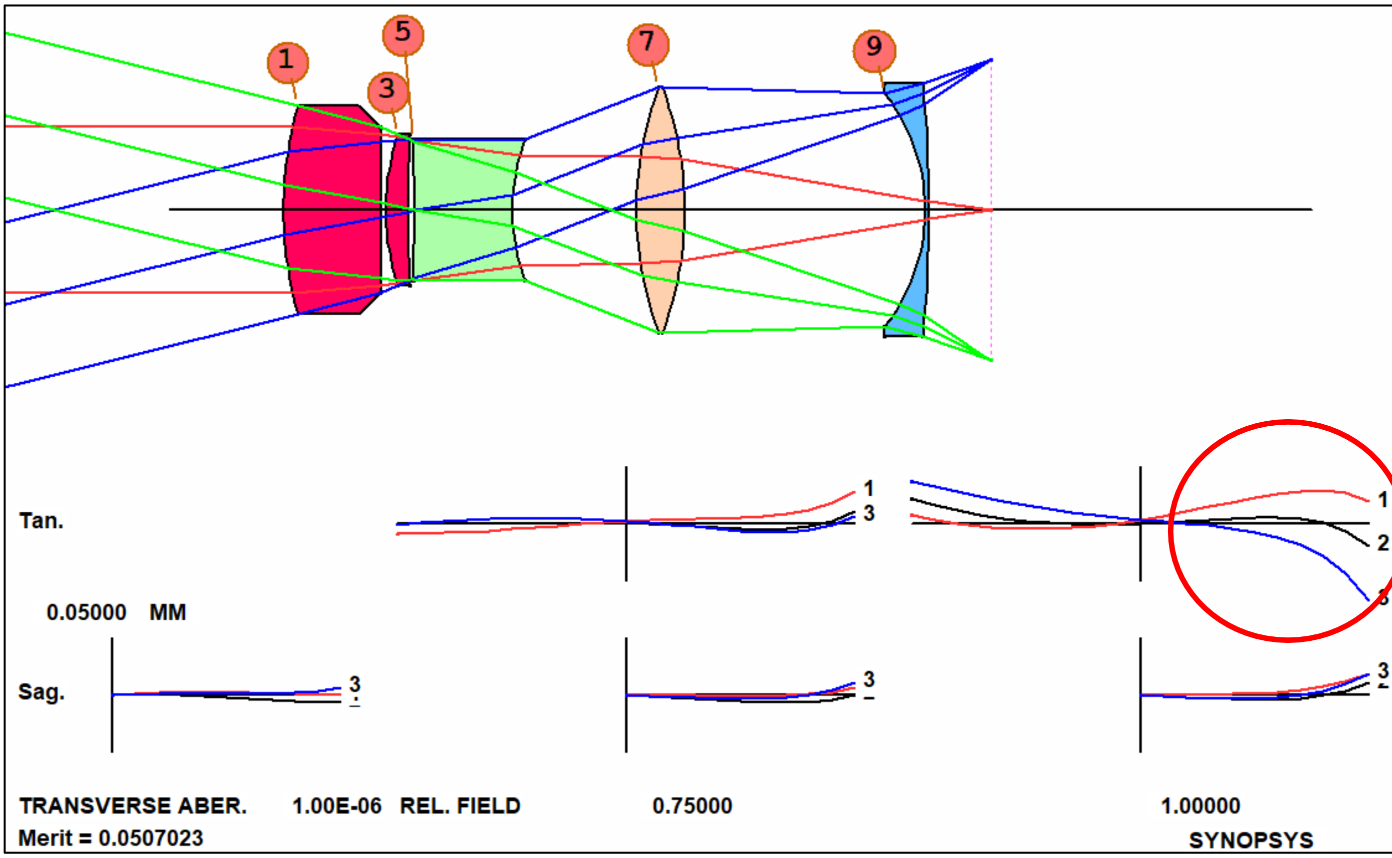


... and find the lowest minimum.

To start the anneal process, click the anneal button in the Top Toolbar to open the anneal dialog. Input the anneal parameter as shown below. Click OK to start the process. For more details on Annealing, refer to the section 'Annealing' in the Optimization & Design Search Menu in the User Manual for Ui-Plus.



Now the lens is much better (note that the rayfan unit is changed to 0.05 from 0.1), but the edge of the field has poor color correction.



Lens design is mostly about modifying the merit function to better control whatever is the worst problem at the moment. Because we saw that in the last page that the lens has poor color correction at the edge of the field. We try to correct it by re-optimizing the lens:

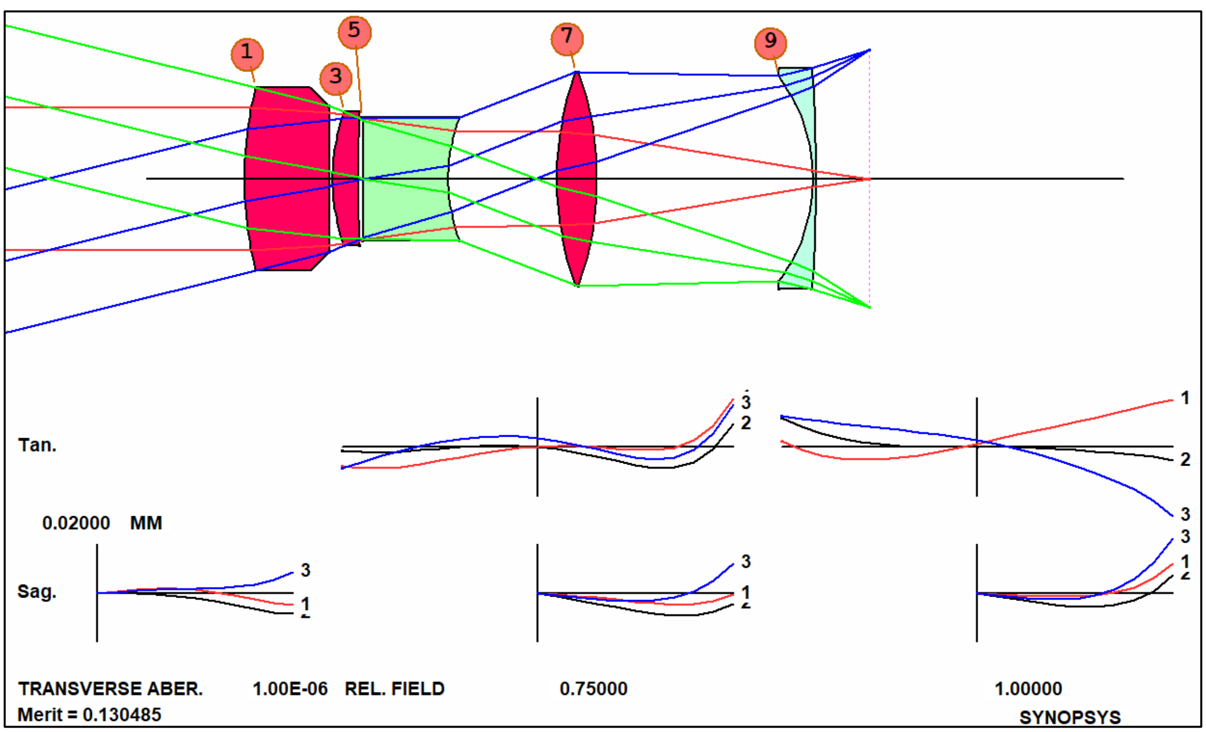
```
LOG
STORE 9
PANT
VLIST RAD ALL
VLIST TH ALL
VLIST GLM ALL
END

AANT
M 150 1 A FOCL
M 16 1 A BACK
LUL 250 1 1 A TOTL
AEC

ACC
GSR .5 10 5 M 0
GNR .5 2 3 M .7
GNR .5 4 3 M 1

END

SNAP
SYNO 30
```

Increase the weight on the rays at the edge of the field from 1 to 4 and run the MACro again to apply stronger control for color correction.

As a good practice, make a checkpoint between optimization stages. You can make a checkpoint by clicking at the CheckPoint button in the Side-toolbar of the SketchPad window.
The lens is further improved with this optimization.
Not bad! And this is from a wild-guess starting point. But there is some knowledge there too:

- The stop was in the middle to gain some symmetry advantage.
- The lenses were bent the way that minimized SA3.

It's not just a wild-guess after all.



Ex2.2 Design by DSEARCH

Now we'll demonstrate how to use another important tool in SYNOPSYS™ , DSEARCH™, to do this problem. With the newer design tools make available by innovative algorithms, you can make system- level decisions, but let the program work out the details.

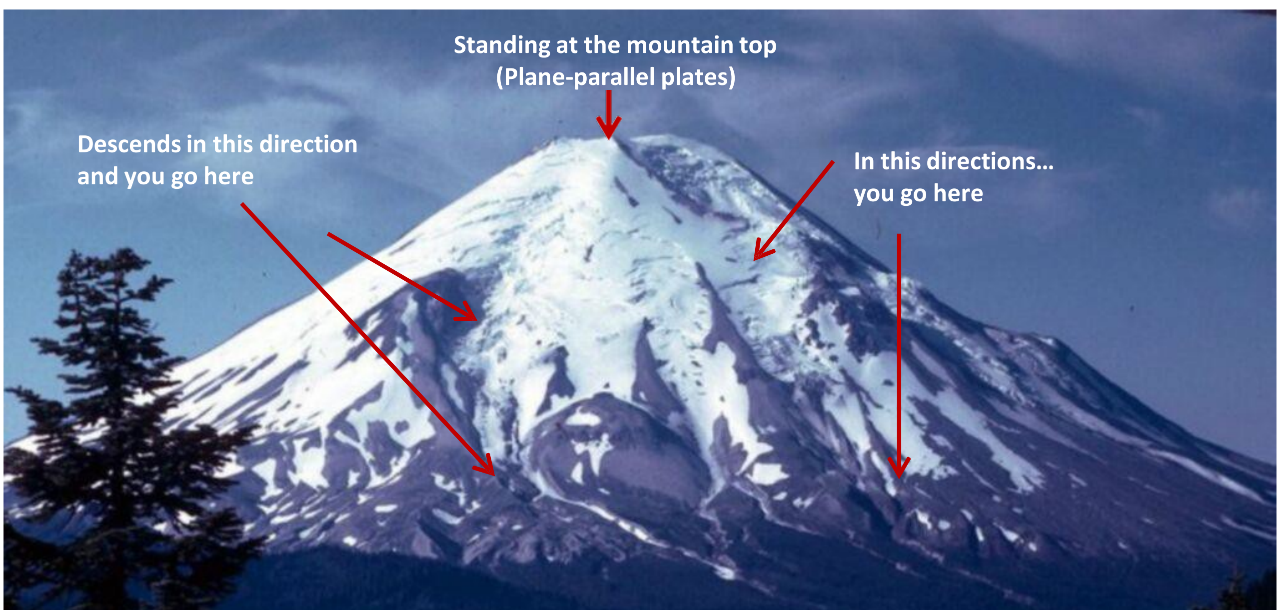
The DSEARCH (Design Search) in SYNOPSYS™ is an Automatic Design tool created to provide an effective, fast, and practical solution for optical design. It is created

1. To ease the burdens on the designers in finding good starting points for their design projects.
2. To explore the design space efficiently to discover alternative design forms that may deliver better performances.

The principle behind it can be visualized easily using the analogy of skiing down the mountain top to find the valleys:

- From the top of a mountain you can see all the valleys.
- To search for the lower valleys, send out multiple probes that descends from the mountain top in different directions.

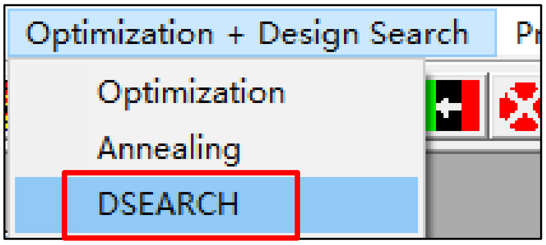
Because the search is not limited to the vicinity of a pre-select starting point (as in the traditional approach), this method is also referred to as the Global Search method.



The distance you jump downhill is an input parameter in the optimization.
How fast you can go depends on the speed of the optimization process.

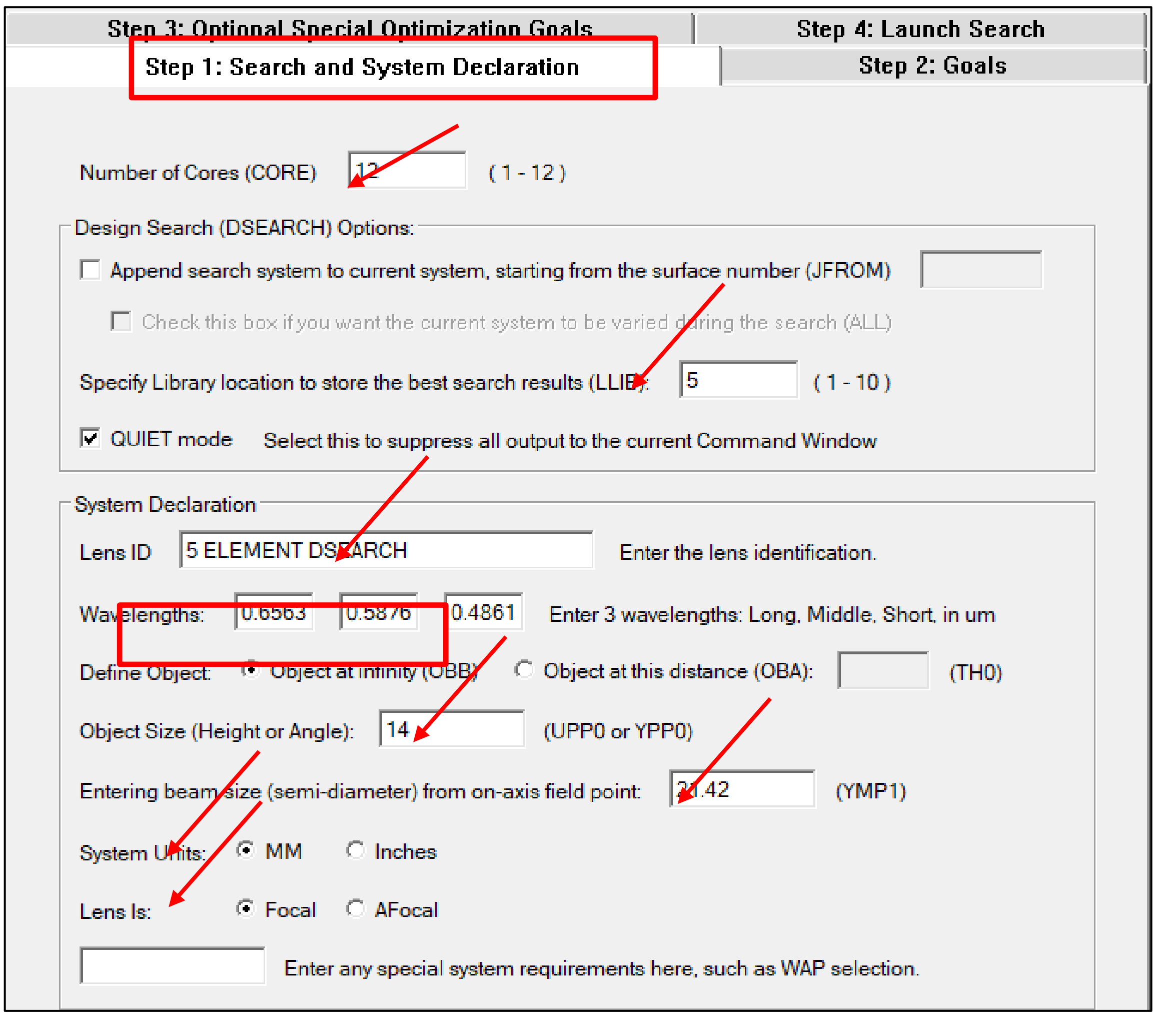
DSEARCH

Select DSEARCH from the “Optimization + Design Search” drop down menu:

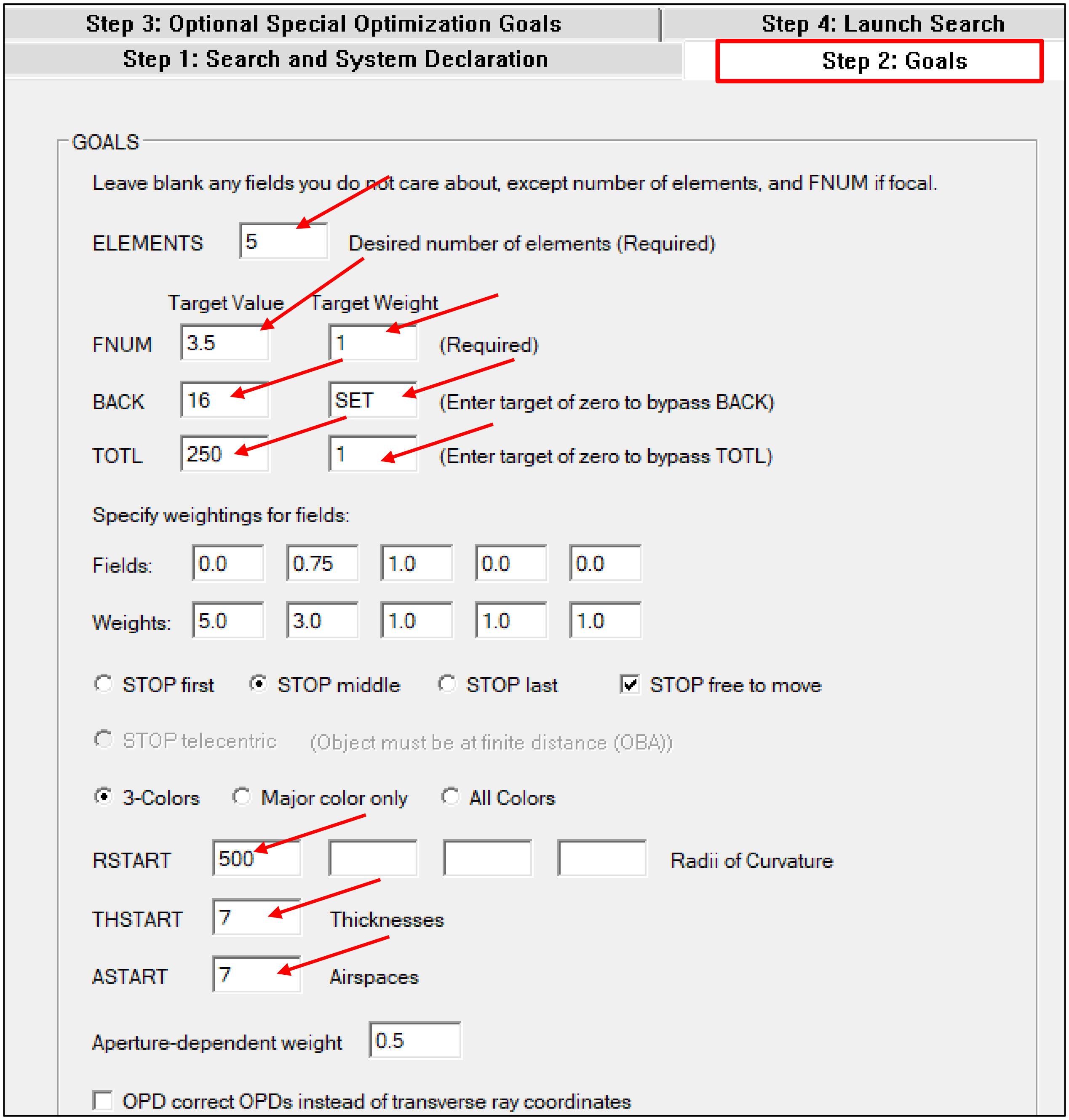


Follow the screenshots below to enter the DSEARCH parameters. For more details, see the ‘DSEACH’ section in the ‘Optimization & Design Search’ Menu in the User Manual for Ui-Plus.

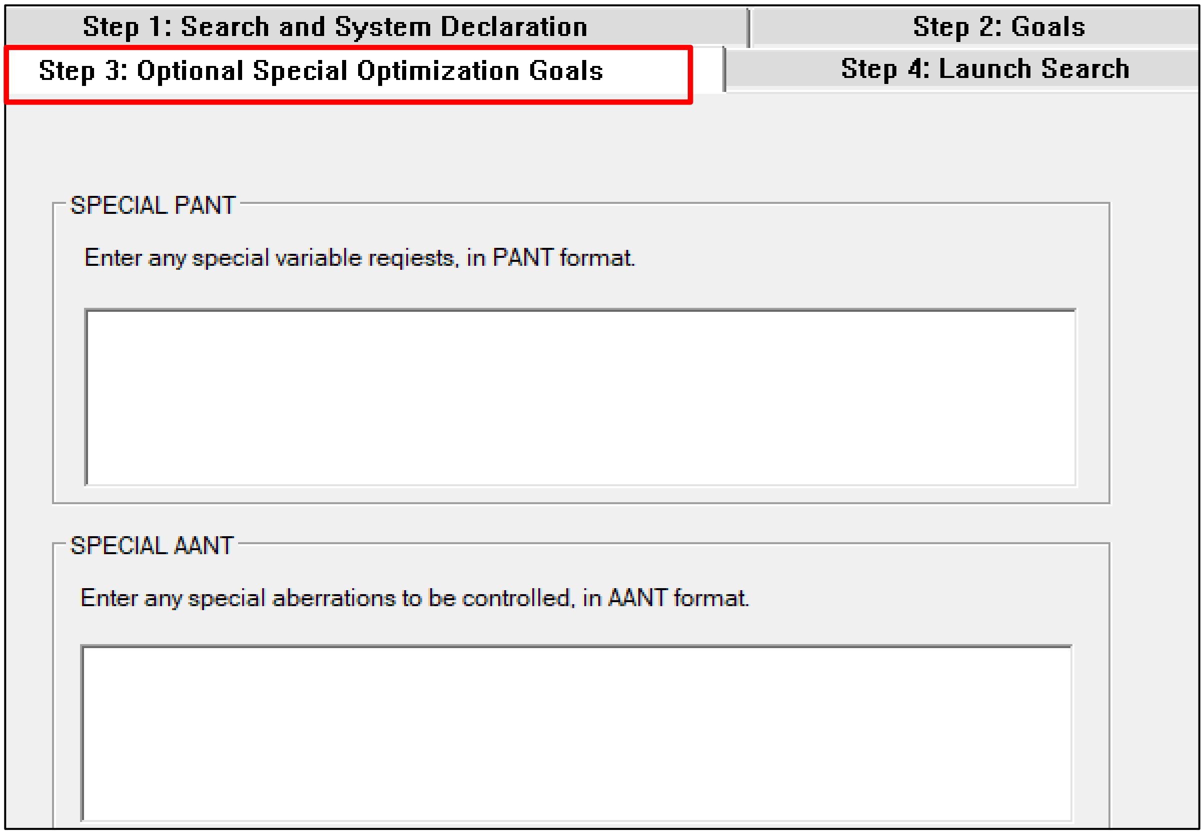
Step 1 Search and System Declarations:



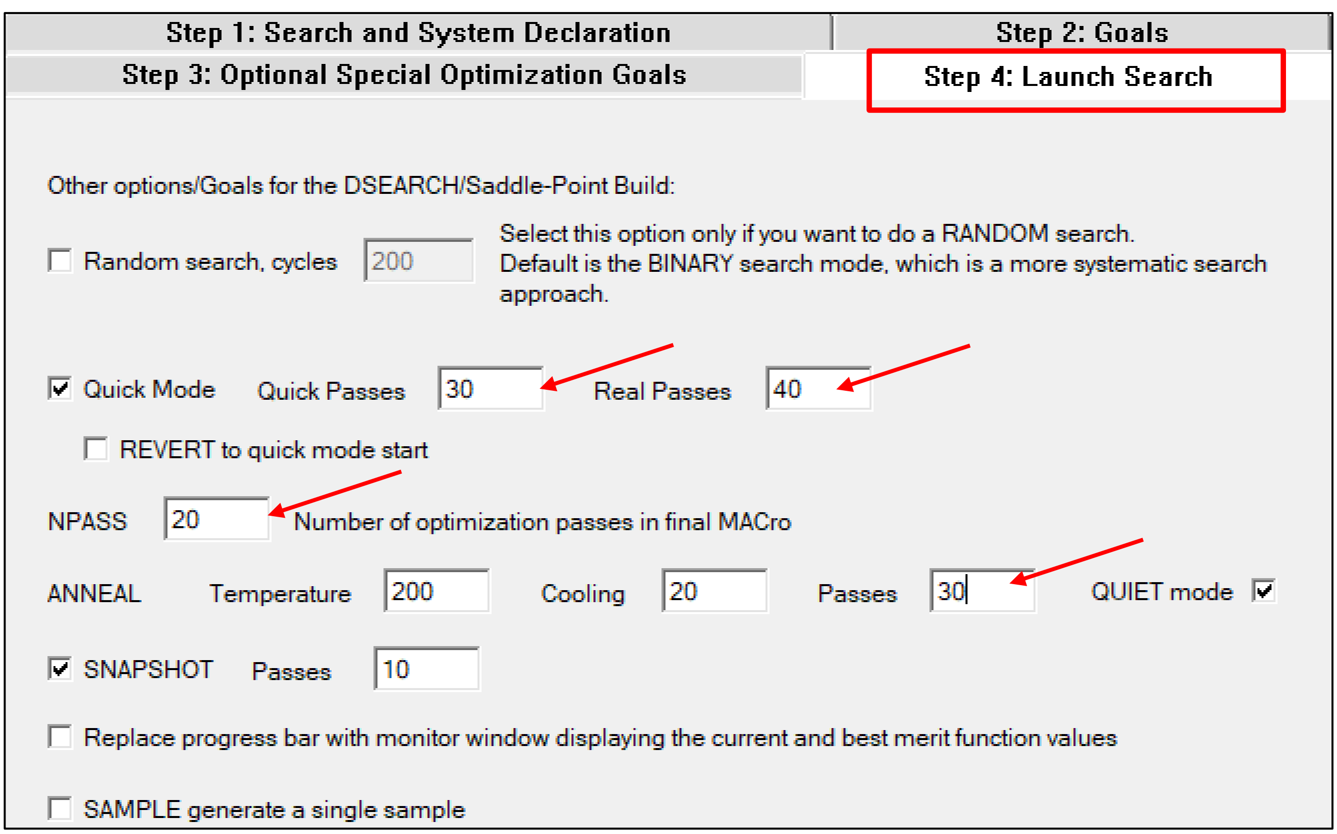
Step 2 Enter the design goals:



Step 3 Optional goals: If there is no special requirement, this step can be skipped.

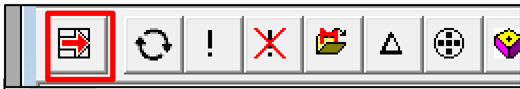


Step 4 Launch Search



After everything is entered, go ahead and click the “Make a MACro” button and name it something descriptive (for example, 5_element_DSEARCH.mac).

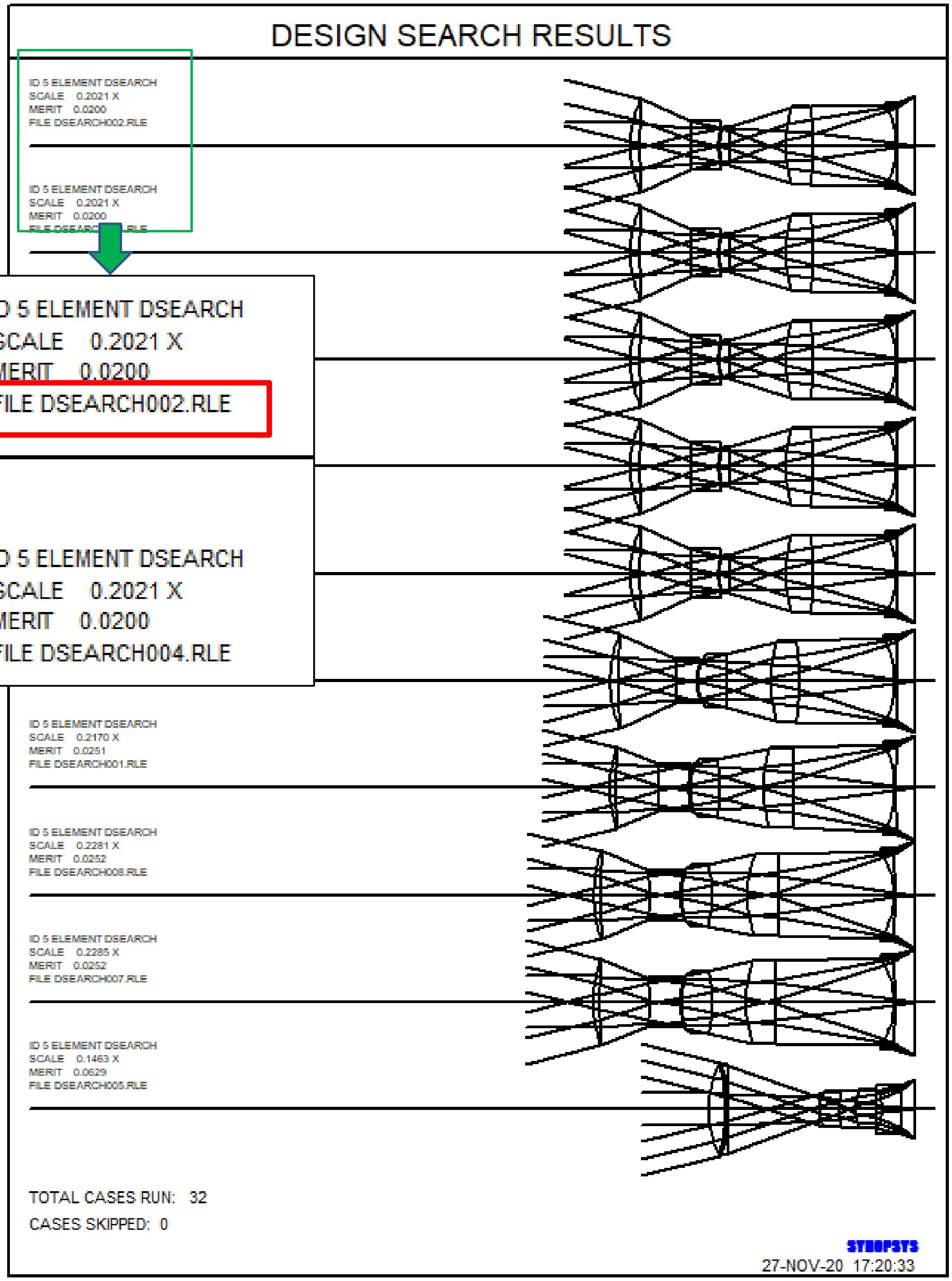
This is the DSEARCH MACro you just created. To run the macro, click the run button at the Macro Editor toolbar.



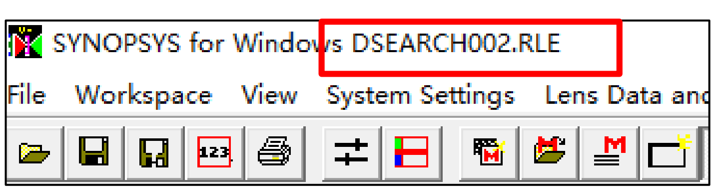
```
CORE 12
DSEARCH 5 QUIET
SYSTEM
ID 5 ELEMENT DSEARCH
OBB 0 14 21.42
WAVL 0.6563 0.5876 0.4861
UNITS MM
END
GOALS
ELEMENTS 5
FNUM 3.5 1
BACK 16 SET
TOTL 250 1
STOP MIDDLE
STOP FREE
COLORS 3
FOV 0.0 0.75 1.0 0.0 0.0
FWT 5.0 3.0 1.0 1.0 1.0
RSTART 500
THSTART 7
ASTART 7
RT 0.5
QUICK 30 40
NPASS 20
ANNEAL 200 20 Q 30
SNAPSHOT 10
END
SPECIAL PANT
END
SPECIAL AANT
END
GO
```

Design Candidates by DSEARCH

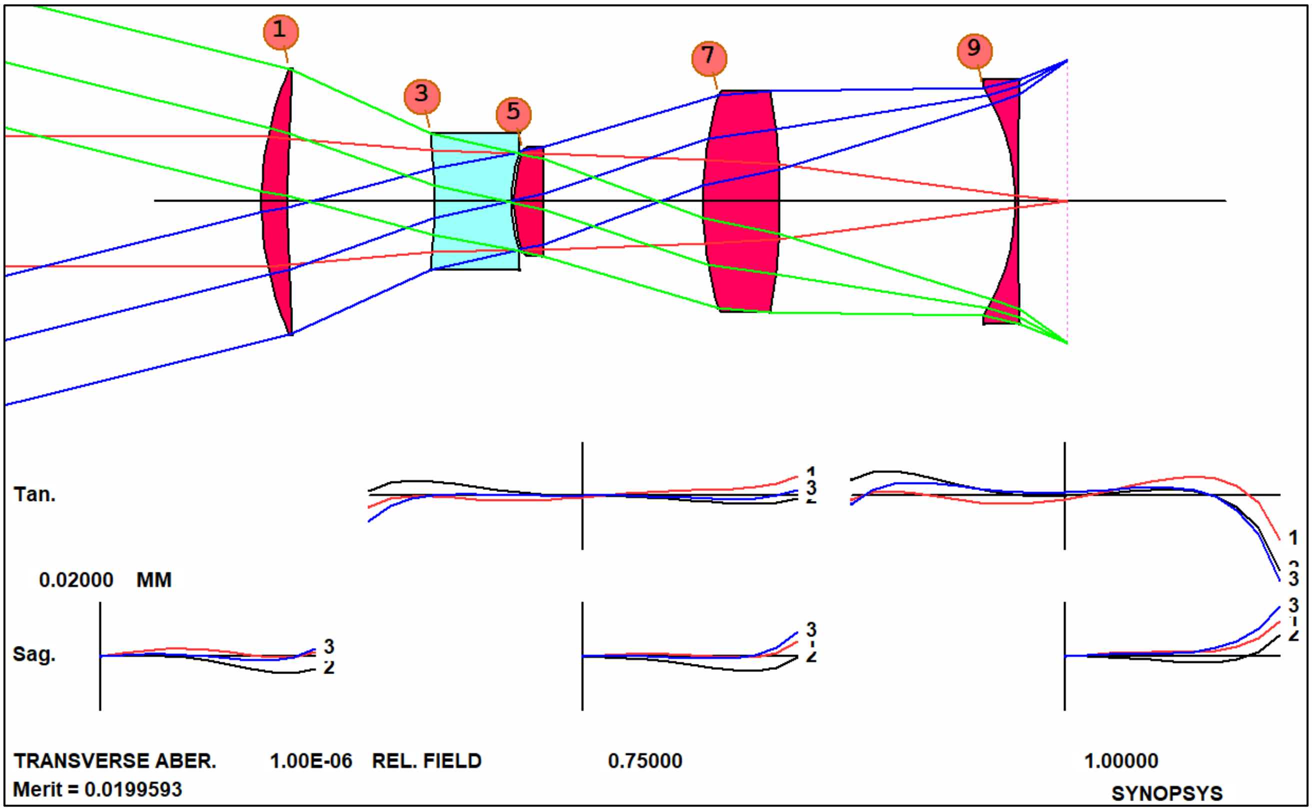
DSEARCH comes back with 10 potential designs. Usually the top one is the best – but not always. You are encouraged to try the others too to explore the design space. Each one has a merit value and a filename.



If you want to read the ranking of the ten best lenses and their filenames, open the macro DSS.MAC that is automatically generated by DSERACH. You can also run the macro by typing the Execute Macro command: **EM DSS.MAC**. SYNOPSYS™ will cycle through each lens at the click of the 'return' key. The filename is displayed at the upper left corner of the SYNOPSYS™ workspace window:



In this demo, we use the top lens returned by DSEARCH. You can select the 2nd best to see how it goes, for the sake of exploring the design space. If you are going to use the top lens from DSEARCH, you don't need to do anything to launch the lens file. It's already launched. If you want to use another file, say the 2nd best, according to the list returned by DSEARCH (see last page), it would be DSEARCH004.rle. You can use the Open File button at the Top Toolbar to open it.



DSEARCH also generates an optimization macro for you to further refine the lens:

```
PANT
VY 0 YP1
VLIST RD ALL
VLIST TH ALL EXCEPT LB1
VLIST GLM ALL
END
AANT P
AEC 3 1 1
ACM 3 1 1
M   0.285714E+00   0.100000E+01 A CONST 1.0 / DIV FNUM
GSR       0.500000      5.000000       4  1     0.000000
GSR       0.500000      5.000000       4  2     0.000000
GSR       0.500000      5.000000       4  3     0.000000
GNR       0.500000      3.000000       4  1     0.750000
GNR       0.500000      3.000000       4  2     0.750000
GNR       0.500000      3.000000       4  3     0.750000
GNR       0.500000      3.000000       4  1     1.000000
GNR       0.500000      3.000000       4  2     1.000000
GNR       0.500000      3.000000       4  3     1.000000
M   0.250000E+03   0.100000E+01 A TOTL
END
SNAP   10/DAMP     1.00000
SYNOPSYS    20
```

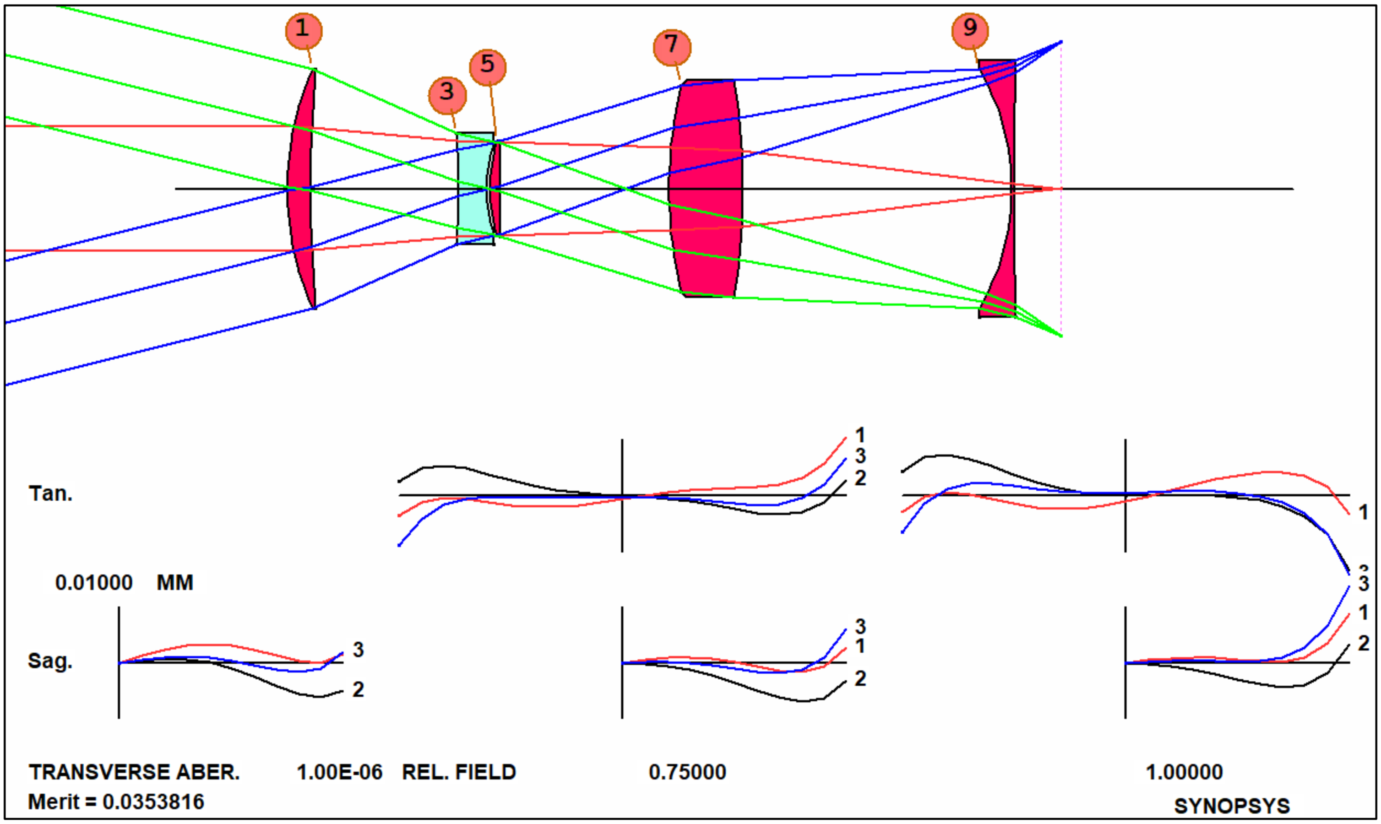
Because there are some thin edges and centers in the design candidate shown above, we increase the target values of the AEC and ACM.

AEC: Keep edge thickness larger than

ACM: Keep center thickness larger than

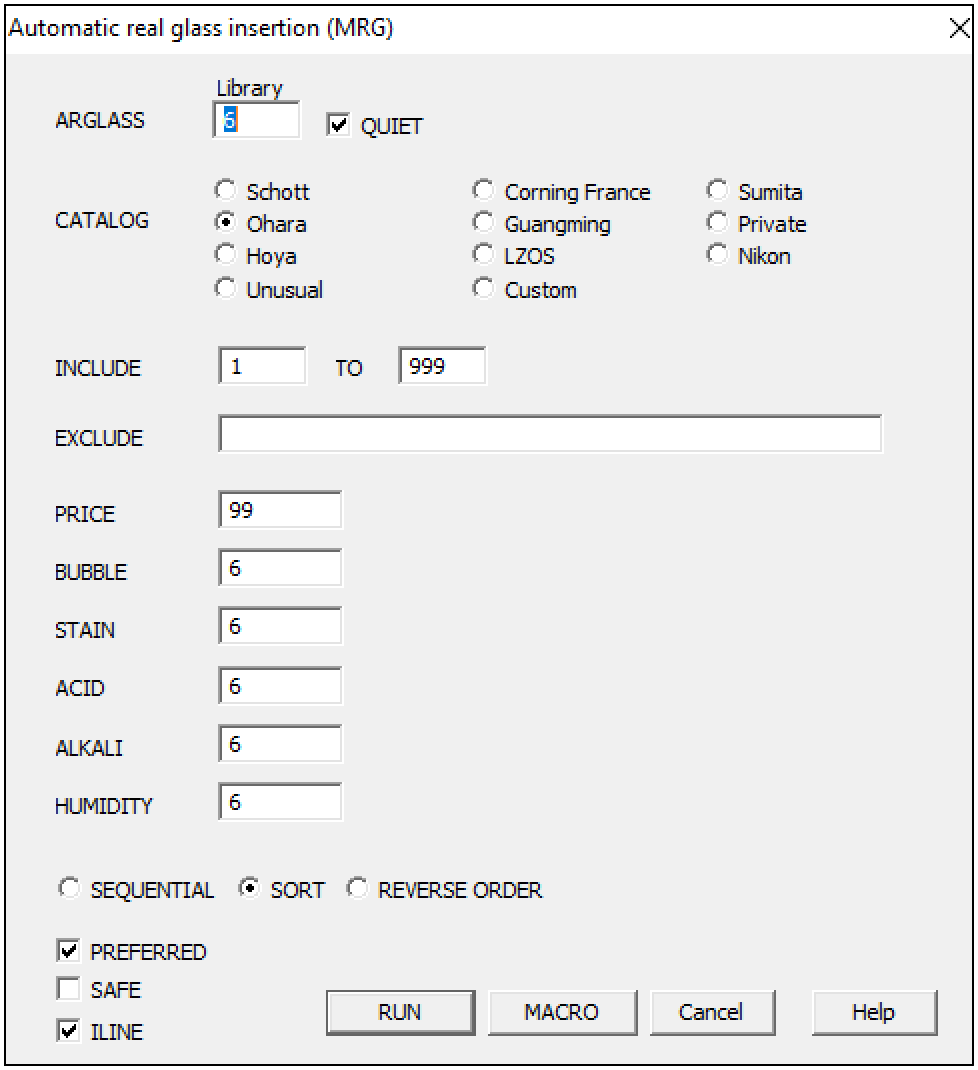
The edge of the field needs a higher weight too.

Run the macro to optimize the lens and then anneal it and you will reach the system below. This lens is quite different from the previous design, where we guessed a starting point. It illustrates a basic truth: for a complex lens, there are many configurations that have roughly equal quality.



Real Glass Insertion

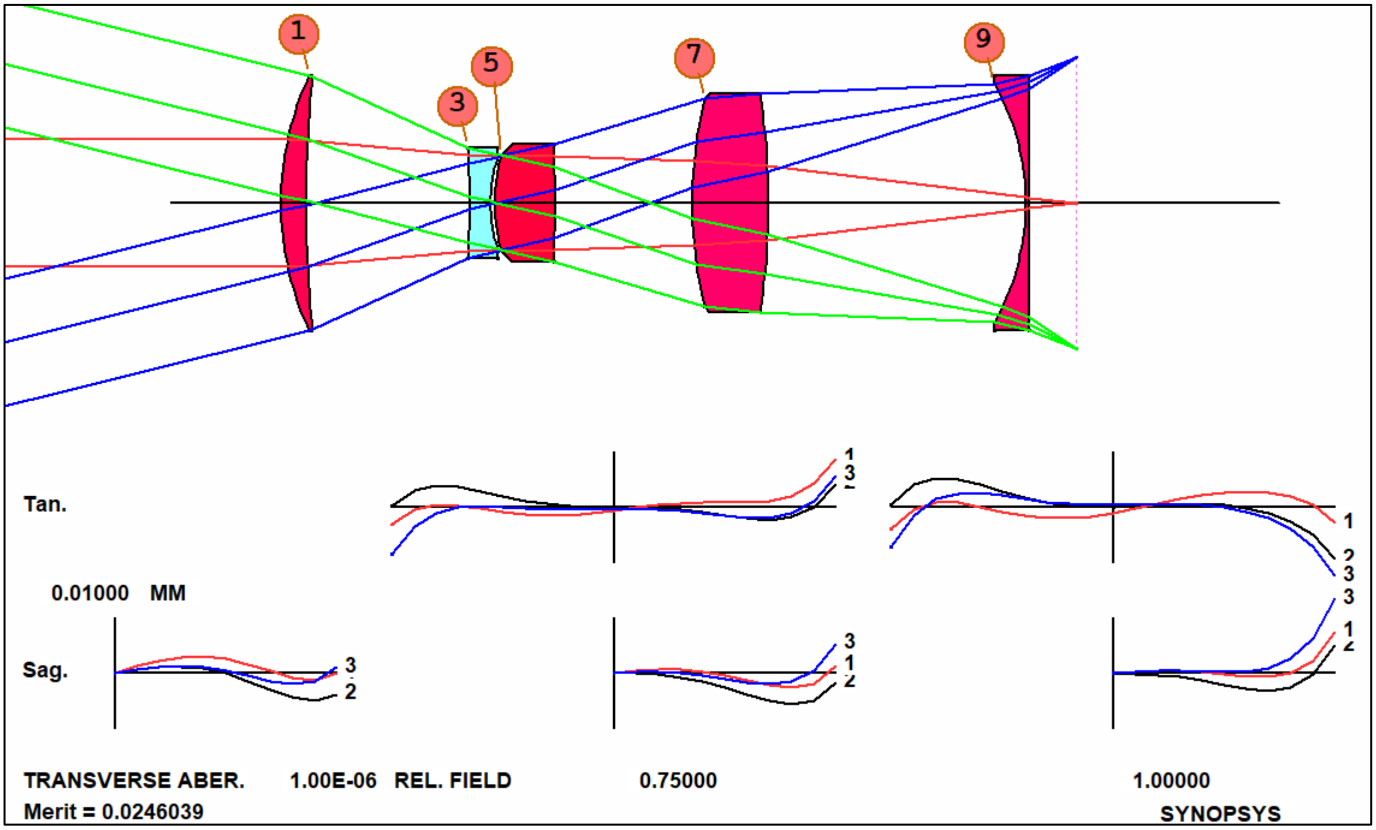
One more step: The lens has model glass types. We need to substitute real glasses for them.
Type MRG to open the 'Automatic real glass insertion' dialog. Make the selections shown, and click OK. For more details, see User Manual 5.47 Automatic Real Glass Insertion.

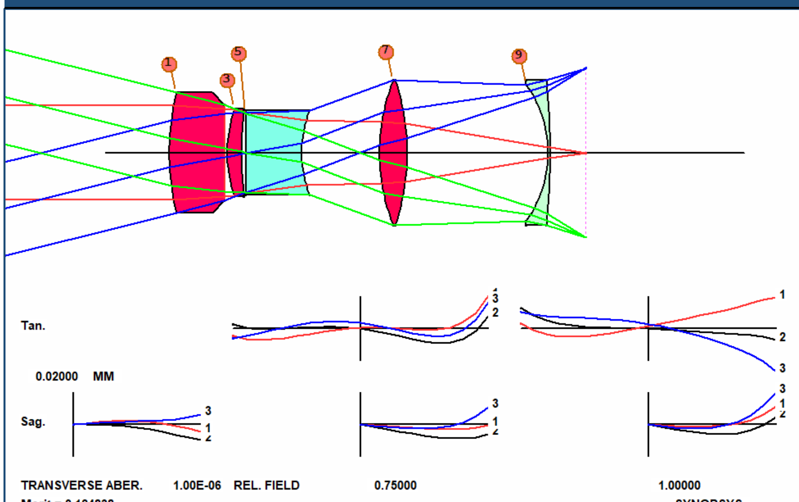


Note: MRG has to be run immediately after a normal optimization. (It uses the same variables and merit function.)

```
 SYNOPSYS AI>MRG

 --- ARGLASS 6 QUIET
Lens number      6 ID 5 ELEMENT DSEARCH
 GLASS S-FPL51          HAS BEEN ASSIGNED TO SURFACE   5; MERIT =    0.287703E-01
 GLASS S-FPM3           HAS BEEN ASSIGNED TO SURFACE   1; MERIT =    0.255770E-01
 GLASS S-FPM2           HAS BEEN ASSIGNED TO SURFACE   7; MERIT =    0.257014E-01
 GLASS S-FPM2           HAS BEEN ASSIGNED TO SURFACE   9; MERIT =    0.248310E-01
 GLASS S-TIL1           HAS BEEN ASSIGNED TO SURFACE   3; MERIT =    0.246039E-01
 Type <ENTER> to return to dialog.
```

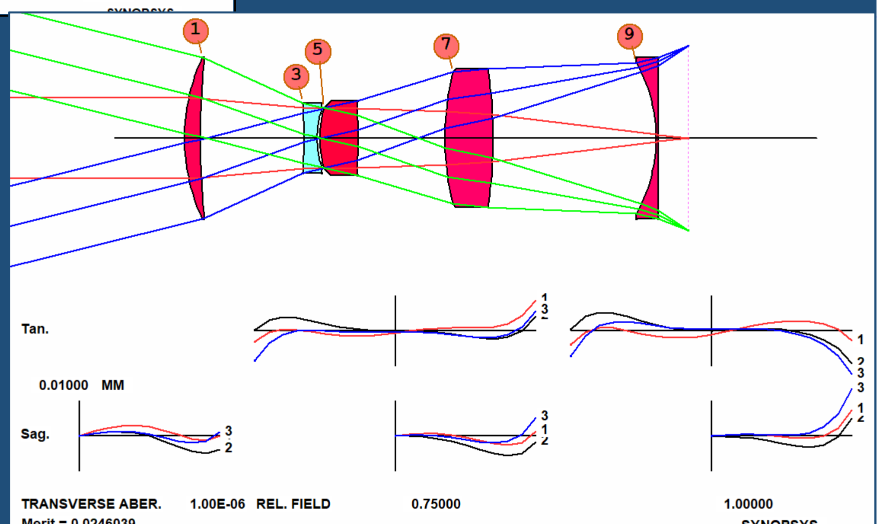
And here's our lens. This is about as good as one can do with five elements to these specifications.





Two potential solutions.

In only a few minutes.



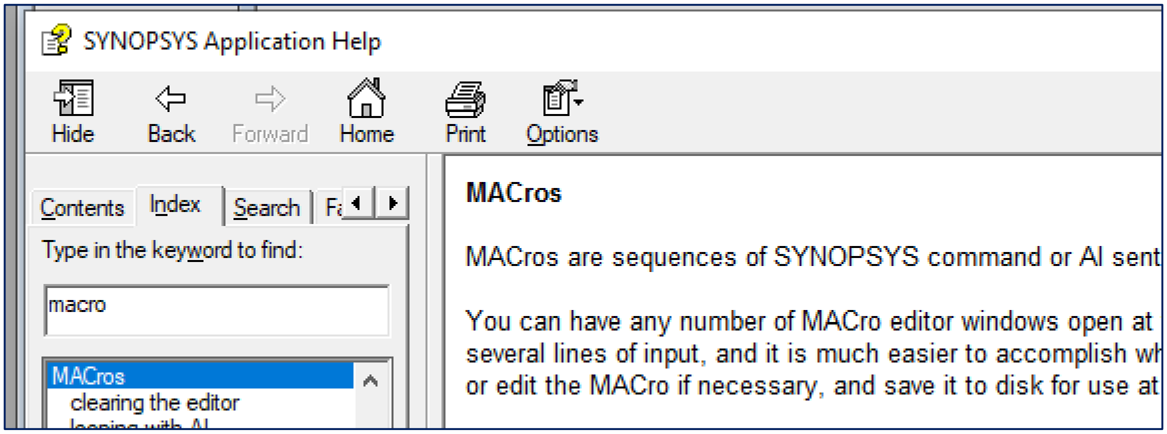
That is a brief introduction in how to use the SYNOPSYS™ lens design software.

- Knowledge of optics theory never hurts.
- But the computer does most of the work.
- It can often find solutions that a 3rd-order study cannot.

APPENDICES

APPENDIX: Macro Files

To read more about the Macros in SYNOPSYS™ , type macro in the Help men to search for the Macros page:



In that page, you will find the description of the macro toolbar buttons:

MACro editor Toolbar: 

 Saves the MACro file with the most recent name and runs it.

 Opens a named MACro.

 Opens a dialog where you can select from a saved MACro file.

 Saves the MACro file, prompting for a new name.

 Saves the MACro with a name equal to the current log number. This does not rename the MACro itself, but only saves a copy with the numeric name. This feature is intended to help you document your lenses. The button appears in two places, on the main window toolbar and on the MACro editor toolbar. When you have run the optimization program and get a lens that you want to save, click on that button in both places. Now you have an RLE file and a MAC file with the same name, making it easy to see how you got there. If you have also run BTOL, the command BTOL SAVE will save a copy of the tolerance budget with the same name and a file type .BTO. This is how you can create a complete record of your work.

 Opens a new MACro window. You can have any number open at a time.

 Erases the contents of the current editor.

 Renames the MACro DEFAULT.MAC. This is useful if you want to make a change and run it without replacing the original MACro on disk.

Commands relating to the manipulation of the Macro files :

The command **LM** filename (Load MACro) will load the named MACro file into an editor. This will use the most recently opened editor window, if any, or a new one if there are none.

The command **LAM** filename (Load Alternate MACro) will load the named MACro file into a new editor window. This will not alter any other editor windows that may be open.

.

The command **EM** filename (Execute MACro) will immediately execute the named MACro without opening an editor.

The command **EAM** filename (Execute Alternate MACro) will immediately execute the named MACro without opening an editor. This form uses the alternate memory, which leaves intact the main MACro memory. Its main use is within a MACro, to permit that MACro to call another as a subroutine so that control will return when the other has finished. Placing an EM command inside a MACro (instead of EAM) would execute (and overwrite) that MACro, and would not then return.

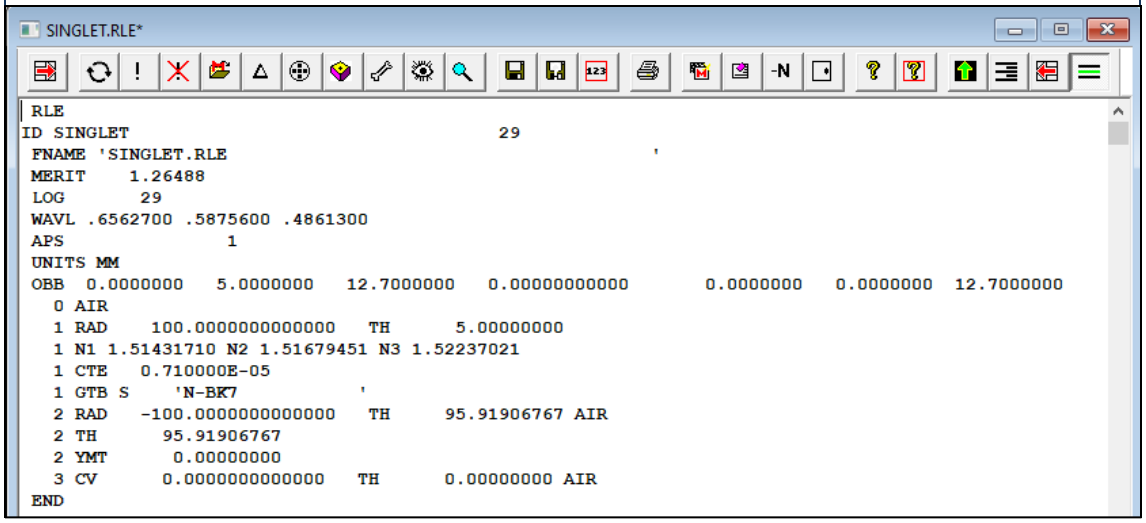
The command **LMM** (Load Menu MACro) will load the MACro editor with the commands that duplicate the most recent action performed by a dialog. This makes it easy to create a MACro that will do what you last did via the dialog. Then you can execute or save that MACro, giving you a convenient way to do that particular task again.

APPENDIX: Editing Lens Data with Lens Editor

In the command line input, key in the command LE (Lens Editor, **User Manual 13.3.3**) to open a dedicated Macro window in which SYNOPSYS™ puts a copy of the lens data in the **RLE** format.

```
SYNOPSYS AI>LE
```

Lens Data of the singlet.rle is displayed in the macro editor




```
RLE
ID SINGLET                             29
 FNAME 'SINGLET.RLE                           '
 MERIT     1.26488
 LOG       29
 WAVL .6562700 .5875600 .4861300
 APS               1
 UNITS MM
 OBB  0.0000000   5.0000000   12.7000000   0.00000000000      0.0000000   0.0000000  12.7000000
   0 AIR
   1 RAD     100.0000000000000    TH      5.00000000
   1 N1 1.51431710 N2 1.51679451 N3 1.52237021
   1 CTE    0.710000E-05
   1 GTB S     'N-BK7            '
   2 RAD    -100.0000000000000    TH     95.91906767 AIR
   2 TH       95.91906767
   2 YMT       0.00000000
   3 CV       0.0000000000000    TH      0.00000000 AIR
 END
```

To make changes to the lens data, you can just change it in place in the Lens Editor by keying in the new data to replace the old one. Or, you can do the same by commenting out the current line and inserting a new line with new data. Then you can click the run button to update the lens.

For example, to change the RAD (radius of curvature) of the 2nd surface from -100 to -50, you will first add an exclamation mark in front of the RAD command line for the 2nd surface to comment it out. Then you will insert the new RAD line below it:

```
RLE
ID EXAMPLE SINGLET                            181
 LOG      181
 WAVL .6562700 .5875600 .4861300
 APS               1
 UNITS MM
 OBB  0.000000      5.00000      12.70000      0.00000
0.00000      0.00000      12.70000
   0 AIR
   1 RAD     100.0000000000000    TH      5.00000000
   1 N1 1.51431710 N2 1.51679451 N3 1.52237021
   1 CTE   0.710000E-05
   1 GTB S     'N-BK7            '
!  2 RAD    -100.0000000000000    TH     95.91906767 AIR
   2 RAD    -50.0000000000000    TH     95.91906767 AIR
   2 TH       95.91906767
   2 YMT       0.00000000
   3 CV       0.0000000000000    TH      0.00000000 AIR
 END
```

Another way to modify the lens data is by using the CHG (Change) file construct in SYNOPSYS™
(**User Manual: 3.6.1 The CHG file):**

To use **CHG**, enter an input file of the following form:

```
CHG
    (data entry lines)
END
```

CHG lines must be in the same format as members of an RLE file. The new values given for a surface parameter replace the old values. If a surface number entered in a **CHG** file exceeds the highest number previously in the lens, the corresponding surface is added to the lens. Surfaces not mentioned in the **CHG** file, and not subject to pickups or solves that are affected, do not change.

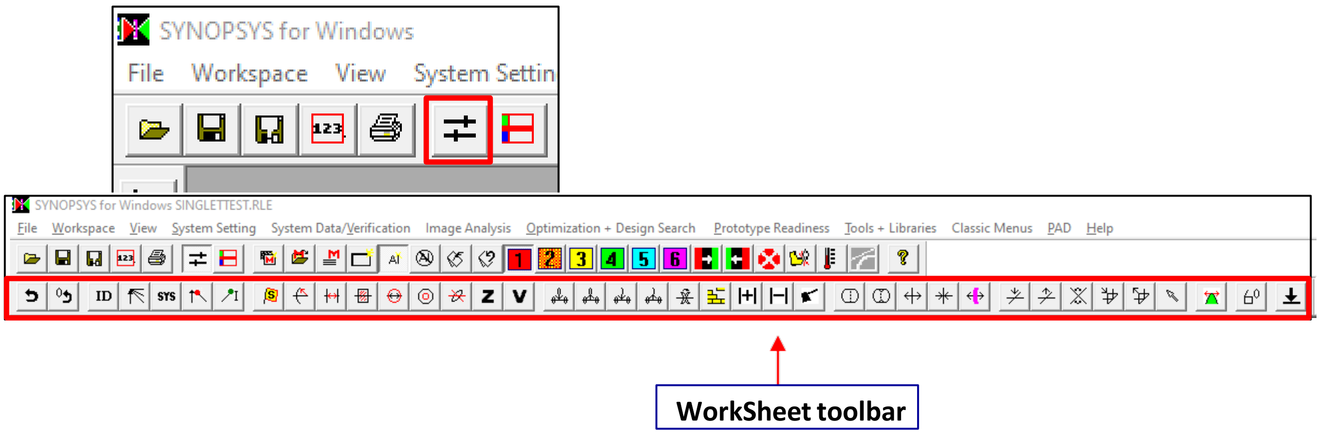
For example, the previous modification to the surface radius can be achieved by the following change file:

```
CHG
  2 RAD -50.0
END
```

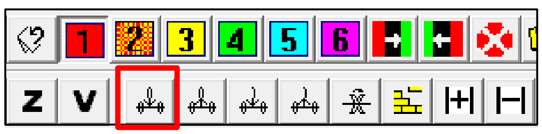
You can enter the commands one by one at the line input of the command window. Or you can put all the commands into one Macro Editor and then run the macro.

APPENDIX: Inserting an Element with WorkSheet

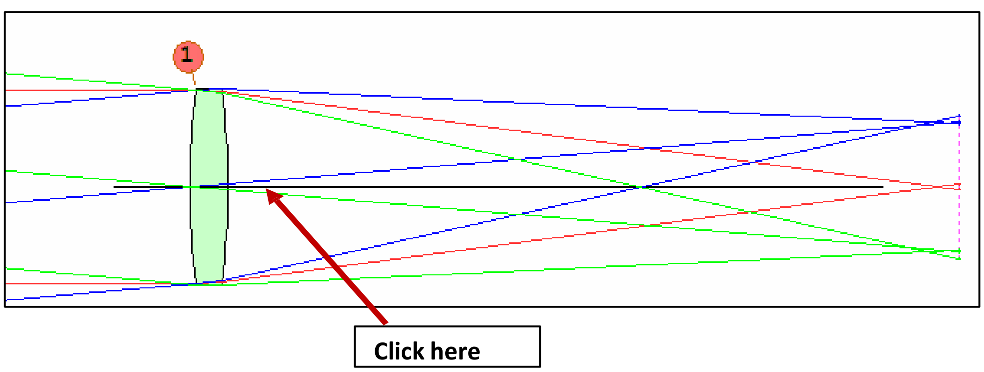
Now we will demonstrate how to insert an element into the current lens system by using the ‘Insert Element button’ in the Worksheet (WS) toolbar.
Open WS by clicking the ‘open worksheet’ butt at the Pad Window or the Command Window top toolbar. Once the Worksheet is open, You will find the Worksheet toolbar underneath the Command Window top toolbar. You can hover your cursor above each button to read its functionality.



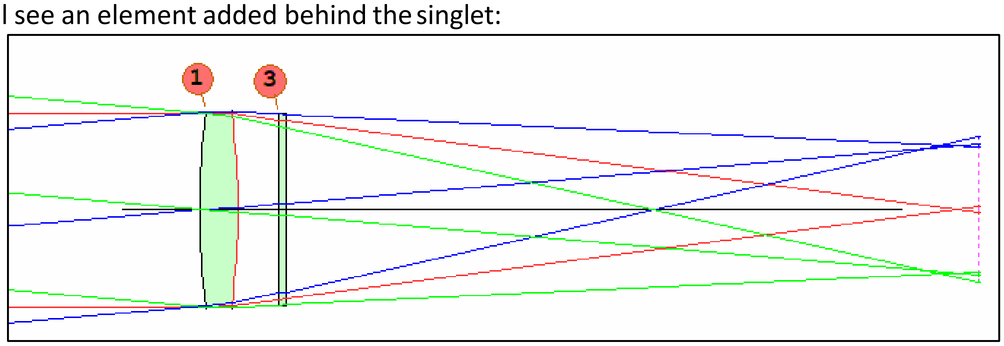
Click the ‘insert an element’ button in the WS toolbar.



Move your cursor into the SketchPad and you will notice that it turns into a small lens element symbol. Click behind the first element, on the axis, to add the new element.



Then you will see an element added behind the singlet:



You’ve just added an element to the lens with WS.

Type LE in the command window to open the Lens Editor. This is your lens data file after adding the glass plate:

```
 RLE
ID EXAMPLE SINGLET    !Set Lens system     181
 LOG       181
 WAVL .6562700 .5875600 .4861300
 APS                  1
 UNITS MM
 OBB  0.000000      5.00000     12.70000      0.00000
0.00000       0.00000     12.70000
   0 AIR
   1 RAD     100.0000000000000    TH       5.00000000
   1 N1 1.51431710 N2 1.51679451 N3 1.52237021
   1 CTE    0.710000E-05
   1 GTB S     'N-BK7           '
   2 RAD   -100.0000000000000    TH       2.13098425 AIR
   3 CV  1.0000000000000E-04    TH       1.00000000
   3 N1 1.51431710 N2 1.51679451 N3 1.52237021
   3 CTE    0.710000E-05
   3 GID 'N-BK7            '
   3 PIN     1
   4 CV  1.0000000000000E-04    TH      93.78808180 AIR
   5 CV       0.0000000000000    TH       0.00000000 AIR
 END
 PAD
```

Glass Plate Surfaces

You notice that the index for the glass plate is the same as the singlet (a N-BK7):

```
  1 N1 1.51431710 N2 1.51679451 N3 1.52237021
  3 N1 1.51431710 N2 1.51679451 N3 1.52237021
```

When you add a new element to the system, the program has no information yet for the index of element 2, so it assigned a pickup of the index of element 1 indicated by the PIN (pickup index) command on surface 3:

```
  3 PIN  1
```

Note:
You can also view the list of pickups and solves in effect in the system, type **POP** (Print Options) in the SYNOPSYS™ command window.

```
SYNOPSYS AI>POP

SUMMARY OF SURFACE CHARACTERISTICS AND ACTIVE OPTIONS

SURF RSPC SURFACE SPECIFICATION          INSPC MEDIUM SPECIFICATION
1   1 RD                       -1 SCHOTT
2   1 RD                        4 AIR
3   2 CV                        3 PICKUP
4   2 CV                        4 AIR
IMG 4 FLAT SURFACE                     4 AIR

SOLVES, PICKUPS, AND OPTIONS

3 PIN 1
SYNOPSYS AI>
```

index pickup

We want to make the following changes to the system:

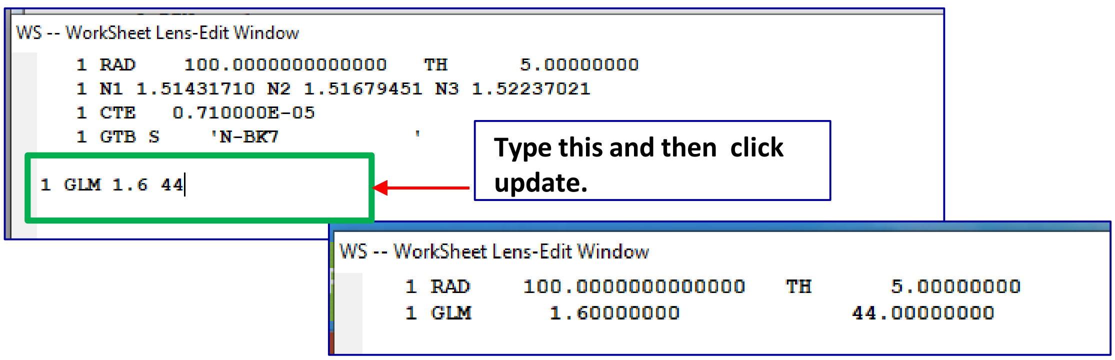
- Remove the index pickup so that the index for the new element is free to vary during optimization.
- Change the index for the two elements. Both elements are currently assigned with an index and V- number corresponding to the Schott BK-7, which sits very close to the boundary of the crown glass in a standard glass map. In this example, we are going to use the optimization method to drive the two elements (with same index and V-number) into a crown-flint doublet. If we start with both elements sitting very close to the crown class boundary, there is not much room for the glass models to move in order to get to the desired configuration (1st glass is a crown glass, and 2nd a flint). Therefore, we want to move the starting point closer to the center of the glass map for the optimization process to move the two glasses in opposite directions.

There are many ways to make these changes:

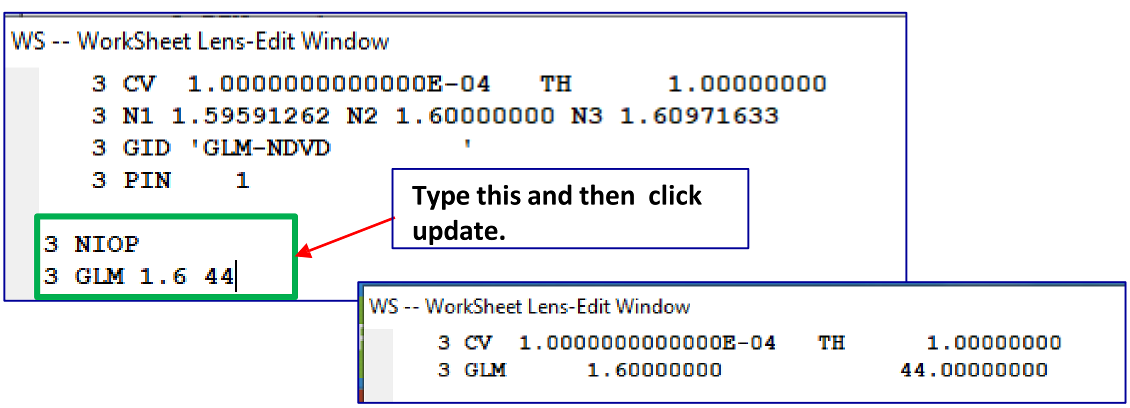
1. Enter a Change (CHG) file in the command window input line or in the Macro Editor (and run):

```
CHG
  1 GLM 1.6 44
  3 NIOP
  3 GLM 1.6 44
END
```

2. Or you can do the changes In WS:
   i. Go to page 1 in WS, in the editor pane, type **`1 GLM 1.6 44.`** Then click update. The surface glass characteristic will be updated to be a Glass Model (GLM)



   ii. Go to page 3 in WS, in the editor pane, type the commands as shown below and then click update.



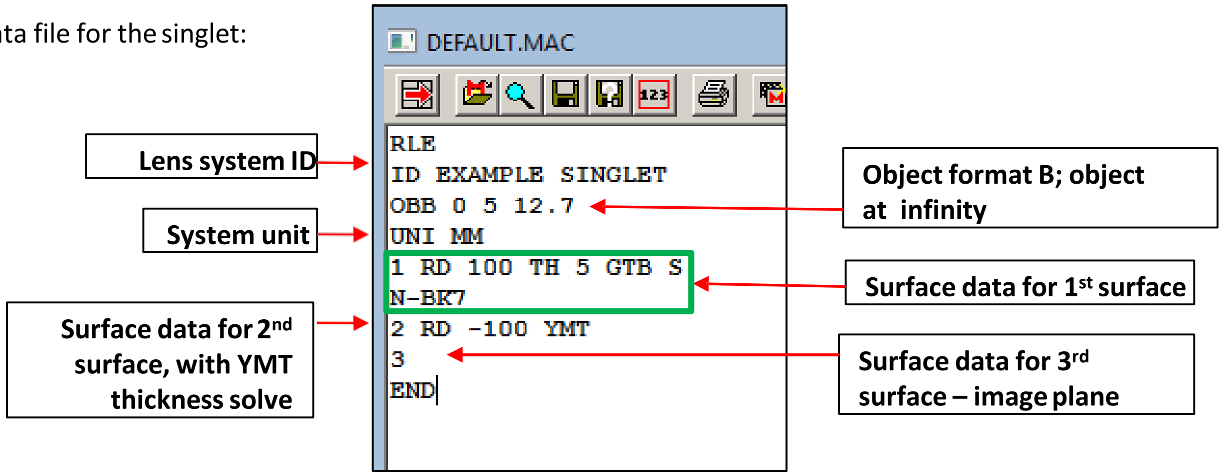
Note:

1. **SN NIOP** is a SYNOPSYS™ command: it removes any index pickup or index calculation (from a GTB, GLM, GLASS, or GDF request). **SN** is the surface number.
2. You can also try to use the WS to continuously change the glass model using the slider. In WS, highlight the 1st number in the glass model (i.e., the index). Click the SEL (select) button. The 1st slider now is assigned to the index. You can change the index of the glass using the slider and see how the system changes in real time. Before you slide it, it is a good practice to first make a check point for the original system so that you can always go back. Things can go crazy easily with the slider.

APPENDIX
Singlet Lens Data File Commands Explained

(Similar but Simplified descriptions on the topics can be found in the System Settings Menu of the User Manual of Ui-Plus)

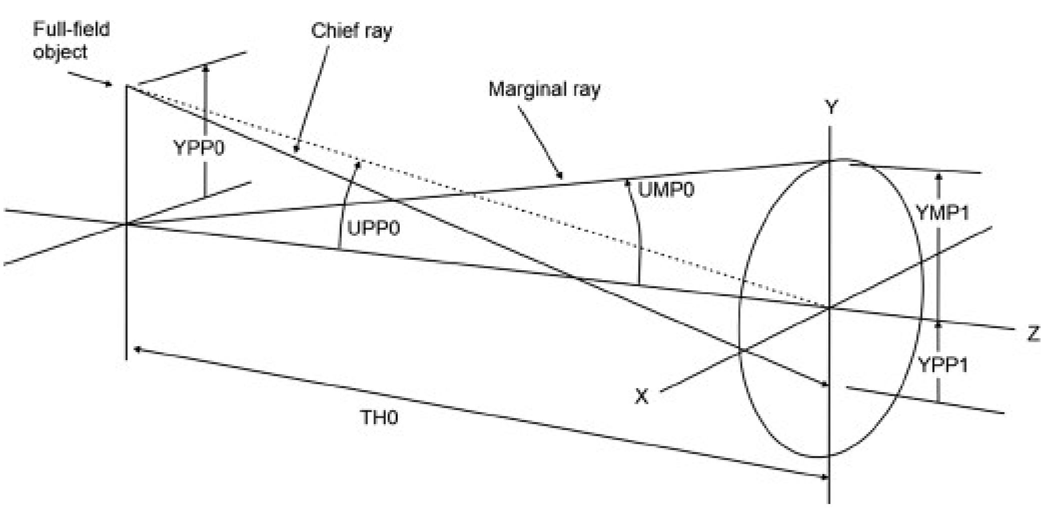
Lens data file for the singlet:



1. OBB (B-type object) syntax (**User Manual 3.1.1 Object Input Description)**:

OBB <u>UMP0</u> <u>UPP0</u> <u>YMP1</u> [<u>YP1</u> <u>UXP0</u> <u>XP1</u> <u>XMP1</u>]

<u>YMP1</u>	axial marginal ray height on surface 1 vertex plane.
<u>YP1</u>	principal ray height on surface 1 vertex plane.
<u>XP1</u>	principal ray height on surface 1 X-axis, from the object at XP0 or UXP0
<u>XMP1</u>	X-dimension of axial marginal ray
<u>UMP0</u>	paraxial marginal ray angle in degrees. Used chiefly for infinite conjugate, for which UMP0 = 0.
<u>UPP0</u>	field angle in degrees of object on Y-axis, measured at the vertex of surface 1. The value must be non-zero.
<u>UXP0</u>	paraxial chief ray angle in degrees for object on X-axis, measured at the vertex of surface 1



Note: SYNOPSYS™ uses Left Hand Coordinate as default. For more on this, see **User Manual 2.4 Coordinate systems.**

2. Surface Data Input

The general syntax for surface data input is:

```
SN opt1 opt2 opt3…
```

where SN is the surface number, and some of the available options are listed below:

Curvature options:
Format: **SN option**
Where **option** is one of the following:

NULL
SPH
RD NB
RAD NB
CV NB
NCOP
PCV NB [M [B]]
UMC NB
UPC NB
YMC NB
YPC NB
VMC NB
VPC NB
XMC NB
XPC NB
AMY
APY
CCY
IMY NB
IPY NB
AMX
APX
CCX
IMX NB
IPX NB

NDEF
DC1 G1 G3 G6 G10 G16
DC2 G2 G4 G5 G7 G8 G9
DC3 G11 G12 G13 G14 G15 G17
AT1 G1 G2 G3 G4
AT2 G5 G6 G7 G8
AT3 G9 G10 G11 G12
AT4 G13 G14 G15 G16 G17
GRATING { X / Y } L/MM ORDER
CC NB
B NB
A NB
TORIC RX
ASTORIC RX
BICONIC KX KY
NCZONE COSPHI
BRD B A C
FRESNEL
USSHAPE TYPE

Thickness options:

SN TH NB
SN PTH NB [M B]

SN YMT NB
SN YPT NB
SN XMT NB
SN XPT NB

SN NTOP

Glass and index options:

SN GTB { S / O / H / C / F / U / G / R } / type

SN { AIR / VACUUM }
SN NIOP
SN PIN NB

Examples of index input:

2 AIR
5 N13 836505 846663 872041
12 GTB S
K5
14 GTB S "SF16"
33 GLM 1.517 64.5

3. YMT Paraxial solves

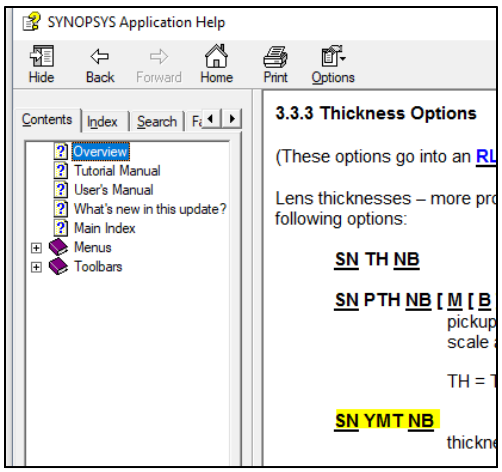
(Similar but Simplified descriptions on the topics can be found in the Thickness Editor Menu of the User Manual of Ui-Plus)

paraxial solves, an important concept that will be used frequently. When a solve is defined, the program will calculate the actual curvature or thickness so as to satisfy a paraxial requirement, and you do not then give it a value yourself.

When we select the YMT solve, SYNOPSYS™ finds the thickness (T) such that the height (Y) of the marginal paraxial ray (M) will be the requested value (zero) at the next surface. In other words, surface 3 will be at the paraxial focus. This is an example of **paraxial solve.**

There are many kinds of solves (see the Table below). Whenever you want to learn about one, or read about any other term used in this guide, we can use the Help file. For example:
Type HELP YMT in the Command Line will open the Help page for YMT:

```
SYNOPSYS AI>HELP YMT
```



List of Paraxial Solves in SYNOPSYS™

	Curvature solves:
UMC NB	U is a paraxial angle
UPC NB	Y is a paraxial height
YMC NB	M is the marginal ran
YPC NB	P is the principal ray (the chief ray)
APC	C designates a curvature solve
CCC	T is a thickness solve
YMT NB	Thickness solves
YPT NB	

APPENDIX
Optimization Introduction

(Similar but Simplified descriptions on the topics can be found in the Optimization Menu of the User Manual of Ui-Plus)

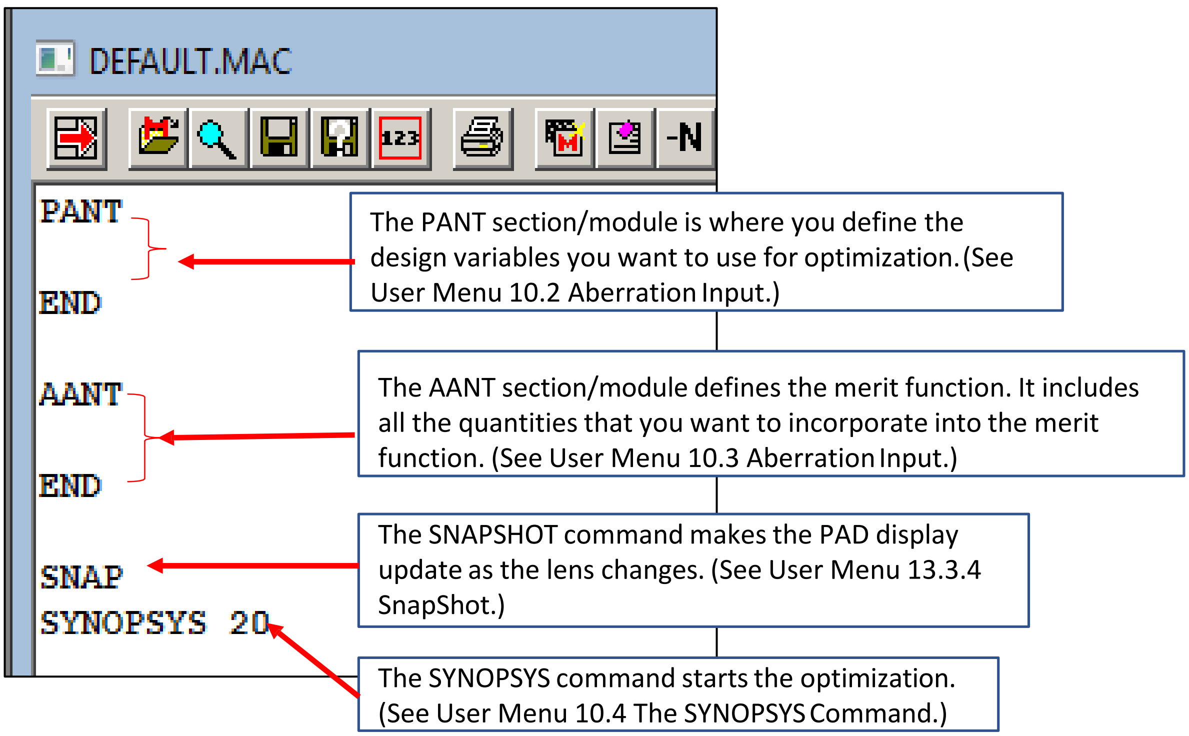
In this appendix, we will give a brief introduction to the optimization method in SYNOPSYS™ .
We will discuss:

1. The optimization PArameter iNpuT (PANT) file/module
2. The optimization AberrAtion iNpuT (AANT) file/module
3. Ready-made merit function

The optimization program can be used for lots of things, not just improving the image. For example, you can constrain the mechanical characteristics of your systems such as total length by including a length target in your merit function.

Optimization is usually done by a set of special commands to be entered, edited, and saved as a Macro. You can modify and run the MACro as often as you want. Unlike other optical design software, you can save the optimization macro as a different file without the lens data. In SYNOPSYS™, lens description data is saved in the .RLE file and can be launched separately from the optimization macro.

Here's the structure of an optimization macro:



1. PANT section/module, to declare optimization variables
2. AANT section/module, to define the merit function, which can include the following quantities:
   - Optical ray aberrations.
   - Mechanical constraints; for example,
     - Aperture limits
     - Length limits
     - Paraxial properties not controlled by a solve
     - Etc.

1. The PANT (Parameter iNpuT) file includes all the design variables for optimization. Below is a list of available parameter inputs. All the inputs need to be enclosed between the keywords PANT and END. You can choose from the list to define your optimization parameters. For more details, see User Manual 10.2 Parameter Input.

```
PANT [P]
[ RDR FRACTION ]
[ CBOUNDS ND1 VD1 ND2 VD1 ]
[ FBOUNDS ND1 VD1 ND2 VD1 ]
[ CLIMIT UPPER LOWER ]
[ TLIMIT UPPER LOWER ]
[SLIMIT UPPER LOWER ]
[ CUL CROWNLIMIT ]
[ FUL FLINTLIMIT ]
[ CLL CROWNLLIMIT ]
[ FLL FLINTLLIMIT ]

VY SN parameter [ UPPER LIMIT LOWER LIMIT [ INCREMENT ] ]
VLIST parameter SN SN SN …
VLIST RAD ALL [ EXCEPT SN SN SN …]
VLIST CSUM ALL [ EXCEPT SN SN SN …]
VLIST CDIFF ALL [ EXCEPT SN SN SN …]
VLIST TH ALL
VLIST TH ALL EXCEPT SN SN SN …
VLIST TH ALL OVER VALUE
VLIST TH ALL OVER VALUE EXCEPT SN SN SN …
VLIST TH ALL GLASS
VLIST TH ALL GLASS EXCEPT SN SN SN …
VLIST TH ALL GLASS OVER VALUE
VLIST TH ALL GLASS OVER VALUE EXCEPT SN SN SN …
VLIST TH ALL AIR
VLIST TH ALL AIR EXCEPT SN SN SN …
VLIST TH ALL AIR OVER VALUE
VLIST TH ALL AIR OVER VALUE EXCEPT SN SN SN …
VLIST GLM ALL [ EXCEPT SN SN SN …]
VLIST CC ALL [ EXCEPT SN SN SN …]
VLIST G ALL [ EXCEPT SN SN SN …]
VY SN NURBS
VY SN XNURBS
VY SN ZERNIKE [ SYMM / RSYMM / NLSYMM ]
VY SN DOE [ SHAPE ] [ UPPER LIMIT LOWER LIMIT INCREMENT ]
VY SN DCA [ SYMM / RSYMM ]
END
```

- The keyword VLIST means 'Vary a LIST' of parameters. For example, VLIST RAD ALL means to vary the radius of curvature for all the surfaces in the system.
- The keywork VY means VarY one parameter on one surface. For example, VY 1 RD means to vary the radius of curvature for surface 1.
- The VLIST optionsutilizes default limits and increments for variables so entered.
- To modify the default limits and bounds, you can use the commands enclosed in the green square to do so. The upper and lower limits give the range through which the parameter is allowed to move. The RDR fraction command is used to control the increment for calculating the derivative with the finite difference method.
- In the default mode of SYNOPSYS™ , the optional [P] on the PANT line has no effect. This mode gives the minimum amount of printout during optimization, and automatically includes a listing of the input data for PANT and AANT (see 10.3). If mode switch 29 is turned off (see 10.5), the program will examine the PANT command for the [P] and will echo the input if this is present. If the P is not present it will print a more lengthy, but readable, record of all

variables for the run. In other words, if you want a very short listing, turn on switch 29. For an input echo, turn off 29 and include the P, and for a longer summary leave the P off as well.

- One can exclude surfaces from the ALL variables by declaring them following the EXCEPT mnemonic, which is in word 4 of the line.
- For the command 'VLIST parameter **SN** **SN** **SN** …', the keyword parameter is taking from one of the following list:

RD, RAD or CV	VZN	AG	AL
TH		BG	BL
INDEX	AP1 NB	GG	GL
VD	AP2 NB	XG	XL
GLASS or GLM	TH0	YG	YL
GBF	YP0	ZG	ZL
GBC	YMP1	AT NB	XDC NB
ASPH	YP1	BT NB	YDC NB
CC	LHG NB	GT NB	ZDC NB
ACCOMMODATE	RHG NB	BTH	GC NB
ZDATA NZOOM	CAO	G NB	GOUT
XP1	XMP1	XE	YE
ZE	AE	BE	GE
GPA	GPB	GPG	ZTH0
PTH0	UP0	UB0	
CSUM	CDIFF	CAX	CAY
PGM			

2. The AANT (AberrAtion iNpuT) file includes all the aberration terms to be considered in the merit function for optimization. For a more complete discussion, please refer to the User Manual 10.3 Aberration Input and Tutorial Manual ch. 6 Optimization with SYNOPSYS™ . The aberration terms can be classified into three categories in accordance to their distinct syntax:
   A. Automatic generation of ray aberrations (ray grid aberrations)
   B. User-specified aberrations
   C. Optimization monitors

This is an exemplary AANT file:

AANT		**Catagory**
AEC	**Automatic Edge Control**	**C. Optimization monitor**
GSR .5 2 5 2 0	**Corrects 5 rays in color 2, on axis**	**A. Auto ray grid aberration**
GNR .5 1 4 1 1	**Ray grid, color 1, full field**	**A. Auto ray grid aberration**
GNR .5 1 4 2 1	**same, color 2**	**A. Auto ray grid aberration**
GNR .5 1 4 3 1	**and color 3**	**A. Auto ray grid aberration**
M 0 10 A 1 YA 1 S 3 YA 1	**Corrects chromatic aberration. The rays in colors 1 and 3 at full field should have the same Y-intercept (YA), with a weight of 10.**	**B. User-specified aberration**
END		

Note:
We can also classify all the aberrations in accordance to their physical properties. For example:
- Ray-based aberrations, including transverse coordinates and OPD’s
- Paraxial aberrations
- Construction parameter aberrations
- Diffraction MTF aberrations

You can also construct **composite aberrations** by combining different aberration terms. (See **User Manual 10.3**)

Automatic Ray Grid Aberration:

The automatic ray-generating feature constructs a ray pattern of a selected type and adds selected properties of the rays to the merit function. The target and weight of each ray or blur size is assigned by the program according to the rules implied in the pattern mnemonic. Input consists of one or more of the following lines:

	GNR RT WT DEL ICOL HBAR GBAR [SN [F [XWT]]]	transverse coordinates
	GXR RT WT DEL ICOL HBAR GBAR [SN [F]]	only correct XC coordinates
	GYR RT WT DEL ICOL HBAR GBAR [SN [F]]	only correct YC coordinates
	GSR RT WT DEL ICOL HBAR GBAR [SN [F]]	sagittal fan only, correct XC
	GTR RT WT DEL ICOL HBAR GBAR [SN [F]]	tangential fan only, correct YC
	GPR RT WT DEL ICOL HBAR GBAR [SN [F [XWT]]]	errors from principal ray
	GNO RT WT DEL ICOL HBAR GBAR [0 F]	OPD targets
	GSO RT WT DEL ICOL HBAR GBAR [0 F]	sagittal fan only
	GTO RT WT DEL ICOL HBAR GBAR [0 F]	tangential fan only
	GPO RT WT DEL ICOL HBAR GBAR [0 F]	reference at principal ray
	GO2 RT WT DEL ICOL HBAR GBAR [0 F]	OPD targets squared
	GNN 0 WT DEL ICOL HBAR GBAR [SN]	correction to centroid
	GNV 0 WT DEL ICOL HBAR GBAR [0 F]	wavefront variance
	GPV 0 WT DEL ICOL HBAR GBAR [0 F]	reference at principal ray
	GTP RT WT DEL ICOL 0 0 SN	pupil aberrations on surface SN
	GDR 0 WT DEL [ICOL / P] HX HY [0 F]	array to correct distortion. **HX** and **HY** give the target XA and YA for the chef ray at full field in X and Y. If XPP0 is zero, only targets in Y are considered. If "F" is in word 9, both positive and negative GBARs are corrected. (This form does not support color "M".)
	GSHEAR SHEAR WT DEL ICOL HBAR GBAR [X / Y [F]]	See below.

Gxy:
x = N -> 2D raygrid
x = S/T -> Sagittal/Tangential ray fan
x = P -> reference to principal ray

Gxy:
y = R -> ray fan aberration (transverse)
y = O -> OPD
y = V -> wavefront variance

- For **GNR** requests, each ray is traced only once even though two aberrations are generated (XC and YC).
- If **GNO** is entered, a single aberration, namely the OPD of the ray, is generated for each ray.
- **GSR** and **GTR** generate rays in the sagittal or tangential fan only.
- **GPR** and **GPO** define the ray error with reference to the *principal* ray location, rather than the chief ray. (The chief ray is always taken in the primary color, while the *principal ray* is in the color of the rayset.) This is useful for designing spectrometers, where the images in several colors are widely separated.
- The chief ray is always taken in the primary color, while the *principal ray* is in the color of the rayset. This is useful for designing spectrometers, where the images in several colors are widely separated.
- **XC/YC** is the X/Y coordinate of the ray with respect to that of the chief ray in the primary color (see next slide for discussion on primary color).

GNN corrects the rays relative to the centroid of that set of rays rather than to the chief ray intercept, and always traces over the full pupil (since the centroid of a pencil over only half the pupil is itself decentered and would be inappropriate). While **GNR** generates two aberrations for each ray, **GNN** generates only one aberration for the whole set: the mean squared spot size measured from the centroid. For best results, a lens should be optimized as far as possible with individual ray aberrations or **GNR** requests, and the **GNN** option used only to peak up the final image. The **GNN** option also permits the centroid coordinates to be controlled explicitly. (See section 10.3.3.) Since the GNN option ignores the location of the chief ray, it will not automatically control later color, and specific targets should be added for that purpose.

GNV causes the variance in the wavefront to be computed for all of the generated rays. It is useful in the final stages of a design to peak up the performance. Note that neither **GNN** nor **GNV** honors a nonzero **RT** entry; all rays are weighted equally. The variance is taken relative to a sphere centered at the primary-color chief ray point. The effects of lateral color are therefore corrected automatically if the requested color is not the primary color. For peaking the MTF at a given frequency, the GSHEAR option is superior.

The **GPV** option is similar to GNV, except that the OPD reference sphere is centered at the image point in the requested color. This is the point that minimizes the variance in that color, and it is usually not exactly at the chief-ray point. GPV is useful when you want each color to form a sharp image,but don't care about lateral color, which is not controlled by this option.

GO2 is similar to GNV but is usually more powerful. Although minimizing the variance (with GNV) in principle should maximize the Strehl ratio, it suffers from two defects. First, the variance is not sensitive to the *average* OPD, since it is defined as the average of the squares minus the square of the average. So if both of these are large the program only controls the difference, and the OPDs themselves are not strongly driven toward a value of zero. Also, the process discards the sign information of each OPD. In contrast, GO2 calculates the *square of each OPD* and then assigns the sign of the OPD itself to the result. The net effect is to reduce the sum of the squares of the OPDs, which reduces the variance as well if the average is zero, while at the same time trying to reduce each OPD to zero to make this the case.

GSHEAR is an alternative to MTF aberrations, which work but can only be used when the design is very close to perfect already. GSHEAR also works best if it is already close to a good solution, but it is more forgiving and can be used earlier in the process. This form creates traces two rays for each point in the pattern, sheared in X or Y in the pupil with respect to that point. The purpose is to improve the convolution MTF at the entered shear value. It also accepts colors "M" and "P". The shear value is a fraction of the semi- aperture. Thus, a shear of 1.0 corresponds to the cutoff frequency, and values of 0.5 or less are usually appropriate. The RT value does not apply to this form. Larger shear values produce fewer rays, since rays sheared out of the pupil are ignored.

GTP generates a TFAN of rays all passing through the center of the entrance pupil. The fan in this case is a collection of HBAR points. This feature is used to correct the spherical aberration of the pupil on a given surface. Be warned that if your lens uses any of the wide-angle (WAP) pupil options or the VFIELD, thenthe chief rays will in general *not* go through the center of the stop, and using the GTP feature may not make sense.

Brief explanation to the GSR and GNR commands (**10.3.1.1 Automatic generation of ray aberrations):**

- GNR and GSR are the built-in ray grid aberration terms that can be included in the AANT file to construct the merit function.
- **GNR** request will generate a YC and an XC aberration for each ray in a grid, the resolution of which is given by the entry **DEL**. This entry represents the number of partitions to be made to the semi-aperture, as shown below. **GSR** (or **GTR)** generate rays in the sagittal (or tangential) fan only for the correction of XC (or YC). XC (or YC) is the X-coordinate (or Y-coordinate) of the ray with respect to that of the chief ray in the primary color.
- Syntax:

  GNR RT WT DEL ICOL HBAR GBAR

  GSR RT WT DEL ICOL HBAR GBAR

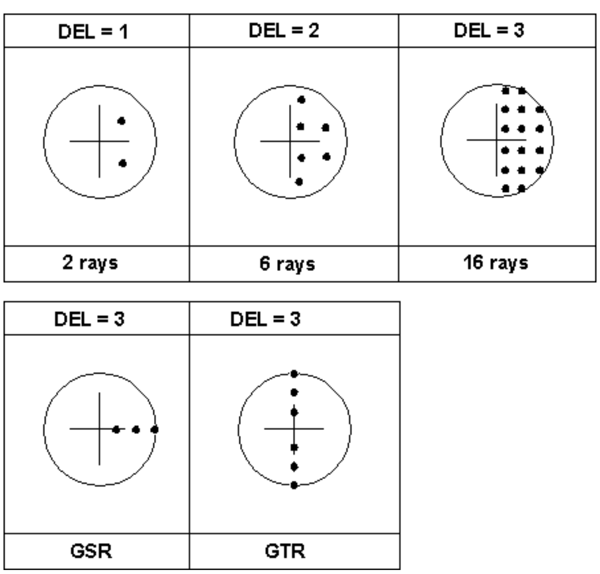
  - **RT** is an aperture-dependent weighting factor which assign different weights to different zone of the pupil according to a preset formula (see **10.3.1.1 Automatic generation of ray aberrations** for more details**)**
  - **WT** defines the weight of the aberration term to the merit function
  - **DEL** defines the resolution of the raygrid (ie, number of rays); see below
  - **ICOL** is the color number: M for multiple color, **P** for the primary color, number 1 stands for the 1st wavelength declare in the system, etc…
  - **HBAR** is the fractional object height in the Y direction
  - **GBAR** is the fractional object height in the X direction

- When you use the letter "**M**" for the **ICOL**, it causes a set of ray aberrations to be generated at all defined colors. If you want different weights on each color, you have to enter separate requests for each one. The multi-color declaration at the left is equivalent to the declaration at the right for a system with 3 wavelengths of equal spectrum weighting:

```
GSR .5 10 5 M 0
GNR .5 2 3 M .7
GNR .5 1 3 M 1
```

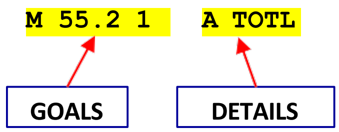
```
GSR .5 10 5 P 0
GSR .5 10 5 1 0
GSR .5 10 5 3 0
GNR .5 2 3 P .7
GNR .5 2 3 1 .7
GNR .5 2 3 3 .7
GNR .5 1 3 P 1
GNR .5 1 3 1 1
GNR .5 1 3 3 1
```

- Illustration of ray grid resolution control (DEL):



B. User-specified aberrations

As shown below, the user-specified aberration always consist of two components: GOALS and DETAILS



Here, the GOALS section says to Minimize to a target value of 55.2 with a relative weight of 1 the quantity in the DETAILS section, in this case the TOTL length of the lens. The "A" in that section means Add this quantity. You may have several items in the DETAILS section, combined with A (Add), S (Subtract), MUL (MULtiply), and DIV (DIVide). For example, to control the sum of thicknesses 4 and 5, you could enter the following commands:

```
M 34.567 A TH 4
A TH 5.
```

Note that the second item in the details (A TH 5) starts in a new line in the following example. But you can also use a '/' to separate the two details and rewrite the last user-specified aberration as

```
M 34.567 A TH 4/A TH 5.
```

The most frequently used format is:

```
M tar wt A aberration
```

It reads as '**M**inimize the *aberration* item **A**dded to the designated *tar* with a weight of *wt*'

Another frequently used format is:

LLL *tar wt wind* **A** *aberration*

This is a one-sided aberration that sets a lower limit (tar) with a weight of wt for the quantity (aberration) in the DETAILS. Similarly

LUL *tar wt wind* **A** *aberration*

sets an upper limit (*tar*) with a weight of *wt* for the quantity (*aberration*) in the DETAILS. For example,

LUL 250 1 1 A TOTL limits the total length to be no larger than 250.

To explain the wind (window) parameter, consider the LUL form first. If the quantity to be controlled is less than tar (target), the aberration is zero because this is an upper limit and we don't care in that case. For values that exceed tar (target), the aberration varies as the square of the departure from tar (target), calculated so that if the excess is just equal to wind (window), the aberration value is equal to wt (weight). So the tar, wt, wind are all connected. You can use this as a guideline to choose the proper value for wind. Nonetheless, you can also use the approach of trial and error to experiment with the wind parameter.

The following table summarizes all the allowable variations for the GOALS. See User Manual 10.3.5.1 Limit Input for the use of the other variations.

GOALS	DETAILS
{ M / L / LIM / MF } TAR WT [SCR / SR] LL A1 F1 A2 F2 C TAR WT [LUL / LLL] TAR WT WIND	{ A / S / MUL / DIV } aberration

You can also use the NAME aname command to add a label to the user-specified aberration. The aname is an optional string of up to 8 characters, consisting of all numbers or starting with a letter with no punctuation marks or spaces within the name. This name will appear on the ALIST and FINAL output to help you identify individual aberrations.

```
[ NAME aname ]

{ { M   }  TAR WT [ SR  ] }
{ { MF  }         [ SCR ] }
{ { C   }                 }
{ { L   }                 }
{ { LIM }                 }
{                         }
{   LL A1 f1 A2 f2        }
{   LUL TAR WT WINDOW     }
{   LLL TAR WT WINDOW     }
```

For the DETAILS section in the user-defined aberration, there are a lot of aberration terms to choose from. See **User Manual 10.3** for more details. Here we only list the format for defining user-specified ray aberrations (**User Manual 10.3.1.2):**

{ A / S / MUL / DIV } { ICOL / P } name HBAR XEN YEN GBAR [SN])

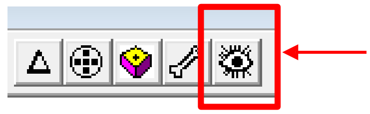
- **A**, **S**, **MUL**, and **DIV** determine how this component of the aberration is to be combined with any previous components to form the combination (added to, subtracted from, multiplied by, or divided into)
- **ICOL** is the color number. You may substitute "**P**" for the primary color, but you may *not* use "M".
- **HBAR** is the fractional object height in the Y direction.
- **XEN** is the fractional entrance pupil coordinate in the X direction.
- **YEN** is the fractional entrance pupil coordinate in the Y direction.
- **GBAR** is the fractional object height in the X direction
- **SN** is the surface number on which the ray intercept is to be computed. The default surface is the image plane. This should not be entered for OPD requests, which are only valid at the image
- **name** is one of the following:

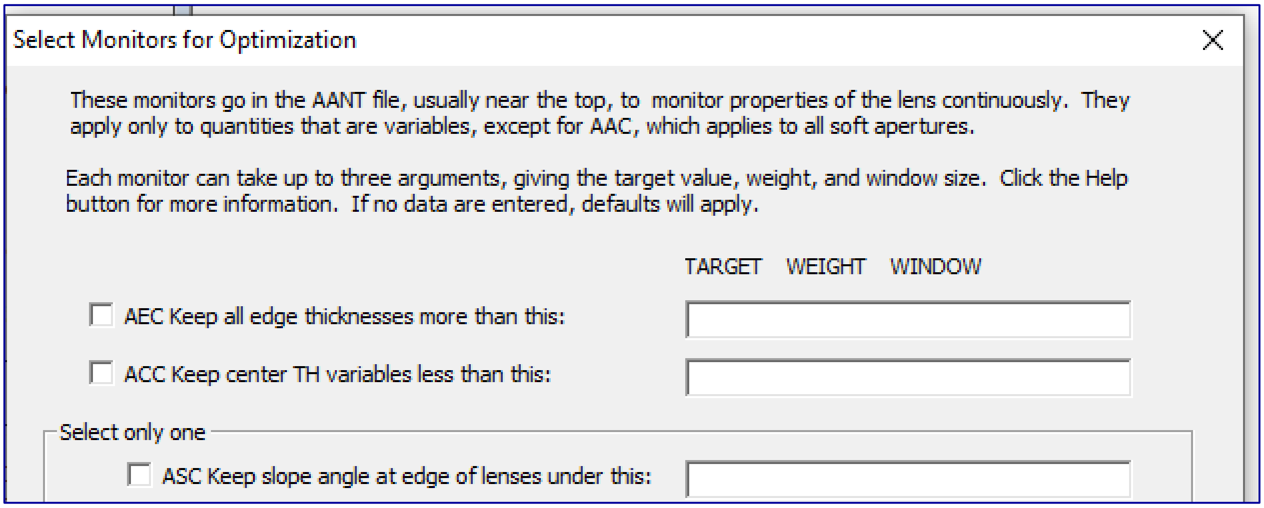
	YA	ZA	RA	XG	XL
	YC	OPD	RC	YG	YL
	YP	OPP	HFREQ	ZG	ZL
	XA	ZZ	HBRAGG	ZZG	ZZL
	XC	HH	HEFFIC	HHG	HHL
	XP	DSLOPE	HSFREQ	FLUX	PL
	XE	YE	ZE	ZZE	HHE
	ERROR	UNI	UNR	OPL	ILLUM

Example user-defined rays:	
M 0 1 A 2 YA 0 0 1 M 0 10 A 1 YA 1 0 0 S 3 YA 1 0 0	M 22 1 A P OPL 0 0 1 0 5 13

C. Optimization monitors (User Manual 10.3 Aberration Input):

The optimization monitors are a set of control that keep certain aspects of the lens from becoming unreasonable. You can use the ‘Monitors’ button in the Macro Editor toolbar to view and select the monitors available in SYNOPSYS™:





AEC to monitor edge thicknesses, where TH is varying.
AGE to monitor edge thickness of glass elements, where TH is varying.
AFE monitors edges, as does AGE, but at the apertures given by EFILE points A and E if defined, or at the CAO if not.
AAE to monitor edge thicknesses of airspaces, where TH is varying.
ACC to control maximum center thicknesses of elements, where TH is varying.
ACM to control minimum center thicknesses, where TH is varying.
ASC to prevent surface slopes from becoming too steep at the rim rays, where CV is varying.
ACS to prevent surface slopes from becoming too steep at the CAO, where CV is varying.
ACA to prevent rays from entering or leaving an element too close to the critical angle, where the CV is varying.
ATC checks the angle from normal of all rays traced by ray errors in the merit function. This is to prevent crItical angle errors if the angle gets too steep.
AAC aperture control, to monitor clear apertures and keep them from getting too large. This applies to all apertures.
AZA to monitor the airspace on both sides, and the edge dimensions, of each zoom group in a ZFILE zoom lens.
ADT to monitor the ratio of lens diameter to thickness.
ADS to monitor the ratio of lens diameter to thickness, adding surface sag to the thickness. This accounts for the greater stiffness of meniscus elements..
AMS to monitor the separation between centers of curvature of meniscus lenses.
ARC to monitor the position of the chief ray within the beam throughout the lens. Each of these has optional parameters to control how they are applied.

D. Ready-made merit function

There are 9 ready-made merit functions that can be accessed using the 'Ready-made merit function(or Rayset)' button in the Macro Editor toolbar.
Most lenses work well with selection 6. This specifies an SFAN of five rays on axis, in three colors, and a grid of three rays in both X and Y at field points 0. 0.7, and 1.0, also in three colors. This option traces more rays than do selections 1 through 5, but will correct for chromatic differences in the aberrations, which the former will not.

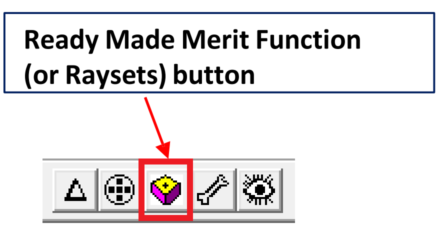
Selections 1 and 2 are for monochromatic systems, while selections 3, 4, and 5 correct three colors by targeting the difference in ray intercept points in the long and short wavelengths, and a grid or fan of rays in the primary color.

Selection 5 has a finer grid than selection 4 and is useful when the lens shows high-order aberrations. Selections 1

and 3 correct the image at just the on-axis point.

Selection 7 is intended for systems without axial symmetry. It traces over both halves of the pupil, and corrects the on-axis point as well as the full-field points in both HBAR and GBAR. You will probably want to add several more field points to the merit function if you select this option, but this depend on the characteristics of your lens.

Number 8 is intended for systems near the diffraction limit. It is often a good idea in that case to include a combination of both transverse aberrations and OPD targets in the merit function. But the relative weights must be carefully adjusted: an OPD error of one wave is usually much better than an image blur of one inch. So the program finds a useful weighting for the OPD errors, based on the current F/number of the lens and the wavelength. You are of course encouraged to adjust the resulting weights as you see how things progress during optimization.



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