

Optimization Tutorial Using OSLO Standard or Premium

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INTRODUCTION

Note: Parts of this tutorial are very similar to the "Optimization Tutorial Using OSLO Light." This has to be the case in order for each tutorial to stand on its own. If you are reading both tutorials, please be aware that steps #1 through #16 are exactly the same and could be skipped in one of the tutorials.

Optimization is the process by which the performance of a lens system is improved by changing the values of some of the lens data (variables) such that a measure of lens performance is improved. This measure of lens performance comes in the form of an error function or merit function.

An error function is a list of targets that OSLO tries to minimize during optimization (when the error function is minimized the lens is improved). When the total value of the error function is as small as it can be, then the system has been fully optimized and is as good as it can be. If the targets (operands) that make up the error function are not exactly zero then the error function has some residual error associated with it. Since the error function is the composite of the individual targets, in a way it is a measure of the composite error of the system - hence the name error function.

This tutorial will consist of performing additional optimization on a lens design form called the "Cooke" triplet. As a historical note, the name of the lens design form comes from the Cooke company which was involved in the initial invention of the Cooke triplet design form. The exact prescription of the lens that we will use (the surface curvatures, glasses and thicknesses) is an adaptation of a design done by R. Kingslake and included in his book "Lens Design Fundamentals," pp286-295, (Acadmeic Press 1978, ISBN 0-12-408650-1). The Cooke triplet design form has been used in millions of low cost cameras, projectors, and various other instruments. We will be using the Cooke Triplet as the starting point of our optimization.

Lenses like the Cooke triplet are typically designed for film cameras. The Cooke triplet lens prescription supplied with OSLO has a 50mm focal length, which suits the 24x36mm format used for 35mm cameras. The lens is not optimum for a typical digital camera, which has a smaller image size, because the focal length is too long. In this example we will redesign the lens to have a focal length of 10mm which is more suited to contemporary digital cameras. In addition, we will make the lens faster (re-design the lens to a lower f/number) so that the paraxial specifications become 10mm EFL, f/2.8 and +/-20 degrees field angle.

OUTLINE

The steps in this tutorial are as follows:

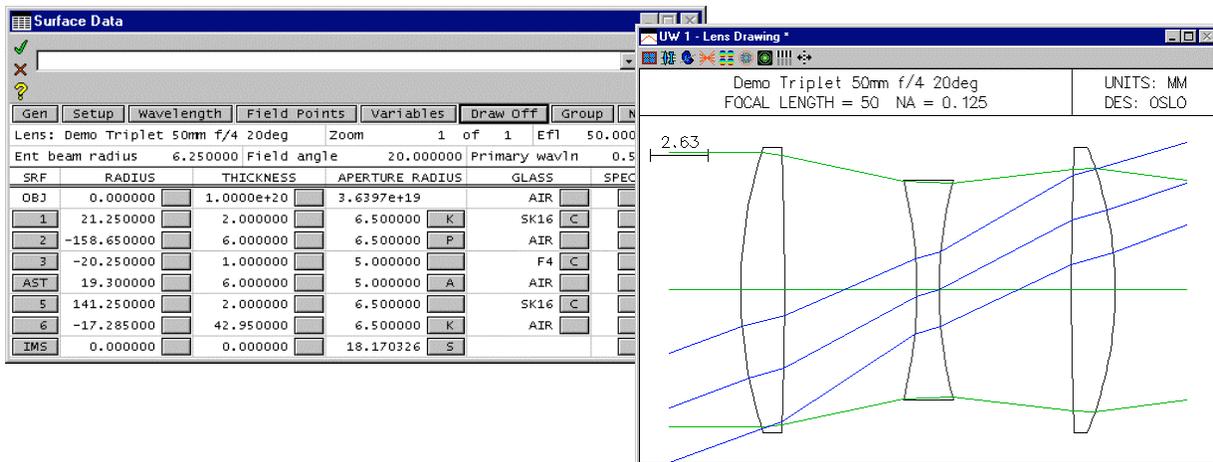
- **Lens Entry** - Create a starting lens that will be used for both optimization approaches in this tutorial.
 - Open the "demotrip.len" lens file.
 - Scale the entire lens to an effective focal length (EFL) of 10mm.
 - Change the Entrance Beam Radius so that the system now has an F-number of f/2.8.
 - Change the apertures radius of all the surfaces to 1.8 so that the larger beam can get through.
 - Increase the thickness of the first and third lens elements to 0.7mm. Increase the thickness of the center lens element to 0.3mm.
 - Apply a solve on the curvature of surface 6 so that the system EFL of 10 is maintained. As soon as you have applied the solve, remove the solve once again so that the EFL is not continually updated.
 - Set variables that vary all curvatures and all air spaces.
 - Update the title of the lens and save the lens as "Triplet10mm_Start.len" in your private directory.

- **Optimization using the GENII Error Function**
 - Perform the Ray Intercept Curves (RIC) Report Graphic analysis as a baseline analysis of current system performance. Lock the graphic window against inadvertent updating.
 - Generate the GENII Ray Aberration Error Function operands.
 - Save the lens as "Triplet10mm_OptGeniiStd.len" in your private directory.
 - Optimize the lens system.
 - Perform the RIC Report Graphic analysis in a new graphic window to compare with the baseline analysis. Lock the graphic window against inadvertent updating.
 - Save the lens with the same "Triplet10mm_OptGeniiStd.len" file name.

- **Optimization using the OSLO Spot Size / Wavefront Error Function**
 - Restore "Triplet10mm_Start.len" from your private directory.
 - Generate the OSLO Spot Size / Wavefront Error Function operands.
 - Correct color using Conrady's D-D method.
 - Control distortion to <0.5%.
 - Keep other defaults.
 - Save the lens as "Triplet10mm_OptOSLO_SS.len" in your private directory.
 - Optimize the lens system.
 - Perform the RIC Report Graphic analysis in a new graphic window to compare with the baseline analysis. Lock the graphic window against inadvertent updating.
 - Save the lens with the same "Triplet10mm_OptOSLO_SS.len" file name.

DETAIL

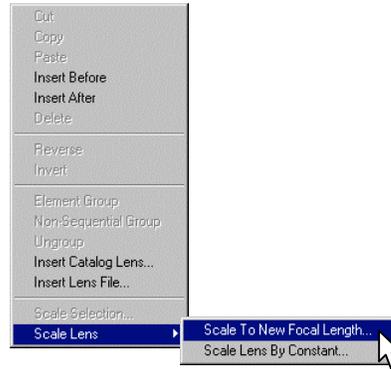
Lens entry



- 1) Open the lens file located at "...\\public\\len\\demo\\LT\\demotrip.len".
- 2) If it is not already open, open the surface data spreadsheet by choosing "Len>>Surface Data Spreadsheet" from the OSLO menu.

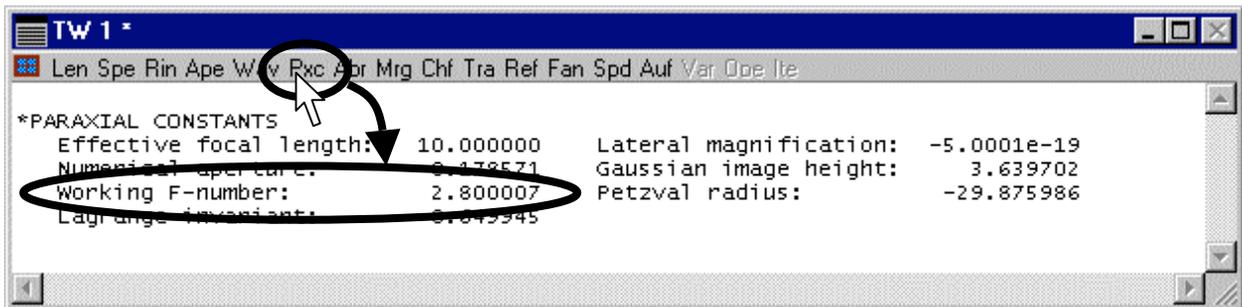
If you have a lens that is a good starting point except for its focal length, it is usually not a wise idea to force the lens to the new focal length through optimization.. Instead, it is better to simply scale the entire lens to the new focal length - of course this will also scale apertures, curvatures and thicknesses as well.

- Right click the mouse in any white cell of the surface data spreadsheet and choose "Scale Lens>>Scale Lens to New Focal Length..." from the resulting pop-up menu and scale the lens to a focal length of 10.



Note: The current system has an f/number of 4.0. To achieve an f/number of 2.8 you need to increase the system aperture by 4.0/2.8

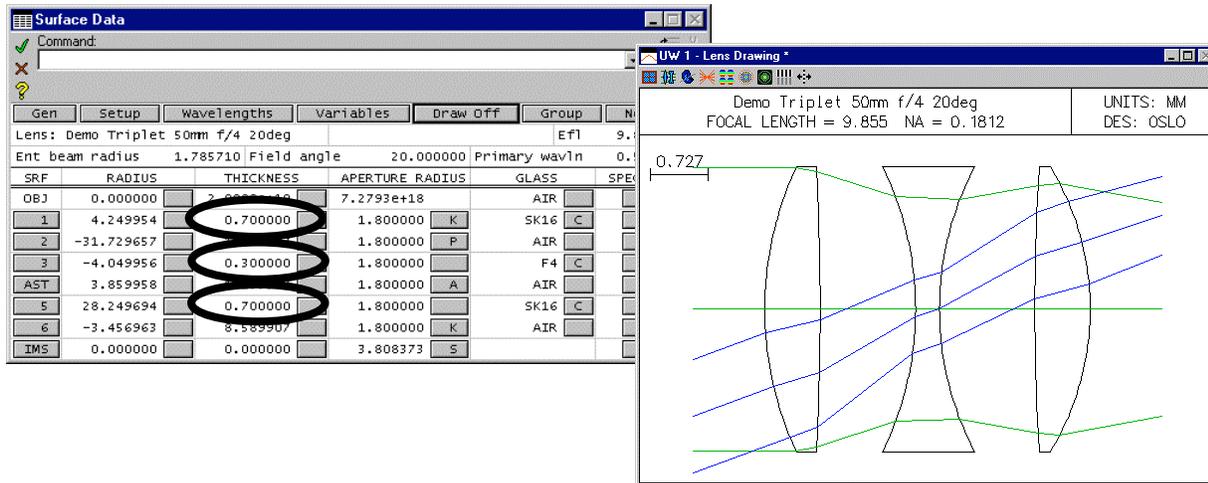
- Note that the almost all the parameters of the lens prescription have been changed. The entrance beam radius is now 1.249986. Change the Entrance Beam Radius value to 1.78571 to force the system to have an F-number of f/2.8.
- The F-number of the system can now be verified by choosing to list Paraxial Constants (Pxc) from the Text Window toolbar. If you are having trouble finding this button or you want to learn more about this button, please refer to Sideline #1 at the end of this tutorial.



- Notice that the apertures in the Aperture Radius column are all smaller than the Entrance Beam Radius just defined. Change the apertures of all the surfaces to 1.8 so that the larger beam can get through.

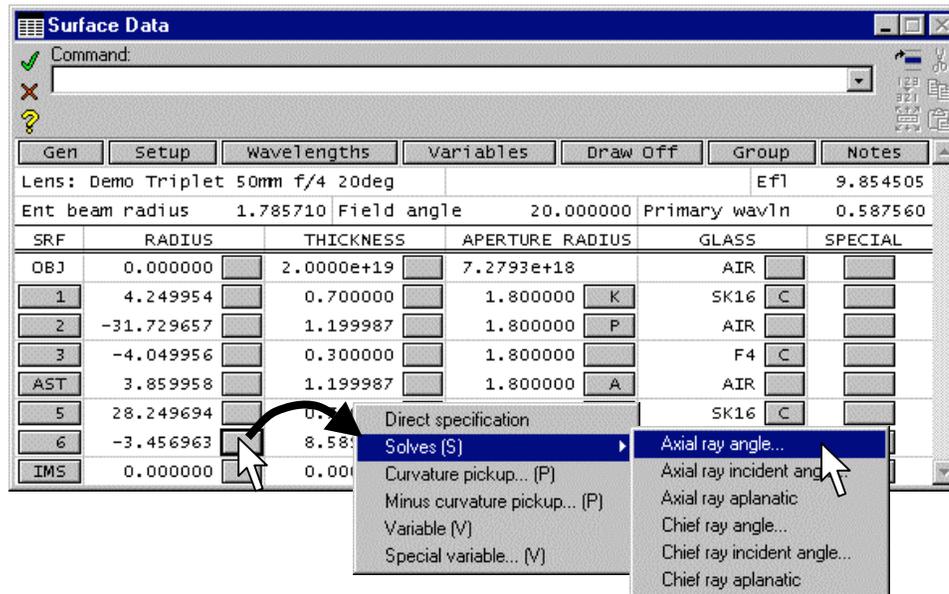
Angle	20.000000	Pr
APERTURE RADIUS		
	7.2793e+18	
	1.800000	K
	1.800000	P
	1.800000	
	1.800000	A
	1.800000	
	1.800000	K
	3.635425	S

- 7) Note that with the scaled lens the elements are too thin to support an aperture of 1.8. Increase the thickness of the front and back elements from ~0.40mm to 0.7 mm, and the thickness of the center element from ~0.2mm to 0.3mm.

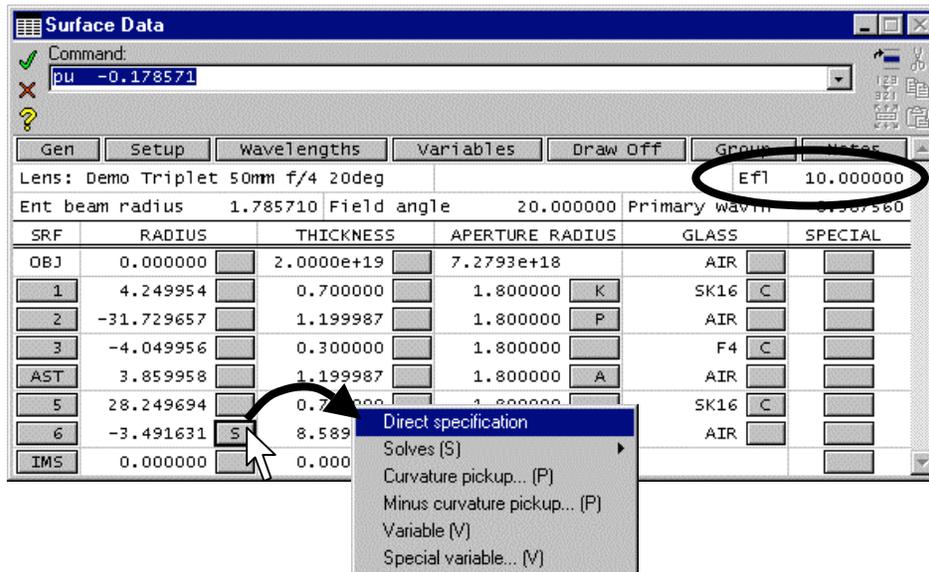


Now the on-axis beam can get through the lens system, but the focal length is no longer exactly 10mm because the thicknesses have been changed. To fix the focal length, we will apply a "solve" to the last refractive surface (surface 6). A "solve" adjusts a system parameter so that some condition is met. We will apply an "axial ray angle solve" which forces the surface curvature of surface 6 to be adjusted so that the angle of the axial ray leaving surface 6 is maintained at a certain value. With an entrance beam radius of 1.78751mm, the focal length of 10mm will be achieved with an axial ray angle solve of -0.178571(radians).

- 8) To access the axial ray solve, click on the grey button on the right side of the radius column on surface 6 and choose "Solves(S)>>Axial Ray Angle..." from the resulting pop-up menu. Enter -0.178571 for the value of the solve.



- 9) Note that the system focal length is now 10mm as desired. Observe the "Efl" cell in the upper right corner of the surface spreadsheet or choose "Pxc" from the Text Window for analysis.

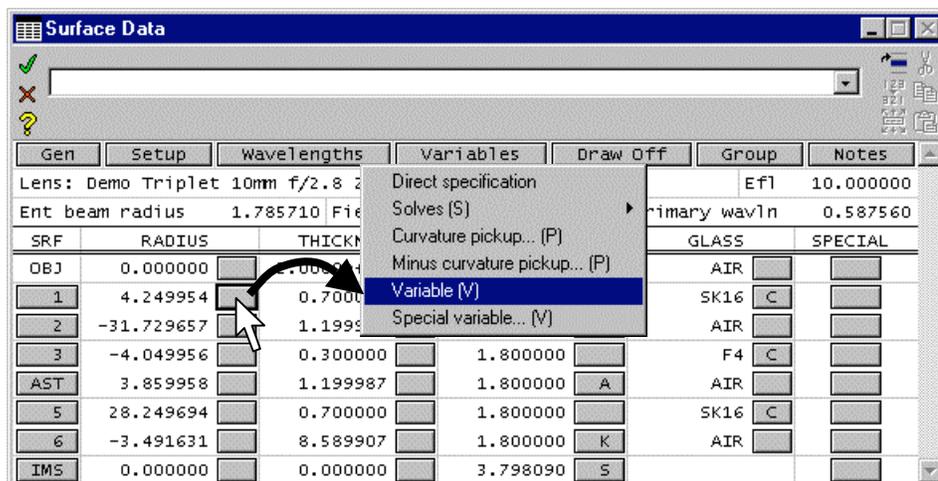


- 10) As soon as you have applied the solve, remove it again by choosing "Direct Specification" from the same pop-up menu. The letter "S" in the grey button of the "Radius" column will disappear, but the surface curvature will still be set to the value that causes the focal length to be 10mm. The surface curvature can now be used later as a variable during optimization (system parameters such as a surface curvature cannot have a solve applied at the same time it is being used as a variable during optimization).

If you are confused about the usage of the terms "Radius" and "Curvature" when describing a surface in a lens system, be aware that a surface "curvature" (cv) is the inverse of a surface "radius" (rd). They both refer to the same property and are mathematically related because $cv=1/rd$. Note the second column of the Surface Data Spreadsheet lists the surface radius by default. However when people discuss an optical design, they usually refer to surface "curvature" so that there is no confusion between surface radius and aperture radius (which is the item listed in the 4th column of the surface data spreadsheet).

- 11) Change the title of the lens to "Demo Triplet 10mm f/2.8 20deg" in the upper left corner of the surface spreadsheet window (next to the "Lens:" designation), and save the file as "Triplet10mm_Start.len" in your "...\private\len" directory.

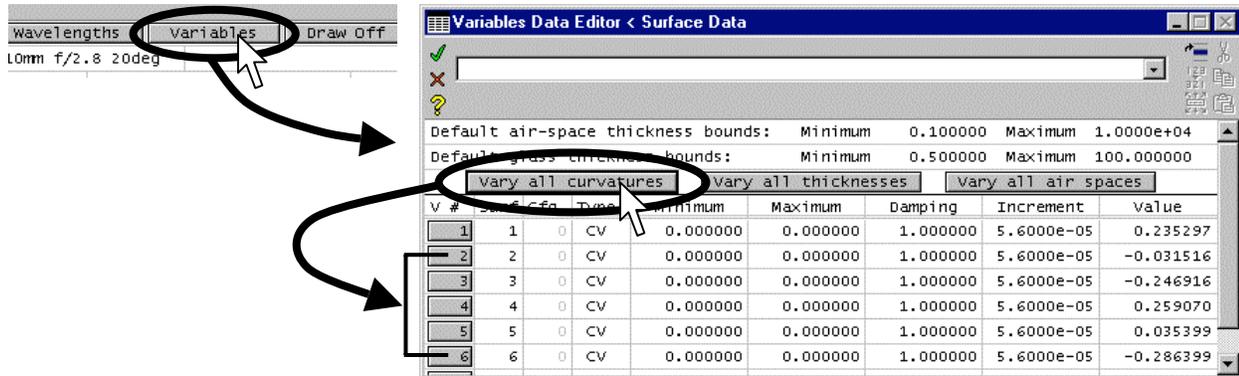
Now that you have the starting design set for our optimization, the next step is to set some system parameters to be variables. Eventually we want to set all 6 surface curvatures to be variables.



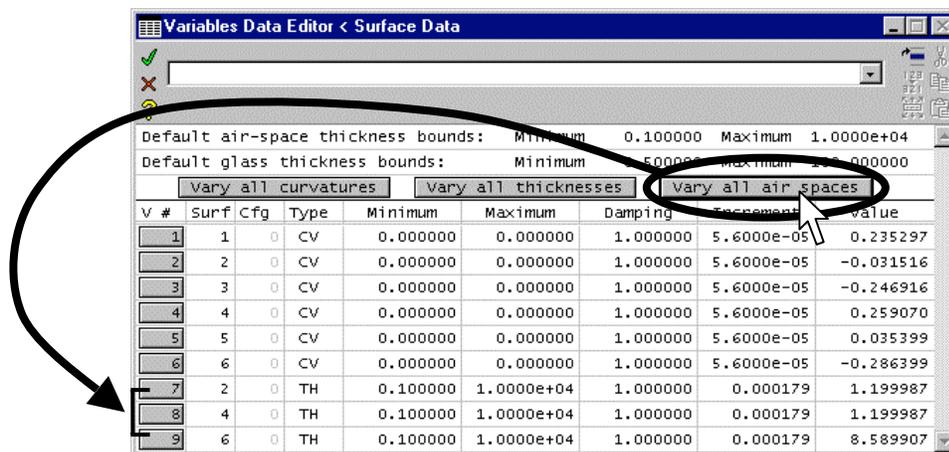
- 12) To set the first surface curvature as a variable, click on the grey button on the right side of the "Radius" column for surface #1, and choose "Variable (V)" from the resulting pop-up dialog. A letter "V" will appear in the grey button when you are done

You can continue doing this for all surfaces, or you can set all surface curvatures as variables all at once. OSLO allows you to manage the variables in your optical system together as a group:

- 13) Open up the Variables Data Editor by clicking on the "Variables" button near the top of the Surface Data Spreadsheet. Then click on the "Vary All Curvatures" button in the resulting dialog. This adds all the remaining surface curvatures to the variable list in the "Variables Data Editor".



- 14) We also want to vary all the air spaces in our design (just the thicknesses between the lenses - not the thickness of the lenses themselves). We do this by clicking on the "Vary All Air Spaces" button in the "Variables Data Editor."



- 15) Click on the green check mark in the upper left corner of the "Variables Data Editor" to accept your changes and close out of this spreadsheet, but do not close the Surface Data Spreadsheet.
- 16) Before moving on, re-save the lens system by choosing "File>>SaveLens" from the OSLO menu or click on the floppy disk icon () from the main OSLO window toolbar.

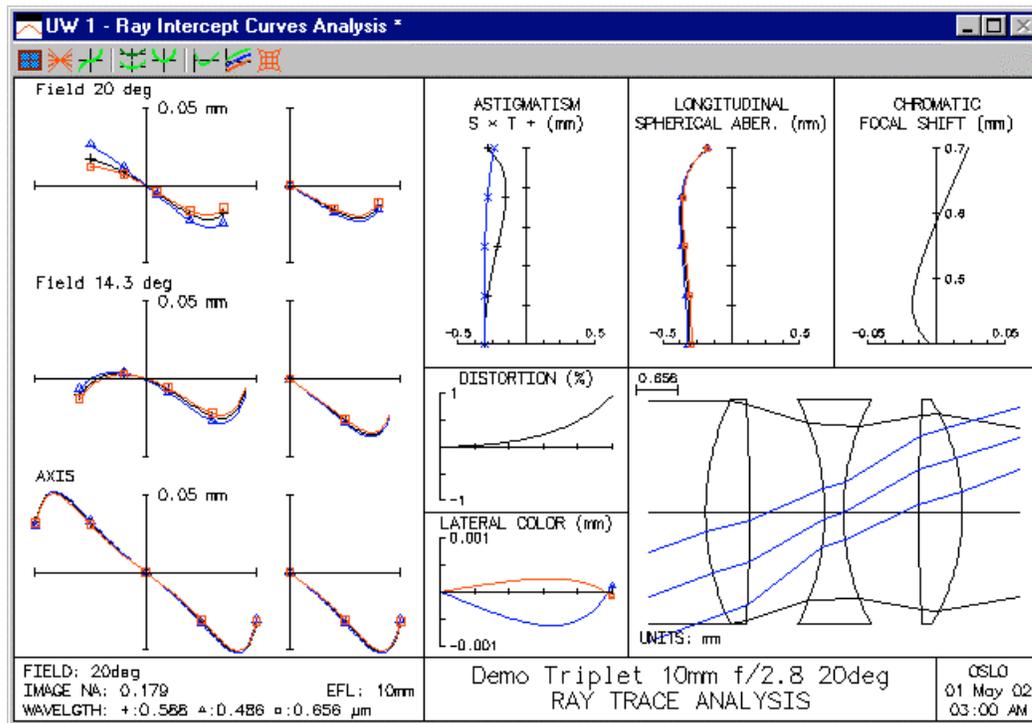
Now that a starting lens system and variables have been defined, we need to specify an error function to control the optimization. Rather than generating an error function from scratch, OSLO allows you to choose from a couple of default error functions. In most cases you can use the default error functions with little modification, but keep in mind that in OSLO you can always manually modify an error function to fit your particular requirements. In this tutorial we will take a look at generating two different types of default error functions.

Optimization using the GENII Error Function:

The GENII (pronounced "jean-ee") error function is based on the default error function of the former GENII optical design program. Some features of the GENII program have since been incorporated into OSLO. The GENII error function uses exact ray data to compute aberration-like operands in a highly efficient manner (it only traces 11 rays and consists of 31 active operands).

As we get ready to optimize, it is a good idea to check the performance of the system in a way that we can compare it with the system performance after the optimization takes place. For this tutorial we will compare the Ray Intercept Curves (RIC) of this beginning design to the RIC analysis of the designs that we have when we finish.

- 17) Choose the "RIC Report Graphic" icon () from the graphic window toolbar to perform the desired analysis. Once the analysis has been performed, lock the graphic against accidental updating by right clicking anywhere in the graphic and choosing "Lock" from the popup list.



- 18) Choose "Optimize>>Generate Error Function>>GENII Ray Aberration..." from the OSLO menu.
 19) In the resulting dialog box that pops up with the title "Geniierf", keep the default values and click on the "OK" button.

After the dialog window closes, it might appear that nothing has happened. However behind the scenes, a set of operands has been created which comprises a complete error function. We will now view the set of operands to see how the error function is constructed.

- 20) View the operand list you just generated by choosing "Optimize>>Operands" from the OSLO menu.

An "Operands Data Editor" window is opened which displays a list of optimization operands that were just created. These operands make up the error function. The function of each column in the Operand Data Editor is identified in the accompanying figure. The optimization error function is simply the composite of this operand list.

Some of the acronyms used in the "Name" column are common abbreviations for optical terms and aberrations. The definition of all these abbreviations are described in the OSLO on-line help under

"Contents>>Optimization>>Error Functions>>Generate Error Functions>>GENII Error Function." In this tutorial we will only discuss a few of the abbreviations we will need to use.

Numerical list showing each **Operand** number. You can add lines to this list just like any other spreadsheet in OSLO

This is the relative **Weight** of each operand when calculating the total error function. A weight of zero will not contribute to the optimization calculation. The important thing to remember is that the weights are relative and can be >1 if desired.

This column contains the mathematical **Definition** that is targeted to zero during optimization. In this example each operand Definition is just one of an array of variables (OCMx) that get calculated behind the scenes. Since the OCMx variables are not all that descriptive, users rely on the NAME column to remember the function of each operand.

Operands Data Editor < Surface Data

OPD(1,2)/O6

OP	MODE	WGT	NAME	DEFINITION
1	Min	0.000000	_Dy tol	0.00666666666667
2	Min	0.000000	_2.1 Dy	0.014
3	Min	0.000000	_2.8 Dy	0.01866666666667
4	Min	0.000000	_3 Dy	0.02
5	Min	0.000000	_4 Dy	0.02666666666667
6	Min	0.000000	_up Dy/3	0.675376888223
7	Min	0.000000	_3.2 up Dy	6.48361812694
8	Min	0.000000	_uprime	PU+0.178571
9	Min	1.000000	Fnb diff	O8/0.0001
10	Min	1.000000	Focus diff	DYY(1,1)/O4
11	Min	1.000000	Axial DY	DY(1,2)/O1
12	Min	1.000000	Axial OPD	OPD(1,2)/O6
13	Min	1.000000	Axial DMD	DMD(1,2)/O6
14	Min	0.000000	_0.7 Dstol	1.0
15	Min	0.000000	_0.7 Dist	100.0*DIST(2,1)
16	Min	1.000000	0.7 Dist	O15/O14
17	Min	1.000000	0.7 YFS	DYY(2,1)/O2
18	Min	1.000000	0.7 XFS	DXX(2,1)/O2
19	Min	1.000000	0.7 Coma	S2T(2,1)/O7

Additional operands viewed by enlarging or scrolling window

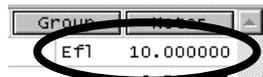
Minimize or Constraint mode setting. To constrain an operand means to solve for it explicitly and take it out of the optimization calculation matrix. Constraint mode should be used sparingly. As an alternative, use a higher weight on an operand instead.

As a user, you can supply a **Name** here to remind you of the function of each operand. This column is simply reported by OSLO, it is not actually used by OSLO in any other way. In this tutorial example, the names were generated by the "opabs_template" command which is associated with the "Aberration Operands..." menu item. The meaning of the names shown are explained in the accompanying text of this tutorial.

Unlike other error functions in OSLO, the GENII error function does not typically need to be adjusted manually. In combination with the values shown in the previous popup dialog, the operands in the error function operate as a complete set and do not need manual adjustment by the user. One particularly interesting item to note is that with the GENII error function, the EFL of the system does not need to be added as an operand. The GENII error

function effectively stores the current EFL of the optical system and targets the system EFL to remain a constant throughout the optimization.

- 21) Note that a few of the operands have a weight of zero. With a weight of zero, these operands do not contribute directly to the error function calculation. These operands store or calculate values that get used by other operands. Note operand #12 which has a definition of "OPD(1,2)/O6". The "O6" refers to operand #6 which is actually used in the calculation of operand #12. To find out more about the OPD(1,2) portion of the operand, definition, read sideline #2 at the end of this tutorial.
- 22) When you are done observing the operands, close the Operands Data Editor by clicking on the Red "X" in the upper left corner of the spreadsheet. You do not want to save any changes you might have inadvertently made in the window.
- 23) Note that in the upper right corner of the Surface Data Spreadsheet (the Operands Data Editor needs to be closed to see the Surface Data Spreadsheet), the EFL is currently 10mm. This system EFL will be maintained at 10mm throughout the optimization by the GENII error function.



- 24) Before proceeding with the optimization, evaluate the current error function by clicking on the OPE button (Ope) in the Text Window toolbar. Again, if you are having trouble finding this button or you want to learn more about this button, please refer to Sideline #1 at the end of this tutorial. Note that the resulting analysis in the text window ensures that the error function is set up properly and that only

A screenshot of the Text Window (TW 1) showing the Operands Data Editor table. The table has columns for OP, MODE, WGT, NAME, VALUE, %CNTRB, and DEFINITION. The table lists various operands and their values. At the bottom, it shows MIN RMS ERROR: 3.821989.

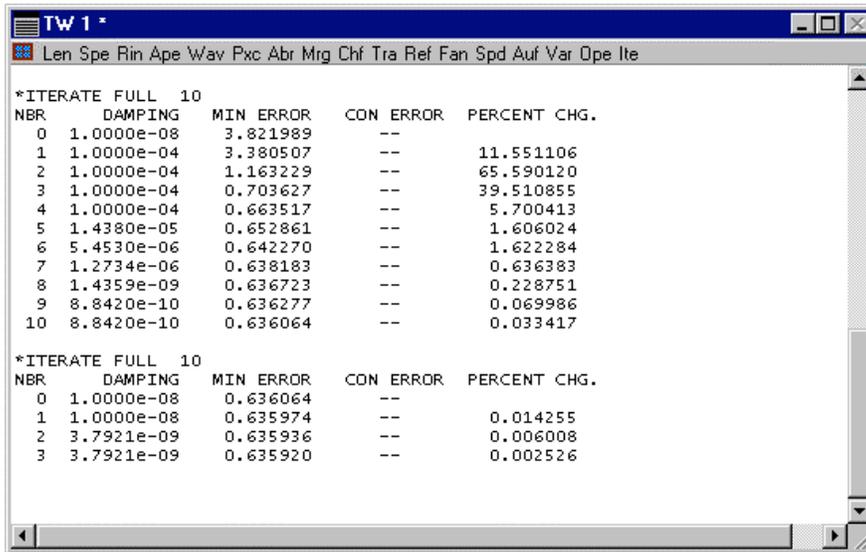
OP	MODE	WGT	NAME	VALUE	%CNTRB	DEFINITION
O 9	M	1.000000	Fnb diff	2.9698e-11	0.00	O8/0.0001
O 10	M	1.000000	Focus diff	-2.717685	1.63	DYY(1,1)/O4
O 11	M	1.000000	Axial DY	-4.922100	5.35	DY(1,2)/O1
O 12	M	1.000000	Axial OPD	13.104220	37.92	OPD(1,2)/O6
O 13	M	1.000000	Axial DMD	0.580152	0.07	DMD(1,2)/O6
O 16	M	1.000000	0.7 Dist	0.332837	0.02	O15/O14
O 17	M	1.000000	0.7 YFS	-1.887871	0.79	DYY(2,1)/O2
O 18	M	1.000000	0.7 XFS	-3.633583	2.92	DXX(2,1)/O2
O 19	M	1.000000	0.7 Coma	1.385732	0.42	S2T(2,1)/O7
O 20	M	1.000000	0.7 DY U	-0.427590	0.04	DY(2,2)/O3
O 21	M	1.000000	0.7 OPD U	5.247948	6.08	OPD(2,2)/O6
O 22	M	1.000000	0.7 DMD U	1.291534	0.37	DMD(2,2)/O6
O 23	M	1.000000	0.7 DY L	-3.946480	3.44	DY(2,3)/O3
O 24	M	1.000000	0.7 OPD L	-4.162142	3.83	OPD(2,3)/O6
O 25	M	1.000000	0.7 DMD L	1.372220	0.42	DMD(2,3)/O6
O 26	M	1.000000	0.7 Sag DX	-1.884340	0.78	DX(2,4)/O3
O 27	M	1.000000	0.7 Sag DY	-1.990562	0.88	DY(2,4)/O1
O 28	M	1.000000	.7 Sag OPD	7.098195	11.13	OPD(2,4)/O6
O 31	M	1.000000	1.0 Dist	0.934756	0.19	O30/O29
O 32	M	1.000000	1.0 YFS	-2.354680	1.22	DYY(3,1)/O4
O 33	M	1.000000	1.0 XFS	-6.121129	8.27	DXX(3,1)/O1
O 34	M	1.000000	1.0 Coma	0.484274	0.05	S2T(3,1)/O7
O 35	M	1.000000	1.0 DY U	-0.305858	0.02	DY(3,2)/O5
O 36	M	1.000000	1.0 OPD U	4.056415	3.63	OPD(3,2)/O6
O 37	M	1.000000	1.0 DMD U	1.618839	0.58	DMD(3,2)/O6
O 38	M	1.000000	1.0 DY L	1.089574	0.26	DY(3,3)/O5
O 39	M	1.000000	1.0 OPD L	3.511281	2.72	OPD(3,3)/O6
O 40	M	1.000000	1.0 DMD L	3.406111	2.56	DMD(3,3)/O6
O 41	M	1.000000	1.0 Sag DX	-0.753095	0.13	DX(3,4)/O5
O 42	M	1.000000	1.0 Sag DY	-2.291776	1.16	DY(3,4)/O1
O 43	M	1.000000	1.0 Sag OPD	3.751035	3.11	OPD(3,4)/O6
MIN RMS ERROR:				3.821989		

Since you now have variables and the error function has been created, you are ready to start the actual optimization. However, just in case something goes wrong, it is always wise to save your lens just before any optimization.

- 25) Save the lens as "Triplet10mm_OptGeniiStd.len" in your private directory.

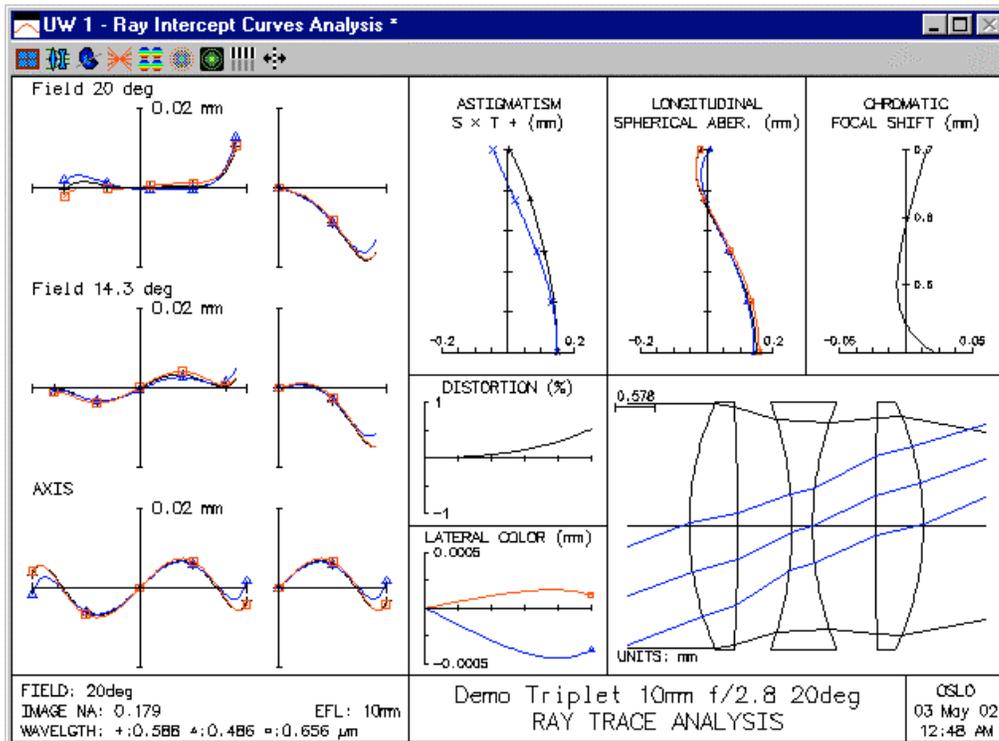
26) Start optimization by clicking on the ITE button () from the text window toolbar. The optimization will then proceed with a maximum of 10 iteration cycles with each button click.

Note that the optimization advances through all 10 cycles. If you click on the "Ite" button again, the optimization does an additional 3 cycles before stopping. This is because the improvement in the error function was less than 0.01% after iteration #3. Look at sideline #3 for more information about changing the default setting of this optimization parameter.



We can now evaluate the optimized lens system in the same way that we did prior to optimization.

27) Open up a new graphics window by choosing "Window>>Graphics>>New" from the OSLO menu and then click on the "RIC Report Graphic" icon () from the new graphic window's toolbar.



- 28) Lock this window in the same way as before by right clicking in the window and choosing "Lock" from the pop up list. You can now compare system performance with the baseline RIC Report graphic generated in step #17.
- 29) If the performance of your system matches what is shown here, choose "File>>Save" from the OSLO menu to save this lens in the "Triplet10mm_OptGeniiStd.len" file. If you encountered some trouble along the way, consider retrieving the lens from Step #16 or #25 and re-perform the intervening steps.

Optimization using the OSLO Spot Size/Wavefront Error Function:

The OSLO Spot Size/Wavefront (SS/WVF) error function creates the necessary ray operands to compute the RMS spot size (transverse ray error) or RMS OPD (wavefront error), averaged over the field and, optionally, control color. In the process of generating the error function, the necessary field point set and ray set are generated so that the rays properly sample the system. Although all generated error functions allow the user to modify and add operands, the OSLO SS/WVF error function is ideally suited for the user to add optional operands such as operands that penalize insufficient edge thicknesses, or excessive distortion.

As you start to work with this different error function, you need to retrieve the lens you stored before the last optimization started.

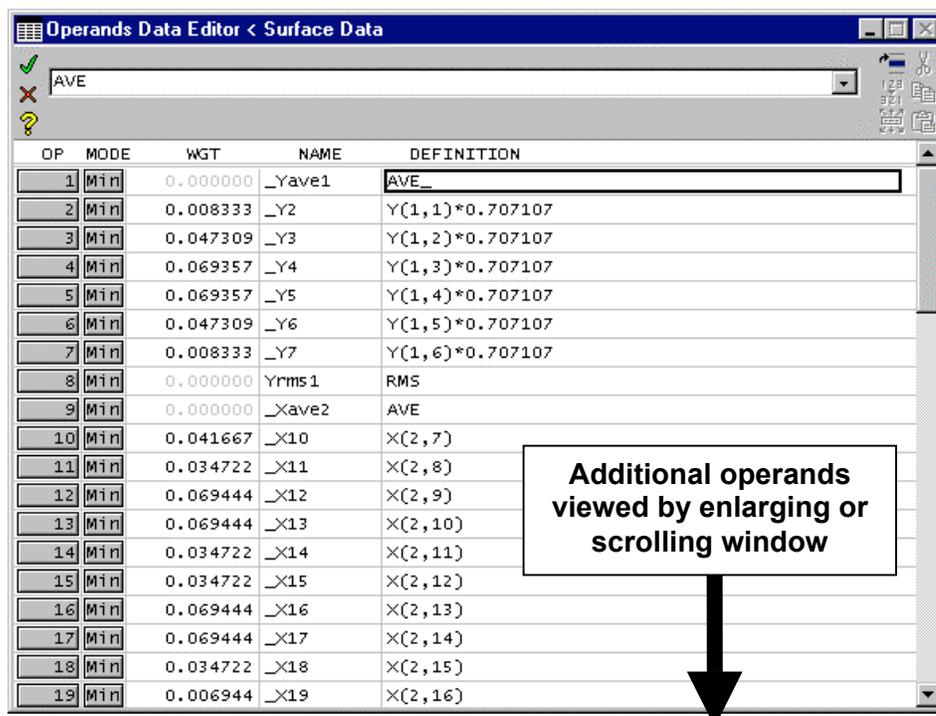
- 30) Choose "File>>Open" from the OSLO menu and open the "Triplet10mm_Start.len" lens stored in your private directory.
- 31) Choose "Optimize>>Generate Error Function>>OSLO Spot Size / Wavefront..." from the OSLO menu.

The resulting "Generate Error Function" dialog box that pops up allows you to choose how you want rays to be sampled across the field and the aperture, whether you want to control Spot Size or Wavefront Error, as well as how you would like to control color, distortion and edge thicknesses.

- 32) Choose the "Color Correction Method" to be "Use CHR/DMD operands"
- 33) Choose the "Correct Distortion Full Field" to be "On" and set to 0.5%.
- 34) Click the "OK" button at the bottom of the "Generate Error Function" dialog to accept the remaining default values in the window without making any other changes.

After the "Generate Error Function" dialog window closes, it might appear that nothing has happened. But once again, behind the scenes a set of operands has been created which comprises a complete error function.

- 35) View the operand list that was just generated by choosing "Optimize>>Operands" from the OSLO menu.



OP	MODE	WGT	NAME	DEFINITION
1	Min	0.000000	_Yave1	AVE_
2	Min	0.008333	_Y2	Y(1,1)*0.707107
3	Min	0.047309	_Y3	Y(1,2)*0.707107
4	Min	0.069357	_Y4	Y(1,3)*0.707107
5	Min	0.069357	_Y5	Y(1,4)*0.707107
6	Min	0.047309	_Y6	Y(1,5)*0.707107
7	Min	0.008333	_Y7	Y(1,6)*0.707107
8	Min	0.000000	Yrms1	RMS
9	Min	0.000000	_Xave2	AVE
10	Min	0.041667	_X10	X(2,7)
11	Min	0.034722	_X11	X(2,8)
12	Min	0.069444	_X12	X(2,9)
13	Min	0.069444	_X13	X(2,10)
14	Min	0.034722	_X14	X(2,11)
15	Min	0.034722	_X15	X(2,12)
16	Min	0.069444	_X16	X(2,13)
17	Min	0.069444	_X17	X(2,14)
18	Min	0.034722	_X18	X(2,15)
19	Min	0.006944	_X19	X(2,16)

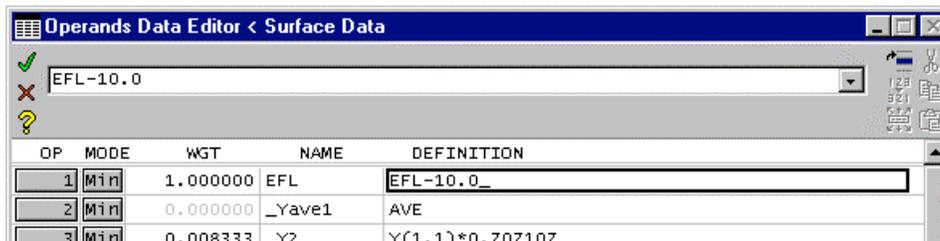
These ray operands control particular rays which are sampled according to the field and aperture sampling that you set up in the "Generate Error Function" dialog window. If you scroll down in the window, you will see that there are 109 operands in this error function, and they are all based on rays (for a better explanation of what the definitions such as "X(2,7)" mean, read sideline #2 at the end of this tutorial).

There is, however, one problem with this current set of operands. If you trace all these rays to try and minimize spot sizes on the image plane, and you are also allowing all glass surfaces to vary curvature, there is no control over focal length as this error function is currently written.

- 36) Insert a line in the "Operands Data Editor" spreadsheet by right clicking anywhere on the line of the 1st operand and choose "Insert before" from the pop up list.

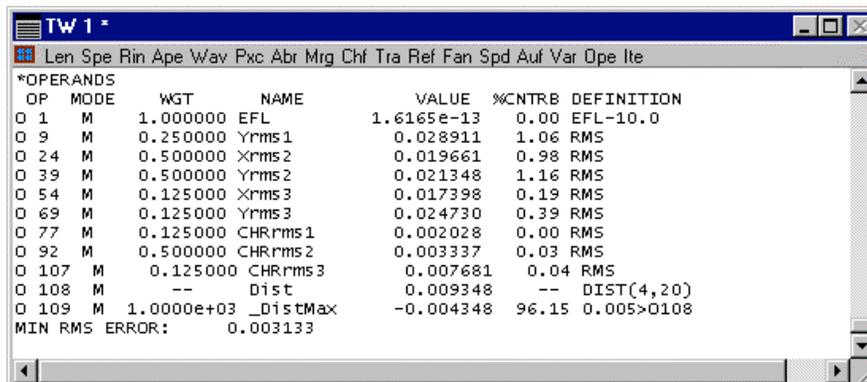
Note that you can add lines for new operands anywhere in the Operands Data Editor list, except between the "AVE" and "RMS" operands "AVE" operands. Out of convenience, it is best to add custom operands either to the beginning or to the end of an error function list.

- 37) In this new first line, enter a weight of 1, a name of "EFL" and a definition of "EFL-10". Since definitions are always targeted to zero in OSLO, this definition is now targeted so that the EFL of the system will be maintained at 10mm throughout the optimization.



- 38) Close the Operands Data Editor window by clicking on the green check in the upper left corner of the spreadsheet.

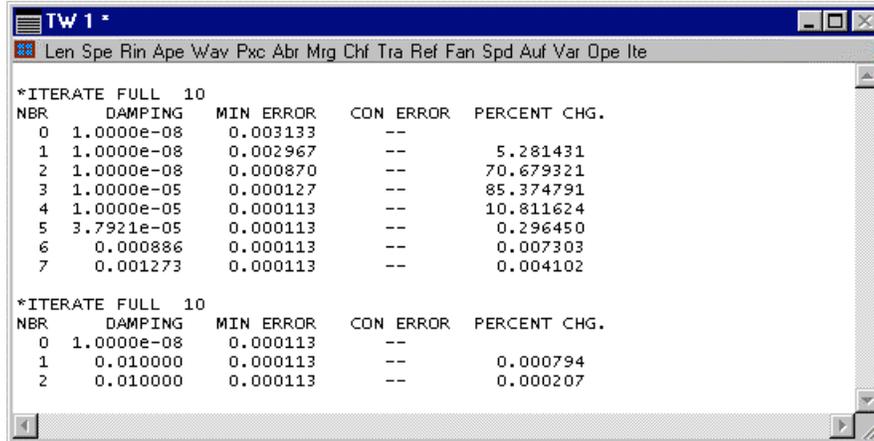
- 39) Before proceeding with the optimization, evaluate the current error function by clicking on the OPE button () in the Text Window toolbar. The resulting analysis in the text window ensures that the error function is set up properly.



Note that the rays in the error function have been evaluated in 5 groups. Each of these groups contain tangential and sagittal ray intercepts (the position where the rays intersect the image plane) that are RMSed together. Additionally there are groups of operands that control color correction and distortion. The first line of the "Ope" analysis demonstrates that the EFL has been successfully added to the operand list.

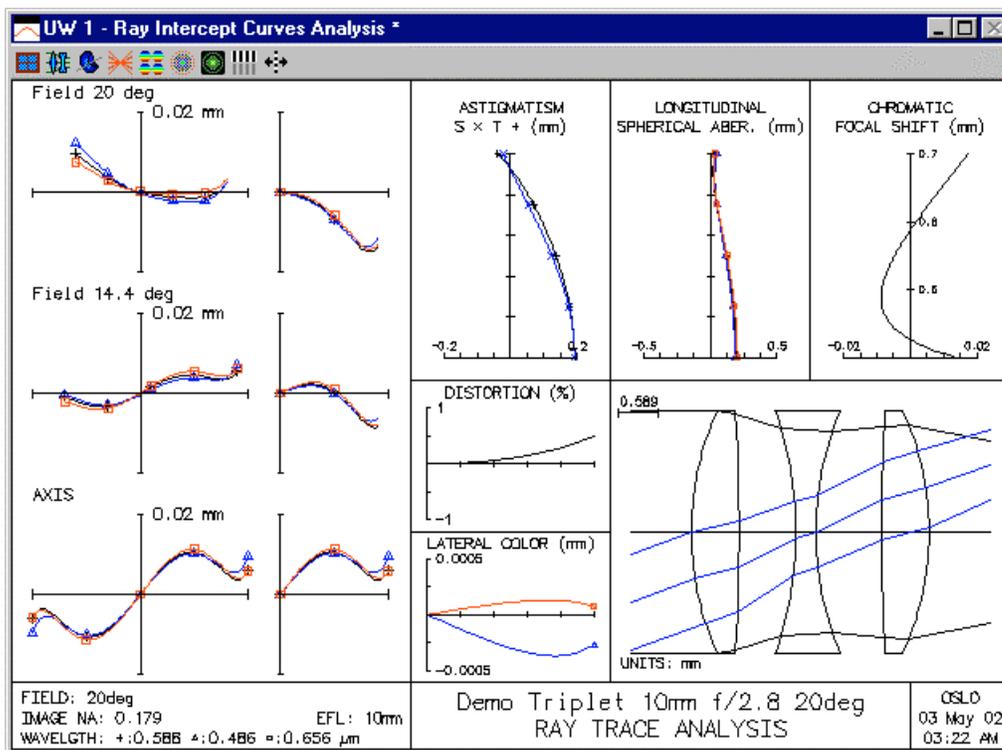
Since we now have variables and the error function set, we are ready to start actual optimization. However, just in case something goes wrong, save your lens in its current state.

- 40) Save the lens as "Triplet10mm_OptOSLO_SS.len" in your private directory.
- 41) Start the optimization by clicking on the "Ite" button from the text window toolbar. The optimization will then proceed with a maximum of 10 iteration cycles with each button click.
- 42) Note that the optimization stops after 7 cycles. This is because the improvement of the error function was less than 0.01% after iteration #7. Look at sideline #3 for more information about changing the default setting of this optimization parameter.



We can now evaluate the optimized lens system in the same way that we did prior to optimization.

- 43) Open up a new graphics window by choosing "Window>>Graphics>>New" from the OSLO menu and then clicking on the "RIC Report Graphic" icon () from the graphic window's toolbar.
- 44) Lock this window in the same way as before by right clicking in the window and choosing "Lock" from the pop up list.

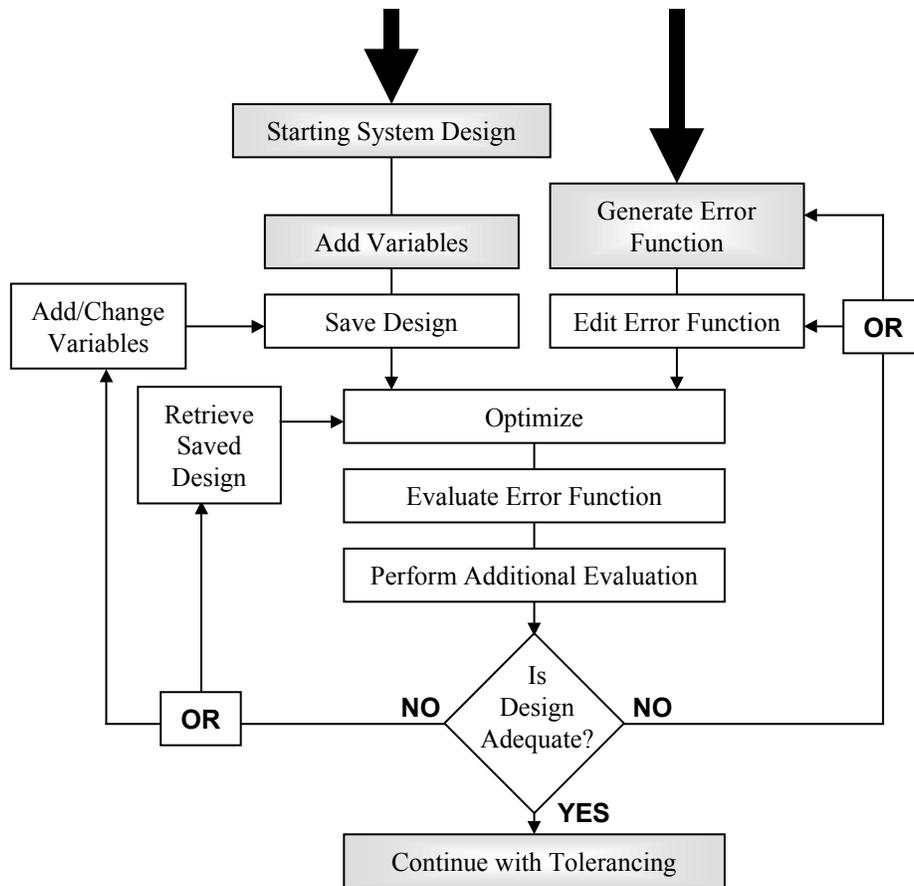


Now you should have three Ray Intercept Curves Analysis windows open: One window before optimization (step#17), one after using the GENII error function (step #27) and one using the OSLO Spot Size / Wavefront error function for optimization (step #43). Of course both of the different optimizations improved the system (note the 2.5x smaller scale on the Ray Intercept Curves after optimization). But in this particular example it is not quite clear which optimization procedure produced a better system. The Ray Intercept Curves for the GENII error function optimization actually appear to be slightly better than the curves for the OSLO Spot Size / Wavefront error function. What design criteria are most important (ray intercept curves, certain aberrations, or something else) is usually dictated by the customer or the application, but for some situations, we might be able to assume that the GENII optimization provided a better system. The on-axis Ray Intercept Curve (lower left corner) of the GENII optimization analysis window appears to have slightly smaller errors across the aperture that the alternative optimization analysis.

As an exercise, you may want to go back to the optimization using the OSLO Spot Size / Wavefront operands and see if there are other operands that could be added or altered in order to make their performance rival that of the GENII error function optimization.

45) If the performance of your system matches what is shown here, choose "File>>Save" from the OSLO menu to save this lens in the "Triplet10mm_OptOSLO_SS.len" file of your private directory. If you encountered some trouble along the way, consider retrieving the lens from Step #30 or #40 and re-perform the intervening steps.

The purpose of this tutorial was to teach some of the mechanics associated with performing optimization in OSLO. What you have covered here is just a small portion of the optical design process. An example matrix of this process is shown below.



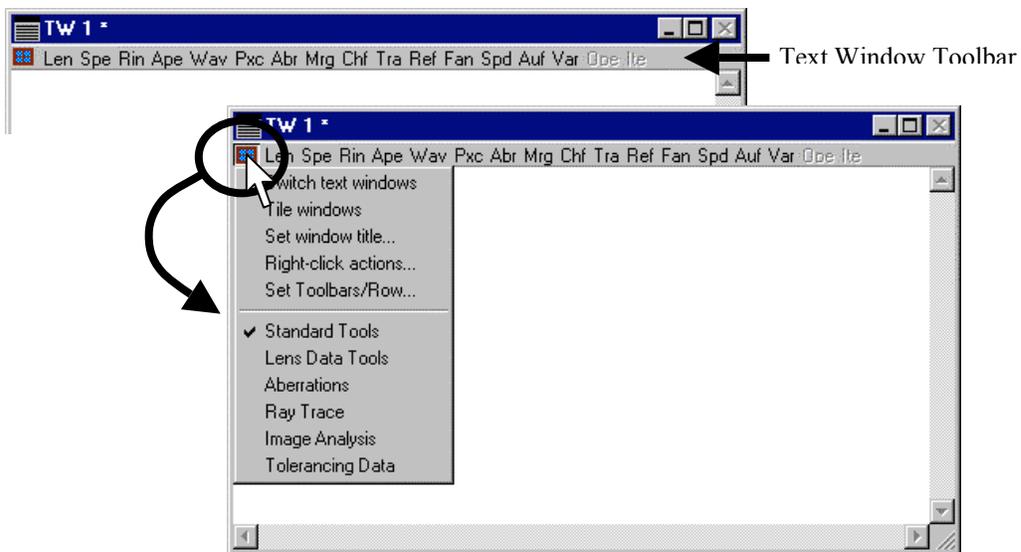
To become an expert optical designer, you will need to gain enough experience to handle all the decision points of the optical design matrix. This however, is way beyond the scope of this tutorial.

SIDELINE #1

Note that there is a series of three letter acronyms (Len, Spe, Rin, ...etc.) underneath the title bar of the text window "TW 1":



These acronyms are actually icons associated with the current set of active toolbars for the window. You can change the toolbars that are shown by clicking on the leftmost icon (a red framed blue window) to expose a checked list of toolbars in the popup list. Note that in the figure below, the "Standard Tools" item is checked which means that the "Standard Tools" is the only toolbar now showing in the text window. The Standard Tools toolbar consists of 17 text icons ranging from "Len" to "Ite". If an icon is greyed out, that means it is unavailable at the time. In the example shown below, the "Ope" icon is unavailable because no operands have been defined yet. Likewise, "Ite" is only available after at least one Variable and one Operand have been defined.



SIDELINE #2

OSLO Standard and Premium use a different method to implement an error function than that in OSLO Light. In OSLO Light, users can only implement operands that have been pre-defined in a CCL or SCP command (these are called "user defined" operand components). In OSLO Standard and Premium, users can directly add and delete operands based on ray, aberration and system parameters (these are called "built-in" operand components). The approach used in OSLO Standard and Premium allows the user to easily add and modify individual operands that in turn affect the operation of the error function as a whole. The user defined approach in OSLO Light does not have this convenience of directly entering or modifying individual operands in the "Operands Data Editor", but it does have extreme flexibility in creating customized user defined operands.

Of course OSLO Standard and Premium have the capability of implementing "user defined" as well as "built-in" operands. You should read the document: Optimization Tutorial Using OSLO Light. Sideline #2 is of special significance since it addresses creating customized operands using the OSLO Light method of user defined operands.

If you are interrupting the following of this tutorial to read this sideline, you may want to save your work before continuing. Some of the steps you perform below may affect the state of your current lens system.

- 1) To learn more about using the type of operands available in OSLO Standard and Premium, we first make sure that an error function has been created. For purposes of discussion, implement the "OSLO Spot Size / Wavefront" error function by choosing "Optimize>>Generate Error Function>>OSLO Spot Size / Wavefront".
- 2) Click the "OK" in the resulting dialog box to accept all the default values.
- 3) Choose "Optimize>>Operands..." from the OSLO menu to open the operand set you just created.
- 4) When the Operands Data Editor opens, note that all the definitions refer to command like "X(2,7)" and "Y(3,10)"
- 5) To investigate what this nomenclature means, go to the on-line help (hit the F1 key at anytime in OSLO). And go to the help page: "Contents>>Optimization>>Error Functions>>Operands".

On the right side of the help window is a page devoted to an "Error Function Overview" and it describes the Built-in Operand Components" (these operands are not available in OSLO Light).

- 6) The ray operands that we just saw in the operand list are general ray operands, so click on the "General Ray" hyperlink.

The screenshot shows the OSLO Online Help window. The left pane displays a tree view of the help contents, with 'Operands' selected under 'Error Functions'. The main pane shows the 'Error function overview' page, which includes the following text:

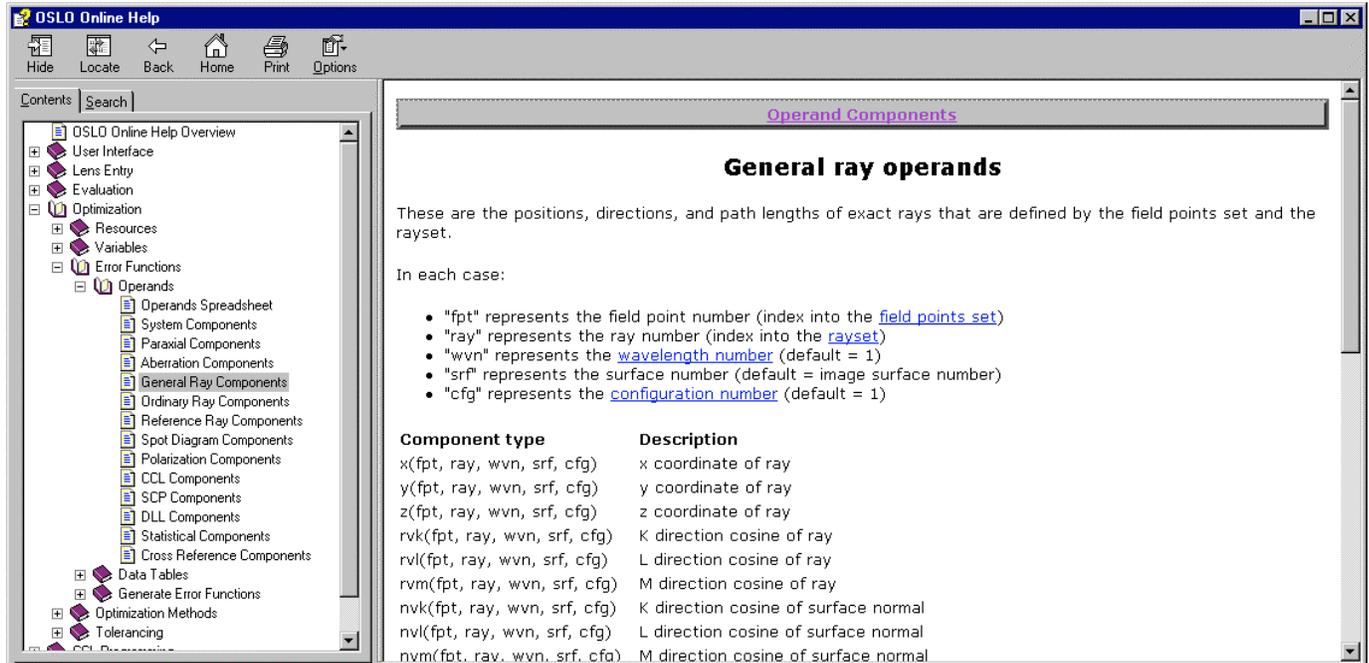
Built-in Operands Components

Operands components are values that are used in the [Operands set spreadsheet](#) to evaluate any optical and physical characteristics of the lens. Help on operands [syntax](#) is available.

OSLO also includes an extensive library of built-in components, as well as user-defined values that can be incorporated into the error function through [CCL operand components](#) or [External \(DLL\) operand components](#):

	System	values of lens construction parameters, plus edge thickness, power, and axial length
	Paraxial	paraxial ray heights and slopes
	Spherical	third and fifth order (plus seventh-order spherical) aberration coefficients
Built-in operand components	General ray	values derived from exact ray tracing that are valid for either ordinary or reference rays
	Reference ray	values derived from exact ray tracing that are valid for reference rays only
	Ordinary ray	values derived from exact ray tracing that are valid for ordinary rays only
	Spot diagram	MTF, RMS wavefront error, or Zernike coefficient values computed by tracing spot diagrams
	Polarization	polarization properties obtained from a polarization ray trace
User-defined operand components	CCL	Define your own operand components with CCL
	SCP	Define operand components using SCP (for OSLO Light users)
	DLL	Define operand components using Windows DLLs
Relational operand components	Statistical	mean or root-mean-square values of groups of operands
	Cross-reference	builds operands from other operands values (complex operands)

This brings you to the "General Ray Operands" page that describes some of the various operand components available to any OSLO Standard or Premium error function. Note that the syntax for the $X()$ operand component is $X(\text{fpt}, \text{ray}, \text{wvn}, \text{srf}, \text{cfg})$. Parameters 3, 4 & 5, are pretty self-explanatory. But what are "fpt" and "ray"?



For the "fpt" parameter, you need to enter the number of the field point in the currently defined field point set. The currently defined field point set is described in the OSLO menu under "Optimize>>Error Function Tables>>Field Point Set...."

Likewise, for the "ray" parameter, you need to enter the number of the ray in the currently defined ray set (a ray set is the composite of ray positions as the rays pass through the pupil plane).

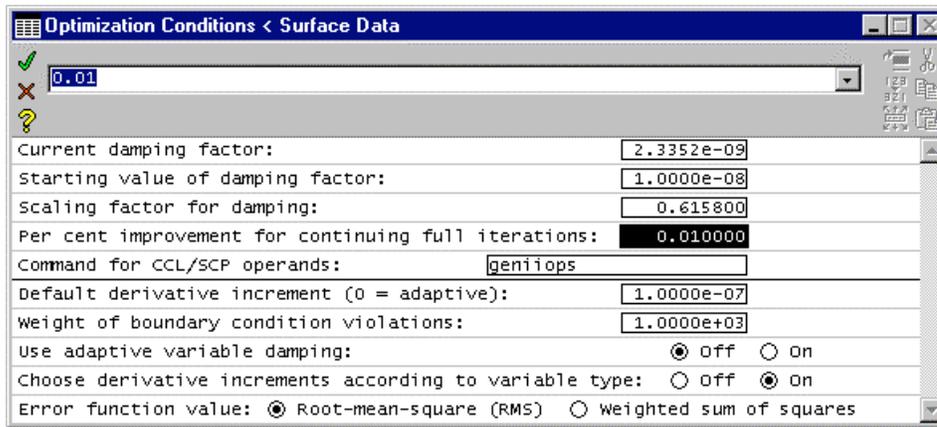
If you want to use the default value for a parameter, you do not have to explicitly enter that parameter when you call a command, as long as you do not wish to override the defaults of any parameter to the right of it in the operand component parameter list.

Note that the EFL operand component that you used in the second example in the body of the tutorial can be found in the "System" operand component list shown in a hyperlink on the "Built-in Operand Components" help page.

There is much more information on the topic of operands in the Optics Reference and in the OSLO on-line help (associated with the pages shown here). The discussion in this tutorial should give you a good starting point for learning more about optimization operands in OSLO.

SIDELINE #3

To adjust parameters that control the optimization process, choose "Optimize>>Optimization Conditions" from the OSLO menu. The resulting dialog box allows you to change a number of optimization parameters. The default value for "Percent improvement for continuing full iterations" is 0.01%. This means that once an error function is reduced by less than 0.01% in a cycle, the optimization process stops before executing another cycle.



The screenshot shows the "Optimization Conditions < Surface Data" dialog box. It contains several input fields and radio buttons for configuring optimization parameters. The values are as follows:

Parameter	Value
Current damping factor:	2.3352e-09
Starting value of damping factor:	1.0000e-08
Scaling factor for damping:	0.615800
Per cent improvement for continuing full iterations:	0.010000
Command for CCL/SCP operands:	geniops
Default derivative increment (0 = adaptive):	1.0000e-07
Weight of boundary condition violations:	1.0000e+03
Use adaptive variable damping:	<input checked="" type="radio"/> Off <input type="radio"/> On
Choose derivative increments according to variable type:	<input type="radio"/> Off <input checked="" type="radio"/> On
Error function value:	<input checked="" type="radio"/> Root-mean-square (RMS) <input type="radio"/> Weighted sum of squares