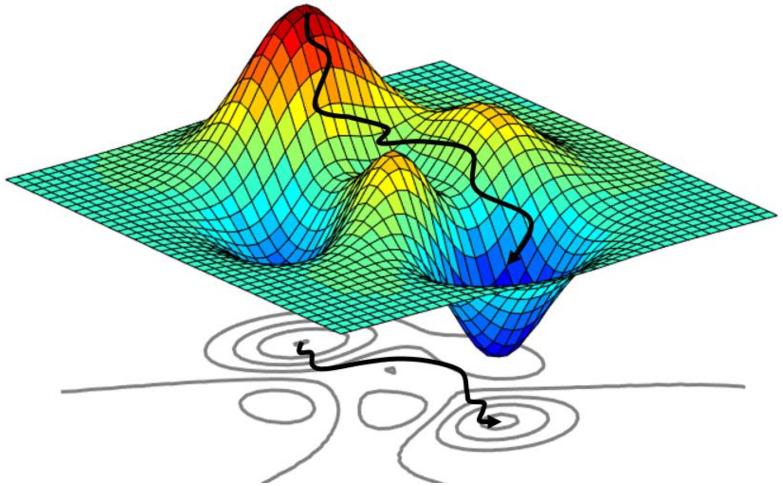
Lectures Notes on Optical Design using Zemax OpticStudio

Lecture 6

Optimization



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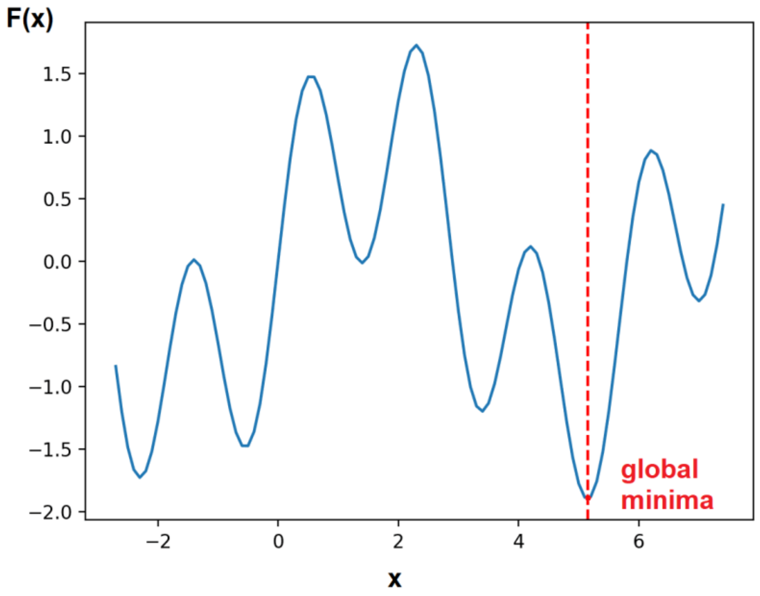
What is Optimization?

- Optimization is an operation to find minimum or maximum value of a function, F(x). Here, F(x) is called the **merit function**.
- F'(x) = 0 where F(x) is optimum. If F''(x) > 0 then F(x) min. If F''(x) < 0 then F(x) is max.

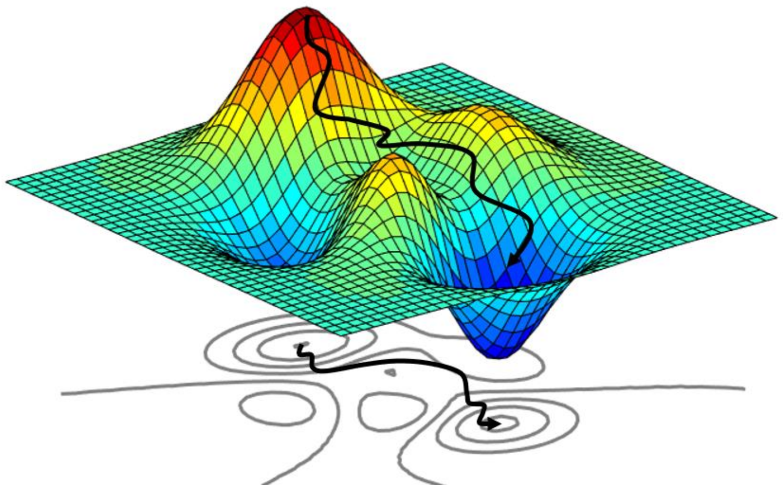


- Function can have multivariable

  $F = F(x_1, x_2, \ldots)$

  To find optimum location of function we use iterative methods:

$$x_{i+1} = x_i - H_i^{-1} \nabla F_i$$



Optimization in Zemax

- In Zemax **merit function** (MF) is partially constructed by user.
- To determine new targets **operand**s are used. The job of Zemax is to reach target values for each operand using numerical methods. So, the main goal is to minimize the MF.

- MF definition definition:

$$MF^2 = \frac{\sum_{i=1}^{N} W_i (V_i - T_i)^2}{\sum_{i=1}^{N} W_i}$$

N = Number of operand

W_i = Weight of the operand

V_i = Current value of operand

T_i = Target value of operand

Merit Function Editor (MFE)

- To setup MF, Merit Function Editor is used.
- **Optimize -> Merit Function Editor** (MFE).
- The usage is similar to LDE.

List of Operands

- Operands are strings made up of 4 letters.
- Using Help Menu, you can list all of the operands used in optimization:

Optimization Operands (Alphabetically)

This section provides a detailed description of each operand, listed alphabetically in a single table.

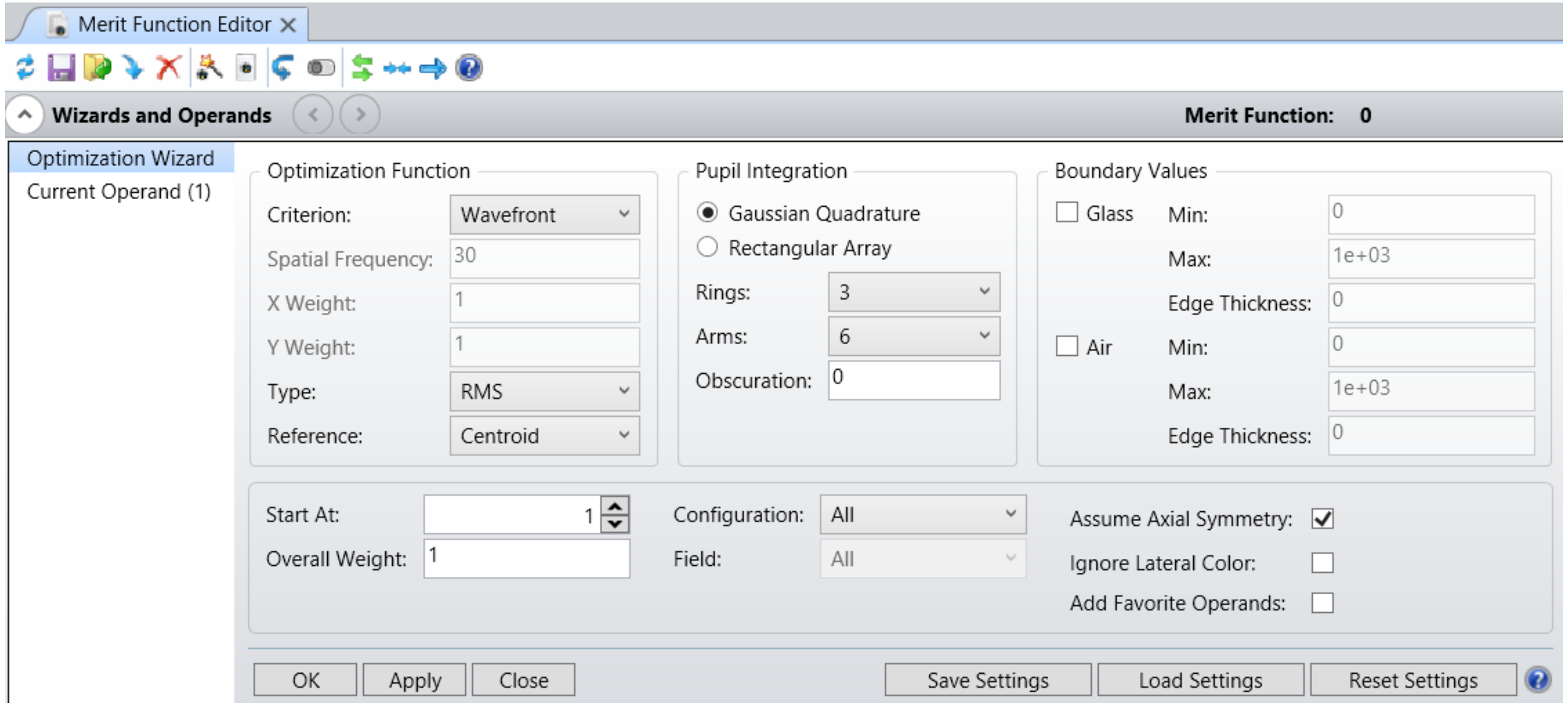
NAME	Description
ABCD	The ABCD values used by the grid distortion feature to compute generalized distortion. See "Grid Distortion". The re defined by Ref Fld. The wavelength number is defined by Wave. Data is 0 for A, 1 for B, 2 for C, and 3 for D. See also
ABGT	Absolute value of operand greater than. This is used to make the absolute value of the operand defined by Op# grea
ABLT	Absolute value of operand less than. This is used to make the absolute value of the operand defined by Op# less tha
ABSO	Absolute value of the operand defined by Op#.
ACOS	Arc cosine of the value of the operand defined by Op#. If Flag is 0, then the units are radians, otherwise, degrees.
AMAG	Angular magnification. This is the ratio of the image to object space paraxial chief ray angles at the wavelength defi non-paraxial systems.
ANAC	Angular aberration radial direction measured in image space with respect to the centroid at the wavelength defined defined as: $\varepsilon = SQRT[(l-l_c)^2 + (m-m_c)^2]$ where l and m are the x and y direction cosines of the ray and the c subscript indicates the centroid. See "Hx, Hy, Px,
	Angular aberration radius measured in image space at the wavelength defined by Wave with respect to the primary quantity is defined as:

Frequently used Operands

WFNO	**Working F-Number** operatörü kullanıldığı optimizasyonda sistemin f sayısını hedeflenen değere götürmeye çalışır.
EFFL	**Effective Focal Length** operandı kullanıldığı optimizasyondaki optik sistemin odak uzaklığını hedeflenen değere götürmeye çalışır.
CTGT	**Center Thickness Greater Than** operandı ile seçilen bir yüzeyden sonraki merkez uzaklığını istenilen değerden büyük tutmaya çalışan operanddır.
CTVA	**Center Thickness Value** operandı tanımlanan yüzeyin anlık merkez uzaklığını belirlemek için kullanılır.
OPLT	**Operand Less Than** komutu ile sistemde daha önce tanımlanan operandların değerleri ayarlanabilir.
OPGT	**Operand Greater Than** komutu ile sistemde daha önce tanımlanan operandların değerleri ayarlanabilir.
MXSD	**Maximum SemiDiameter** operandı ile bir yüzeyin alabileceği maksimum çap belirlenebilir.
MNSD	**Minimum SemiDiameter** operandı ile bir yüzeyin alabileceği minimum çap belirlenebilir.
TOTR	**Total Track (length)** oprerandı ile sistemin boyu hedeflenen değere doğru zorlanabilir.
ABSO	**Abosute Value** bir operand değerlerinin mutlak değerlerinin hesaplanmasında kullanılır.
DIFF	**Difference** Iki operand değerinin farkının bulunmasında kullanılır.
SUMM	**Sum of two operands** Iki operand değerinin toplanmasında kullanılır.

Merit Function Wizard

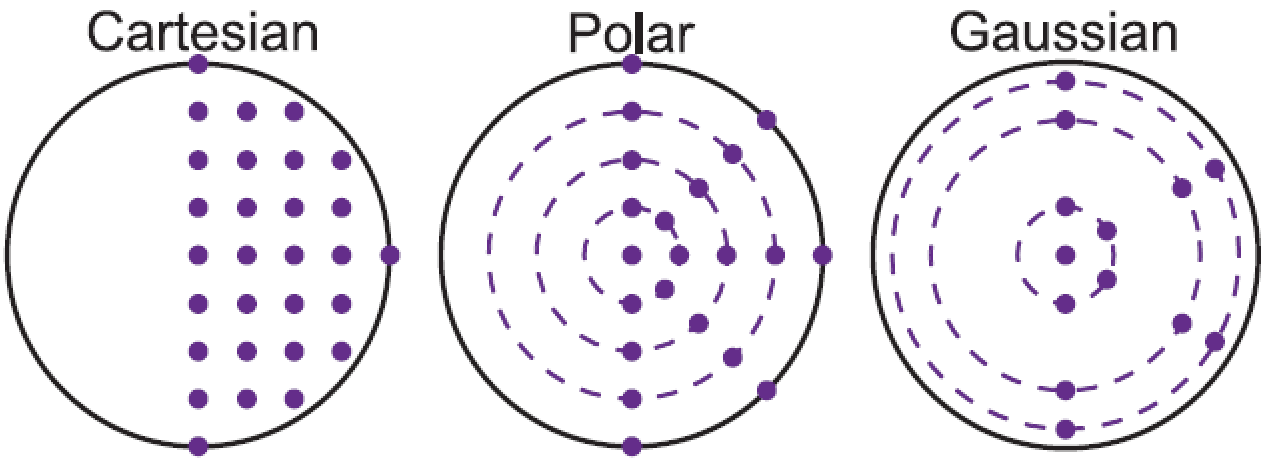
- Easiest way to setup MF is to use **Optimization Wizard**
- It will be activated when you click on **Apply** or **OK** buttons.

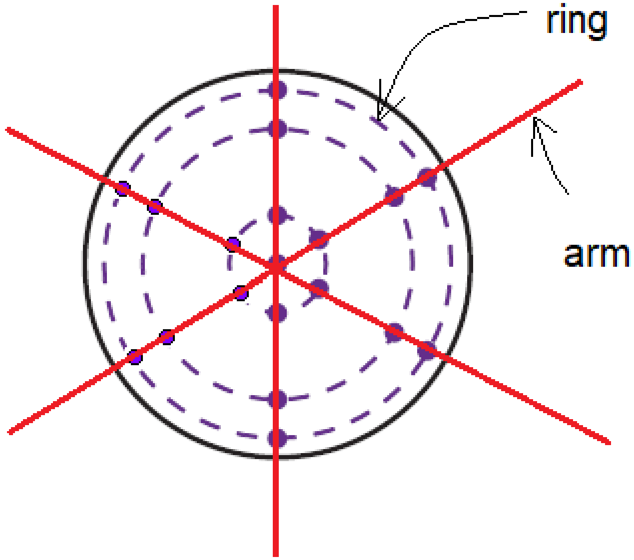


Pupil Sampling

Pupil sampling defines the number and the distribution of the rays traced through the pupil and is critical for optimization.

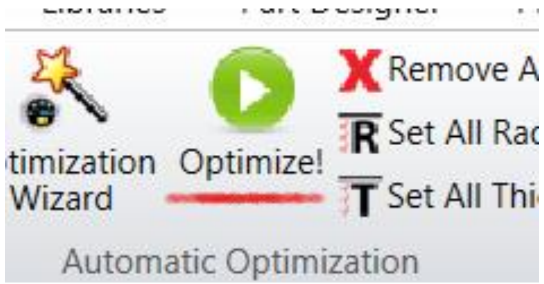
Common pupil sampling methods:





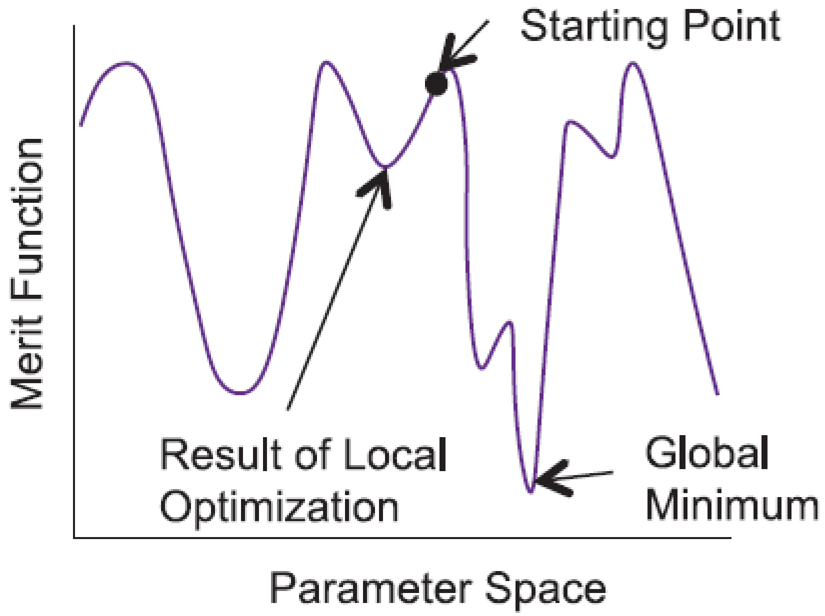
Gaussian quadrature (GQ) sampling uses a very small number of skew rays at very specific pupil coordinates and weightings. GQ sampling returns a mathematically exact integral of the pupil with fewer rays and provides higher sampling near the edge. GQ is the fastest sampling for the majority of cases.n and analysis.

Local Optimization



- This is the the simple optimization technique.
  The algorithm usually falls to a local minimum and stops quickly.
- To start Local Optimization, click on **Optimize** button under Optimization tab.

Local optimization uses gradient search to find the nearest merit function minimum and moves “downhill.” Global optimization attempts to find the global minimum by allowing both uphill and downhill movement in the merit function.
However, global optimization can require extensive computation time.



Hammer Optimization

- Hammer Current uses better **algorithm** to minimize MF.
- It allows you to change the glass type as well.
- It is useful for the complex optical system design.

Global Search

- Global Search, is an advanced search method to get global minimum of MF. See help.

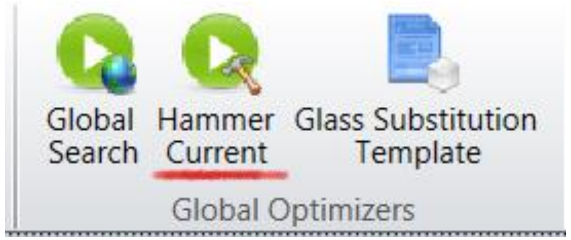
Variable Solves

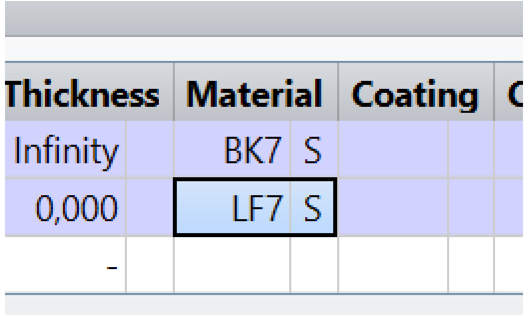
- To minimize MF, optimization tool has to change value of radius or thickness. To do that, we need to define **variables** in Zemax.
- After you double click on any radius or thickness value, you can assign variable to this parameter. If a cell is assigned as variable you will see letter ‘**V**’ on the right.
- Keyboard short cut to set a cell as variable is **CTRL + Z**

nt	Radius		Thickness	
	Infinity		Infinity	
	15,000	V	20,000	V
	Infinity		-	

Glass Selection

- The material (glass) can also be variable. To to that, materal on has to be assigned as Substitute. Glass is directly taken from Material Catolog.
- This option only works for Hammer Optimization.





Basic Optimization Examples

Example 1: Single Lens Design (via f/#)

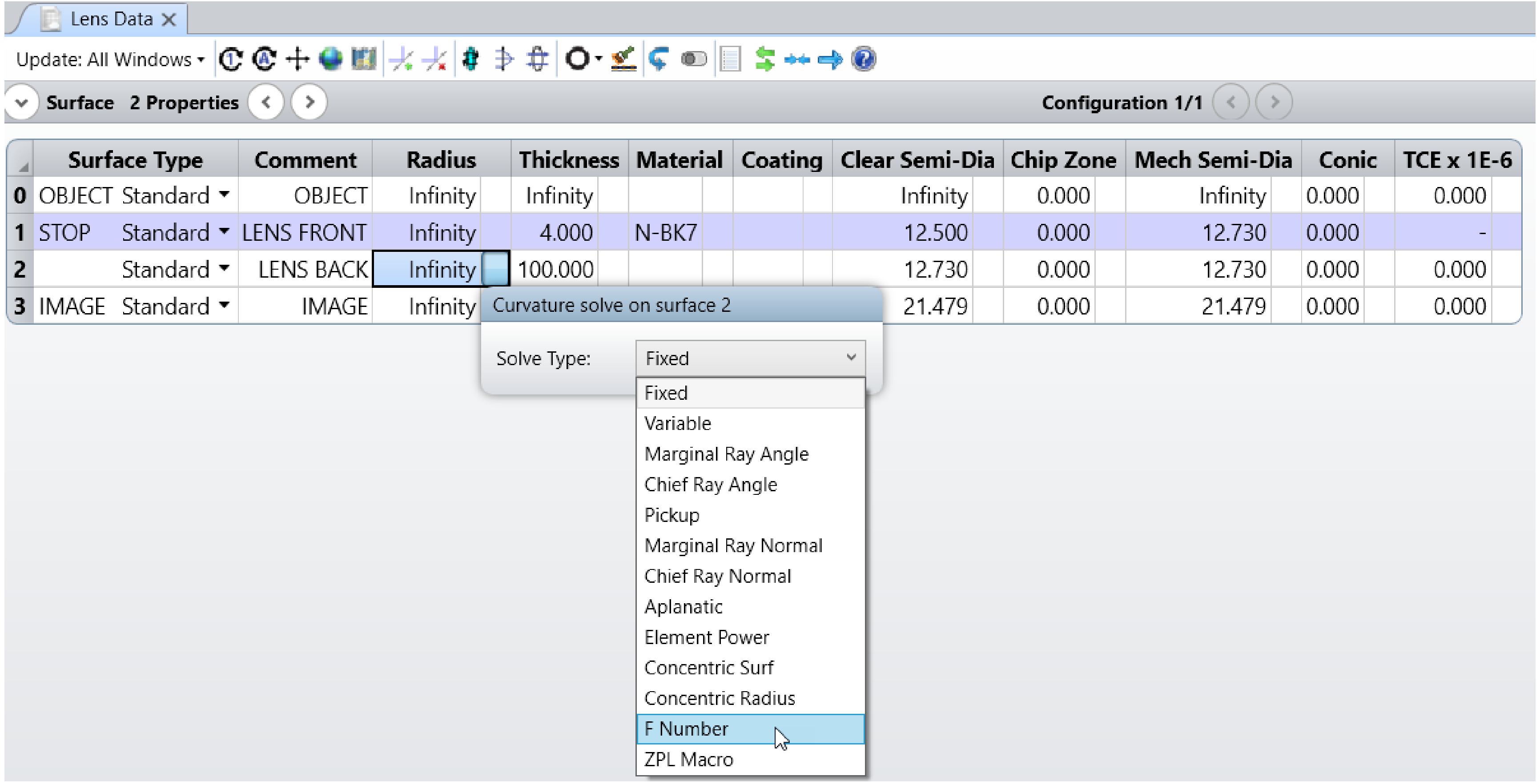
We will design and optimize an F/4 singlet lens made of N-BK7 glass.

The final design solution shall meet the following specifications and constraints:

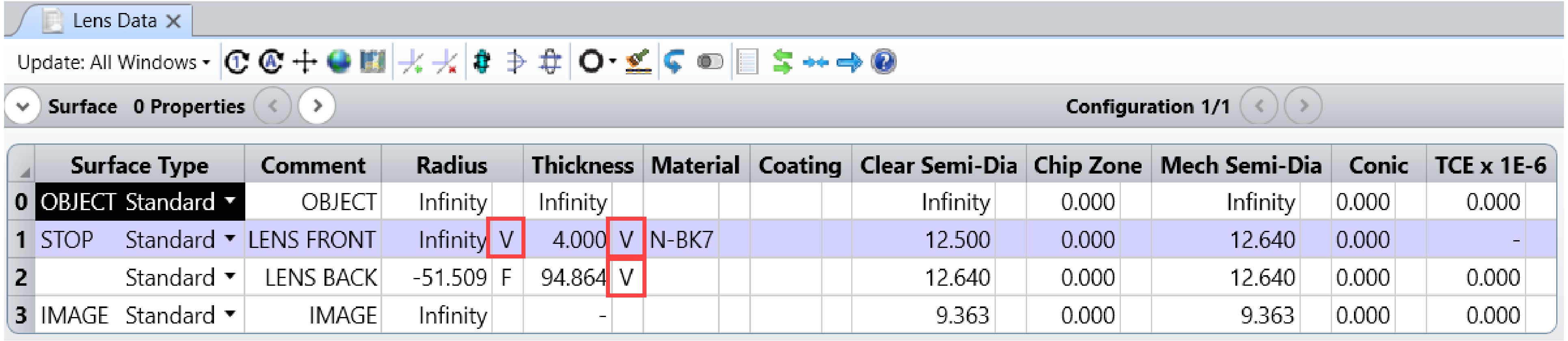
Specification	Constraint
Focal Length	100 mm
Semi-Field of View (SFOV)	5 degrees
Wavelength	632.8 nm (HeNe)
Center Thickness of singlet	Between 2 mm and 12 mm
Edge Thickness of singlet	Larger than 2 mm
Optimization criteria	RMS Spot Size averaged over FOV
Object location	At infinity

Click on second surface of the lens and select **F Number**.
Since f = 100 mm, Diameter (ENPD) is automatically computed as

D = f/(f/#) = 100/4 = 25 mm.

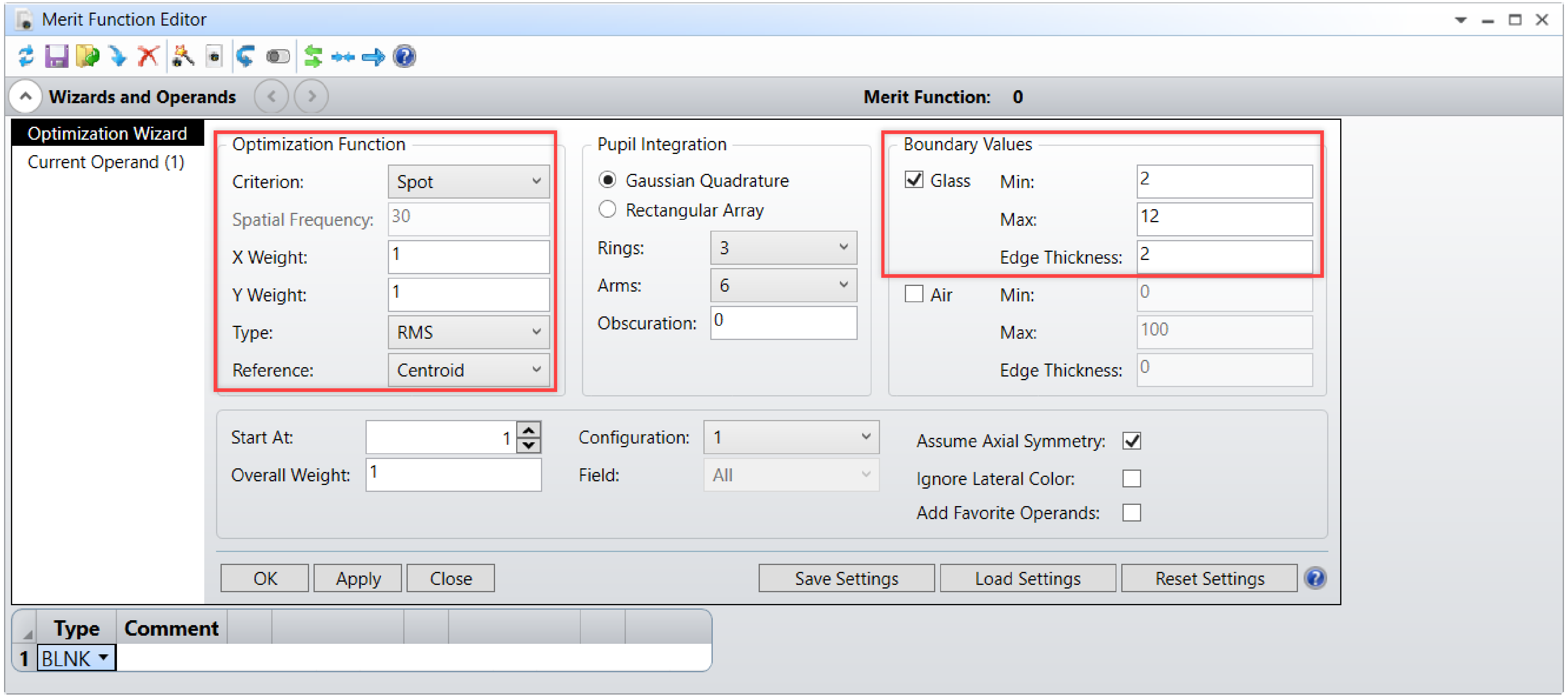


Set Radius of first surface, center thickness and distance between image plane and last surface of the lens are variables.



	Surface Type		Comment	Radius		Thickness		Material	Coating	Clear Semi-Dia	Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard	OBJECT	Infinity		Infinity				Infinity	0.000	Infinity	0.000	0.000
1	STOP	Standard	LENS FRONT	Infinity	V	4.000	V	N-BK7		12.500	0.000	12.640	0.000	-
2		Standard	LENS BACK	-51.509	F	94.864	V			12.640	0.000	12.640	0.000	0.000
3	IMAGE	Standard	IMAGE	Infinity		-				9.363	0.000	9.363	0.000	0.000

- In MFE, setup the following confiurations and click on **Apply** button.
- Then, press **Start** button to start local optimization.
  (Variables will be calculated automatically)



Example 2: Single Lens Design (via EFFL)

Using Zemax design the following singlet lens:

- Aperture D = 80 mm
- f/# = 4 (namely f/D = 4, or f = 320 mm)
- center thickness ct = 15 mm
- Glass is SF2
- λ = 632.8 nm (HeNe).
- Radius of curvature of the first surface is R_1 = +300 mm

Lens should be optimized for smallest RMS spot Radius averaged over the field of view at the given wavelength.

Determine the radius of curvature of the second surface (R_2 = ?).

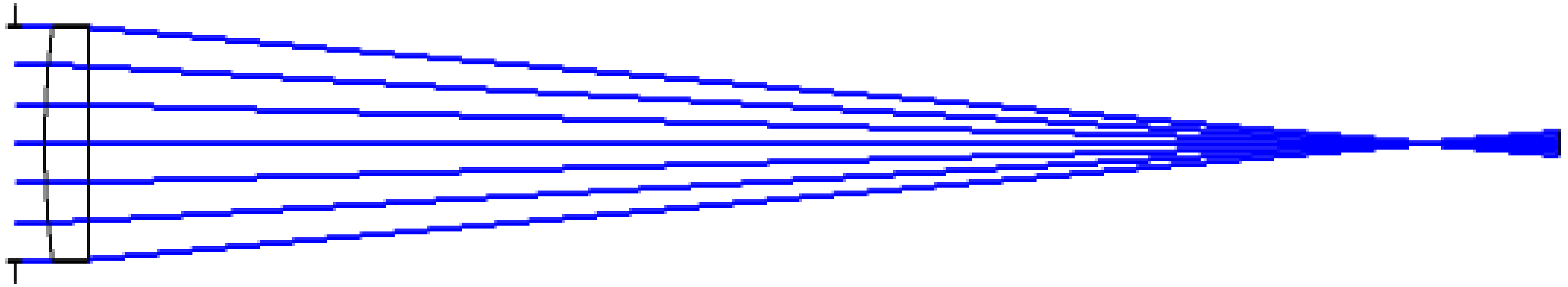
LDE and Layout (cross section)

Lens Data

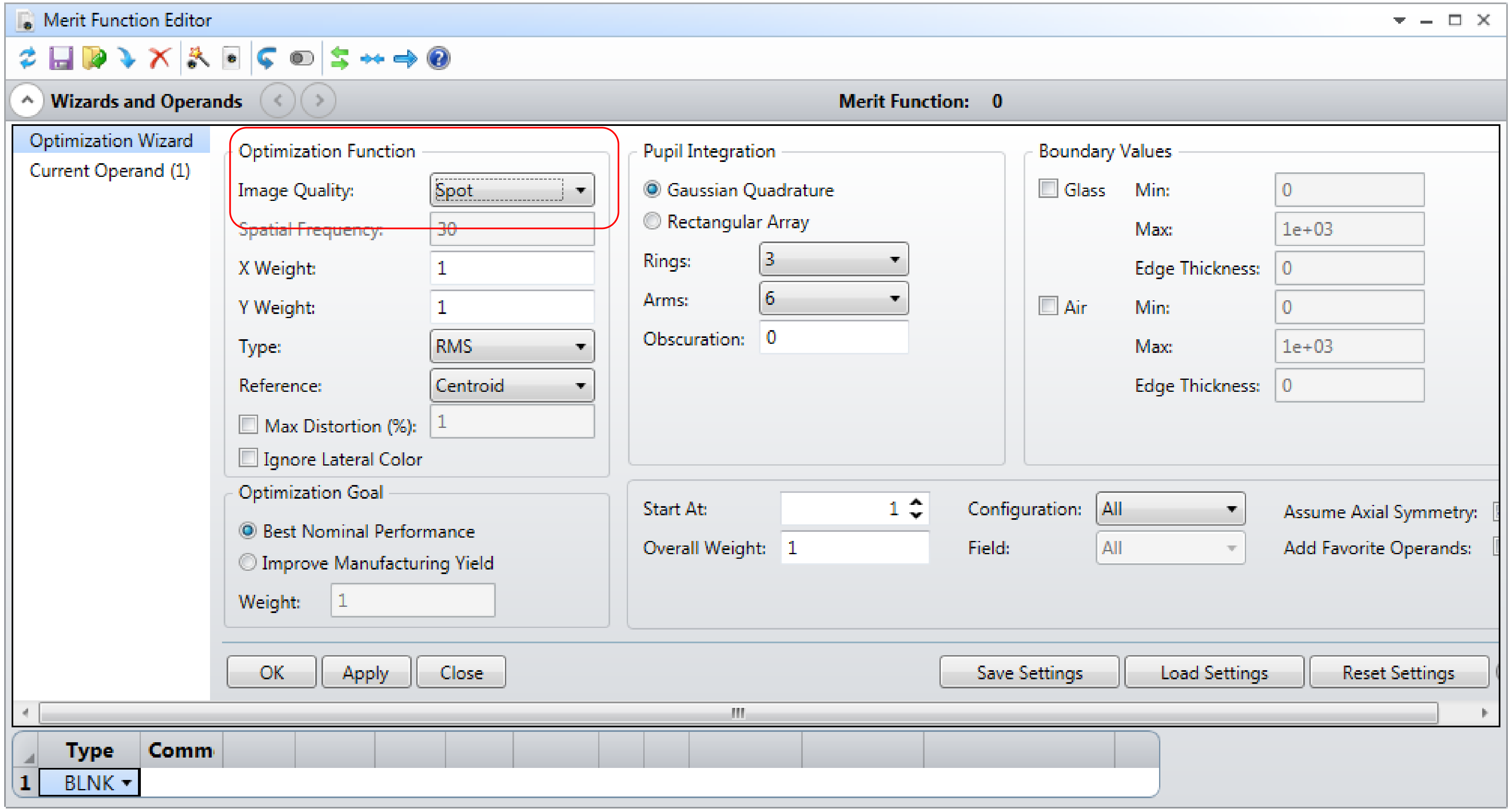
Update: All Windows

Surface 3 Properties — Configuration 1/1

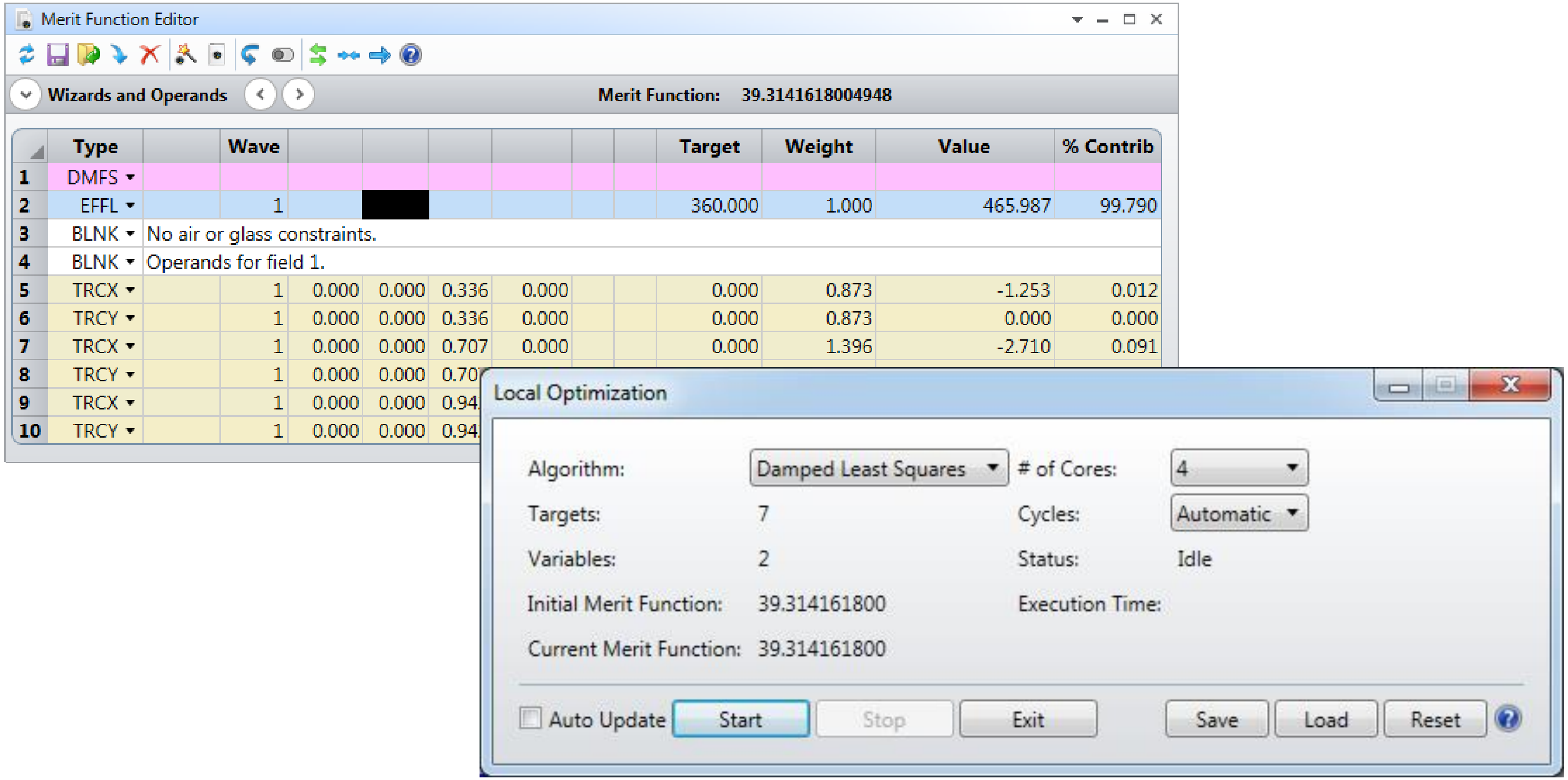
	Surface Type		Comment	Radius		Thickness		Material		Coating		Clear Semi-Dia		Chip Zone
0	OBJECT	Standard		Infinity		Infinity						0.000		0.000
1	STOP	Standard		Infinity		10.000						40.000		0.000
2		Standard		300.000		15.000		SF2				40.000		0.000
3		Standard		Infinity	V	500.000	V					39.352		0.000
4	IMAGE	Standard		Infinity		-						3.963		0.000



In MFE'de, Select **Spot** for Image Quality.



- Set EFFL operand. Target = 360 (mm) ve Weight = 1.
- First click on **Optimize** then press **Start** buttons.



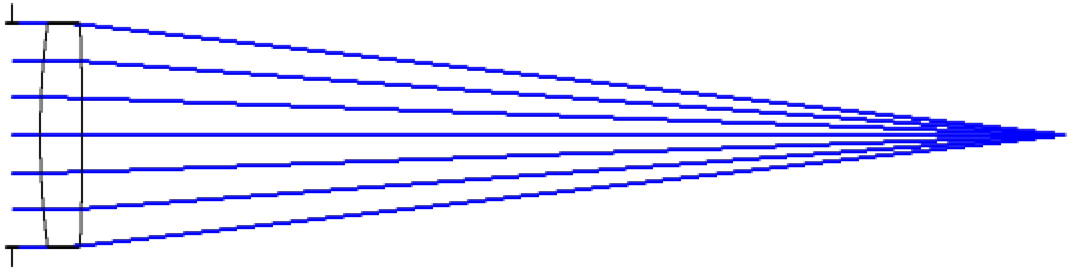
- At the end of optimization we have $R_2 \approx -999$ mm. Investigate the performace plots (spot, OPD, etc).

Lens Data

Update: All Windows

Surface 3 Properties — Configuration 1/1

	Surface Type		Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia	Chip Zone
0	OBJECT	Standard		Infinity	Infinity			0.000	0.000
1	STOP	Standard		Infinity	10.000			40.000	0.000
2		Standard		300.000	15.000	SF2		40.000	0.000
3		Standard		-999.037 V	350.413 V			39.393	0.000
4	IMAGE	Standard		Infinity	-			0.143	0.000



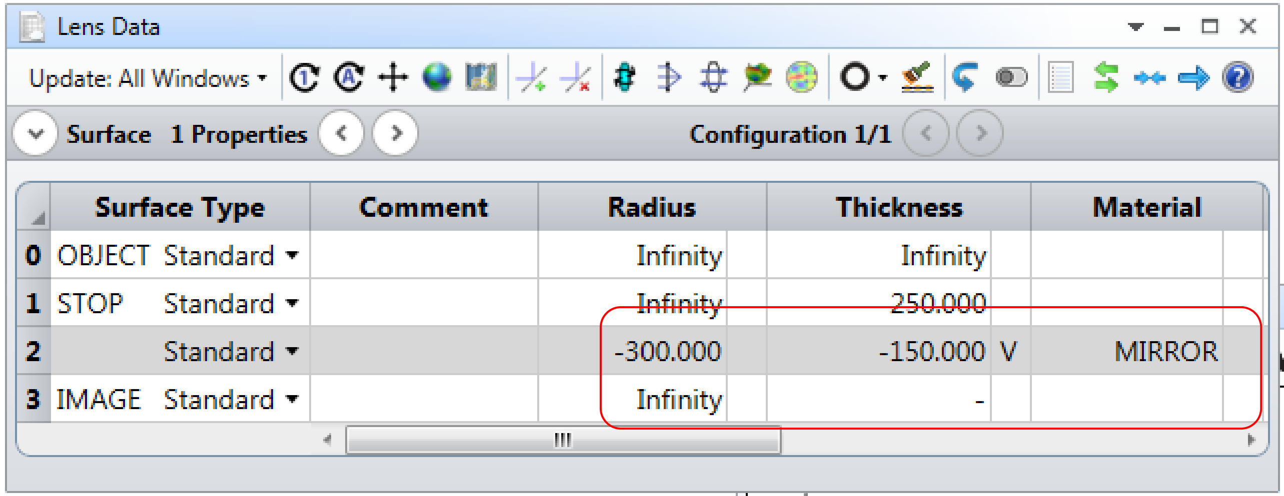
Example 3: Simple Concave Mirror Design

Using Zemax design the following mirror:

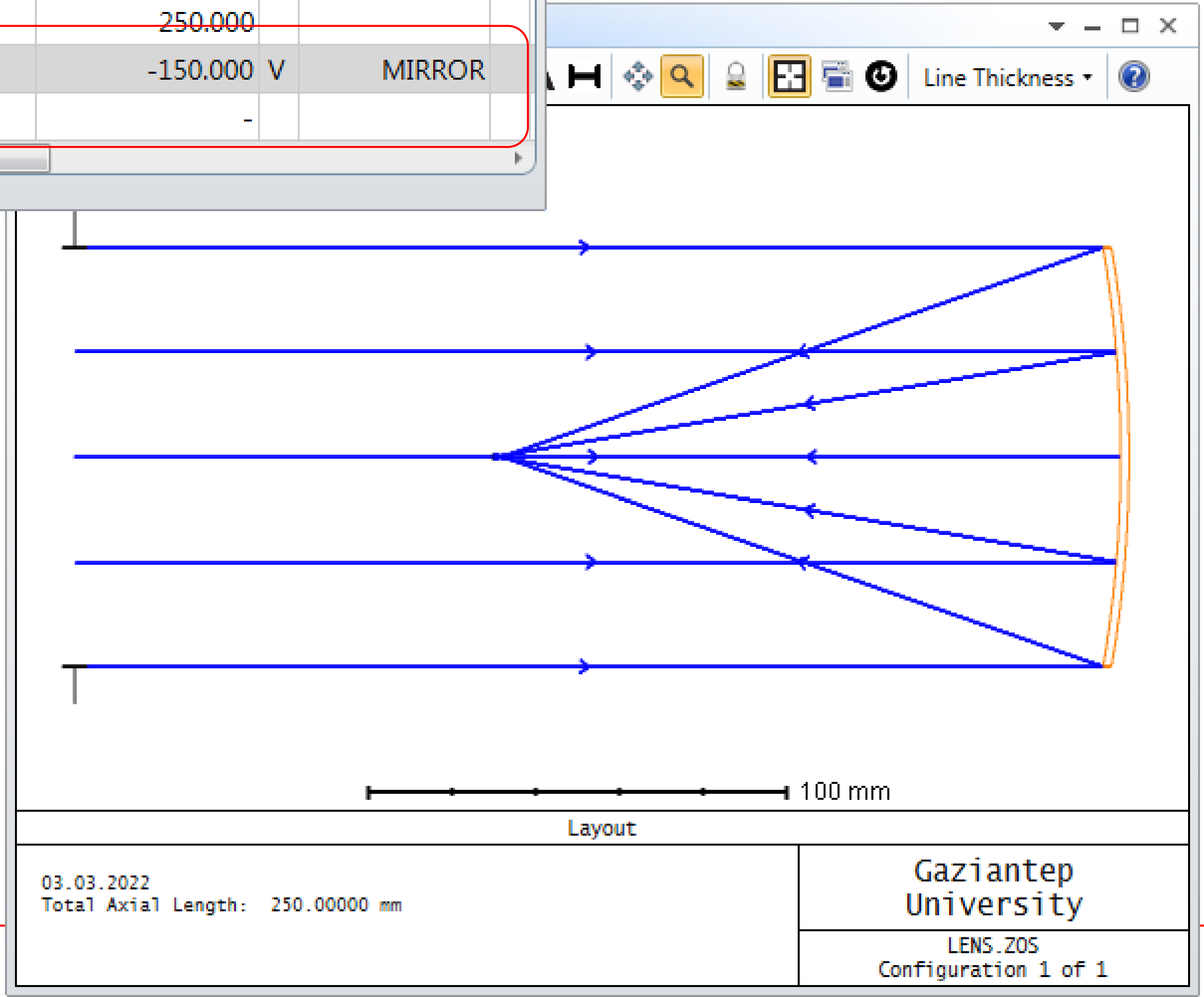
- Aperture D = 100 mm
- f = 150 mm

(a) Determine the Radius of Curvature [Ans:for mirrors: $R = 2f = 300$ mm]

(b) Find distance between mirror and the image plane where we have the smallest spot size.



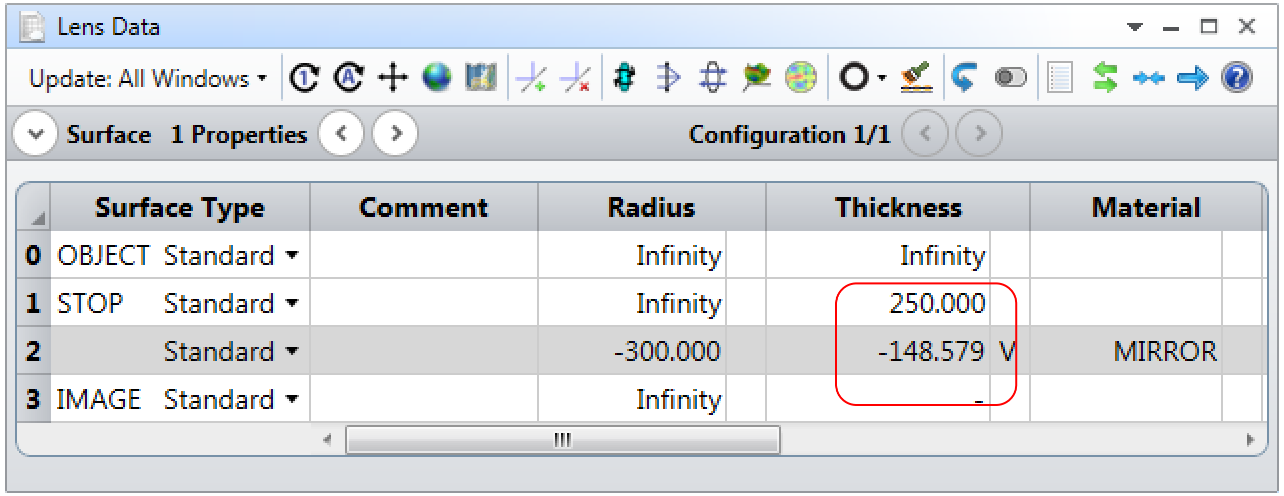
	Surface Type		Comment	Radius	Thickness		Material
0	OBJECT	Standard		Infinity	Infinity		
1	STOP	Standard		Infinity	250.000		
2		Standard		-300.000	-150.000	V	MIRROR
3	IMAGE	Standard		Infinity	-		



Optimization

Optimization can be performed as in the previous in example. (Set EFFL=150 mm).

After optimization:

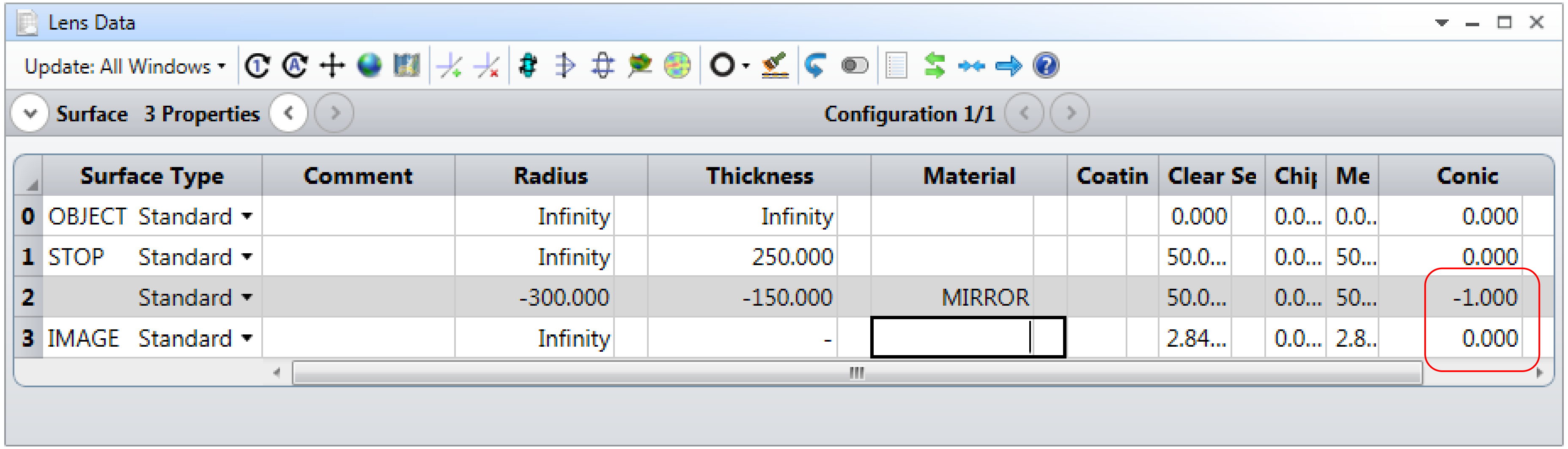


	Surface Type		Comment	Radius	Thickness		Material
0	OBJECT	Standard		Infinity	Infinity		
1	STOP	Standard		Infinity	250.000		
2		Standard		-300.000	-148.579	V	MIRROR
3	IMAGE	Standard		Infinity	-		

The smallest spot (best focus) is obtained at 148.579 mm from the mirror.
(Not 150 mm). Please compare standart spot diagrams.

Parabolic Mirror

Spherical mirrors results in spherical aberrations. Only parabolic surfaces can focus parallel rays to single point. We can change the surface of a spherical mirror to a parabolic one by putting **-1** for conic constant. *(We will see the meaning of* **-1** *later*).



	Surface Type		Comment	Radius	Thickness	Material	Coatin	Clear Se	Chip	Me	Conic
0	OBJECT	Standard		Infinity	Infinity			0.000	0.0...	0.0..	0.000
1	STOP	Standard		Infinity	250.000			50.0...	0.0...	50...	0.000
2		Standard		-300.000	-150.000	MIRROR		50.0...	0.0...	50...	-1.000
3	IMAGE	Standard		Infinity	-			2.84...	0.0...	2.8..	0.000

In this case, we observe a perfect focus.