

Lectures Notes on Optical Design using Zemax OpticStudio

# Lecture 6 Optimization



#### **Ahmet Bingül**

Gaziantep University Department of Optical Engineering

Feb 2024

# 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.</li>
- Function can have multivariable  $F = F(x_1, x_2, ...)$

To find optimum location of function we may use iterative techniques such as Newtonian Method:

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



## **Optimization in Zemax**

- In Zemax merit function (MF) is partially constructed by user.
- To determine new targets operands 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.

_												
	■ Merit Function Editor ×											
	≉ 🔜 🖗 🍾 🗙 💿 🧲 💿 😫 ↔ 🛶 🔞											
	Wizards and Operands     Image: Additional State Sta											
ſ	Type Comment											
lt	1 BLNK -											

# **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 <u>chief ray</u> angles at the wavelength definon-paraxial systems.
ANAC	Angular aberration radial direction measured in image space with respect to the centroid at the wavelength defined defined as: $\epsilon = SQRT[(I-I_c)^2 + (m-m_c)^2]$
	where I 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	<b>Working F-Number</b> operatörü kullanıldığı optimizasyonda sistemin f sayısını hedeflenen değere götürmeye çalışır.
EFFL	<b>Effective Focal Length</b> operandı kullanıldığı optimizasyondaki optik sistemin odak uzaklığını hedeflenen değere götürmeye çalışır.
CTGT	<b>Center Thickness Greater Than</b> operandı ile seçilen bir yüzeyden sonraki merkez uzaklığını istenilen değerden büyük tutmaya çalışan operanddır.
CTVA	<b>Center Thickness Value</b> 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.

🕞 Merit Function Edit	tor 🗙													
🗧 🔜 🕪 🔖 🛪 🖪	) 🧲 💿 😫 🚧 🄿	0												
<ul> <li>Wizards and Operan</li> </ul>	Wizards and Operands () Merit Function: 0													
Optimization Wizard	Optimization Functi	on		- Pupil Integrat	ion		Boundary	/alues						
Current Operand (1)	Criterion:	Wavefront	~	Gaussian (	Quadratu	ire	Glass	Min:	0					
	Spatial Frequency:	30		O Rectangul	ar Array			Max:	1e+03					
	X Weight:	1		Rings:	3	~		Edge Thickness:	0					
	Y Weight:	1		Arms:	6	~	Air	Min:	0					
	Туре:	RMS	~	Obscuration:	0			Max:	1e+03					
	Reference:	Centroid	~					Edge Thickness:	0					
	Start At:	1	÷	Configuration:	All	~	Assume A	Axial Symmetry: 🛛						
	Overall Weight: 1			Field:	All	~	Ignore La	teral Color:	]					
							Add Favo	orite Operands:	]					
	OK Apply	Close				Save Settin	gs Lo	oad Settings	Reset Settings					

# **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.

# **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.





Parameter Space

### **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	Radiu	IS	Thickness						
	Infinity		Infinity						
	15,000	۷	20,000	۷					
	Infinity		-						

#### **Glass Selection**

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



Thickness	Materi	al	Coating	C
Infinity	BK7	S		
0,000	LF7	S		
-				

#### **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.

ſ	📄 Lens	Data 🗙										
U	odate: All	Windows -	: 🕲 🕂 🕲 📖	<b>⅓ ⅓ \$</b>	∌ ‡ 0· ⊻	( 🔍 🔊	🛾 😂 👐 e	• 🕡				
•	Surface	2 Properties					Configuration 1/1 <>					
	Surf	ace 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 $\bullet$	LENS FRONT	Infinity	4.000	N-BK7		12.500	0.000	12.730	0.000	-
2		Standard 🔻	LENS BACK	Infinity	100.000			12.730	0.000	12.730	0.000	0.000
3	IMAGE	Standard 🔻	IMAGE	Infinity	Curvature solve	on surface 2		21.479	0.000	21.479	0.000	0.000
3 IMAGE Standard •					Solve Type:	Fixed Fixed Variable Marginal F Chief Ray Pickup Marginal F Chief Ray Aplanatic Element P Concentric Concentric <b>F</b> Number ZPL Macro	Ray Angle Angle Ray Normal Normal ower c Surf c Radius	~				

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

ſ	E Lens Data X													
U	pdate: All	Windows 🕶 🚺	: 🕲 🕂 🕘 📖	<del>/</del> , -/ <b>↓</b> ₿	∌	• # O	• 🙎	<u>(</u> 🔍 🔊 🗌	\$ ** •	⇒ 😧				
•	Surface 0 Properties ( ) Configuration 1/1 ( )													
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			g	Infinity	0.000	Infinity	0.000	0.000
1	STOP	Standard 🔻	LENS FRONT	Infinity	٧	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)

🔓 Merit Function Editor									<b>▼</b> - □ ×		
🗢 🔜 📦 🔖 🗙 🖪	🧲 💿 😫 🚧 🤿	•									
Wizards and Operan	ds < 🔊				Me	erit Function	: 0				
Optimization Wizard Current Operand (1)	<ul> <li>Optimization Functi</li> </ul>	on	Pupil Integration			- Boundary Values					
	Criterion:	Spot ~	Gaussian	Quadrature		✓ Glass	Min:	2			
	Spatial Frequency:	30	Rectangu	lar Array	_		Max:	12			
	X Weight:	1	Rings:	3	~		Edge Thickness:	2			
	Y Weight:	1	Arms:	6	~	🗌 Air	Min:	0			
	Туре:	RMS ~	Obscuration:	0			Max:	100			
	Reference:	Centroid ~					Edge Thickness:	0			
	Start At: Overall Weight: 1	1 🗸	Configuration: Field:	1 All	<b>&gt;</b>	Assume A	Axial Symmetry: 💽	2			
	Add Favorite Operands:										
	OK Apply	Close		Sav	e Setting	gs Lo	oad Settings	Reset Settings			
Type Comment											

## **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  $R_1 = +300 \text{ mm}$

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)

P	Lens Data											▼ - □ ×			
U	Ipdate: All Windows -	; 🕲 🕂 🚭 🕅 🖯	k -/∡   \$ ⊅ \$	: 🟓	e 😔 🔿 - 🗲 🥌		📃 😫 🕶 🔿 (	?							
•	Surface 3 Properties     Surface 3 Properties														
	Surface Type	Comment	Radius		Thickness		Material		Coating	Clear Semi-Dia	1	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	۷				39.352		0.000			
4	IMAGE Standard •		Infinity		-					3.963		0.000			
C		4													



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

limit Function Editor					▼ - □ ×						
🗢 🔜 📦 🔖 🛪 🚴		0									
Wizards and Operat	nds < 🔊		Merit Function: 0								
Optimization Wizard Current Operand (1)	Optimization Function – Image Quality: Spatial Frequency: X Weight: Y Weight: Type: Reference: Max Distortion (%): Ignore Lateral Color Optimization Goal Best Nominal Perform	Spot   Spot  Solution  Spot  Solution  Solutio	Pupil Integration   Image: Gaussian Quadrature   Rectangular Array   Rings: Gaussian Quadrature   Arms: Gaussian Quadrature   Obscuration: O     Start At: 1    Overall Weight: 1	Boundary Values         Glass       Min:         Max:       Edge Thickness:         Air       Min:         Max:       Edge Thickness:         Edge Thickness:       Image: Configuration:         All       Thickness:	0 1e+03 0 0 1e+03 0 Assume Axial Symmetry: [ Add Favorite Operands: [						
Type Comm	O Improve Manufacturin       Weight:       OK       Apply	Close		Save Settings Load Settings	Reset Settings						

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

Image: Second		Merit Functio	n Editor										▼ - □ ×
Wizards and Operands         Image: Second seco	\$	🔒 🕪 🔖	XX	• Ϛ 🗉	) 💲 🕶	-> 🕜							
Type         Wave         Target         Weight         Value         % Contrib           1         DMFS •         0         360.000         1.000         465.987         99.790           3         BLNK •         No air or glass constraints.         360.000         0.000         465.987         99.790           3         BLNK •         Operands for field 1.         5         TRCX •         1         0.000         0.336         0.000         0.873         -1.253         0.012           6         TRCY •         1         0.000         0.000         0.873         -0.253         0.000           7         TRCX •         1         0.000         0.000         0.000         0.873         0.000         0.000           8         TRCY •         1         0.000         0.000         0.000         1.396         -2.710         0.091           8         TRCY •         1         0.000         0.000         0.94         Iocal Optimization         Iocal Optimizat	•	Wizards and	d Operand	is 🔇	>			м	lerit Fur	nction: 39	.3141618004948		
1       DMFS •       1       360.000       1.000       465.987       99.790         3       BLNK • No air or glass constraints.       4       BLNK • Operands for field 1.       5       TRCX •       1       0.000       0.336       0.000       0.000       0.873       -1.253       0.012         6       TRCY •       1       0.000       0.336       0.000       0.000       0.873       -0.000       0.000         7       TRCX •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         9       TRCX •       1       0.000       0.000       0.94       Local Optimization       Local Optimization       4       Algorithm:       Damped Least Squares •       # of Cores:         Targets:       7       Cycles:       Variables:       2       Status:       Initial Merit Function:       39.314161800       Execution Time:		Туре		Wave						Target	Weight	Value	% Contrib
2       EFFL •       1       360.000       1.000       465.987       99.790         3       BLNK • No air or glass constraints.       4       BLNK • Operands for field 1.       5         5       TRCX •       1       0.000       0.336       0.000       0.000       0.873       -1.253       0.012         6       TRCY •       1       0.000       0.000       0.873       -0.000       0.000         7       TRCX •       1       0.000       0.000       0.000       0.873       -0.000       0.000         6       TRCY •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.707       Inccal Optimization       Intraction       Intrac	1	DMFS -											
3       BLNK • No air or glass constraints.         4       BLNK •       Operands for field 1.         5       TRCX •       1       0.000       0.336       0.000       0.000       0.873       -1.253       0.012         6       TRCY •       1       0.000       0.000       0.336       0.000       0.000       0.873       -0.000       0.000         7       TRCX •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.94       Local Optimization       Iocal Optimization       Iocal Optimization       Iocal Optimization         10       TRCY •       1       0.000       0.000       0.94       Iargets:       7       Cycles:         Variables:       2       Status:       Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800       Image:       Image:       Image:       Image:         I       Auto Update       St	2	EFFL 🔻		1						360.000	1.000	465.987	99.790
4       BLNK • Operands for field 1.         5       TRCX •       1       0.000       0.336       0.000       0.873       -1.253       0.012         6       TRCY •       1       0.000       0.336       0.000       0.000       0.873       0.000       0.000         7       TRCX •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.94       Local Optimization       Local Optimization         10       TRCY •       1       0.000       0.000       0.94       Local Optimization       Image: Targets:       7       Cycles:       Cycles:       Variables:       2       Status:       Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800       Image: Target Start       Stop       Exit	3	BLNK 🔻	No air o	r glass c	onstraint	s.							
5       TRCX •       1       0.000       0.336       0.000       0.000       0.873       -1.253       0.012         6       TRCY •       1       0.000       0.000       0.336       0.000       0.000       0.873       0.000       0.000         7       TRCX •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.94       Local Optimization       Image: Targets:       7       Cycles:         10       TRCY •       1       0.000       0.000       0.94       Image: Targets:       7       Cycles:       Variables:       2       Status:       Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800       Image: Targets:       7       Cycles:       Current Merit Function:       39.314161800	4	BLNK 🕶	Operand	ds for fie	ld 1.								
6       TRCY •       1       0.000       0.336       0.000       0.000       0.873       0.000       0.000         7       TRCX •       1       0.000       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.707       0.000       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.94       Local Optimization       Image: Constant of the second of	5	TRCX -		1	0.000	0.000	0.336	0.000		0.000	0.873	-1.253	0.012
7       IRCX •       1       0.000       0.707       0.000       1.396       -2.710       0.091         8       TRCY •       1       0.000       0.000       0.707       0.000       1.396       -2.710       0.091         9       TRCX •       1       0.000       0.000       0.94       Local Optimization         10       TRCY •       1       0.000       0.000       0.94         Algorithm:       Damped Least Squares •       # of Cores:         Targets:       7       Cycles:         Variables:       2       Status:         Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800       Execution Time:         Auto Update       Start       Stop       Exit	6	TRCY -		1	0.000	0.000	0.336	0.000		0.000	0.873	0.000	0.000
B       TRCY •       1       0.000       0.000       0.70         9       TRCX •       1       0.000       0.000       0.94         10       TRCY •       1       0.000       0.000       0.94         Algorithm:       Damped Least Squares •       # of Cores:         Targets:       7       Cycles:         Variables:       2       Status:         Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800       Execution Time:	7	TRCX •		1	0.000	0.000	0.707	0.000		0.000	1.396	-2.710	0.091
Image: start       Image: start <th< th=""><th>8</th><th>TRCY -</th><th></th><th>1</th><th>0.000</th><th>0.000</th><th>0.70</th><th>Local Optimi</th><th>zation</th><th></th><th></th><th></th><th></th></th<>	8	TRCY -		1	0.000	0.000	0.70	Local Optimi	zation				
Algorithm:       Damped Least Squares       # of Cores:         Targets:       7       Cycles:         Variables:       2       Status:         Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800       Execution Time:         Auto Update       Start       Stop	9			1	0.000	0.000	0.94						
Algorithm:       Damped Least Squares       # of Cores:         Targets:       7       Cycles:         Variables:       2       Status:         Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800       Execution Time:         Auto Update       Start       Stop       Exit		Ther -		1	0.000	0.000	0.54			0			~
Targets:       7       Cycles:         Variables:       2       Status:         Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800       Execution Time:         Auto Update       Start       Stop								Algorithm	n:	l	Damped Least S	quares • # of	Cores:
Variables:       2       Status:         Initial Merit Function:       39.314161800       Execution Time:         Current Merit Function:       39.314161800         Auto Update       Start       Stop         Exit       Stop								Targets:			7	Cycl	es:
Initial Merit Function: 39.314161800 Execution Time: Current Merit Function: 39.314161800								Variables	:		2	Stat	us:
Current Merit Function: 39.314161800								Initial Me	rit Fun	ction:	39.3 <mark>14161</mark> 800	Exec	ution Time:
Auto Update Start Stop Exit								Current	Aarit Eu	Inction	20 21/161800		
Auto Update Start Stop Exit								Current N	nent ri	unction.	55.514101000		
Auto Update Start Stop Exit													
								Auto U	pdate	Star	t Stop	Exit	

At the end of optimization we have R<sub>2</sub> ≈ -999 mm. Investigate the performace plots (spot, OPD, etc).

Lens Data		<b>→</b> – □ ×												
Update: All Windows 🗸 🕐 🚱 🚻 🦂 🤸 🋊 🏦 🏝 🌐 🏶 🥮 🔿 🛛 ≰ 🤝 💿 🗐 😂 🖘 🔿 🔞														
Surface 3 Properties	< >			Configuration 1/1 <>										
Surface Type	Comment	Radius	Tł	nickness		Material	Coating	Cl	ear Semi-Dia	Chip Zone				
OBJECT Standard -		Infinity		Infinity					0.000	0.000				
STOP Standard •		Infinity		10.000					40.000	0.000				
Standard 🔻		300.000		15.000		SF2			40.000	0.000				
Standard 🔻		-999.037	V	350.413	v				39.393	0.000				
IMAGE Standard -		Infinity		-					0.143	0.000				
	٠ [									+)				
	date: All Windows • Surface 3 Properties Surface Type OBJECT Standard • STOP Standard • Standard • IMAGE Standard •	Lens Data date: All Windows	Lens Data         date: All Windows ▼       ① ②        ① ③        ↓ ↓ ↓ ②        ②          Surface 3 Properties       ③ ○       ○       ○         Surface Type       Comment       Radius         OBJECT Standard ▼       Infinity         STOP       Standard ▼       300.000         Standard ▼       -999.037         IMAGE       Standard ▼	Lens Data         date: All Windows ▼	Lens Data         date: All Windows ▼       ⑦       ②       Image: Second seco	Lens Data         date: All Windows ▼       ①       ②       +       ②       >       ●       <	Infinity Infinity   Infinity Infinity   Standard • 300.000   Standard • -999.037   V 350.413   V Infinity	Lens Data         date: All Windows ▼       C       C       +       <	Lens Data         date: All Windows •       ①       ①       +       <	Surface Type       Comment       Radius       Thickness       Material       Coating       Clear Semi-Dia         OBJECT Standard ▼       Infinity       Infinity       Infinity       0.000       40.000       40.000       140.000       10.000       15.000       SF2       40.000       40.000       10				



# **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.



# Optimization

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

After optimization:

e	🖹 Lens Data 📃 👻 – 🗆 🗧												
Update: All Windows - 🛛 🐨 🕂 🔮 💹 🦟 🤸 🋊 🛊 🛊 🏚 🏶 🚳 🔿 - ≰ 🥥 🗐 🚍 端 🛶 🔞													
Surface 1 Properties < > Configuration 1/1 < >													
	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										
		4											
		×											

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)*.

Lens Data Update: All Windows • 🛈	@+• ¥	: 🔸 😫 🕈 🛱 🗯	🍪 O- <u> </u> 🔊	□ \$ @	)				▼ - □ 3
Surface 3 Properties      Configuration 1/1									
Surface Type	Comment	Radius	Thickness	Material	Coatin	Clear Se	Chij	Me	Conic
OBJECT Standard ▼		Infinity	Infinity			0.000	0.0	0.0	0.000
L 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
B IMAGE Standard ▼		Infinity	-			2.84	0.0	2.8	0.000
	4								

Sayfa 27

