

**Tutorial for design and integration of 1D and 2D Diffractive
Beam Splitters (Multi-spot) into optical systems in Sequential
and non-Sequential mode of ZEMAX™**

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1. Introduction

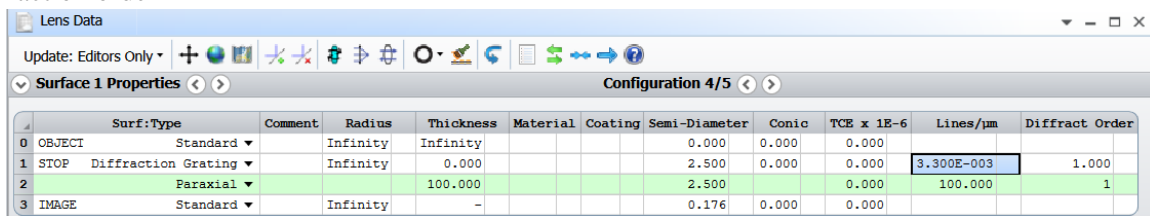
1.1. Preliminary reading

1. HOLO/OR's application note for Diffractive Beam Splitters
http://holoor.co.il/Diffractive_optics_Applications/Application_Notes_BeamSplitters.htm
2. Articles about definition of diffractive functionality in ZEMAX
<http://www.zemax.com/support/resource-center/knowledgebase/how-diffractive-surfaces-are-modeled-in-zemax>
<http://www.zemax.com/support/resource-center/knowledgebase/how-to-design-diffractive-optics-using-the-binary>
3. ZEMAX user manual for Diffractive Grating surface

1.2. Definition of Diffraction Grating Surface in ZEMAX

Diffractive Grating surface has two key parameters:

1. Lines/ μm (equivalent to grating period)
2. Diffraction order



	Surf: Type	Comment	Radius	Thickness	Material	Coating	Semi-Diameter	Conic	TCE x 1E-6	Lines/ μm	Diffract Order
0	OBJECT	Standard	Infinity	Infinity			0.000	0.000	0.000		
1	STOP	Diffractive Grating	Infinity	0.000			2.500	0.000	0.000	3.300E-003	1.000
2		Paraxial		100.000			2.500	0.000	0.000	100.000	1
3	IMAGE	Standard	Infinity	-			0.176	0.000	0.000		

1.3. Calculation of Lines/ μm

According to the Grating Equation:

$$\Lambda = \frac{m\lambda}{\sin \alpha}$$

Where:

- Λ : grating period
- m: order number (from Zero Order)
- α : separation angle (for example for m=1 means separation angle between Zero Order and Order +/- 1)
- λ : wavelength

$$\text{Lines} / \mu\text{m} = \frac{1}{\Lambda[\mu\text{m}]}$$

1.3.1. Example:

- $\lambda = 532 \text{ nm}$
- $\alpha = 0.1^\circ$ (More information about separation angle for even and odd orders can be found [here](#))
- Calculated $\Lambda = 304.814 \mu\text{m}$
- Lines/ $\mu\text{m} = 1 / \Lambda = 1 / 304.814 = 0.0033 \text{ [Lines}/\mu\text{m}]$

Holo/Or's online grating calculator can be used:

http://holoor.co.il/Diffractive_Optics_Products/Calculators.htm (section "Gratings")

2. Three techniques to model diffractive beam splitters – two in Sequential and one in Non-Sequential modes:

- A. Sequential mode: Diffraction Grating surface and multi-configuration
- B. Sequential mode: Fields' angle
- C. Non-Sequential mode: Diffraction Grating surface with special definitions

2.1. Sequential Mode

2.1.1. Method A: Diffraction Grating surface and multi-configuration

2.1.1.1. Development steps

1. Inserting general parameters for simulation (wavelength, aperture, ...)
2. Inserting Diffraction Grating surface into Lens editor
 - a) Lines/ μm (equivalent to grating period)
 - b) Diffraction order
3. Definition of Multi-Configuration Editor

Example for 1D case of 5 spots splitter – diffraction orders -2 to 2



Lens Data editor view

Lens Data											
Configuration 3/5											
Surface 1 Properties											
	Surf.Type	Cor	Radius	Thickness	Ma	Coa	Semi-Diameter	Conic	TCE x 1E-6	Lines/ μm	Diffract Order
0	OBJECT	Standard	Infinity	Infinity			0.000	0.000	0.000		
1	STOP	Diffraction Grating	Infinity	0.000			2.500	0.000	0.000	3.300E-003	0.000
2	Paraxial			100.000			2.500		0.000	100.000	1
3	IMAGE	Standard	Infinity	-			4.441E-016	0.000	0.000		

2.1.1.2. Advantages of the method

- Realistic physical model (consistent with Diffraction Grating equation)
- Allows optimization of the optical system including diffractive beam splitter
- Allows 2D beam splitter modeling

2.1.2. Method B: Fields' angle

2.1.2.1. Development steps

1. Entering Fields' angle in "System Explorer" (The field angles are equivalent to propagation angle of the Multi-Spot orders)

Example for defining a 5 spot beam splitter with separation angle of 0.1 degrees

The image shows two screenshots from a software application. The top screenshot is the 'System Explorer' window, which has a left sidebar with 'Aperture', 'Fields', and 'Settings'. The 'Fields' section is expanded, showing a list of fields with their coordinates (X, Y) and weights. The 'Settings' section shows 'Type' set to 'Angle' and 'Normalization' set to 'Radial'. The 'Field Data' table is visible, showing 12 rows of field data. The bottom screenshot is the 'Lens Data' editor window, showing a table of lens surfaces. The table has columns for Surf.Type, Comm, Radius, Thickness, Material, Coatin, Semi-Diame, Conic, TCE x 1E-, and Par 1(unu). The surfaces are: 0 OBJECT (Standard, Infinity, Infinity), 1 STOP (Paraxial, 100.0...), and 2 IMAGE (Standard, Infinity, -).

	X	Y	Weight	VDX	VDY	VCX	VCY	VAN
1	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
2	0.0	-0.1	1.0	0.0	0.0	0.0	0.0	0.0
3	0.0	-0.2	1.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.2	1.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0

Surf.Type	Comm	Radius	Thickness	Material	Coatin	Semi-Diame	Conic	TCE x 1E-	Par 1(unu)
0 OBJECT	Standard	Infinity	Infinity			Infinity	0.0...	0.000	
1 STOP	Paraxial		100.0...			2.500		0.000	100.000
2 IMAGE	Standard	Infinity	-			0.349	0.0...	0.000	

Object surface contains two functionalities – a source and a multi-spot. Distance from multi-spot and the following optical surfaces can be defined by adding distance between surface 0 and surface 1.

2.1.2.2. Advantages of the method

- Simplest way to build and analyze results
- Allows optimization of the optical system including diffractive beam splitter
- Allows 2D beam splitter modeling

2.1.3. Sequential mode - Displaying and analyzing results:



2.1.3.1. 3D Layout Diagram

1: 3D Layout

Line Thickness ▾

First Surface: 1 Wavelength: 1
Last Surface: 3 Field: All
Number Of Rays: 7 Ray Pattern: XY Fan
Scale Bar: On Color Rays By: Config #

Rotation
X: -8.74681E-06 Y: 0 Z: -6.66068E-07

Delete Vignetted: ☐ Suppress Frame: ☐
Hide Lens Faces: ☐ Fletch Rays: ☐
Hide Lens Edges: ☐ Split NSC Rays: ☐
Hide X Bars: ☐ Scatter NSC Rays: ☐

Configuration
All
Current
1 / 5
2 / 5
3 / 5
4 / 5

Settings for multi-configuration - Method A

2: 3D Layout

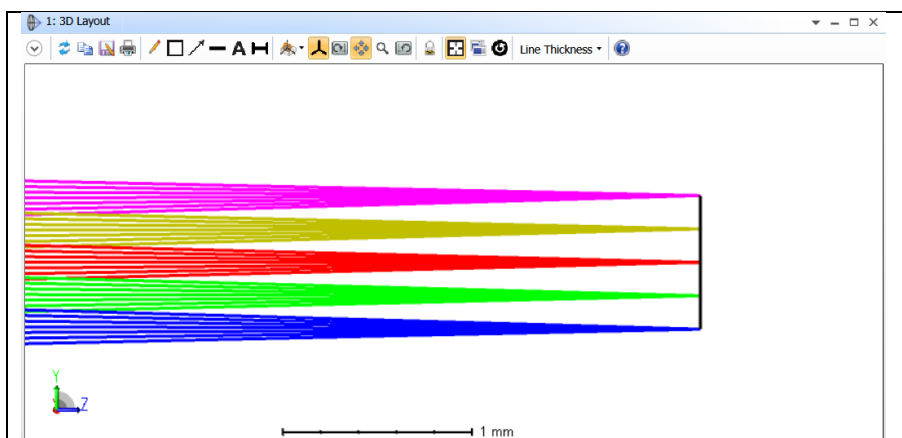
Line Thickness ▾

First Surface: 1 Wavelength: 1
Last Surface: 2 Field: All
Number Of Rays: 7 Ray Pattern: XY Fan
Scale Bar: On Color Rays By: Field #

Rotation
X: 7.23811E-08 Y: 0 Z: 0

Delete Vignetted: ☐ Suppress Frame: ☐
Hide Lens Faces: ☐ Fletch Rays: ☐
Hide Lens Edges: ☐ Split NSC Rays: ☐
Hide X Bars: ☐ Scatter NSC Rays: ☐

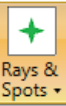
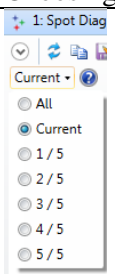
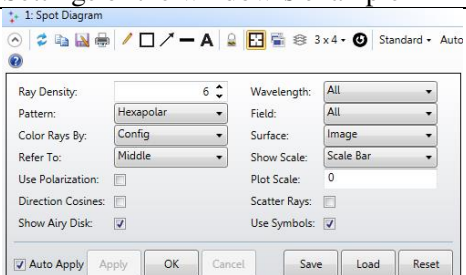
Settings for Field Angles - Method B

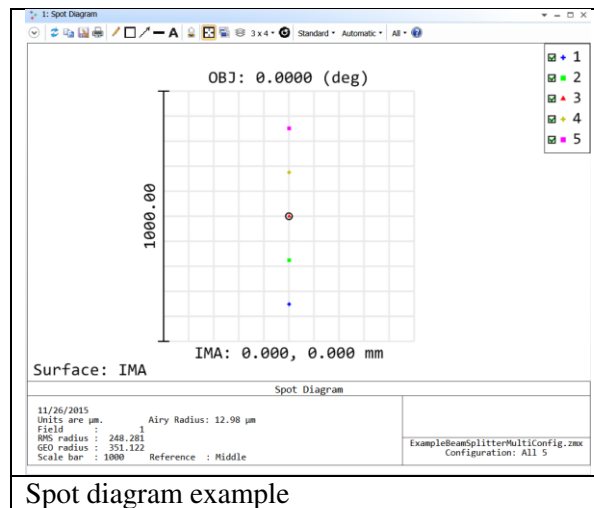


Rays near focal position

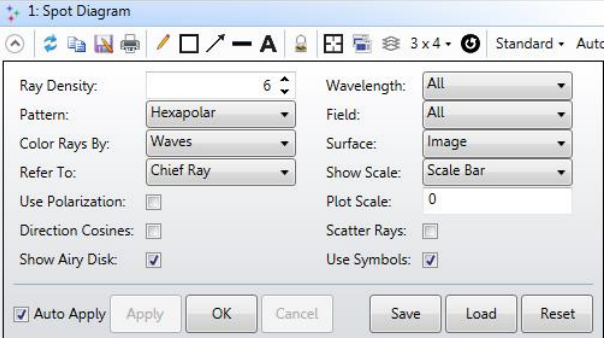
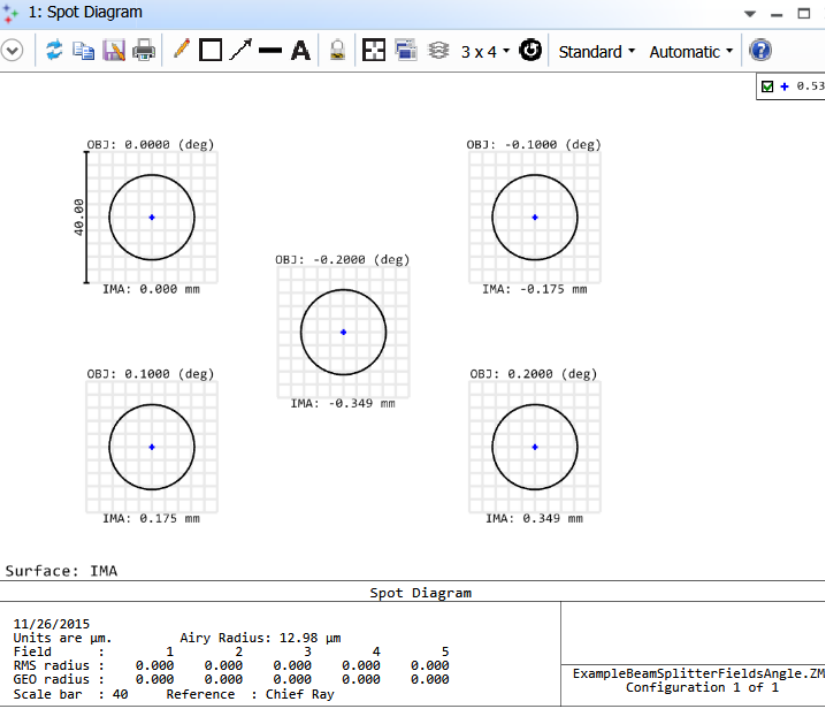
2.1.3.2. Spot diagram

Method A - Window's setting definition in 3 steps:

Spot diagram in tools bar	Choosing "All" configurations in opened window	Settings of the window's example
 Rays & Spots Aberrations Wavefr Single Ray Trace Ray Aberration Standard Spot Diagram	 1: Spot Diag Current All Current 1/5 2/5 3/5 4/5 5/5	 1: Spot Diagram Ray Density: 6 Pattern: Hexapolar Color Rays By: Config Refer To: Middle Use Polarization: Direction Cosines: Show Airy Disk: Wavelength: All Field: All Surface: Image Show Scale: Scale Bar Plot Scale: 0 Scatter Rays: Use Symbols: Auto Apply Apply OK Cancel Save Load Reset



Method B - Window's setting definition

Window's settings	Spot diagram example
 1: Spot Diagram Ray Density: 6 Pattern: Hexapolar Color Rays By: Waves Refer To: Chief Ray Use Polarization: Direction Cosines: Show Airy Disk: Wavelength: All Field: All Surface: Image Show Scale: Scale Bar Plot Scale: 0 Scatter Rays: Use Symbols: Auto Apply Apply OK Cancel Save Load Reset	 1: Spot Diagram OBJ: 0.0000 (deg) IMA: 0.000 mm OBJ: -0.1000 (deg) IMA: -0.175 mm OBJ: -0.2000 (deg) IMA: -0.349 mm OBJ: 0.1000 (deg) IMA: 0.175 mm OBJ: 0.2000 (deg) IMA: 0.349 mm Surface: IMA Spot Diagram 11/26/2015 Units are μm . Airy Radius: 12.98 μm Field : 1 2 3 4 5 RMS radius : 0.000 0.000 0.000 0.000 0.000 GEO radius : 0.000 0.000 0.000 0.000 0.000 Scale bar : 40 Reference : Chief Ray ExampleBeamSplitterFieldsAngle.ZMX Configuration 1 of 1

2.2. Non-Sequential mode

2.2.1. Method C: Diffraction Grating surface with special definitions

2.2.1.1. Development steps

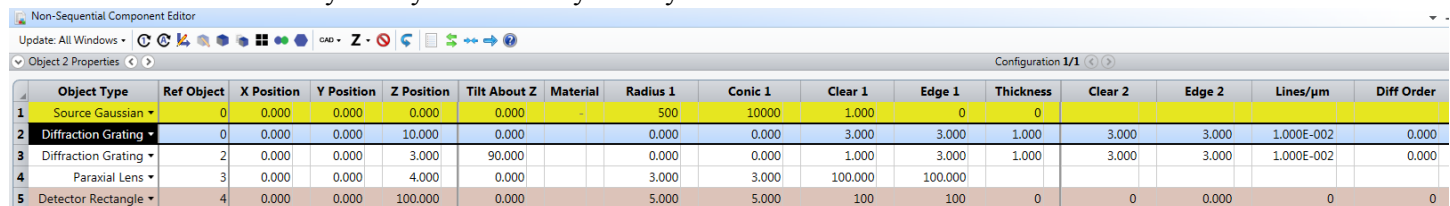
*The design starts with calculation of lines / μm value.

1. Open a new file in NSC mode

2. Insert Source surface

Define general properties of the design (wavelength ...)

Number of “#Analysis Rays” and “# Layout Rays”



Object Type	Ref Object	X Position	Y Position	Z Position	Tilt About Z	Material	Radius 1	Conic 1	Clear 1	Edge 1	Thickness	Clear 2	Edge 2	Lines/ μm	Diff Order
Source Gaussian	0	0.000	0.000	0.000	0.000		500	10000	1.000	0	0				
Diffraction Grating	0	0.000	0.000	10.000	0.000		0.000	0.000	3.000	3.000	1.000	3.000	3.000	1.000E-002	0.000
Diffraction Grating	2	0.000	0.000	3.000	90.000		0.000	0.000	1.000	3.000	1.000		3.000	1.000E-002	0.000
Paraxial Lens	3	0.000	0.000	4.000	0.000		3.000	3.000	100.000	100.000					
Detector Rectangle	4	0.000	0.000	100.000	0.000		5.000	5.000	100	100	0	0	0.000	0	0

3. Insert Diffraction Grating surface

a) Define basic parameters for the element (material, thickness, clear aperture)

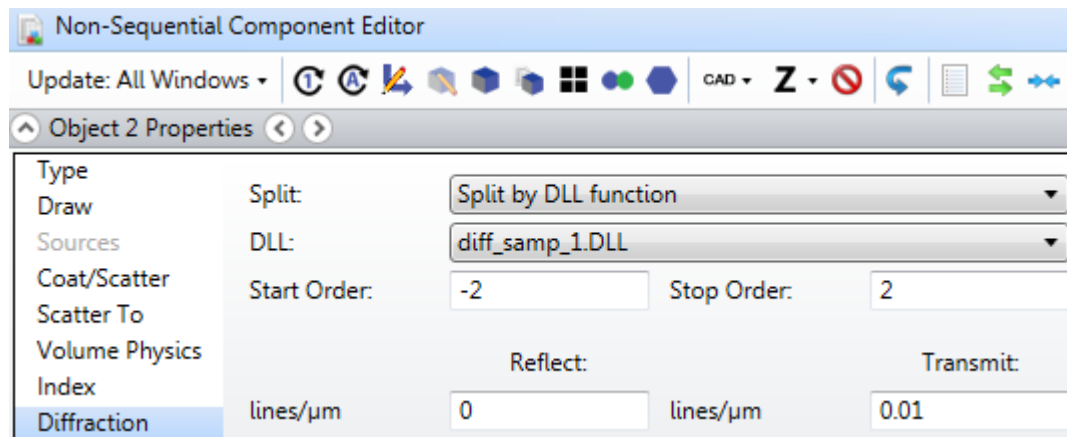
b) Insert Lines / μm parameter

c) Open properties of Diffraction grating surface and go to Diffraction property

d) In “Split” option choose “Split by DLL function” and then choose file diff_samp_1.DLL

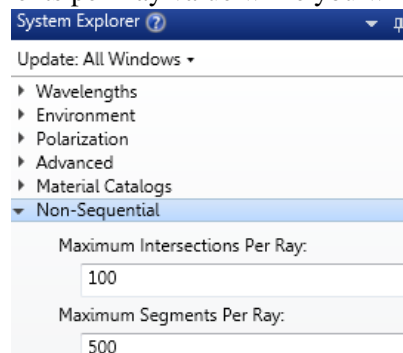
e) Enter Start Order and Stop Order. For example for 5 spots beam splitter -2 and 2

f) Insert period size in lines/ μm units into reflection and transmission sections.



* For a 2D beam splitter another Diffraction Grating surface needs to be entered with a 90 degrees rotation around the optical axis (typically “tilt Z”).

** For large number of orders, some modification in general properties of the non-sequential mode might be required to get correct results. Increase Maximum Segments per Ray value while you will get efficient number for the specific case.

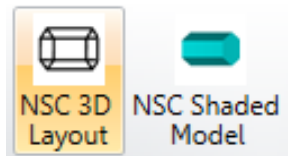


2.2.1.2. Advantages of the method

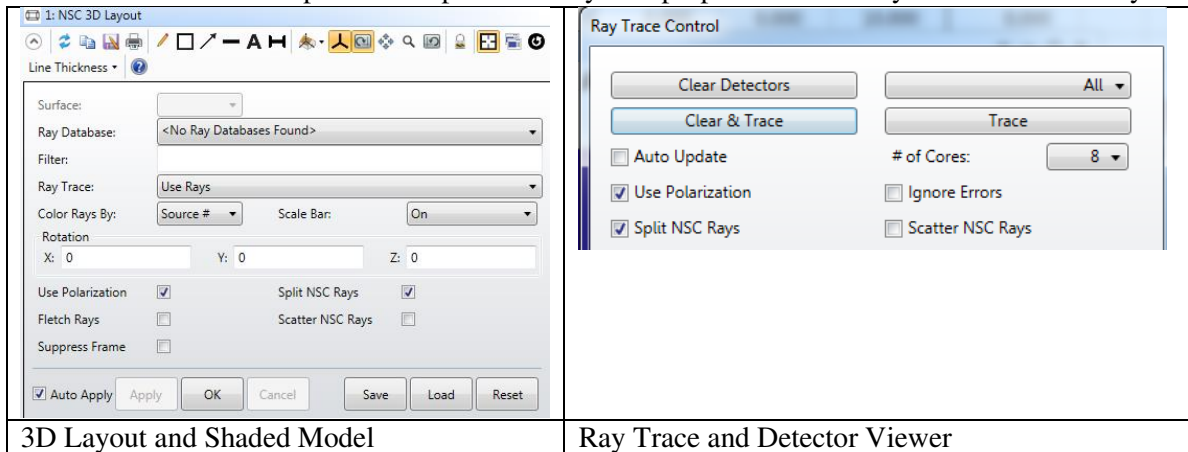
- More realistic physical model (chromatic behavior)
- Allows the modeling of all orders at once for a 2D beam splitter
- Enables integration of a diffractive element into any optical system
- Very useful for illumination systems

2.2.2. Displaying Results

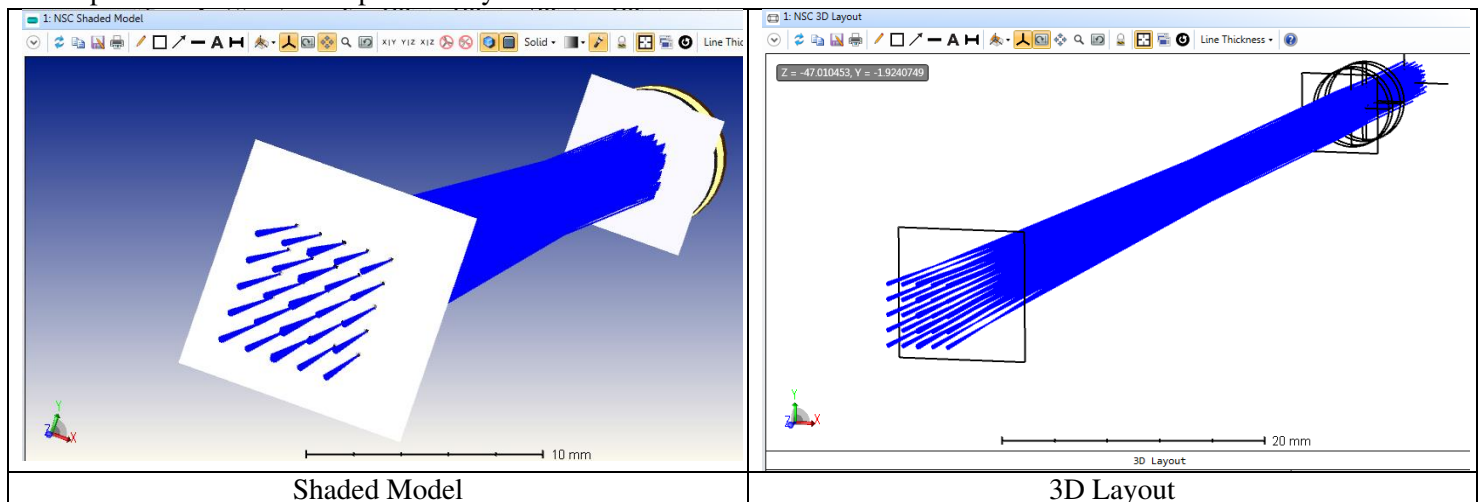
2.2.2.1. NSC 3D Layout and NSC Shaded Model



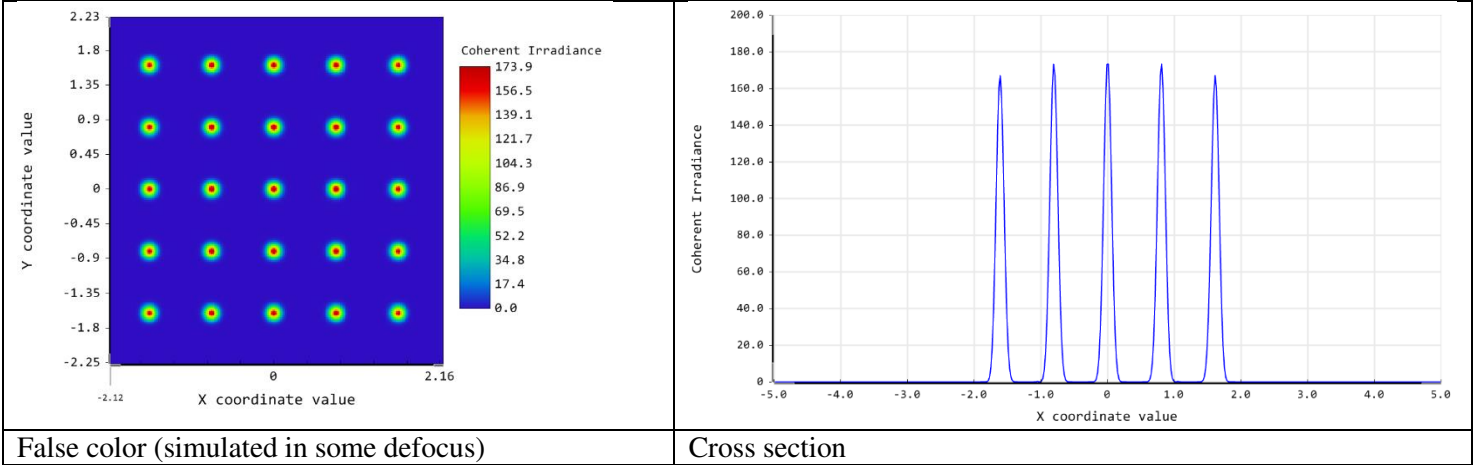
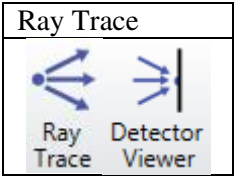
To see diffraction orders mark the option for “Split NSC Rays” in properties of 3D Layout and also for Ray Trace Control



Example - results for beam splitter array 5x5



2.2.2.2. Ray Tracing Results



3. Comparison table for Sequential and Non Sequential models

	Method A	Method B	Method C
Ideal model	Yes	Yes	Yes
Geometrical method	Yes	Yes	Yes
Optimization of multi element optical system	Natural	Requires adaptation per wavelength	Complex
Aberrations analysis	Natural	Natural	Complex
Simultaneous analysis of all spots	No	No	Yes

4. Summary:

1. Three methods to model Diffractive Beam Splitter in ZEMAX were shown
2. The methods are based on geometrical concept and assume an ideal element
3. The Sequential mode based methods benefit optimization and design capability by using multi configuration or field angles
3. The Non-Sequential mode method brings more realistic result by allowing to propagate all spots at once
4. The methods allow integration and analysis of Diffractive Beam Splitter within different optical systems design

5. Example files links and existing products from Holo/Or:

Files:

- [ExampleBeamSplitterMultiConfig](#)
- [ExampleBeamSplitterFieldsAngle](#)
- [MS-NSC](#)

Available products:

http://holoor.co.il/Diffractive_Optics_Products/Diffractive_Beam_Splitters/BeamSplitter-multispot.htm