

Design and integration of 1D and 2D diffractive beam splitters (multi-spot) into optical systems in sequential and non-sequential mode of ZEMAX™

TUTORIAL

HOLO/OR

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1. Introduction

1.1. Preliminary reading

1.1.1. HOLO/OR's application note for Diffractive Beam Splitters

- http://holoor.co.il/Diffractive_optics_Applications/Application_Notes_BeamSplitters.htm

1.1.2. Articles about definition of diffractive functionality in ZEMAX

- [How diffractive surfaces are modeled in OpticStudio](#)
- [How to model diffractive optics using the Binary 2 surface](#)

1.1.3. ZEMAX user manual - Diffractive Grating surface

1.2. Definition of Diffraction Grating Surface in ZEMAX™

1.2.1. Diffraction grating surfaces have two key parameters:

- Lines/ μm (equivalent to grating period)
- Diffraction order

1.3. Calculation of Lines/ μm

1.3.1. 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

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

1.3.2. Example:

- $\lambda = 532 \text{ nm}$

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

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

- <https://www.holor.co.il/optical-calculator/gratings-optical-calculator/> (section "Gratings")

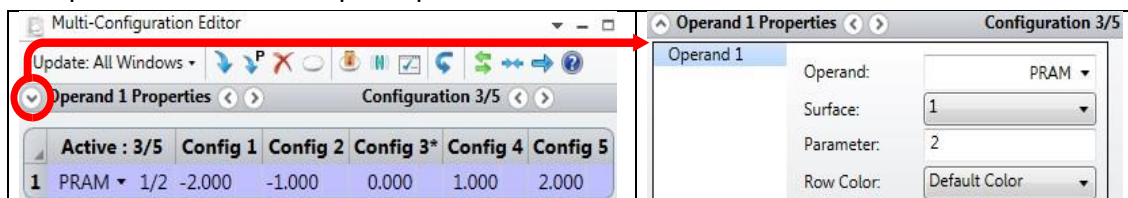
2. Three techniques to model diffractive beam splitters – two in sequential mode and one in non-sequential mode:

2.1. Sequential mode - Method A: Diffraction grating surface and multi-configuration

2.1.1. Development steps

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

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



Lens data editor view:

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		

2.1.3. 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

2.2. Sequential mode - Method B: Field's angle

2.2.1. Development steps

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

2.2.2. Example for defining a 5-spot beam splitter with separation angle of 0.1 degrees:

The screenshot shows the 'System Explorer' window with the 'Field Data' table and settings. The table lists 12 fields, with fields 1 through 5 checked. The settings are: Type: Angle, Normalization: Radial, Number Of Fields: 3, Maximum Field: 0.0, and Equal-Area Fields checked.

	X	Y	Weight	VDX	VDY	VCX	VCY	VAN
<input checked="" type="checkbox"/>	1	0.0	0.0	1.0	0.0	0.0	0.0	0.0
<input checked="" type="checkbox"/>	2	0.0	-0.1	1.0	0.0	0.0	0.0	0.0
<input checked="" type="checkbox"/>	3	0.0	-0.2	1.0	0.0	0.0	0.0	0.0
<input checked="" type="checkbox"/>	4	0.0	0.1	1.0	0.0	0.0	0.0	0.0
<input checked="" type="checkbox"/>	5	0.0	0.2	1.0	0.0	0.0	0.0	0.0
<input type="checkbox"/>	6	0.0	0.0	1.0	0.0	0.0	0.0	0.0
<input type="checkbox"/>	7	0.0	0.0	1.0	0.0	0.0	0.0	0.0
<input type="checkbox"/>	8	0.0	0.0	1.0	0.0	0.0	0.0	0.0
<input type="checkbox"/>	9	0.0	0.0	1.0	0.0	0.0	0.0	0.0
<input type="checkbox"/>	10	0.0	0.0	1.0	0.0	0.0	0.0	0.0
<input type="checkbox"/>	11	0.0	0.0	1.0	0.0	0.0	0.0	0.0
<input type="checkbox"/>	12	0.0	0.0	1.0	0.0	0.0	0.0	0.0

Lens data editor view:

The screenshot shows the 'Lens Data' editor window with the 'Surface Properties' table. The table has columns: Surf.Type, Comm, Radius, Thickness, Materia, Coatin, Semi-Diame, Conic, TCE x 1E-, and Par 1(unu). The rows are: 0 OBJECT Standard Infinity Infinity, 1 STOP Paraxial 100.0..., 2 IMAGE Standard Infinity - 0.349 0.0... 0.000.

	Surf.Type	Comm	Radius	Thickness	Materia	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.

2.2.3. 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

2.3. Sequential mode – displaying and analyzing results

2.3.1. 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

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:

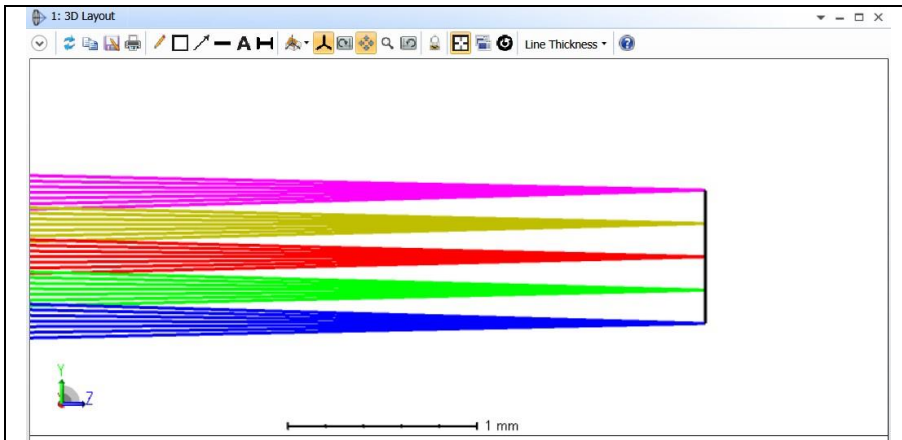
Hide Lens Faces: Fletch Rays:

Hide Lens Edges: Split NSC Rays:

Hide X Bars: Scatter NSC Rays:

Settings for multi-configuration - **Method A**

Settings for Field Angles - **Method B**

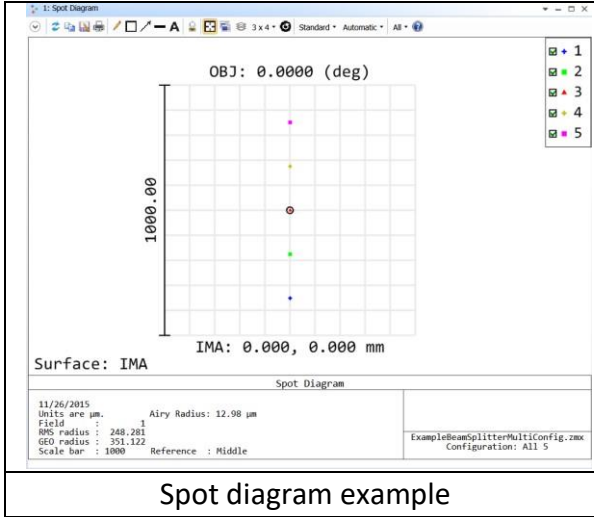


Rays near focal position

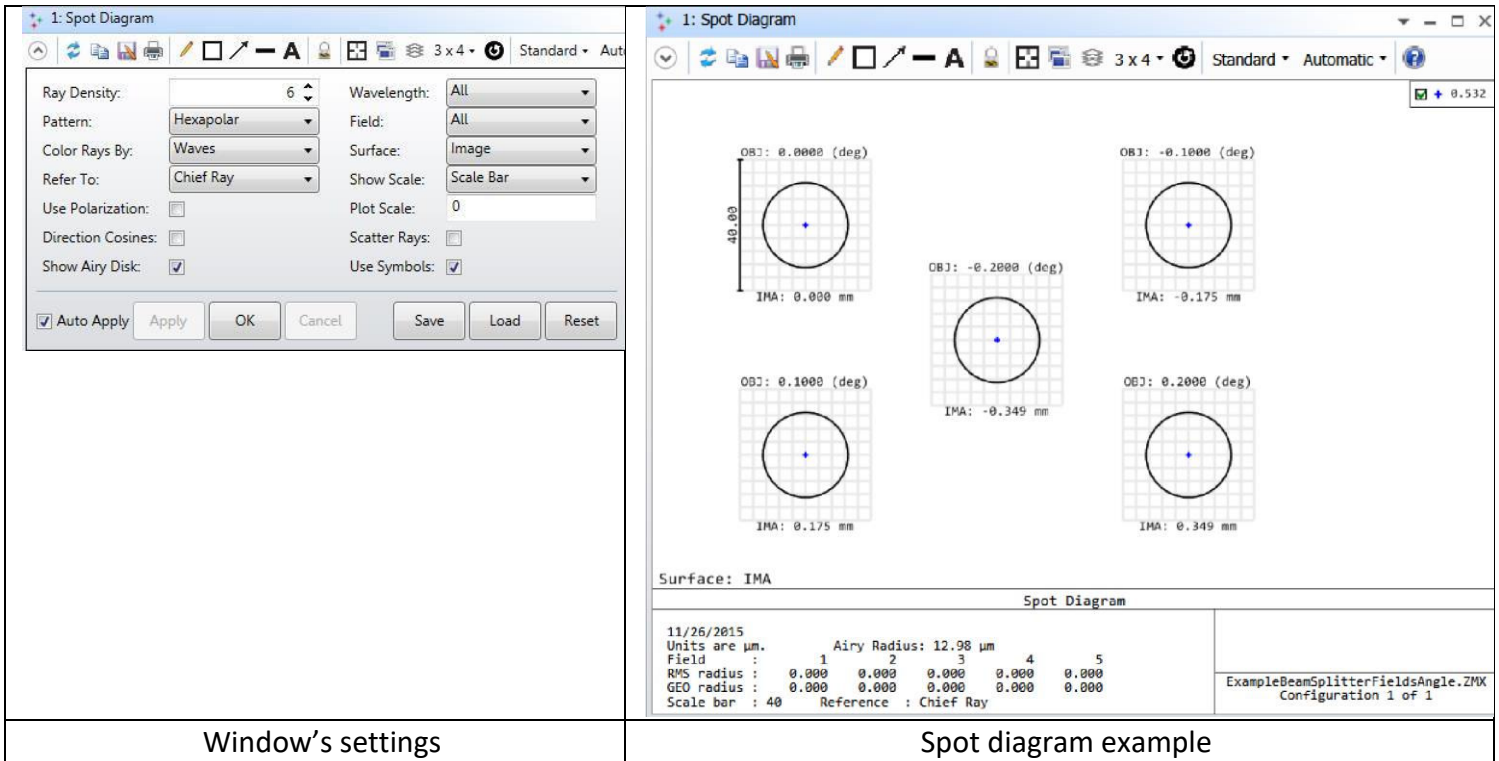
2.3.2. Spot diagram

- 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
<p>Optimize Tolerance Libr</p> <p>Rays & Spots</p> <p>Aberrations Wavefr</p> <p>Single Ray Trace</p> <p>Ray Aberration</p> <p>Standard Spot Diagram</p>	<p>1: Spot Diag</p> <p>Current</p> <p>All</p> <p>Current</p> <p>1 / 5</p> <p>2 / 5</p> <p>3 / 5</p> <p>4 / 5</p> <p>5 / 5</p>	<p>1: Spot Diagram</p> <p>Ray Density: 6</p> <p>Pattern: Hexapolar</p> <p>Color Rays By: Config</p> <p>Refer To: Middle</p> <p>Use Polarization: <input type="checkbox"/></p> <p>Direction Cosines: <input type="checkbox"/></p> <p>Show Airy Disk: <input checked="" type="checkbox"/></p> <p>Wavelength: All</p> <p>Field: All</p> <p>Surface: Image</p> <p>Show Scale: Scale Bar</p> <p>Plot Scale: 0</p> <p>Scatter Rays: <input type="checkbox"/></p> <p>Use Symbols: <input checked="" type="checkbox"/></p> <p>Auto Apply Apply OK Cancel Save Load Reset</p>



- Method B - Window's setting definition



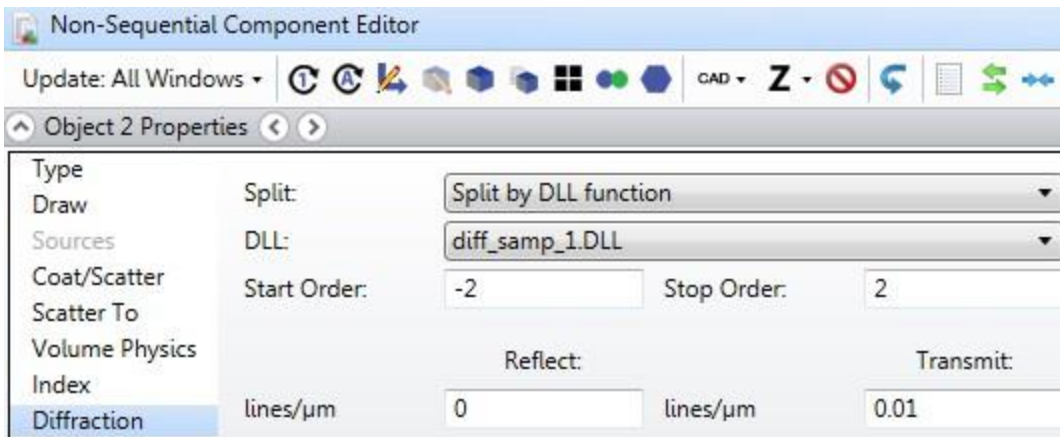
2.4. Non-sequential mode – Method C: Diffraction Grating surface with special definitions

2.4.1. Development steps

- The design starts with the calculation of lines / μm value.
- Open a new file in NSC mode
- Insert Source surface Define general properties of the design (wavelength ...)
- Number of “#Analysis Rays” and “# Layout Rays”

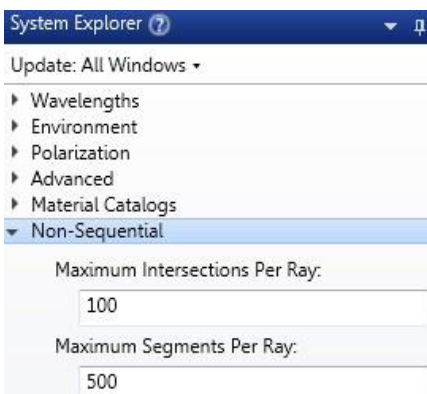
Object Type	Ref Object	X Position	Y Position	Z Position	Tilt About Z	Material	Radius 1	Conic 1	Clear 1	Edge 1	Thickness	Clear 2	Edge 2	Lines/μm	Diff Order
Source Gaussian	0	0.000	0.000	0.000	0.000		500	10000	1.000	0	0				
Diffraction Grating	0	0.000	0.000	10.000	0.000		0.000	0.000	3.000	3.000	1.000	3.000	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	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

- Insert Diffraction Grating surface
 - Define basic parameters for the element (material, thickness, clear aperture)
 - Insert Lines / μm parameter
 - Open properties of Diffraction grating surface and go to Diffraction property
 - In “Split” option choose “Split by DLL function” and then choose file diff_samp_1.DLL
 - Enter Start Order and Stop Order. For example, for 5 spots beam splitter -2 and 2
 - 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.

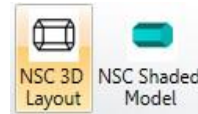


2.4.2. Advantages of the method

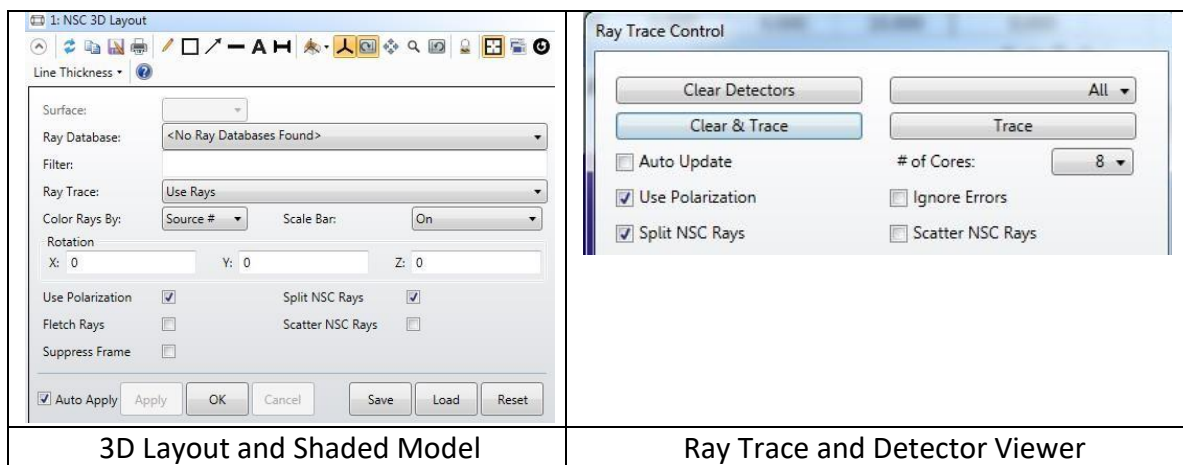
- More realistic physical model (chromatic behavior)
- Allows the modeling of all orders at once for a 2D beam splitter
- Enables integration of a diffractive element into any optical system
- Very useful for illumination systems

2.5. Non-sequential mode - displaying and analyzing results

2.5.1. NSC 3D Layout and NSC Shaded Model:



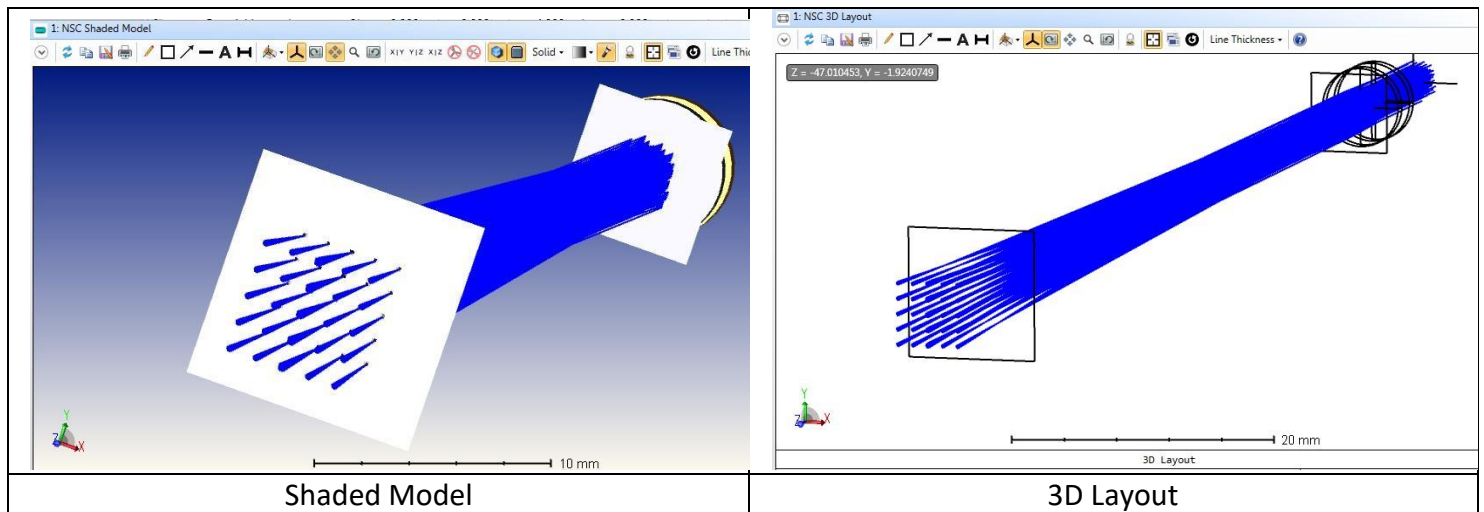
- To see the diffraction orders, mark the option for “Split NSC Rays” in properties of 3D Layout and also for Ray Trace Control



3D Layout and Shaded Model

Ray Trace and Detector Viewer

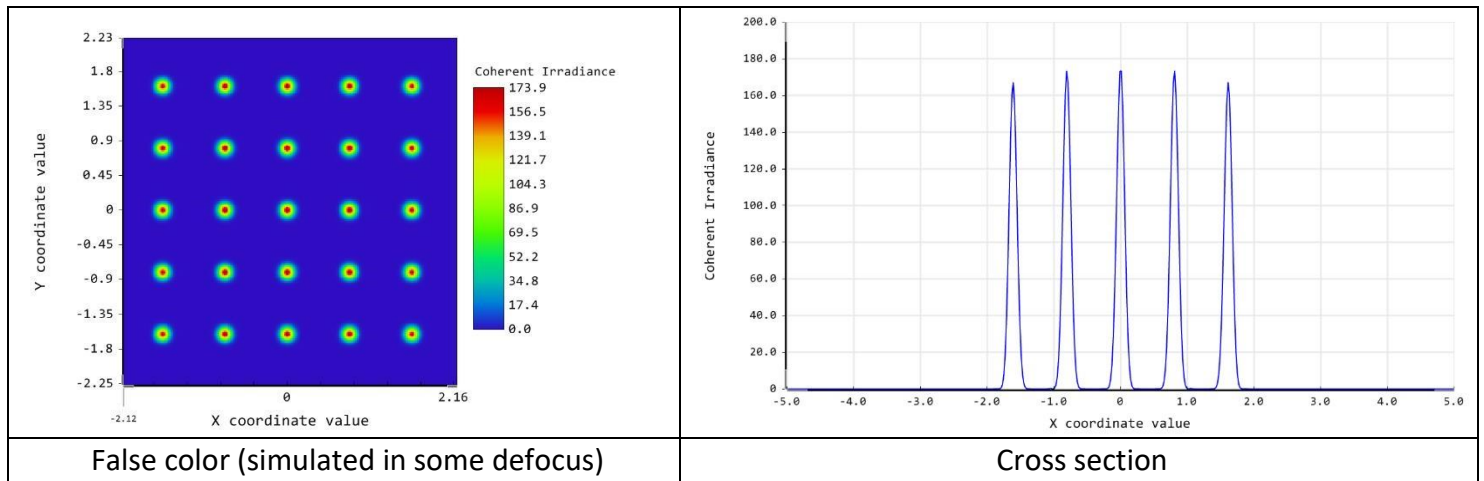
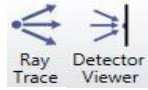
- Example - results for beam splitter array 5x5



Shaded Model

3D Layout

2.5.2. Ray Tracing Results



3. Methods comparison and summary

3.1. 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
Aberration analysis	Natural	Natural	Complex
Simultaneous analysis of all spots	No	No	Yes

3.2. Summary

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

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

4.1. Files

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

4.2. Available products

[http://holoor.co.il/Diffractive Optics Products/Diffractive Beam Splitters/BeamSplitter-multispot.htm](http://holoor.co.il/Diffractive_Optics_Products/Diffractive_Beam_Splitters/BeamSplitter-multispot.htm)