

**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™**

Written by *HOLO/OR* Ltd.

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1. Introduction

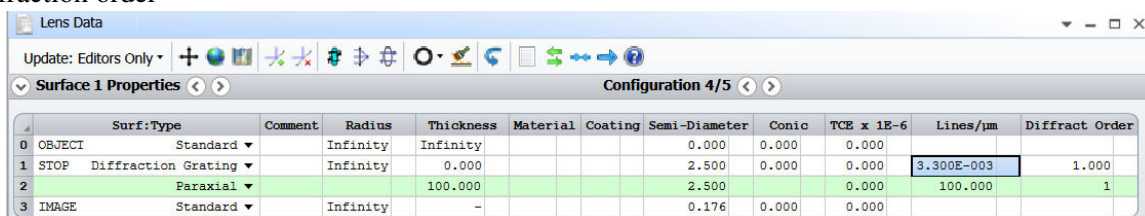
1.1. Preliminary reading

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. # | 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 | 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/ $\mu\text{m} = 1 / \Lambda = 1 / 304.814 = 0.0033$ [Lines/ μm]

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 | | | | | | | | | | | |
|----------------------|-----------|---------------------|----------|-----------|----|-----|---------------|-------|------------|----------------------|----------------|
| 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

| | 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 |

| 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 | |

Lens Data editor example

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

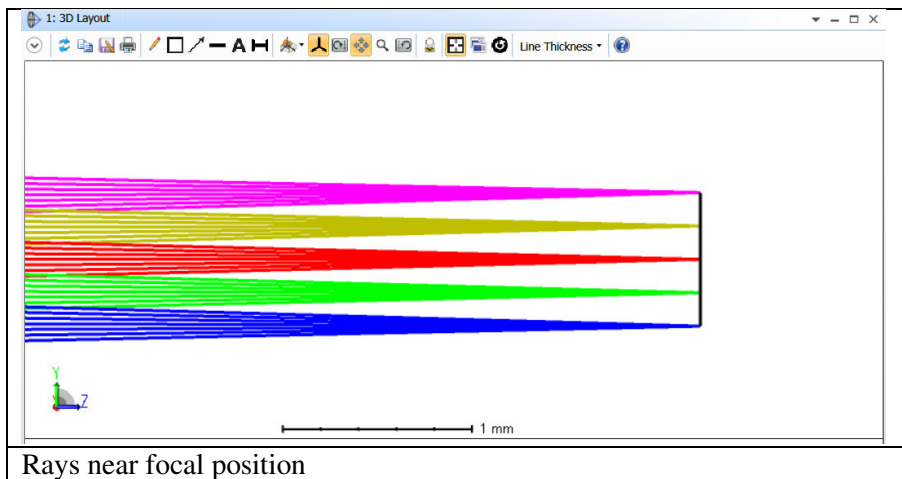
- Simplest way to build and analyze results
- Allows optimization of the optical system including diffractive beam splitter
- Allows 2D beam splitter modeling

2.1.3. Sequential mode - Displaying and analyzing results:



2.1.3.1. 3D Layout Diagram

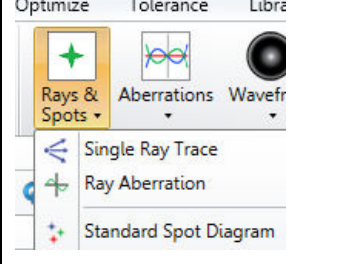

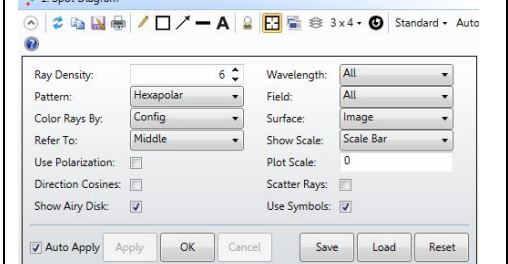
| 1: 3D Layout | 2: 3D Layout |
|---|---|
| <p>Line Thickness</p> <p>First Surface: 1 Wavelength: 1</p> <p>Last Surface: 3 Field: All</p> <p>Number Of Rays: 7 Ray Pattern: XY Fan</p> <p>Scale Bar: On Color Rays By: Config #</p> <p>Rotation X: -8.74681E-06 Y: 0 Z: -6.66068E-07</p> <p>Delete Vignetted: <input type="checkbox"/> Suppress Frame: <input type="checkbox"/></p> <p>Hide Lens Faces: <input type="checkbox"/> Fletch Rays: <input type="checkbox"/></p> <p>Hide Lens Edges: <input type="checkbox"/> Split NSC Rays: <input type="checkbox"/></p> <p>Hide X Bars: <input type="checkbox"/> Scatter NSC Rays: <input type="checkbox"/></p> <p>Configuration All Current 1 / 5 2 / 5 3 / 5 4 / 5</p> | <p>Line Thickness</p> <p>First Surface: 1 Wavelength: 1</p> <p>Last Surface: 2 Field: All</p> <p>Number Of Rays: 7 Ray Pattern: XY Fan</p> <p>Scale Bar: On Color Rays By: Field #</p> <p>Rotation X: 7.23811E-08 Y: 0 Z: 0</p> <p>Delete Vignetted: <input type="checkbox"/> Suppress Frame: <input type="checkbox"/></p> <p>Hide Lens Faces: <input type="checkbox"/> Fletch Rays: <input type="checkbox"/></p> <p>Hide Lens Edges: <input type="checkbox"/> Split NSC Rays: <input type="checkbox"/></p> <p>Hide X Bars: <input type="checkbox"/> Scatter NSC Rays: <input type="checkbox"/></p> |
| Settings for multi-configuration - Method A | Settings for Field Angles - Method B |

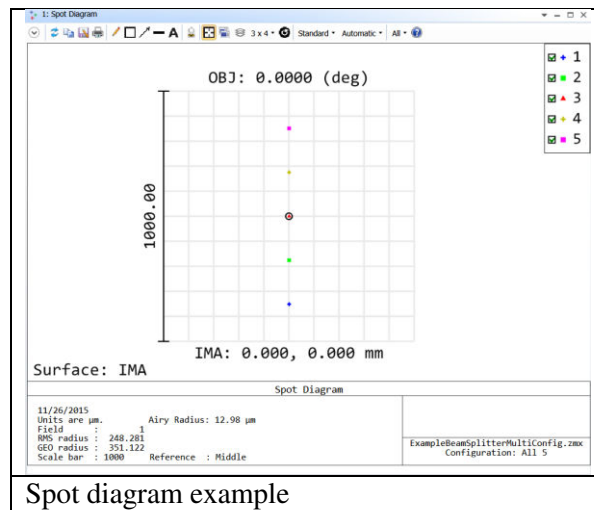


Rays near focal position

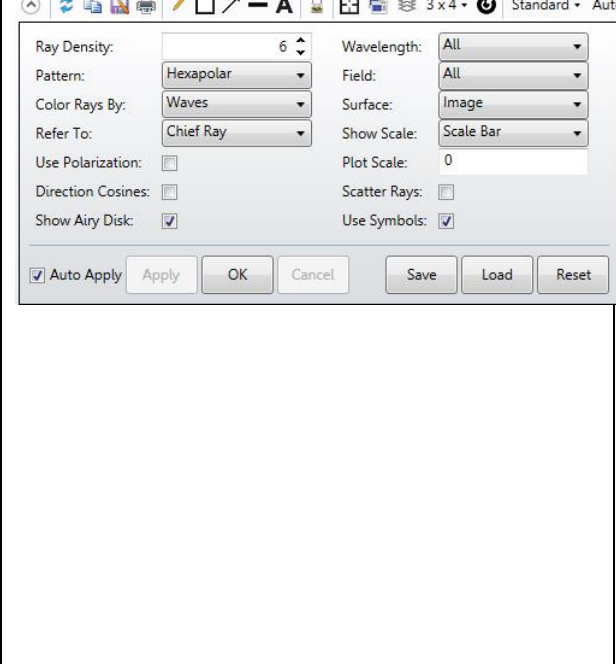
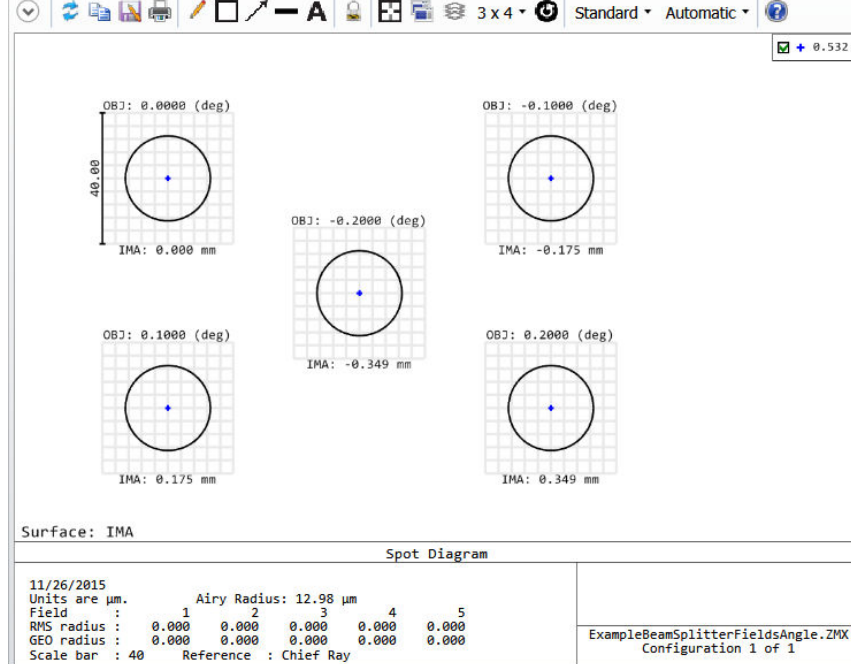
2.1.3.2. Spot diagram

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 |
|--|--|---|
|  |  |  |



Method B - Window's setting definition

| Window's settings | Spot diagram example |
|--|--|
|  |  |

2.2. Non-Sequential mode

2.2.1. Method C: Diffraction Grating surface with special definitions

2.2.1.1. Development steps

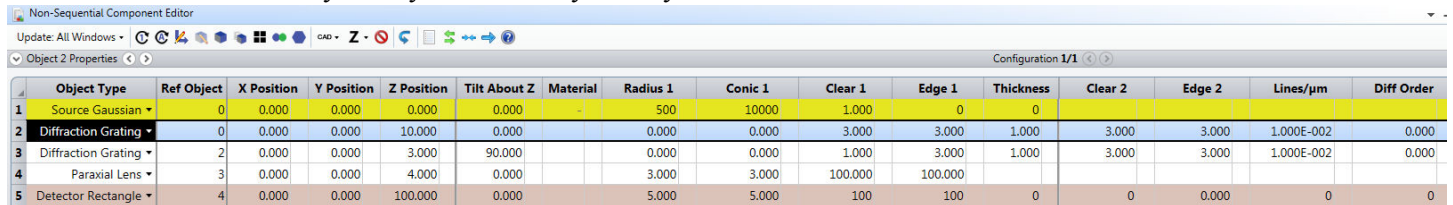
*The design starts with calculation of lines / μm value.

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 | 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)

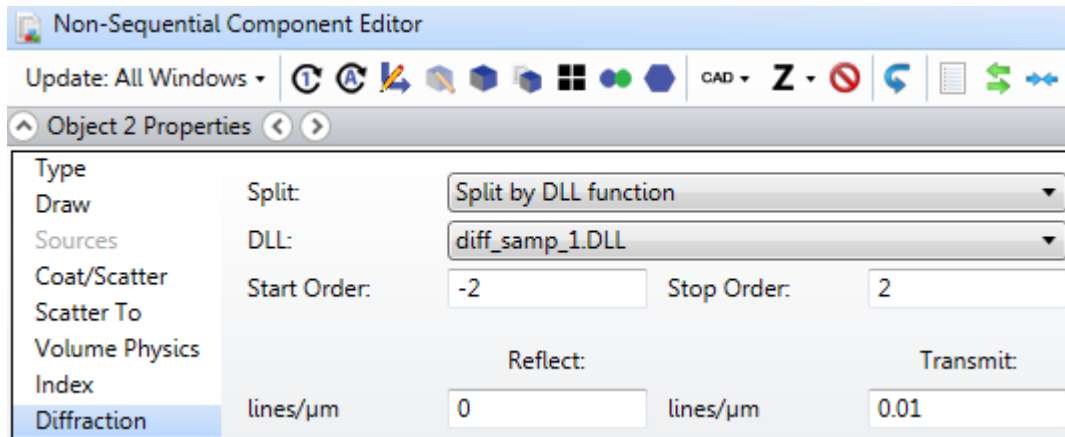
b) Insert Lines / μm parameter

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

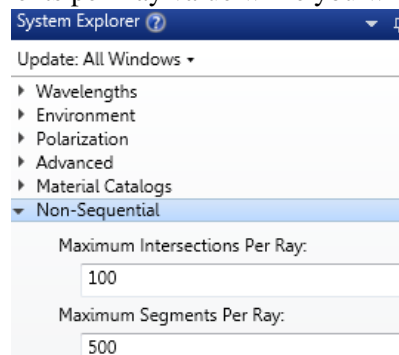
e) Enter Start Order and Stop Order. For example for 5 spots beam splitter -2 and 2

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.

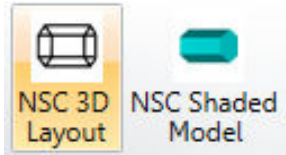


2.2.1.2. Advantages of the method

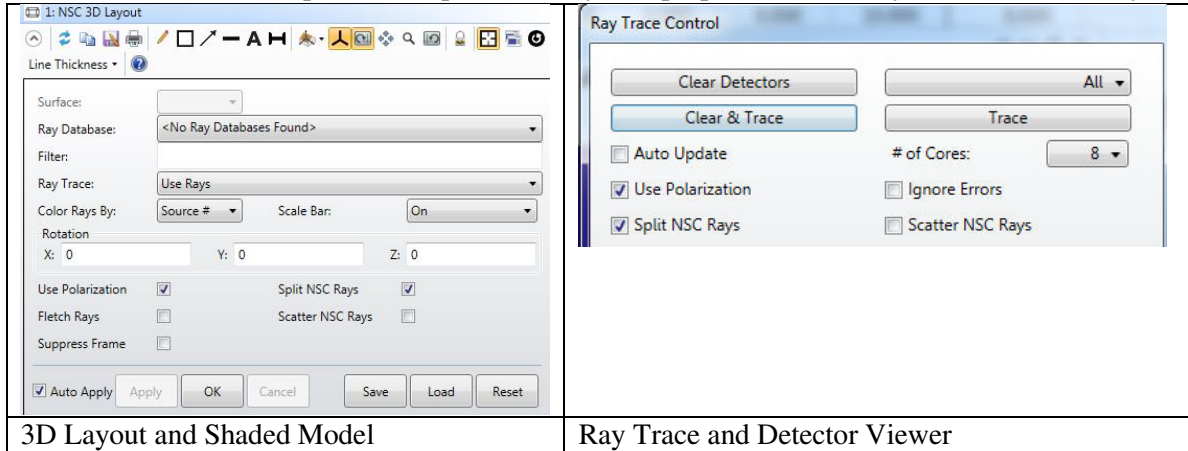
- More realistic physical model (chromatic behavior)
- Allows the modeling of all orders at once for a 2D beam splitter
- Enables integration of a diffractive element into any optical system
- Very useful for illumination systems

2.2.2. Displaying Results

2.2.2.1. NSC 3D Layout and NSC Shaded Model



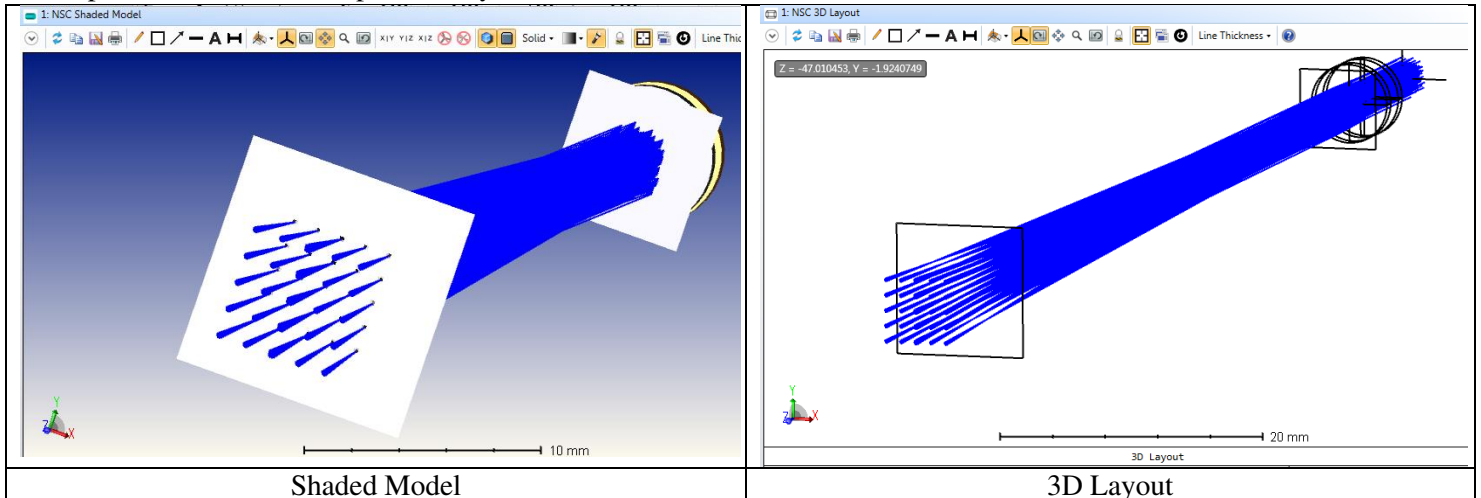
To see diffraction orders mark the option for “Split NSC Rays” in properties of 3D Layout and also for Ray Trace Control



3D Layout and Shaded Model

Ray Trace and Detector Viewer

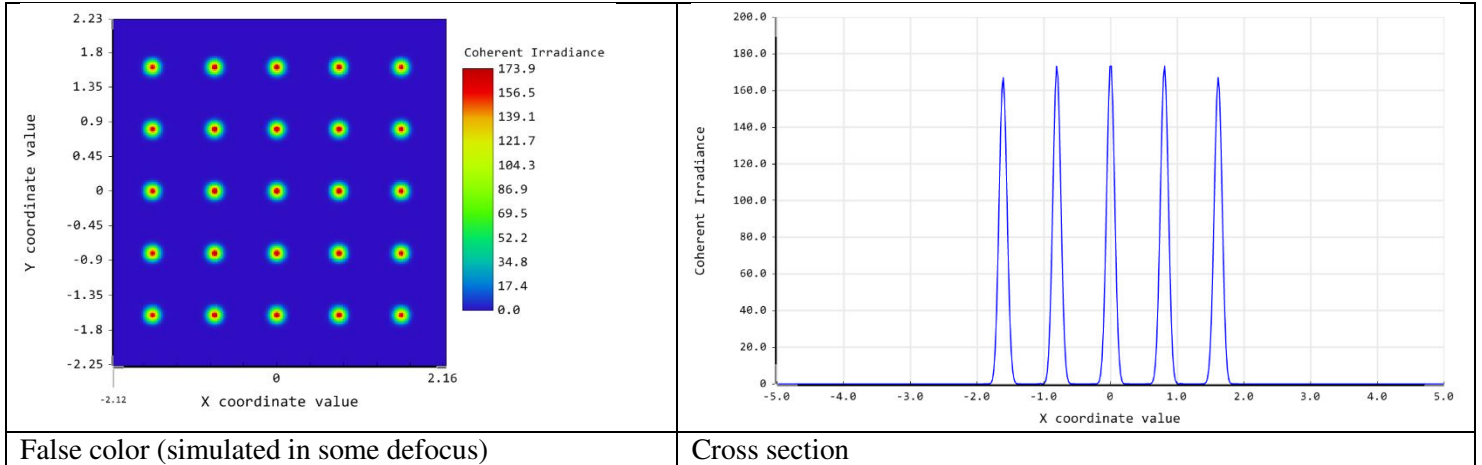
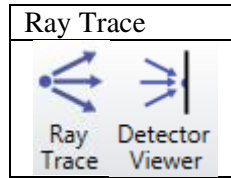
Example - results for beam splitter array 5x5



Shaded Model

3D Layout

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