

Optimization of Lightguide with Continuously Modulated Grating Regions

Abstract



In the design process of lightguide devices in the field of augmented and mixed reality applications (AR & MR), lateral uniformity (per field of view mode) and overall efficiency are two of the most important merit functions. In order to achieve appropriate values for the uniformity and efficiency in a lightguide system, it is necessary to allow for a variation of the grating parameters, particularly in the expander and/or outcoupling region. For this purpose, VirtualLab Fusion enables the introduction of smoothly varying grating parameters in a grating region along with the necessary tools to run an optimization according to a defined merit function. This use case demonstrates the optimization of a lightguide with continuously varied values of the fill factor in order to obtain an adequate uniformity.

Task Description

<u>**Task:</u>** How to optimize the continuously varied fill factor of the grating regions to achieve adequate lateral uniformity in the eyebox (for a single FOV mode)?</u>



Source

- Plane Wave
- 532nm wavelength
- 1 mm × 1 mm diameter

Outcoupler

- binary grating
- 380nm period
- height 165nm
- linearly varying fill factor

Eye Pupil Expander

- binary grating
- 268.7 nm period
- height 150nm
- linearly varying
 fill factor

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binary grating with continuously

varied fill factor

binary grating with continuously varied fill factor

Incoupler

- slanted grating
- 380nm period
- fill factor 50%
- height 300nm
- angle 45°

slanted grating with constant fill factor

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Light Guide Component



With the *Light Guide Component*, lightguide systems with complex-shaped regions can easily be defined. Furthermore, these regions can be equipped with idealized or real grating structures to act as incoupler, outcoupler or exit pupil expanders. More information under:

Construction of a Light Guide



Grating Regions



For the incoupler, outcoupler and eye pupil expander (EPE) real gratings were used. Their Rayleigh matrices and the corresponding efficiencies are calculated rigorously with FMM (RCWA). You can find more information on how to set this up under:





Uniformity Detector



The Uniformity Detector evaluates the impinging intensity in configured local areas, which are called pupils. Each pupil is defined by its size $(dx \times dy)$ and shape, which can be set either elliptical or rectangular.

You can find more information on how to set this up under:

Uniformity Detector for Lightguide Systems



Summary – Components...



of Optical System	in VirtualLab Fusion	Model/Solver/Detected Value
1. Source	Plane Wave source	Truncated Ideal Plane Wave
2. Incoupler	Slanted grating in Rectangular Region	Fourier Modal Method (FMM)/RCWA
3. Eye Pupil Expansion	Binary grating in Polygonal Region	Fourier Modal Method (FMM)/RCWA
4. Outcoupler	Binary grating in Rectangular Region	Fourier Modal Method (FMM)/RCWA
5. Detector	Camera Detector, Uniformity Detector	Energy density measurement

General Workflow with Additional Guidance

- Configuration of basic optical lightguide setup (not part of this use case)
- 2. Application of the *Footprint and Grating Analysis* tool including the generation of the optical setup equipped with all requirements for the parameter modulation
- 3. Definition of desired modulation of grating parameters
- 4. Select variables and define merit functions to optimize the modulated grating parameters.

The starting point is an existing, executable lightguide system, where the basic geometries (desired distances and positioned grating regions) and grating specifications (orientation, period, orders) are already included. This example is taken from:

- <u>Construction of a Light Guide [Use Case]</u>
- Light Guide Layout Design Tool [Use Case]

The real grating structures of the grating regions are configured, a necessary step before applying a continuous or smooth variation of the grating parameters:

- How to Set Up a Lightguide with Real Grating Structures [Use Case]
- Simulation of 1D-1D Pupil Expander with Real Gratings [Use Case]

The *Footprint and Grating Analysis* tool is used to specify the desired range for the variation of the grating parameters and to pre-calculate the according Rayleigh coefficients for the specific conditions (wavelength and directions). As a next step, an optical setup is generated, where the smooth parameter variation can be defined:

- Footprint Analysis of Lightguides for AR/MR Applications [Use Case]
- <u>Grating Analysis and Smoothly Modulated Grating Parameters on Lightguides</u> [Use Case]

Note:

The grating modulation is defined for individual grating regions.

Footprint & Grating Analysis



With the help of the *Footprint & Grating Analysis Tool*, the grating characteristics (complex valued) are pre-calculated and stored in lookup tables for a specified range of the chosen parameter (e.g. fill factor). The initial range of the fill factor is chosen according to the range of available efficiency modulation. More information can be found in:

Parameters to be Optimized	Initial Values
varied range of fill factor (EPE)	10% – 50%
varied range of fill factor (outcoupler)	40% – 90%

Grating Analysis and Smoothly Modulated Grating Parameters on Lightguides

Generation of the Initial System



grating regions without smooth modulation



- A lightguide setup with a so-called grating parameter modulation function is generated from the *Footprint & Grating Analysis Tool* (including the grating characteristics).
- The *Uniformity Detector* is used to define the merit function for the optimization.

Define Modulation Function of the Grating Region

Edit Light Guide Component X	Edit Grating Region X	Edit Grating Parameter Modulation Function
Solid Surface Layouts Surface Name Edit Systems Surface Name Vertice Edit Surface Systems Vertice Vertice Edit Surface Surface Layout Edit Surface Vertice Edit Surface Surface Layout Edit Surface Gott Surface Layout Vertice Edit Surface Surface Layout Vertice Vertice Vertice Surface Layout Vertice Vertice Vertice	Shape Region Channels Grating D-Periodic (Lamellar) 2D-Periodic Grating Period 380 nm Orientation (Rotation about z-Axis) 90° Orientation (Rotation about z-Axis) 90° Order Selection Efficiencies Image: Constant Programmable Image: From Real Gratings O Lose Modulated Grating Parameters within Region Grating Stack Image: Constant Image: Constant	□ Define Grating Parameter Function for Two Grating Parameters Settings for Grating Parameter #1 Name Fill Factor (Bottom) Property Percentage Minimum 10 % Maximum 90 % Modulation Defined by O sampled Data
Transforms	Number of different wavelength(s): 1 Number of different direction vector(s): 1 See the full use case for setting up a smooth Help	Show Grating Parameter Variation Function × Selected Parameter to Show Fill Factor (Bottom) Fill Factor (Bottom)
Validity: OK Cancel Help	modulation based on mathematical function: Grating Analysis and Smoothly Modulated Grating Parameters on Lightguides	50% 90%

0

-2

0 2

linear modulation for outcoupler

- Open the edit dialogue of the region in the lightguide component; the grating characteristics and the lookup tables are stored in the grating regions.
- Edit the *Grating Parameter Modulation Function* so that it's defined as a programmable function, the intended linear modulation of the grating parameters is defined by the value at the start and end position (left to right border for EPE & top to bottom for the outcoupler).

Generation of the Initial System



After defining the modulation for the EPE and outcoupler respectively, the *Parametric Optimization* document can be started via *Optical Setup > New Parameter Optimization*.

Parameters to be Optimized	Initial Values
varied range of fill factor (EPE)	10% – 50%
varied range of fill factor (outcoupler)	40% – 90%

Optimization Settings – Select Parameters

1. 0-					Edit Grating Parameter Modulation Function
≥ 1: Parametric Optimization Parameter Selection Select the parameters which shall be varied during optimization.					Define Grating Parameter Function for Two Grating Parameters Settings for Grating Parameter #1 Name Fill Factor (Bottom)
You ca Filter	n select one or more parameter whit	ch shall be varied within t	he optimization.	X Show Only Varied Parameters	Property Percentage Minimum 10 % Maximum 90 %
1 2 '	• Object	Category	Parameter	Vary Original Value	Modulation Defined by O Sampled Data Programmable Function
	"Light Guide (After Surface Layout)" (# 1)	Surface #1 (Plane Surface)	Surface Region #2 (Expansion Grating) Grating Parameter Modul Surface Region #2 (Expansion Grating) Grating Parameter Modul Surface Region #3 (Outcoupling Grating) Grating Parameter Mod Surface Region #3 (Outcoupling Grating) Grating Parameter Mod	ation Function ValueAtStar 10 % ation Function ValueAtEnd 50 % Julation Function ValueAtS 40 % Julation Function ValueAtE 90 %	
i				Edit Grating Parameter Modulation Function	ValueAtStartPosition
Select the value of the fill factor at the start and end positions of the modulation for the EPE and outcouple gratings, respectively.		□ Define Grating Parameter Function for Two Grating Parameters Settings for Grating Parameter #1 Name Fill Factor (Bottom) Property Percentage Minimum 0 % Maximum 90 % Modulation Defined by ○ Sampled Data Image: Percentage Image: Property Fill Factor (Bottom) ● Property	Edit grating parameter modulation function for EPE region.		
TI ac ec	ne initial values ccording to the ditor.	s are auto settings i	matically filled in n the modulation function	StartPositionLine EndPositionLine ValueAtStartPosition ValueAtEndPosition Edit grating parameter m function for outcoupler re	1 mm -1.75 mm 1 mm 7.75 mm 40 % 90 % Podulation egion.

🔍 View 📘

OK

Cancel

Help

×

-5 mm

-5 mm 10 % 50 %

Help

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Optimization Settings – Specify Constraints

	Constraint Specifications								
	Select and specify the constraints which sh	all be considered during optimization.							
ſ	Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution
		Surface #1 (Plane Surface) Surface Region #2		1000	Range	10 %	90 %	10 %	0 9
	"Light Guide (After Surface Layout)" (# 1)	Surface #1 (Plane Surface) Surface Region #2		1000	Range	10 %	90 %	50 %	0
	Light Guide (Alter Sufface Layout) (# 1)	Surface #1 (Plane Surface) Surface Region #3		1000	Range	10 %	90 %	40 %	0
		Surface #1 (Plane Surface) Surface Region #3		1000	Range	10 %	90 %	90 %	0
		Minimum							
		Maximum							
"Uniformity Detector" (# 602)	Uniformity Error	\checkmark	1	Target Value	0 %		99.91592315 %	99.97144607	
		Arithmetic Mean		100000	Target Value	0.0002 (V/m) ²		0.0001466014283 (V/m)2	0.02855392699
		Standard Deviation							
n increased weight for the <i>Arithmetic Mean</i> was chosen to raise the contribution (weight of the erit) for this value. Otherwise, the algorithm may									
cl er sa	hosen to raise the co rit) for this value. Oth acrifice more efficient	ontribution (weight of the erwise, the algorithm m cy for a better uniformity	e nay /.			_	Target Fi	Target Function Va	Target Function Value 0.9986043100 < Back Next >

- Define available range of the variables (here: fill factors of EPE and outcoupler).
- In order to achieve a low uniformity error with acceptable intensity distribution, the target value for the uniformity error is set to 0%, and a target value of the arithmetic mean is specified.
- By defining the weight value for the merit functions, the contribution (relevance or priority) for the optimization can be adapted.

In this optimization, the initial values are quite close to the limits of the available range. Hence, the weights for the *Range* constraints are increased, in order to ensure that the values in the optimization stay inside the given range (the downhillsimplex does not provide hard boundaries for the parameter ranges). And because the *Start Values* are inside the allowed value range, the associated *Contribution* is regarded as 0%.

merit function	Values	
Uniformity Error	0%	
Arithmetic Mean	0.0002(V/m) ²	

Optimization Result



initial system

merit function	Values
Uniformity Error	99.92%
Arithmetic Mean	1.47E-04 (V/m)²

optimized system

merit function	Values
Uniformity Error	6.84%
Arithmetic Mean	1.40E-04 (V/m) ²

Optimization Result



Parameters	Initial Values	Optimized Values	
varied range of fill factor (EPE)	10% – 50%	10.0% – 17.1%	
varied range of fill factor (Outcoupler)	40% – 90%	24.1% - 41.4%	

Optimization Uniformity vs. Energy Density



The line scan through the eyebox for the initial and optimized systems reveals the difference in uniformity and local energy density.



VirtualLab Fusion Technologies





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further reading	 Grating Analysis and Smoothly Modulated Grating Parameters on Lightguides Uniformity Detector for Lightguide Systems Light Guide Layout Design Tool Flexible Region Configuration How to Set Up a Lightguide with Real Grating Structures