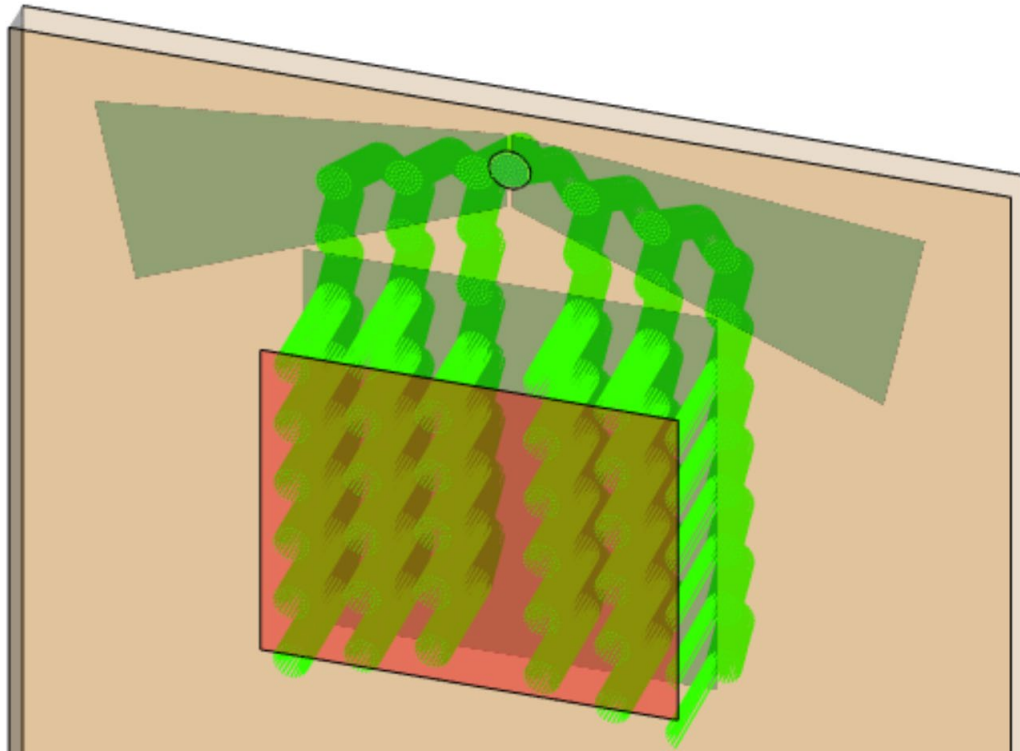# Lightguide with Butterfly Eye-Pupil Expander based on Patent by Microsoft

Abstract

In the process of the design of lightguide devices for augmented and mixed reality (AR&MR) applications, parameters like the provided Field of View (FOV) are of major interest. In order to push the limits of the maximum FOV achievable, various approaches have been investigated, such as systems that split the FOV during the propagation from incoupler to outcoupler. One very popular approach is the so-called "butterfly pupil expansion", where two separate EPE grating regions are used for the positive and negative parts of the FOV, and which is also applied in Microsoft's Hololens 2. In this document, we show the realization of such an EPE concept in VirtualLab Fusion, based on patent US9791703B1 by Microsoft.

FIG. 4

Task Description

Source
- Plane Wave
- 532 nm wavelength
- 1 mm × 1 mm diameter
- FOV 40° × 20°

Eye Pupil Expander #1 (-20°– 0°)
- idealized grating
- 340 nm period (1D)
- rotation (in x-y plane): ±35°
- diffraction efficiency:
  R1 = 10%, R0 = 90%
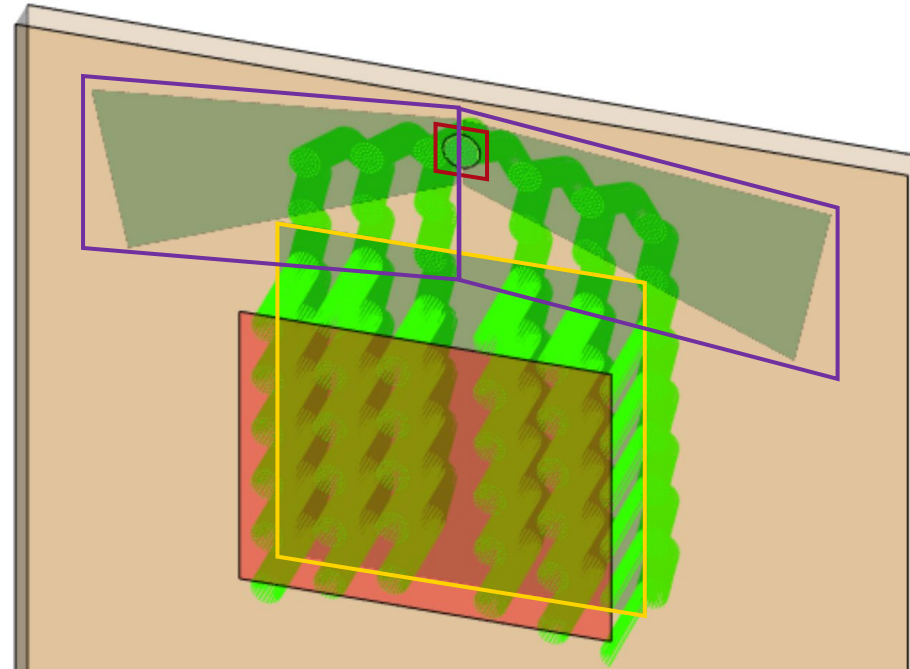
Incoupler(s)
- idealized gratings (first and second surface)
- 400 nm period (1D)
- rotation (in x-y plane): ±15°
- diffraction efficiency:
  T+1 = 10%, R–1 = 50%

Eye Pupil Expander #2 (0° – 20°)
- idealized grating
- 340 nm period (1D)
- rotation (in x-y plane): ±35°
- diffraction efficiency:
  R1 = 10%, R0 = 90%

Outcoupler
- idealized grating
- 440 nm period
- rotation (in x-y plane): –90°
- diffraction efficiency:
  T1 = 10%, R0 = 90%

Light Guide Component

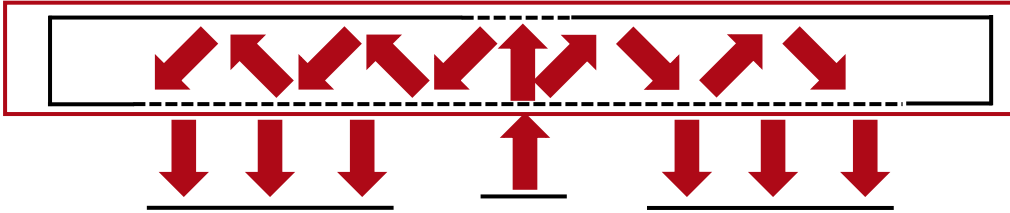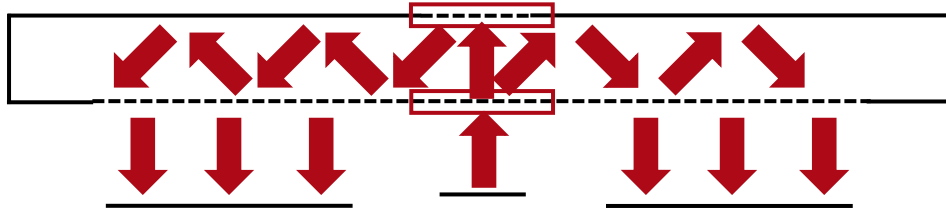With the *Light Guide Component*, systems with regions with complex shapes can easily be defined. Furthermore, these regions can be equipped with idealized or real grating structures to act as incoupler, outcoupler or eye pupil expanders. More information under:

➦ Construction of a Light Guide
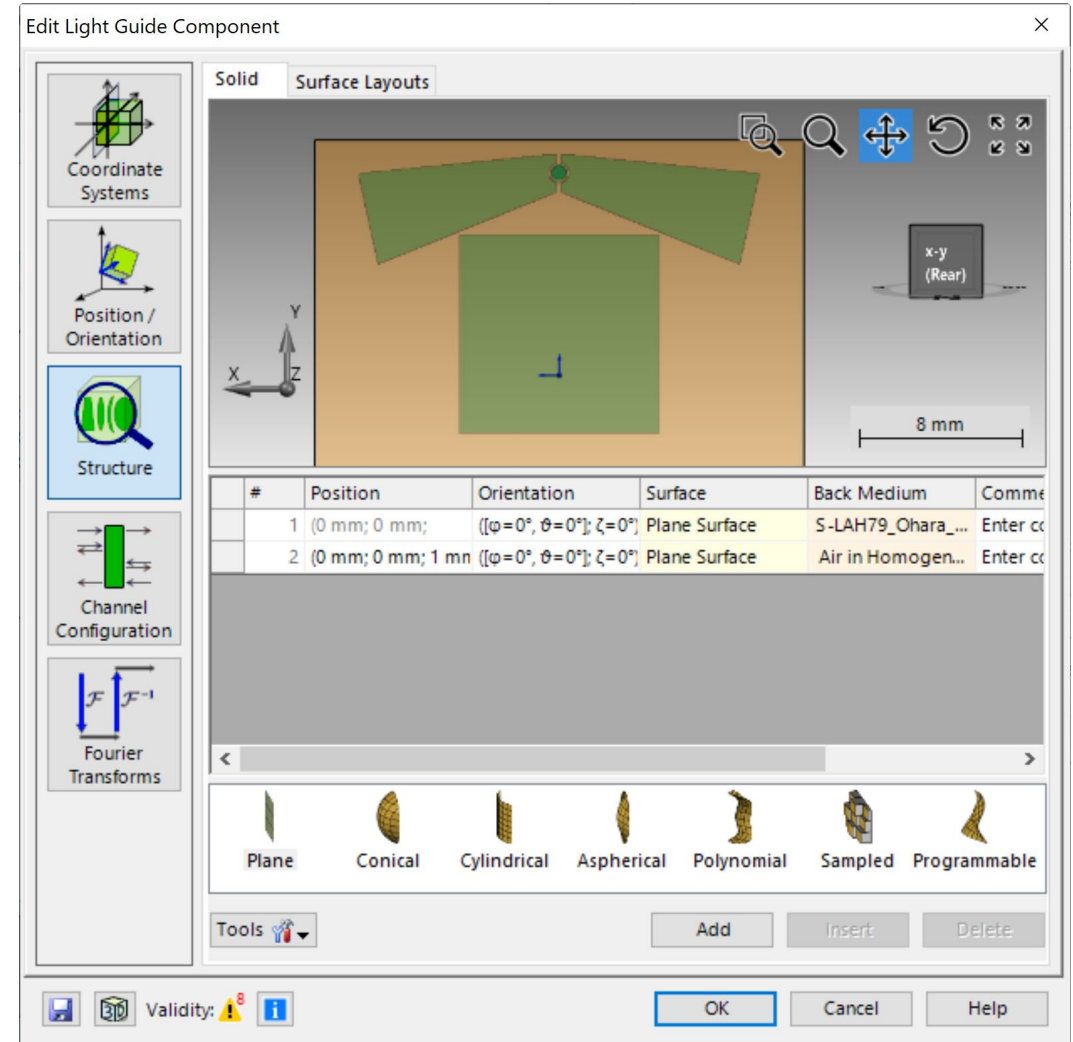
Incoupling & Outcoupling Grating Regions

For the sake of simplicity, we use two 1D-periodic incoupler gratings (one on the first surface and one on the second one) in circularly shaped regions. This will lead to a slightly asymmetric behavior for the left and right part of the FOV, but it is possible to overcome this by combining both gratings into a single 2D-periodic structure (located either on the first or second surface).

In order to recombine and outcouple the light, a 1D-periodic outcoupler is applied, with a rectangular shaped region. This is a specific configuration and to allow for further flexibility in the design it is possible to exchange it by a 2D-periodic outcoupler instead.
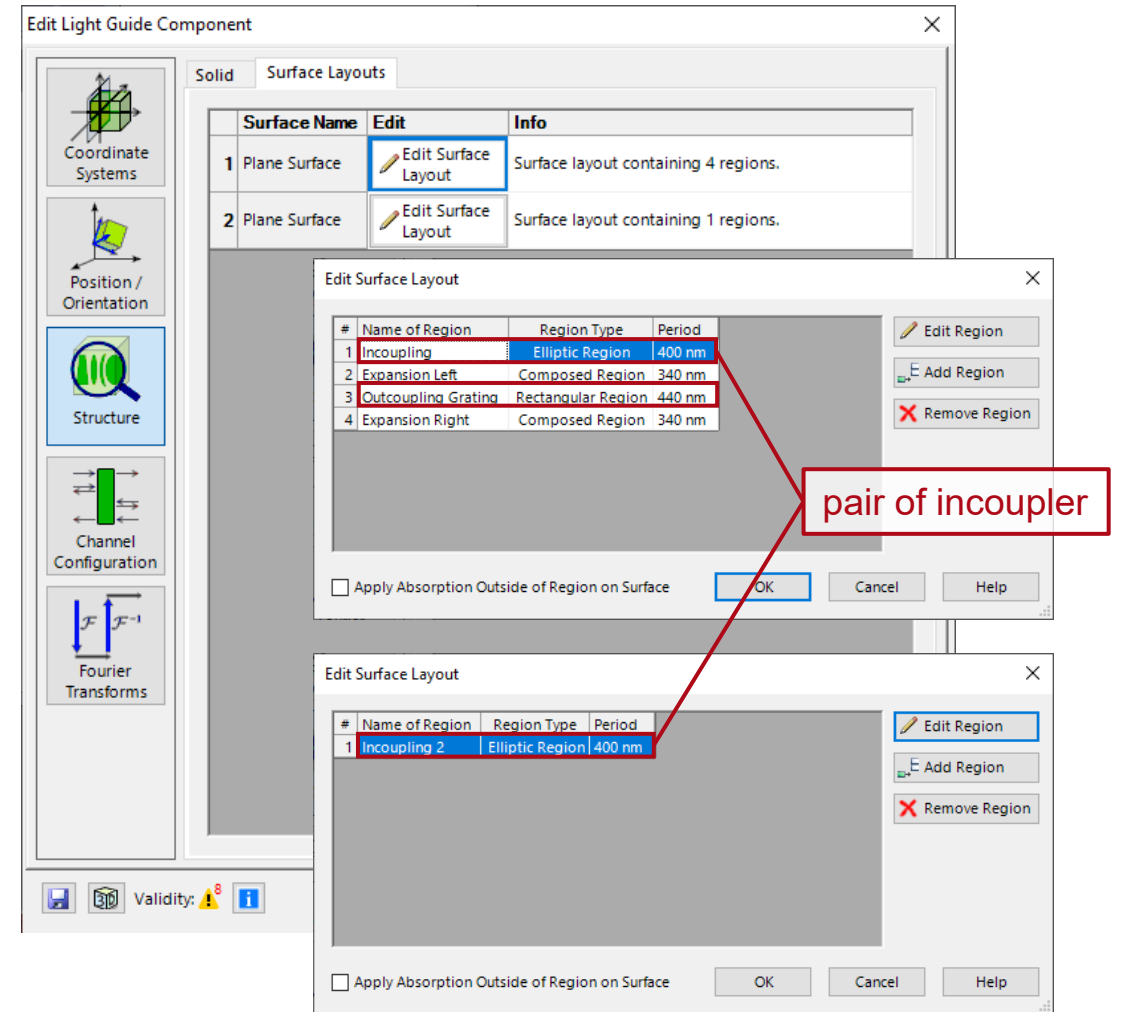
Eye-Pupil-Expander (EPE) Region
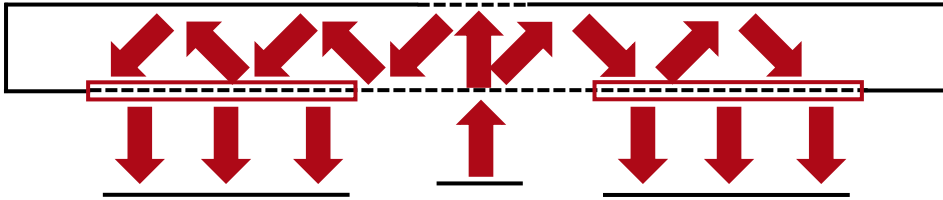
The shape of each region can be defined very flexibly using different approaches and definition strategies. In this example, both EPEs are defined by polygonal regions in combination with two ellipsoids to cut the inner part. The gratings are 1D-periodic and rotated by ±35° (for left and right respectively). More information about region definition under:

→ Flexible Region Configuration
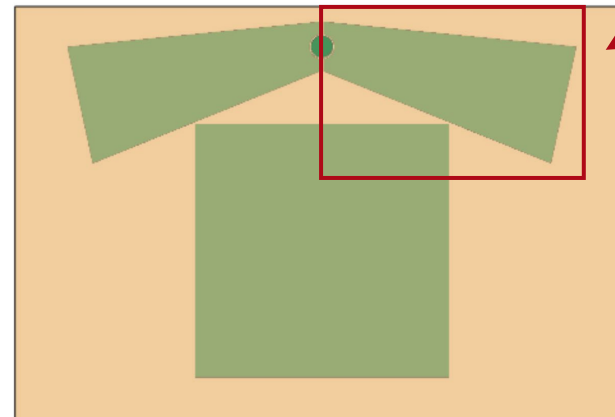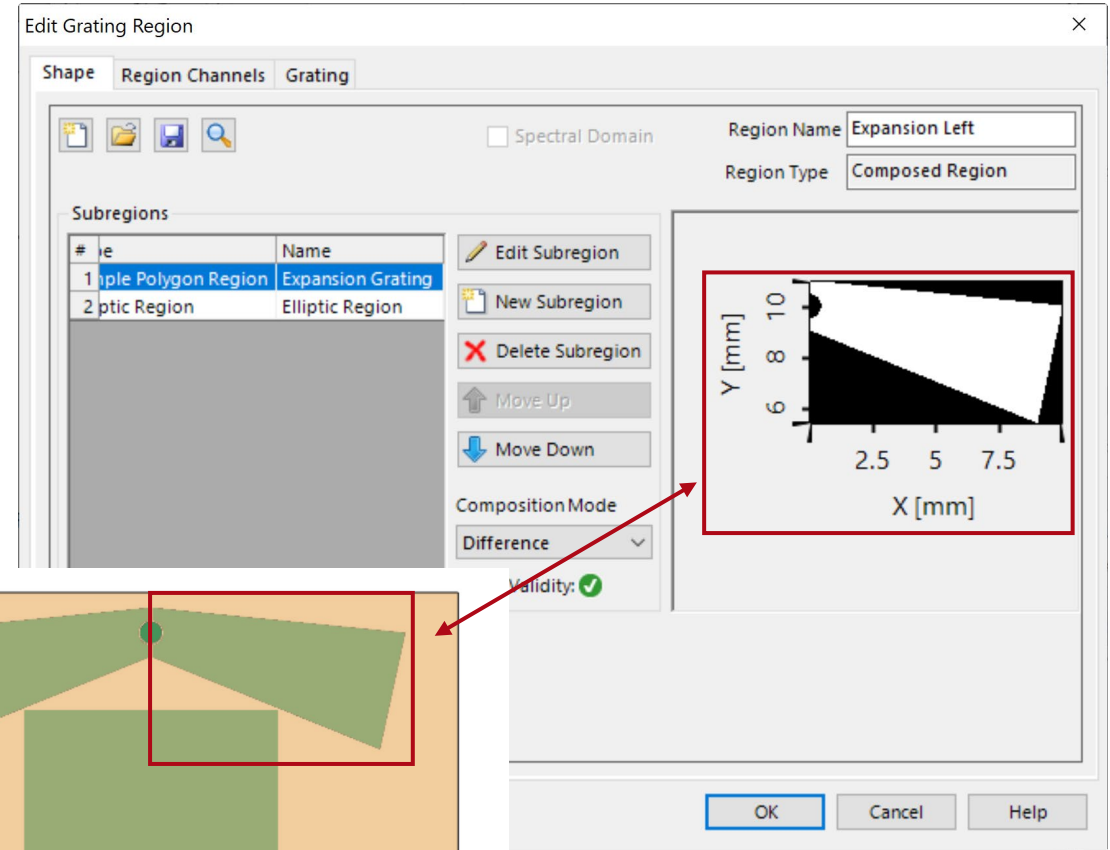
Design & Analysis Tools

VirtualLab Fusion provides a series of tools to help the optical engineer in the task of designing and analyzing lightguide systems, including:

- **Lightguide Layout Design Tool:**
  Design a lightguide with 1D-1D pupil expansion, which can serve as the basis of your system.
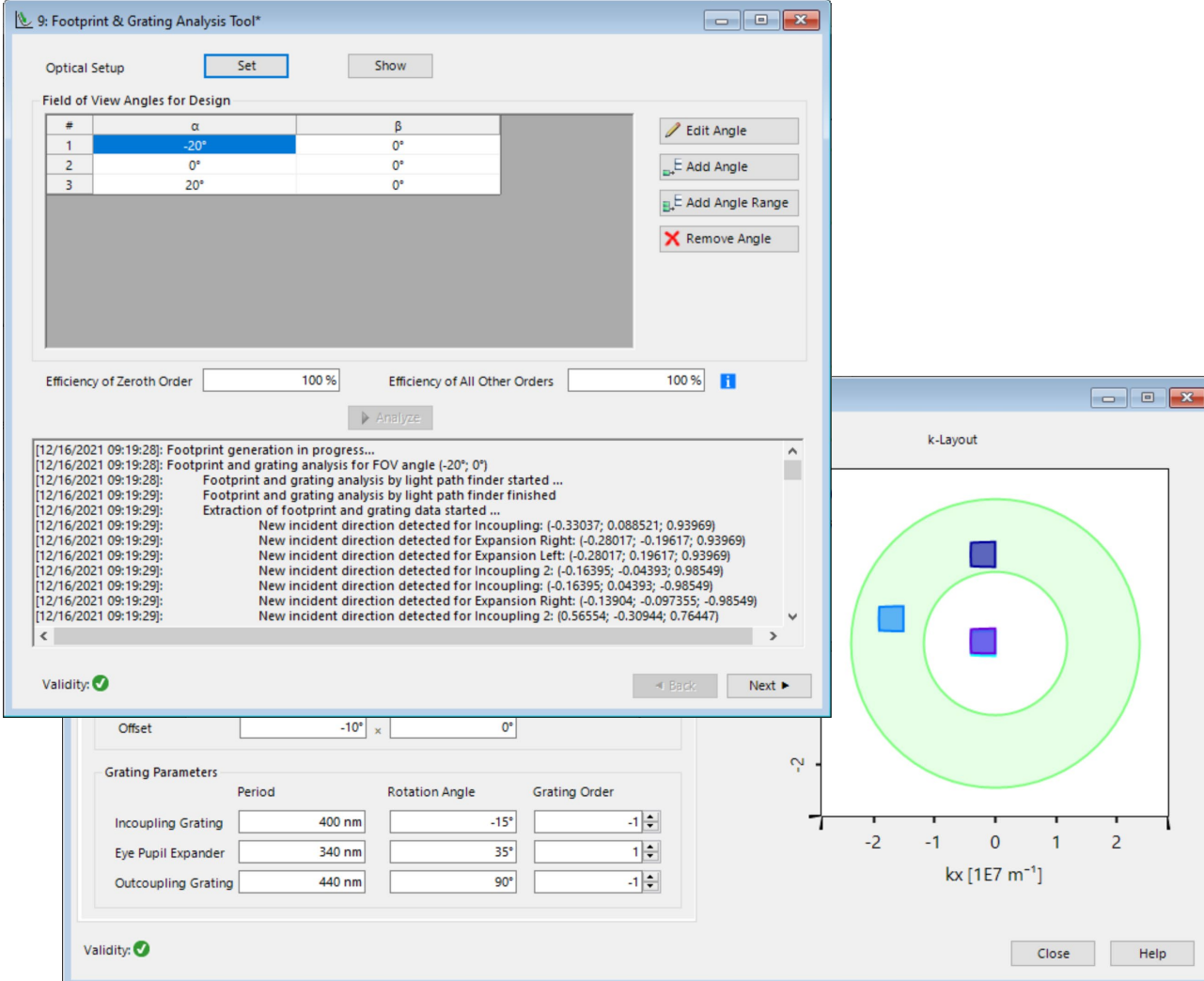
  ➡ Light Guide Layout Design Tool

- **k-Domain Layout Tool:**
  Analyze coupling conditions of your design.

  ➡ k-Domain Layout Visualization

- **Footprint & Grating Analysis Tool:**
  Detect the footprints in your system to determine the size and shape of your regions.

  ➡ Footprint Analysis of Lightguides for AR/MR Applications

Summary – Components...

| … of Optical System	… in VirtualLab Fusion	Model/Solver/Detected Value
1. Source	*Scanning Source*	Truncated ideal plane waves with different incident angle
2. Incoupler	Idealized grating in *Rectangular Region*	Idealized Rayleigh matrices
3. Eye Pupil Expansion	Idealized grating in *Polygonal Region*	Idealized Rayleigh matrices
4. Outcoupler	Idealized grating in *Rectangular Region*	Idealized Rayleigh matrices
5. Eye	*Camera Detector*	Energy density measurement

Result: Rays in System

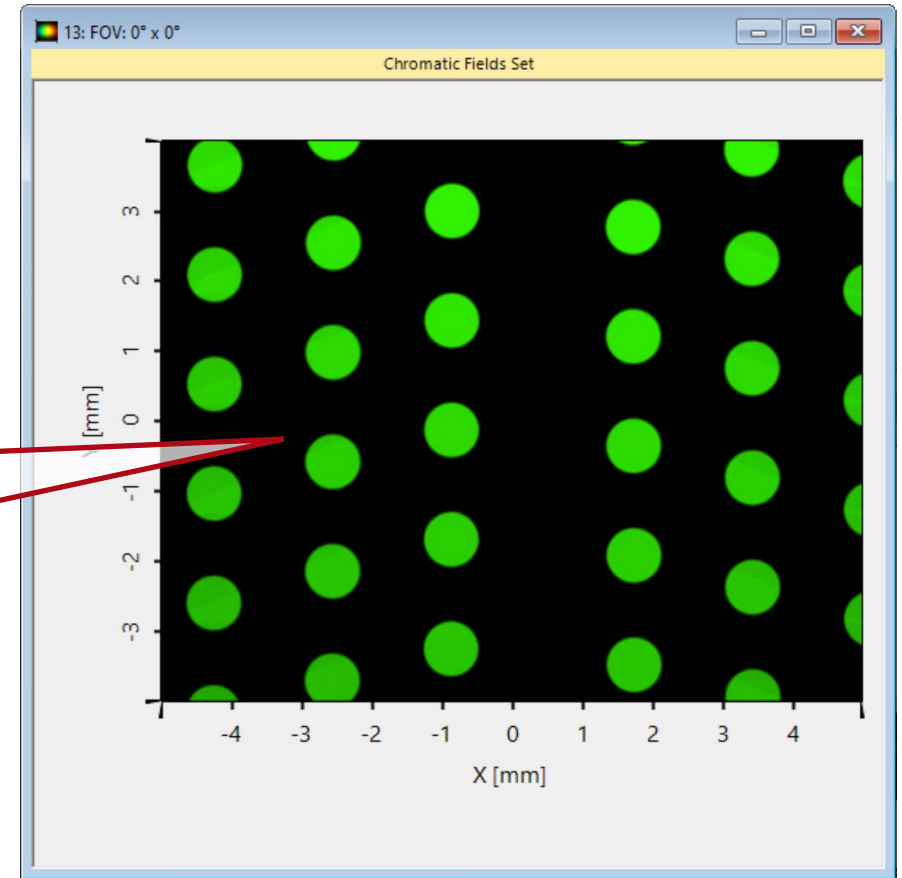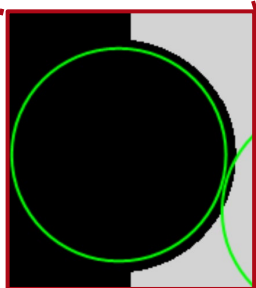only light hitting the "eye-box" (camera detector):
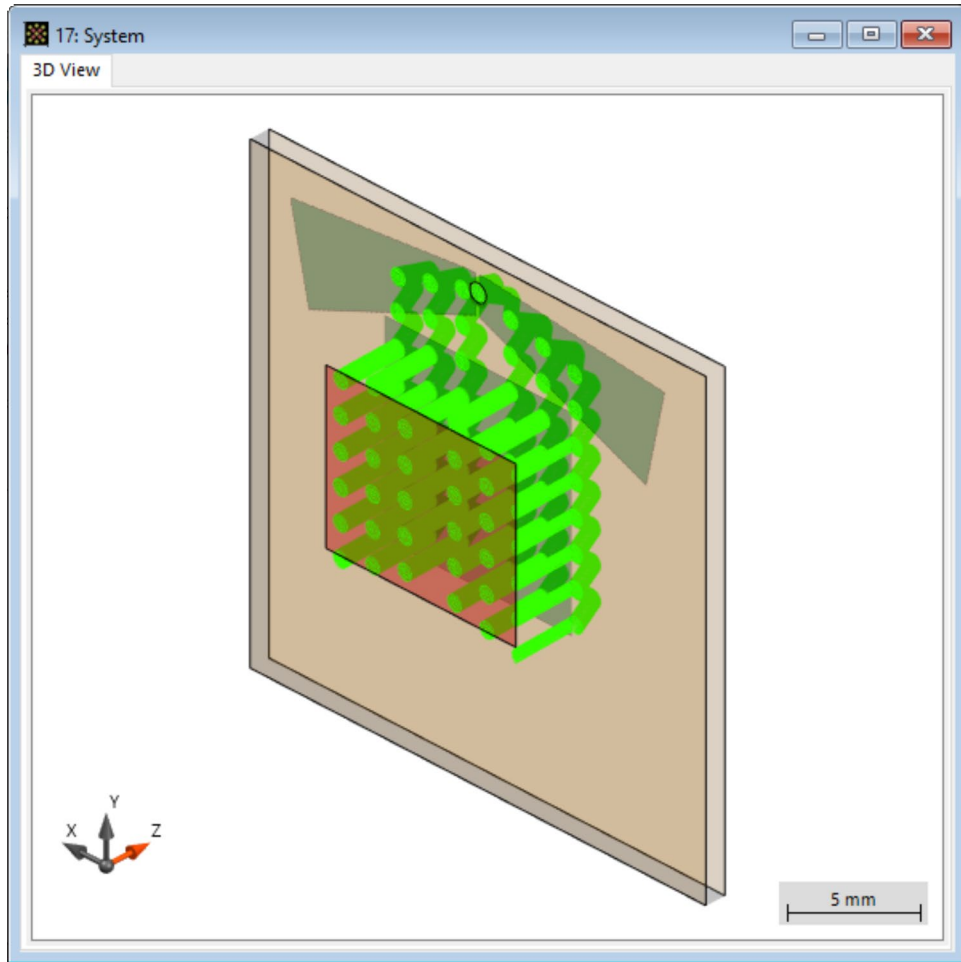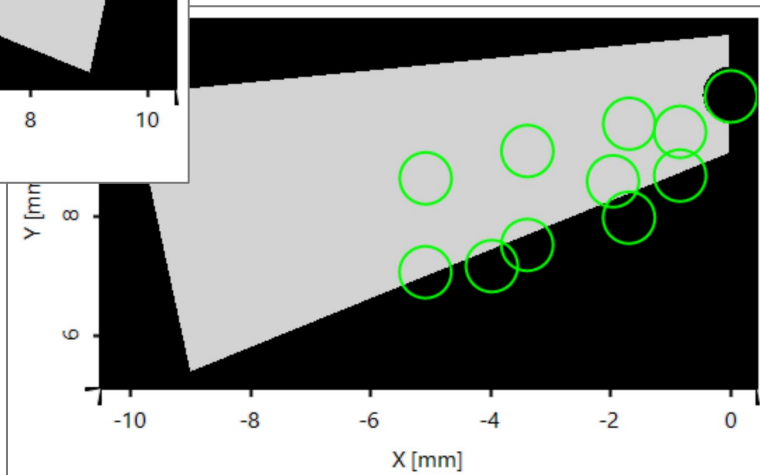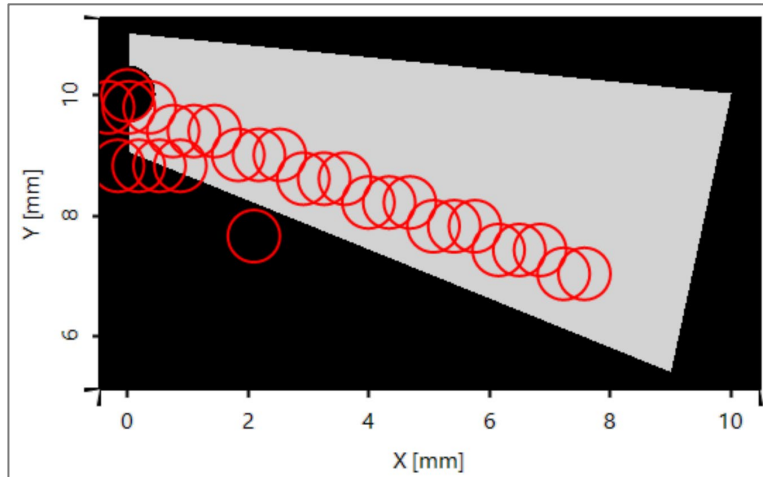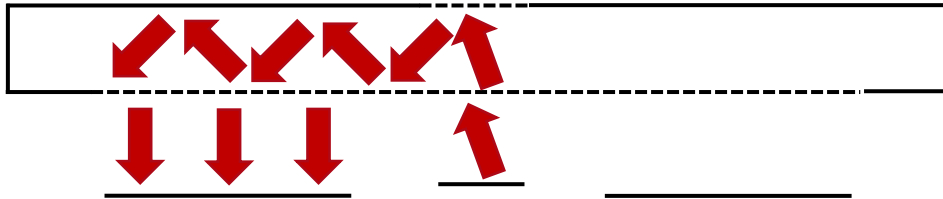
all light propagating inside the light guide:
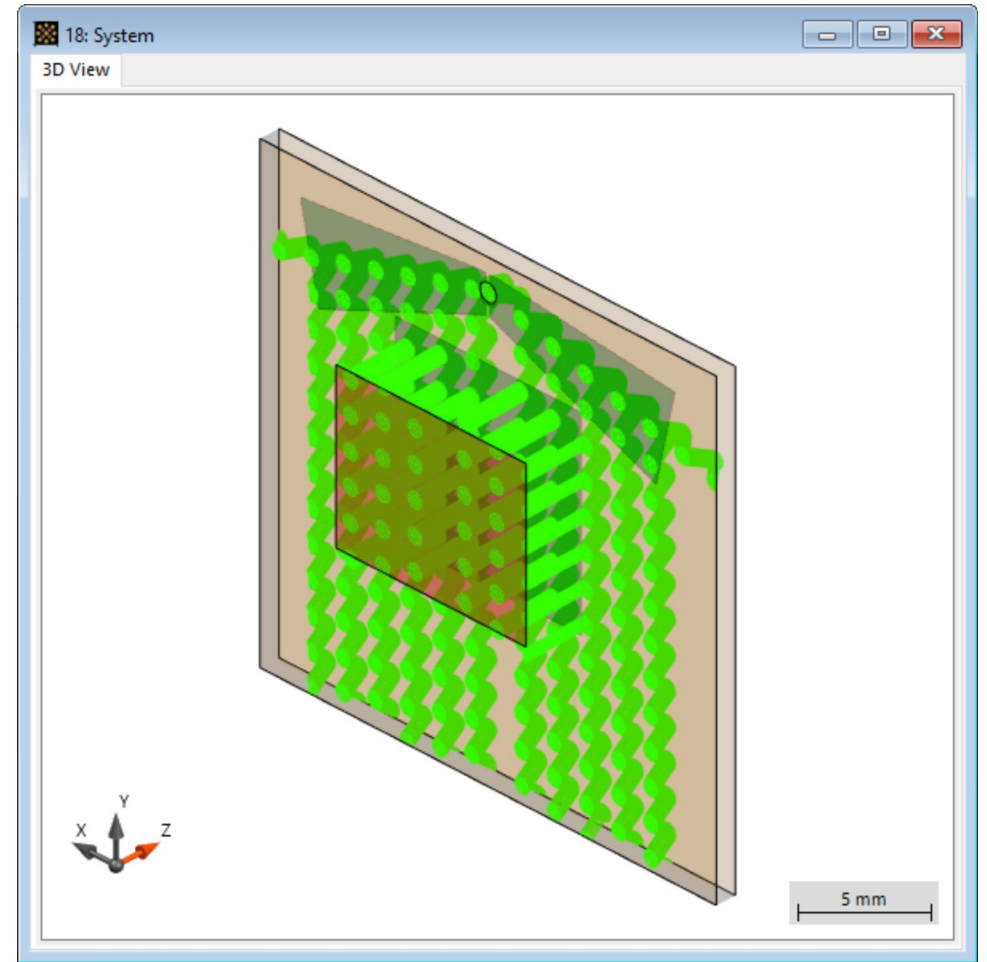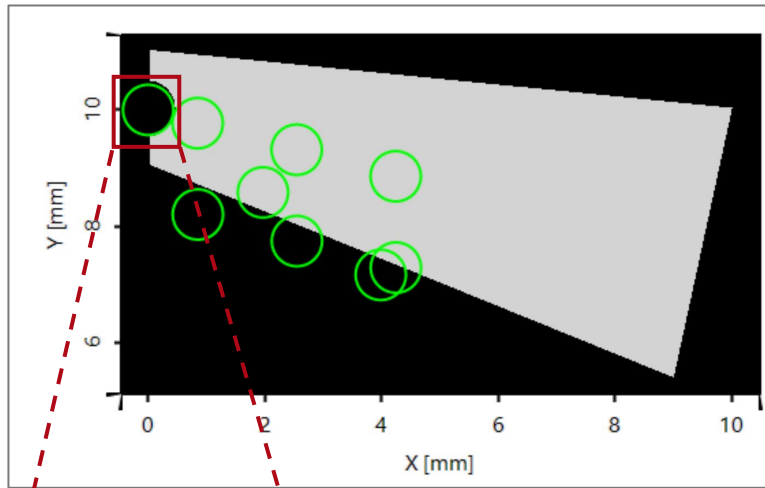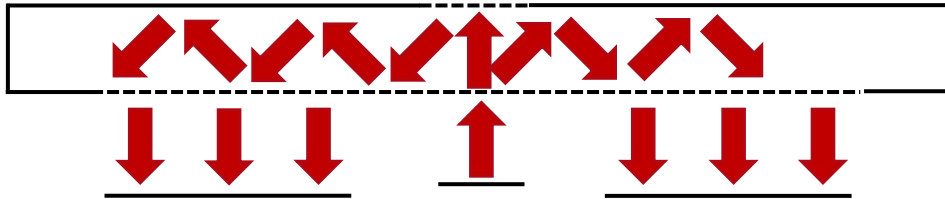
Slightly asymmetric light distribution, because of the two incouplers (first and second surface).

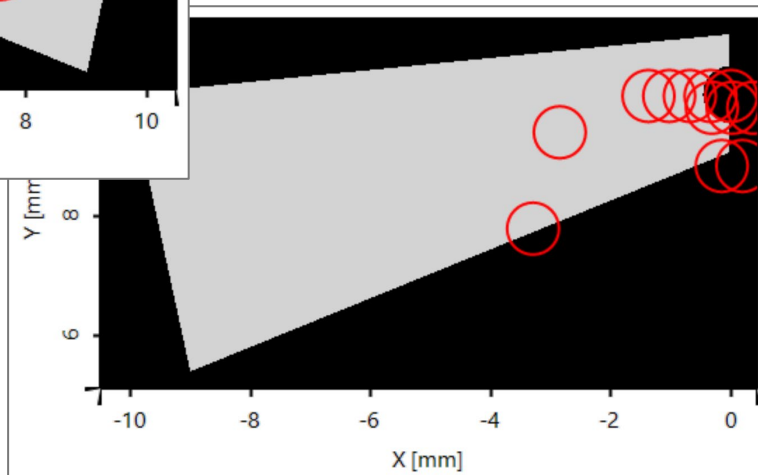*Note:* *The footprint display refers to the coordinate system (CS) of the region's surface. Their visualization is therefore mirrored.*

Aperture effects are introduced by multiple interactions due to the inclined impinging beam.

Note: The footprint display refers to the coordinate system (CS) of the region's surface. Their visualization is therefore mirrored.

The nonsequential model can also be used to evaluate undesired effects generated by multiple grating interactions.

Note: *The footprint display refers to the coordinate system (CS) of the region's surface. Their visualization is therefore mirrored.*
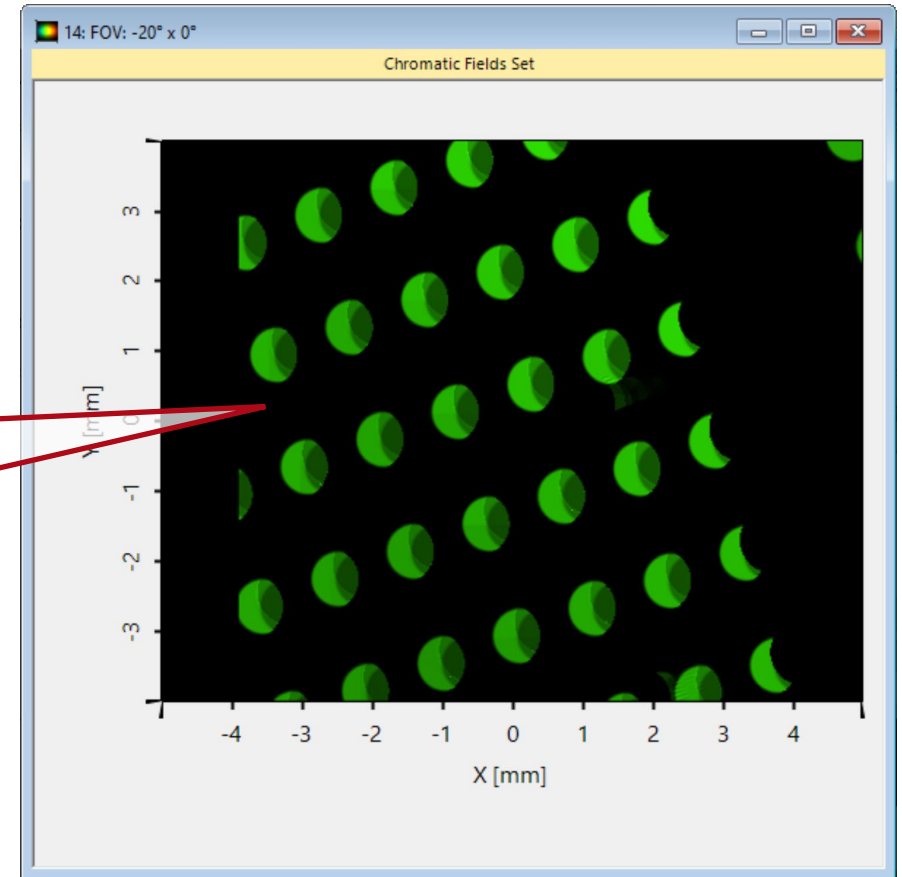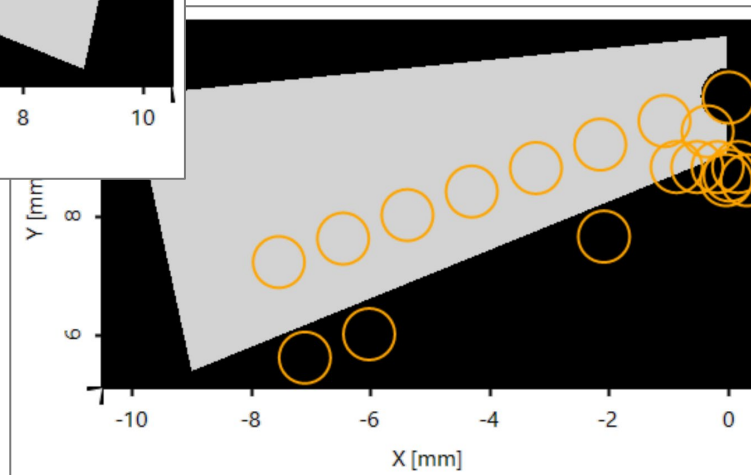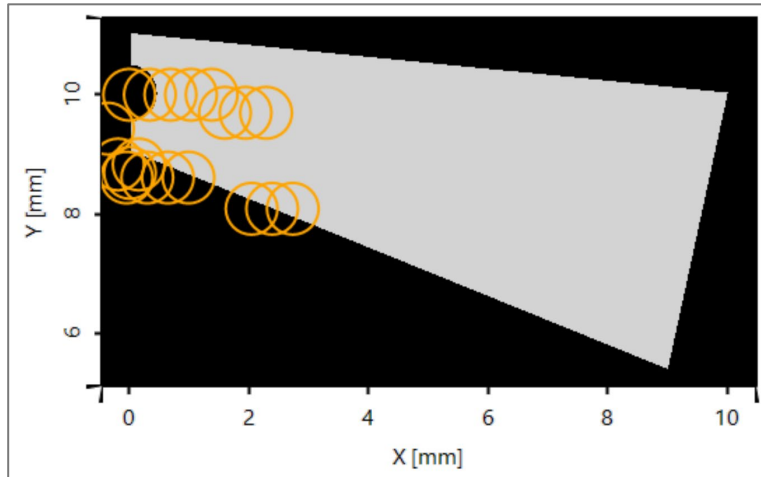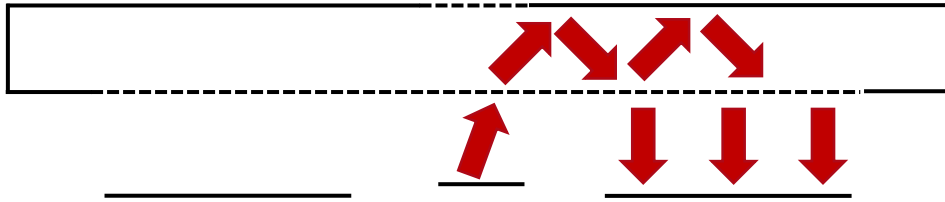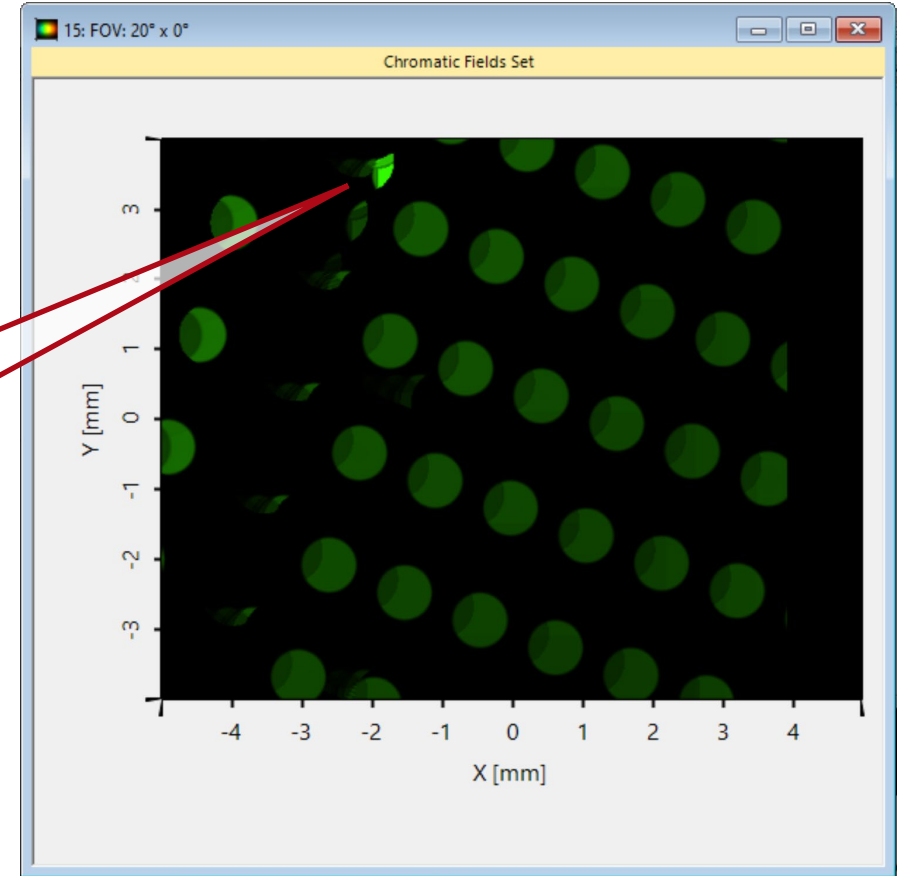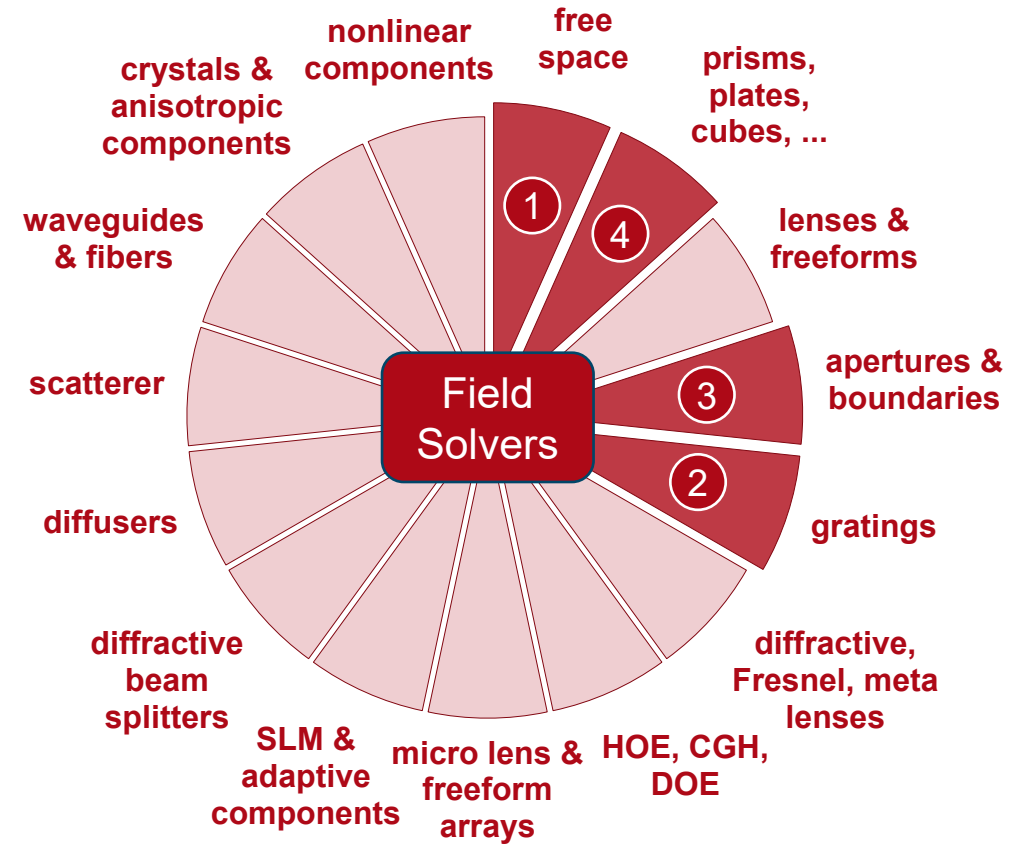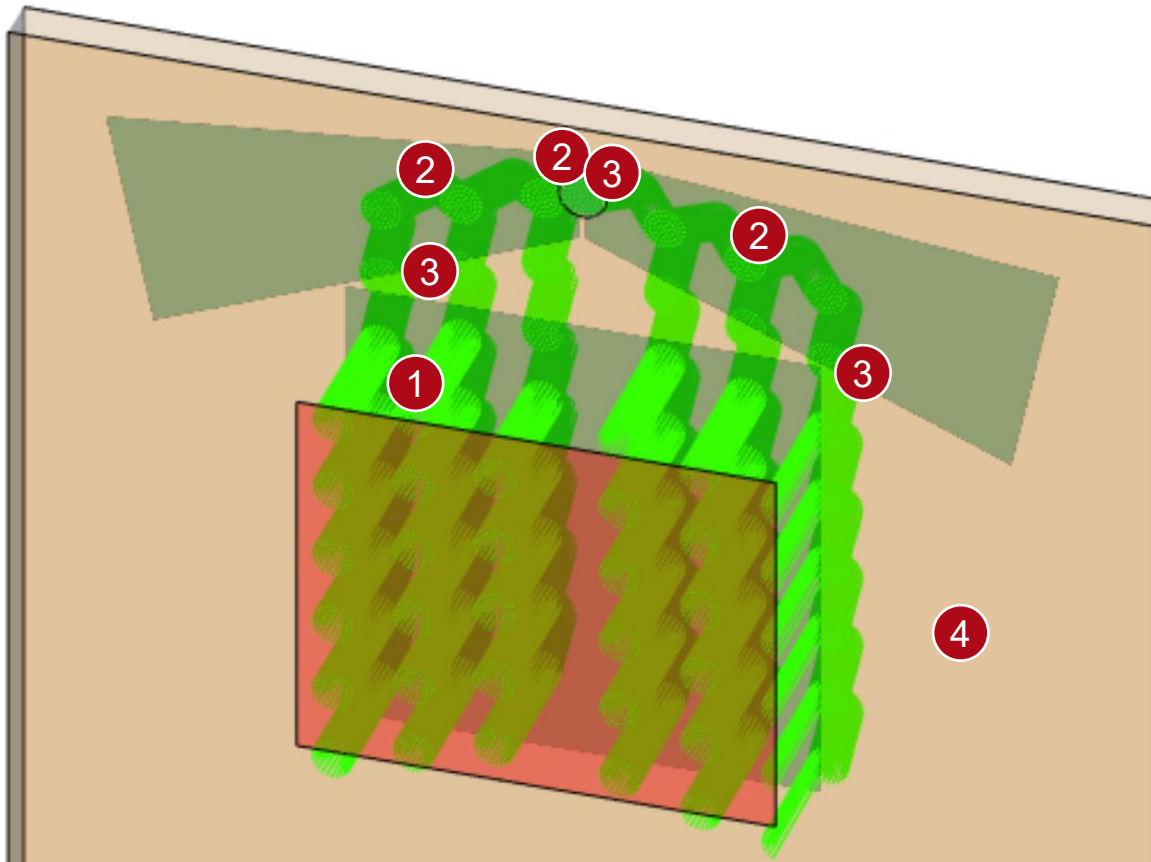
VirtualLab Fusion Technologies

Document Information

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further reading	- Construction of a Light Guide - Light Guide Layout Design Tool - Flexible Region Configuration - k-Domain Layout Visualization - Footprint Analysis of Lightguides for AR/MR Applications - Lightguide with 2D-periodic Grating Structures (diamond-shaped) based on Patent by Wave Optics