

Designing Augmented/Virtual Reality Devices using Multi-Domain Optical Simulations

Simulation and Design Using RSoft Tools and LightTools



Optics is Key for VR/AR

- “Optics remains the key challenge in developing the ultimate virtual experience”

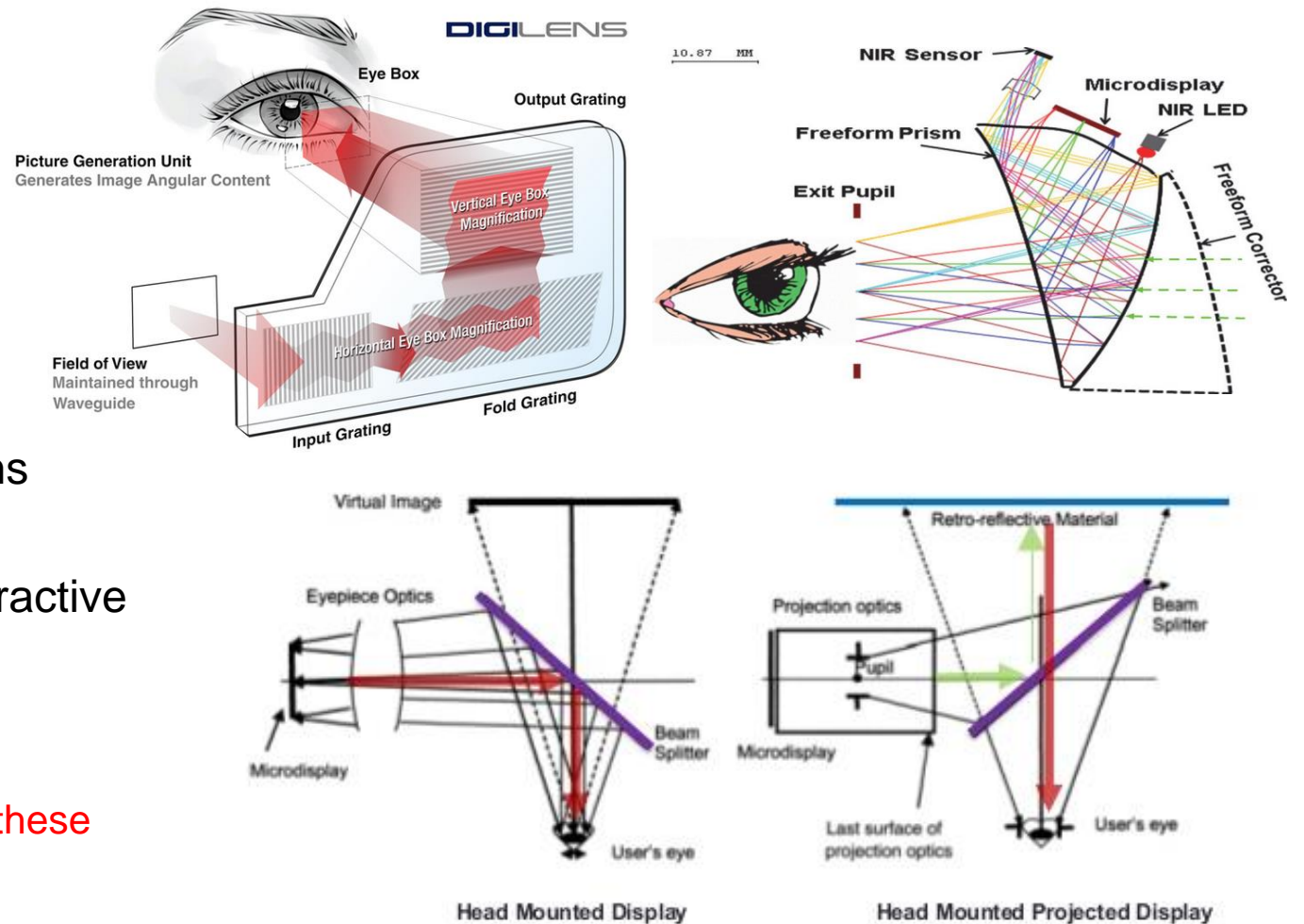
Bernard Kress, Microsoft's HoloLens Division @ SPIE Photonics West 2018:

- New types of optical and photonics technologies need to be implemented in next-generation VR/AR systems in order to provide greater visual comfort for prolonged usage, and to achieve a better sense of display immersion or the user.



AR/VR Requirements

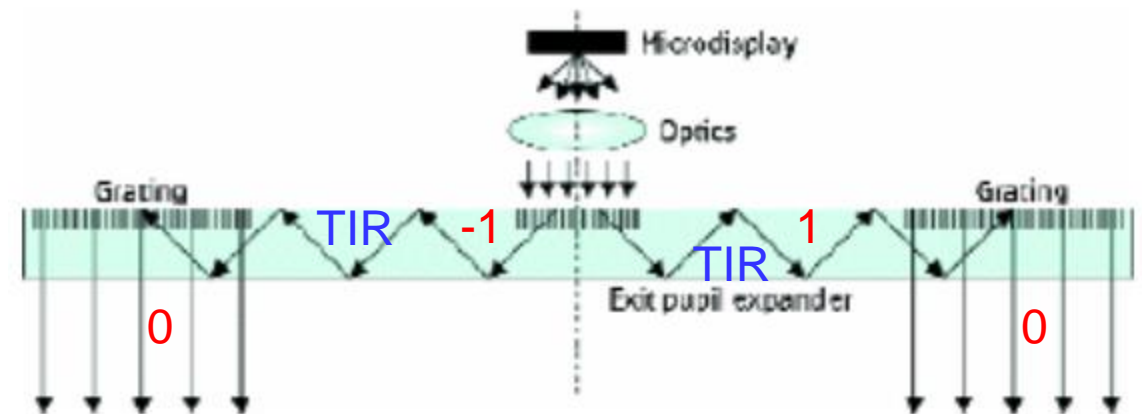
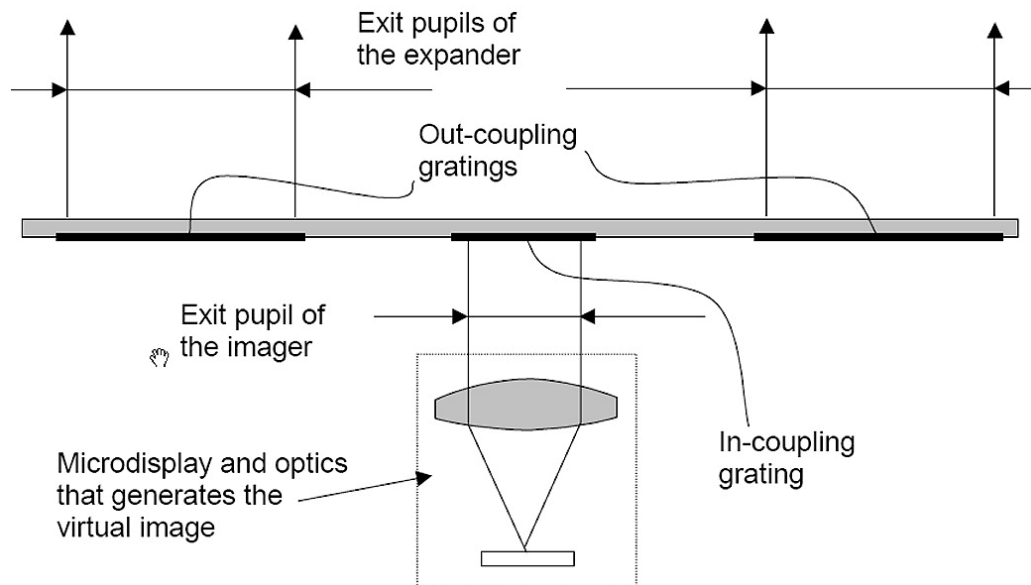
- Main VR/AR requirements:
 - Low weight
 - Small Size
 - Insensitive to vibration
 - Comfortableness
- Types of existing systems include:
 - Freeform optical prisms projection systems
 - Retina scanning
 - Reflective systems or hybrid reflective/refractive systems
 - **Optical planar waveguides with diffraction gratings**
 - This system type has the potential to meet these requirements, Synopsys tools can help!



Basic Schematic of Optical Waveguide System

Near-Eye-Display (NED) Systems

- Diffractive Gratings Functions:
 - Couple light into waveguide plate and couple light out of plate into eyes
 - Wavelength selection
 - Wavefront reshaping
- Gratings must be designed properly so that the optical system produces good images



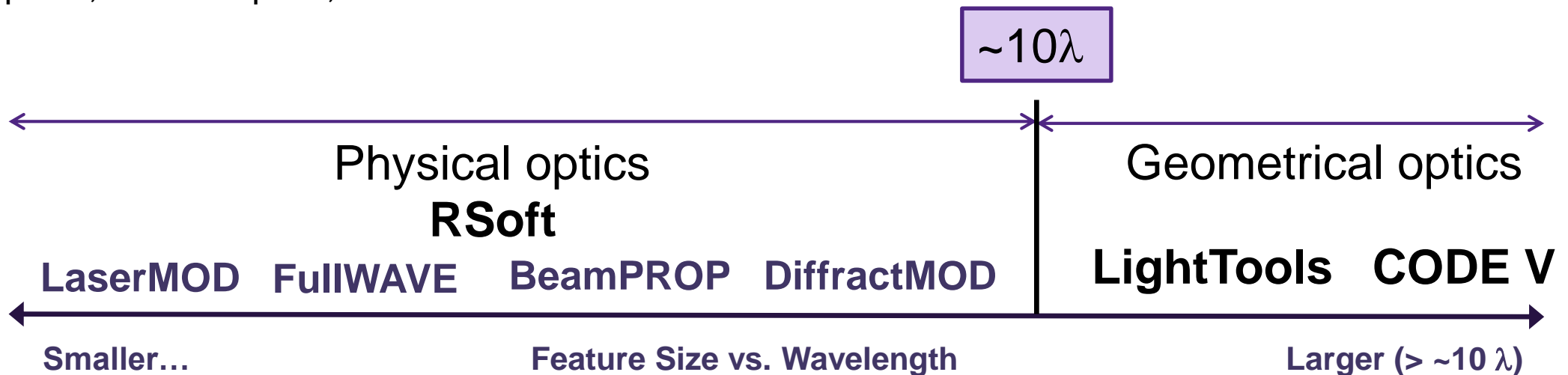
RSoft and LightTools Co-Simulation

• RSoft Component Tools

- Based on physical optics
- Maxwell's equations, etc
- Small photonics devices
- Wave propagation and multi-physics
- Diffraction, polarization, nonlinearity, electro-optical, thermo-optics, etc.

• LightTools

- Based on geometrical optics
- Snell's law, etc.
- Large bulk optical system
- Ray tracing and beam propagation
- Reflection, refraction, diffraction

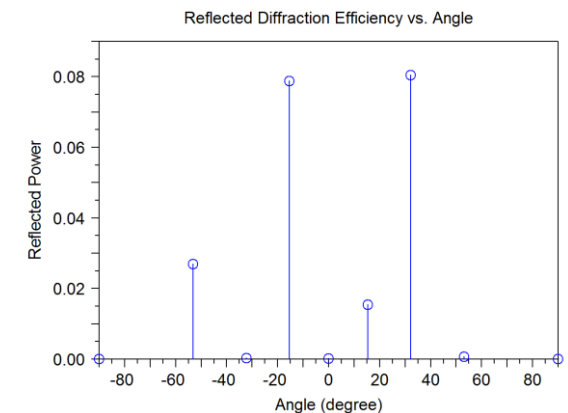
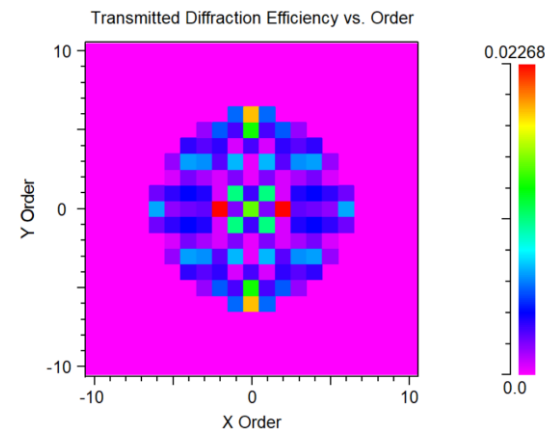
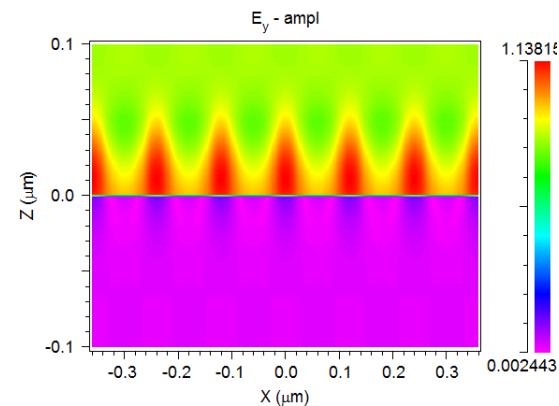
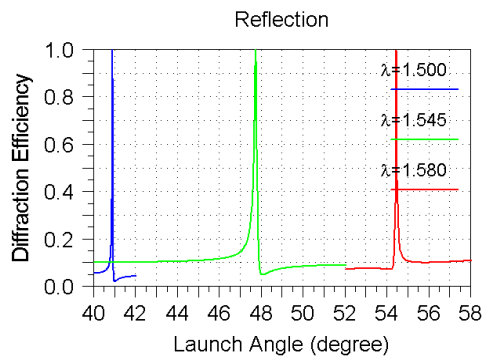
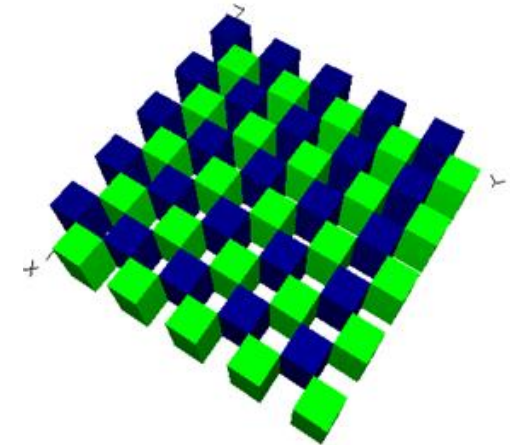
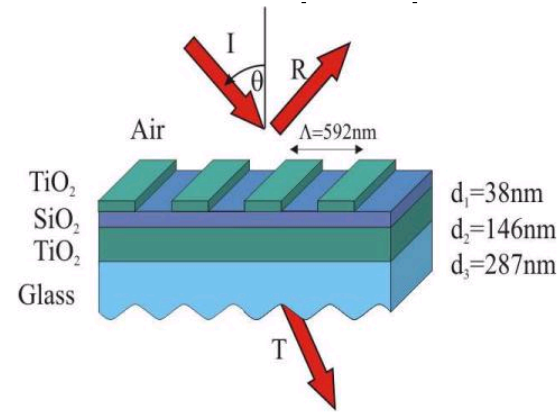


Simulating the Grating with RSoft Device Tools



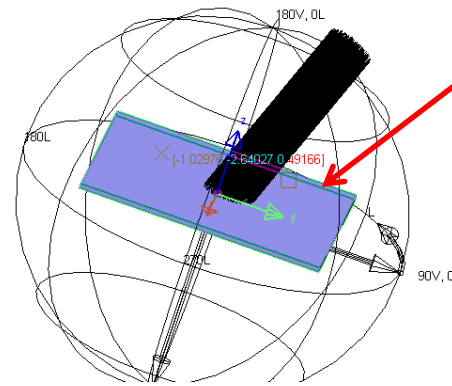
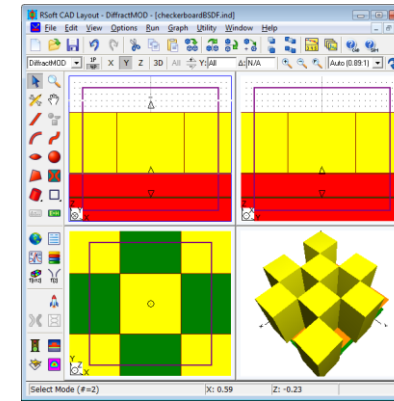
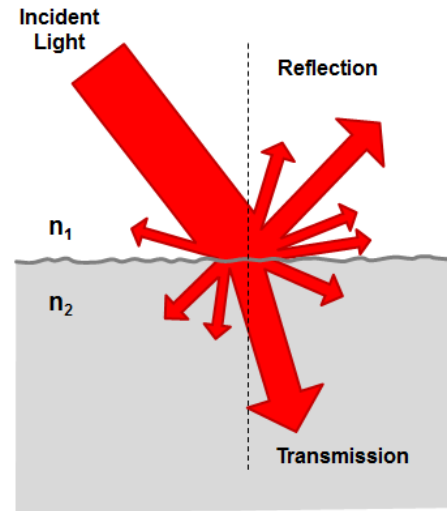
DiffractMOD: RSoft's RCWA tool

- DiffractMOD is a very efficient tool to rigorously calculate diffraction properties of transversely periodic devices
- DiffractMOD outputs :
 - Reflection/Transmission power for each diffraction order
 - Total reflection/transmission
 - Amplitude/Phase/Angle for each diffraction order
 - Field distribution in simulation domain

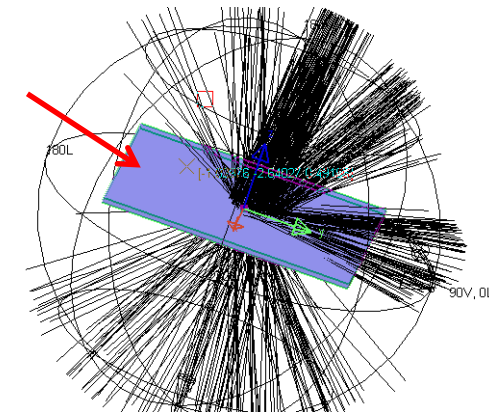


RSoft/LightTools BSDF Interface

- RSoft BSDF files:
 - Automatically calculated using RSoft's FullWAVE or DiffractMOD packages
 - Contains information about how a surface (thin film, patterns, etc) scatters light
 - Reflection/transmission data is stored for illumination from both sides of the surface
 - Scatter information is stored as a function of two incident angles, wavelength, and polarization
- The RSoft BSDF file is then used in LightTools to define a surface property
 - Rays that hit the surface in LightTools are 'diffracted' according to the data in the RSoft BSDF file



BSDF Surface

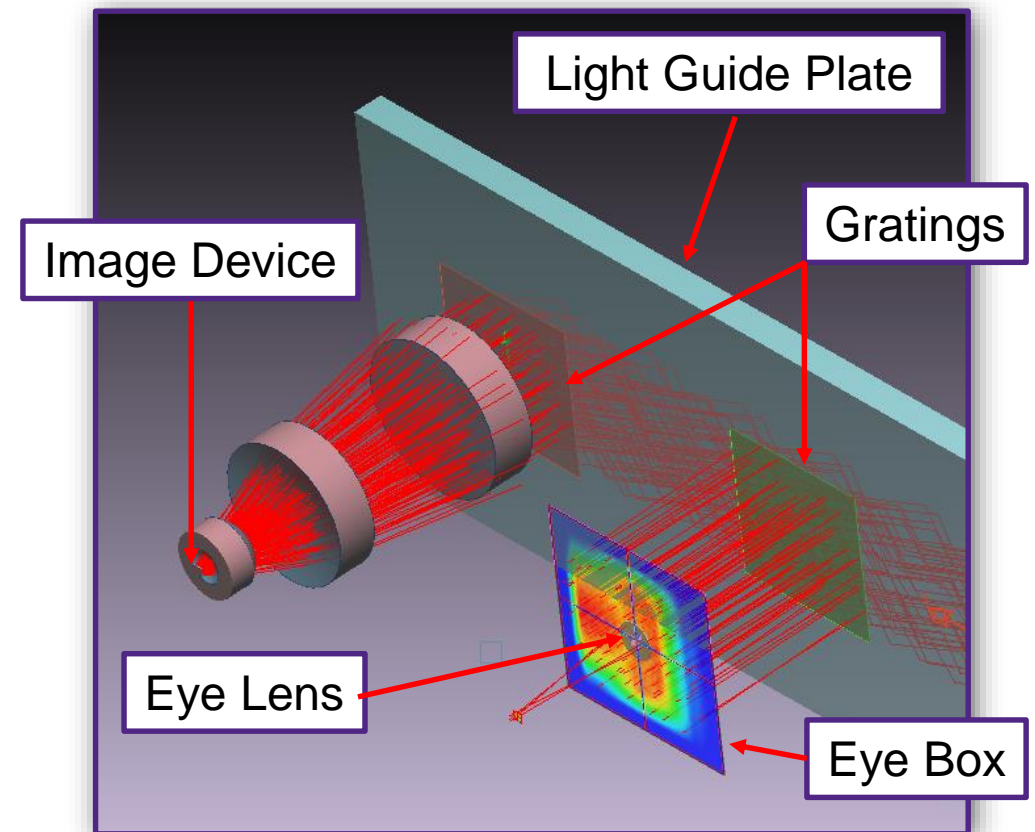


Design Case 1



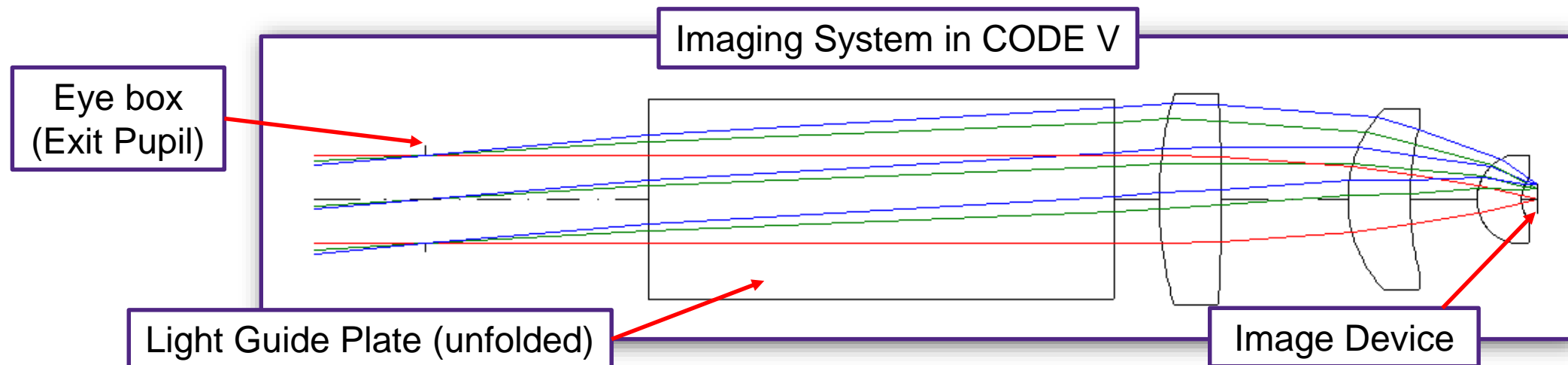
Use LightTools to Design the Nominal System

- AR systems are complex and involve not only illumination optics but also imaging optics as well as ergonomic considerations
- It is usual to lay the system out in LightTools using idealized gratings in order to explore the system more easily and to discover the required grating settings that can then be designed in Rsoft
 - Since the imaging properties of the system are critical to a successful design, it may be necessary to design at least part of the system in an imaging package such as Synopsys' CODE V
- Here we see half of a simple system using an imaging system, a light guide plate and two idealized gratings to transfer the image to the left eye while creating a well defined eye box (exit pupil)



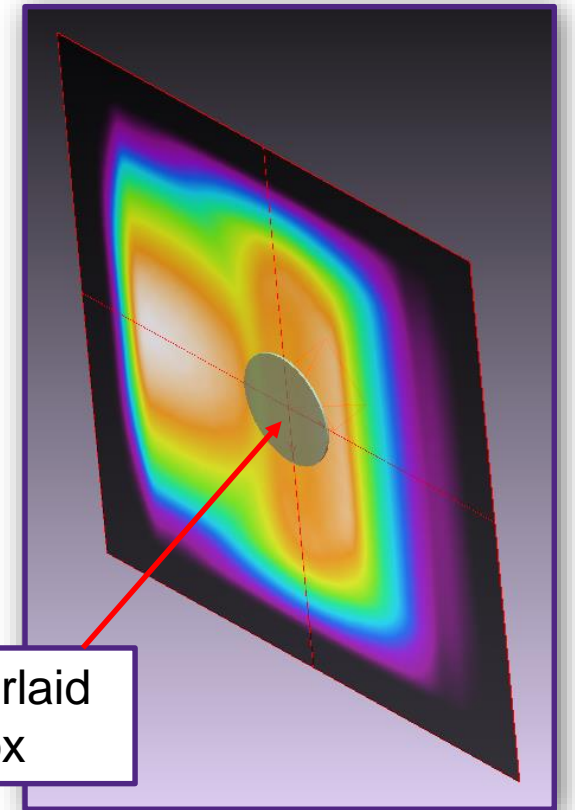
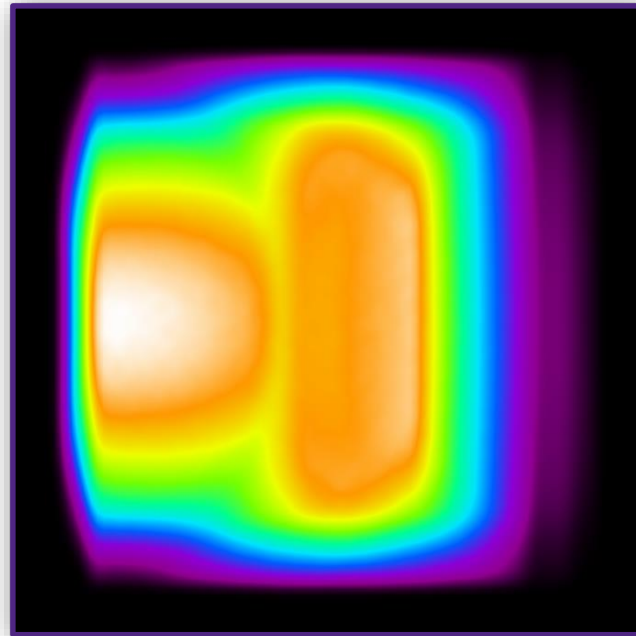
The Importance of the Eye Box

- For wearable optical systems, the designer must make accommodations for variances in human size and usage
 - Specifically, the inter-ocular distance can vary significantly with each user
 - The device may also be worn at a different height with respect to the eye from user to user
 - This, then, requires a defined eye box
- Because of this, it is critical that an AR/VR system create a proper exit pupil so that variations in the position of the eye don't cause parts of the projected image to drop out
 - With a properly constructed pupil rays from every part of the image device will be found in every part of the eye box



Eye Box Results for Our Nominal System

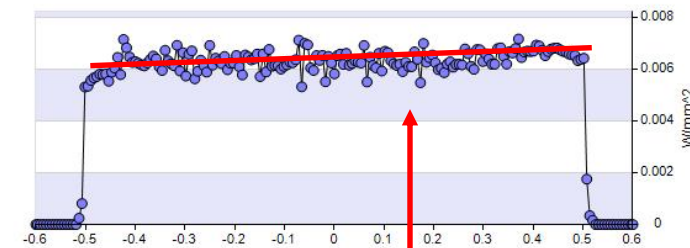
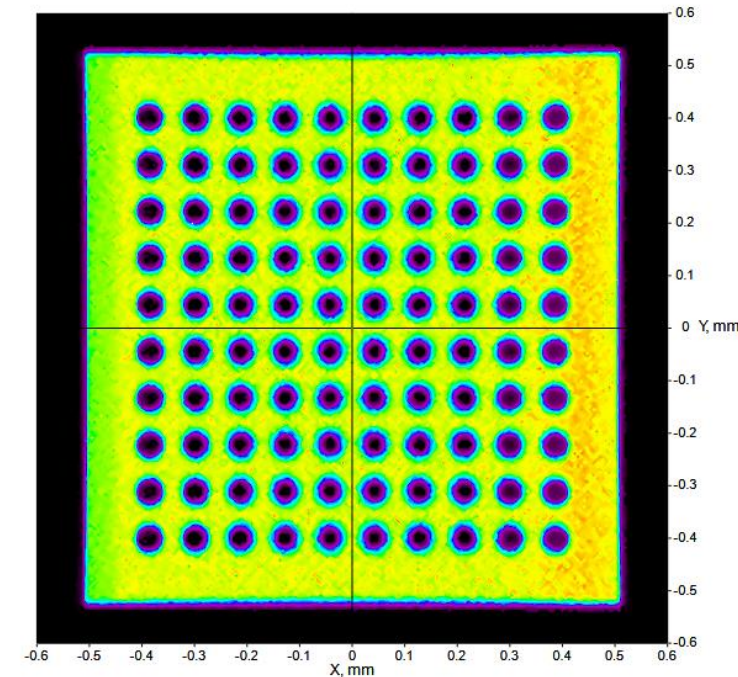
- Here we see a false color illuminance map of our eye box
 - The eye box shows some complex structure due to the multiple bounces and extraction events on input and exit grids
 - However, the image rays are uniformly represented across the eye box as we shall see later



5mm Iris overlaid
on eye box

Image Quality

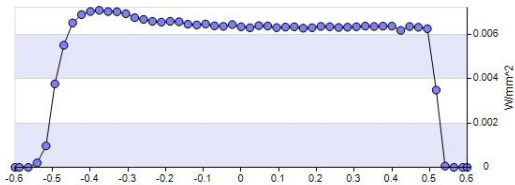
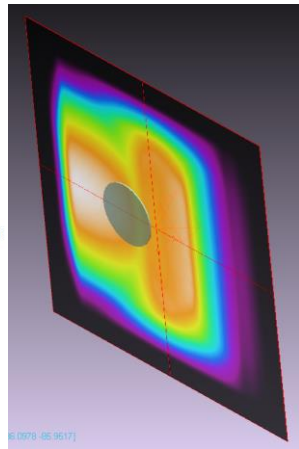
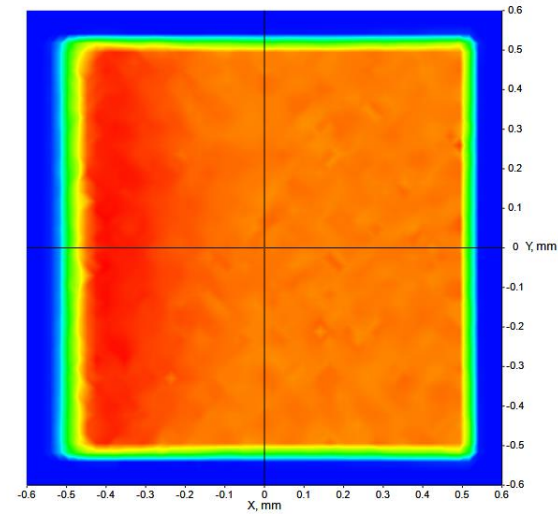
- The imaging system is designed to put the virtual image at an infinite distance from the eye
 - Collimated light
 - The system can be designed for a different virtual image distance, something closer to the user (diverging light), but care should be taken to avoid converging light at the eye box as the eye cannot focus converging beams
- The image quality seen here is good
 - The field of view is ± 5 degrees horizontal and vertical
 - There is a small amount of pincushion distortion
 - The circle pattern has been added in order to visualize the imaging performance



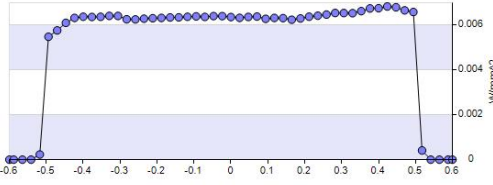
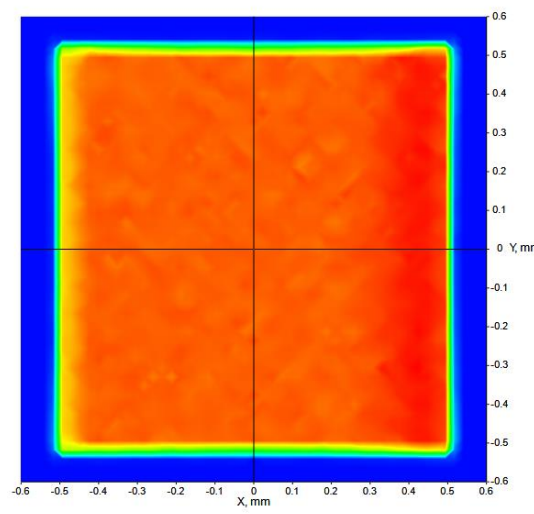
Notice a very slight slope in the illuminance across the field

Imaging Quality at Different Eye Positions

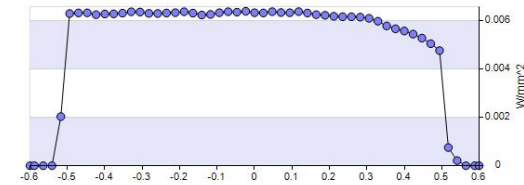
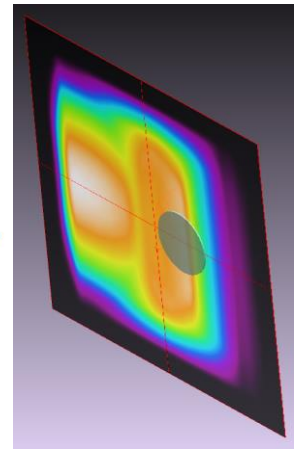
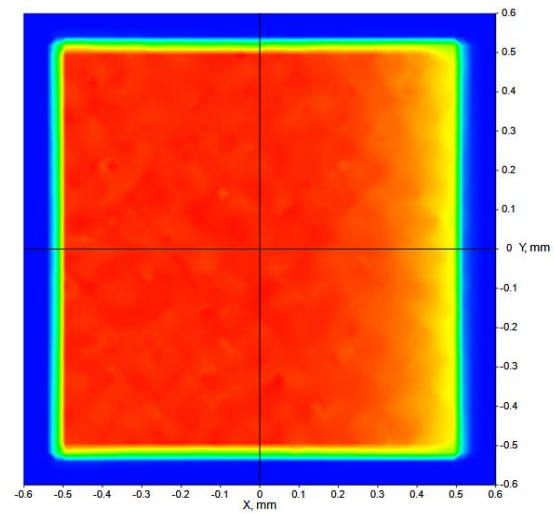
- Here we show the imaging quality at different eye positions
 - What we are looking for is variations in illuminance for different parts of the image (e.g. some parts may disappear)
 - We have removed the dots and lowered the resolution



3mm Left



Nominal

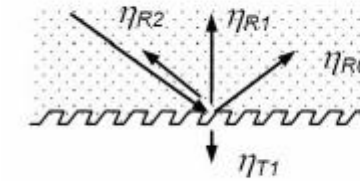
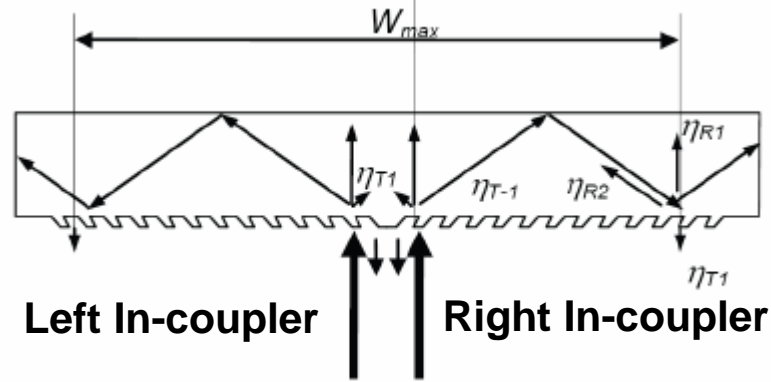
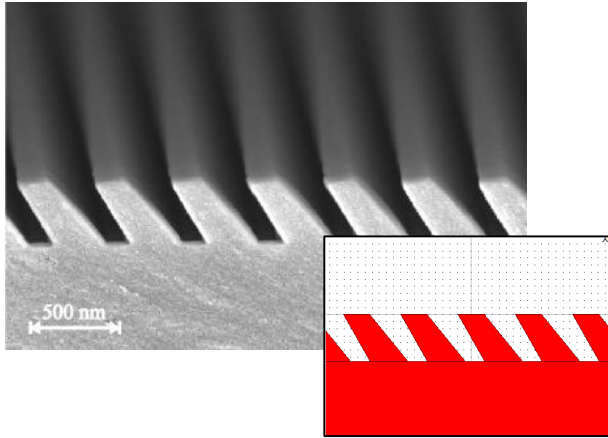


3mm Right

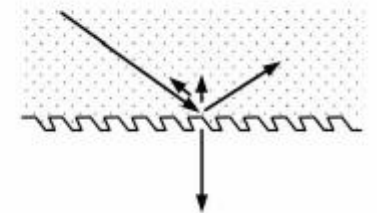
Designing Gratings

- Once the nominal system has been developed and the designer is satisfied with the performance the ideal gratings must be converted to actual gratings
- For this we use the RSoft Device suite to design actual gratings as near to the nominal specifications as possible
- Once designed, the grating performance can then be transferred back into the LightTools model using the BSDF utility
 - The nominal gratings are simply replaced with the imported BSDF data
- Further optimization can then be done to adjust the performance

Design Case 1: Structure Overview



Reflection Type
Out-coupling



Transmission Type
Out-coupling

- Diffractive slanted gratings are manufactured onto a high refractive index plastic waveguide with simple UV replication technology. Large quantity manufacturing is possible

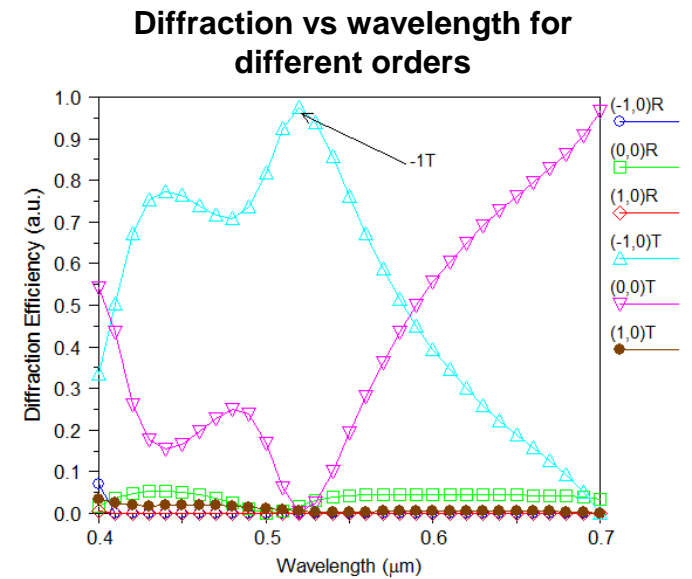
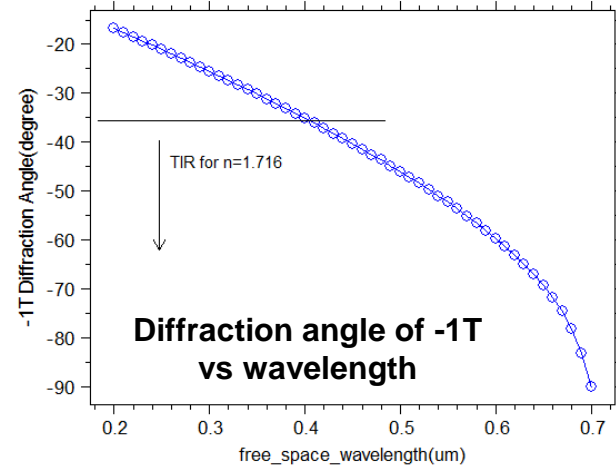
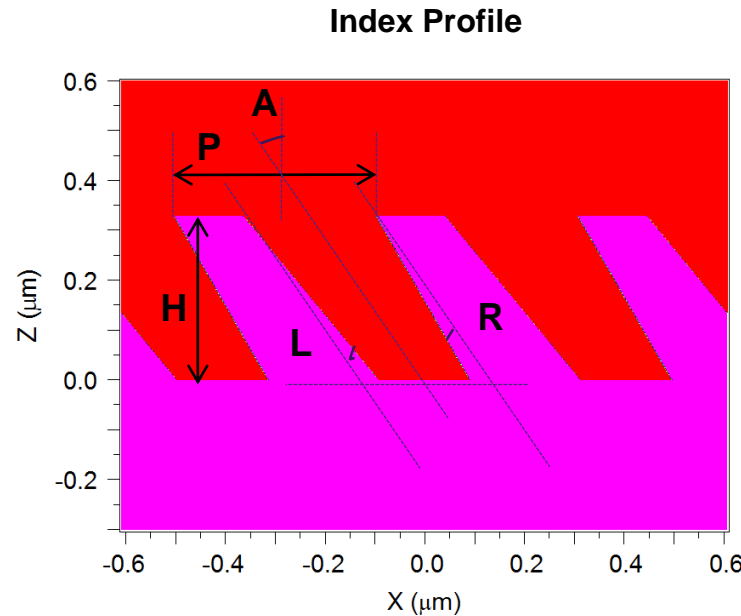
- The slanted gratings can be optimized to have high 1st order transmission efficient for right in-coupler and high -1st order transmission efficient for left in-coupling (> 92%).

- Two types of slanted gratings for out-coupler. The efficiency can be optimized as well.

T Levola et al, "Replicated slanted gratings with a high refractive index material for in and outcoupling of light", Optics Express, 15 (2007)

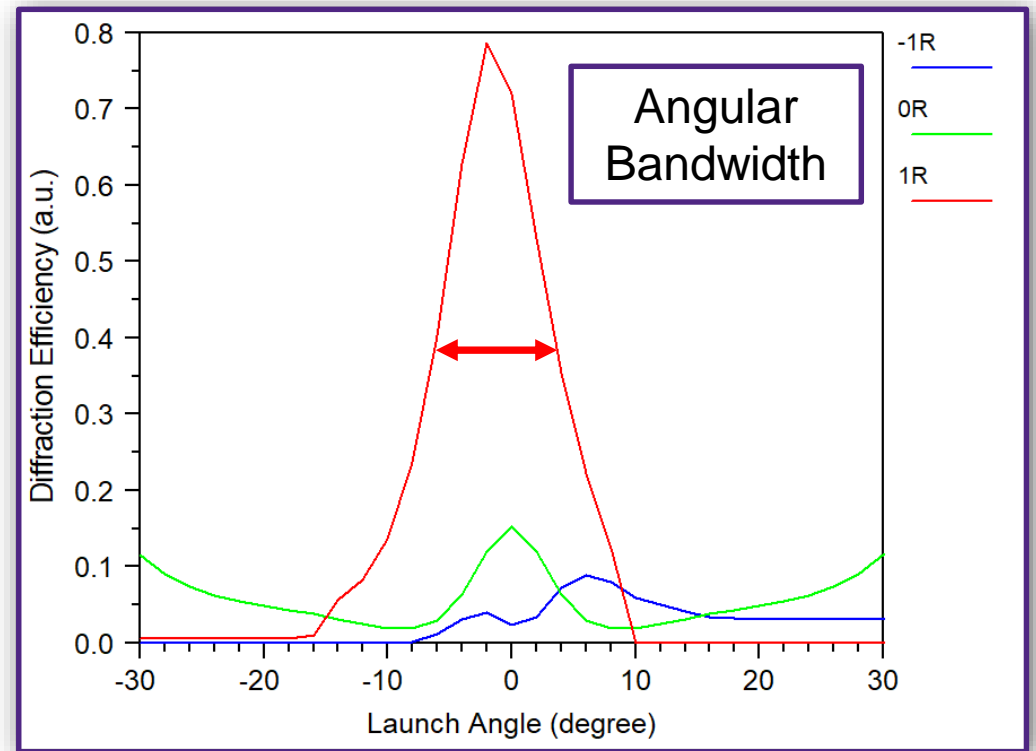
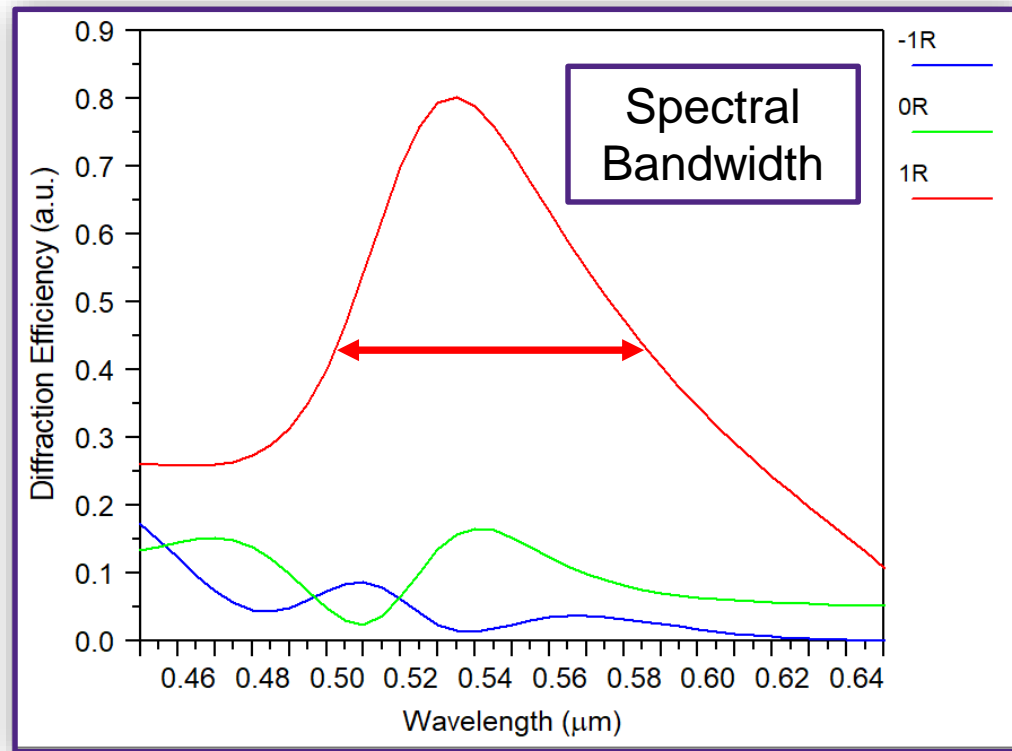
Using DiffractMOD for Grating Design

- Grating Properties:
 - **Wavelength:** 0.52 μm
 - **Period:** 0.405 μm
 - **H:** grating height
 - **A:** slant angle
 - **L:** Left slope angle from slant axis
 - **R:** right slope angle from slant axis
 - **Fill:** duty ratio
 - **Index:** 1.716



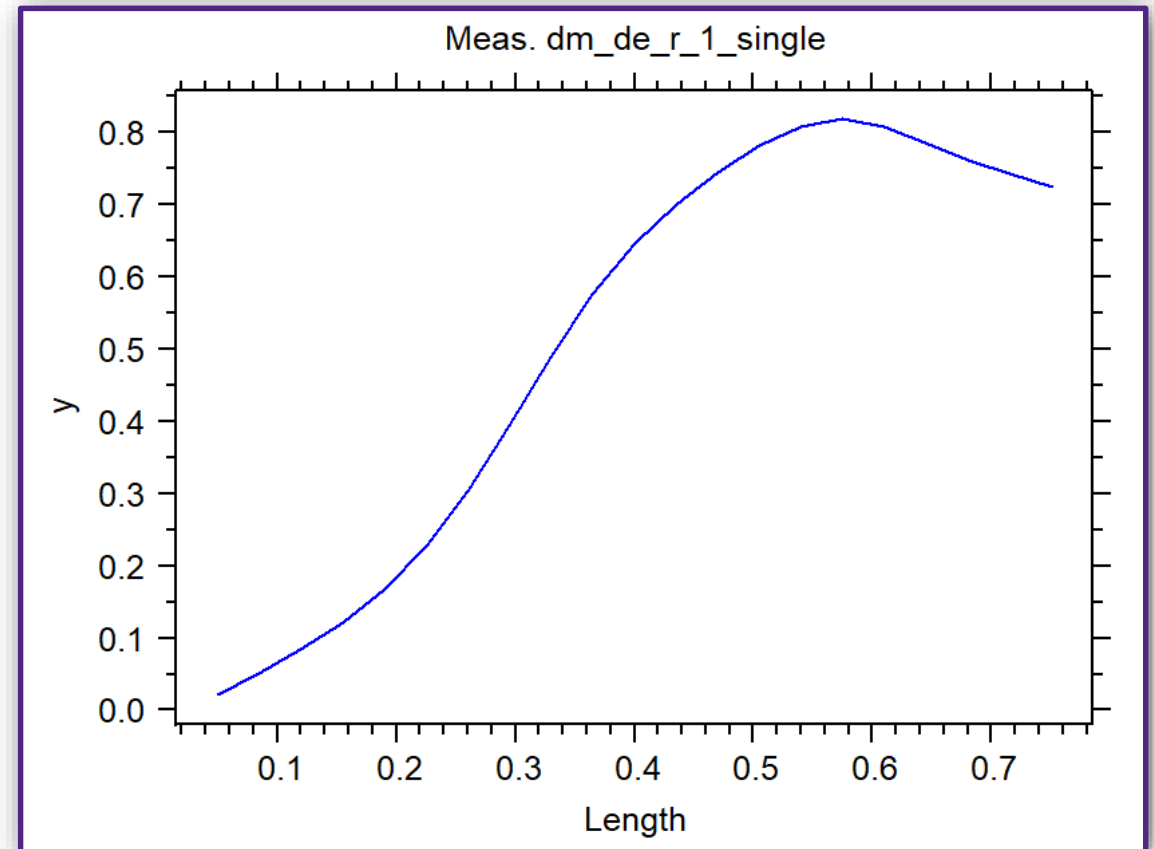
Grating Performance

- The charts below show the spectral bandwidth of the designed grating for the -1 through +1 orders (Reflected) as well as the diffraction efficiency as a function of angle
 - The angular bandwidth will limit the field of view of the projected image



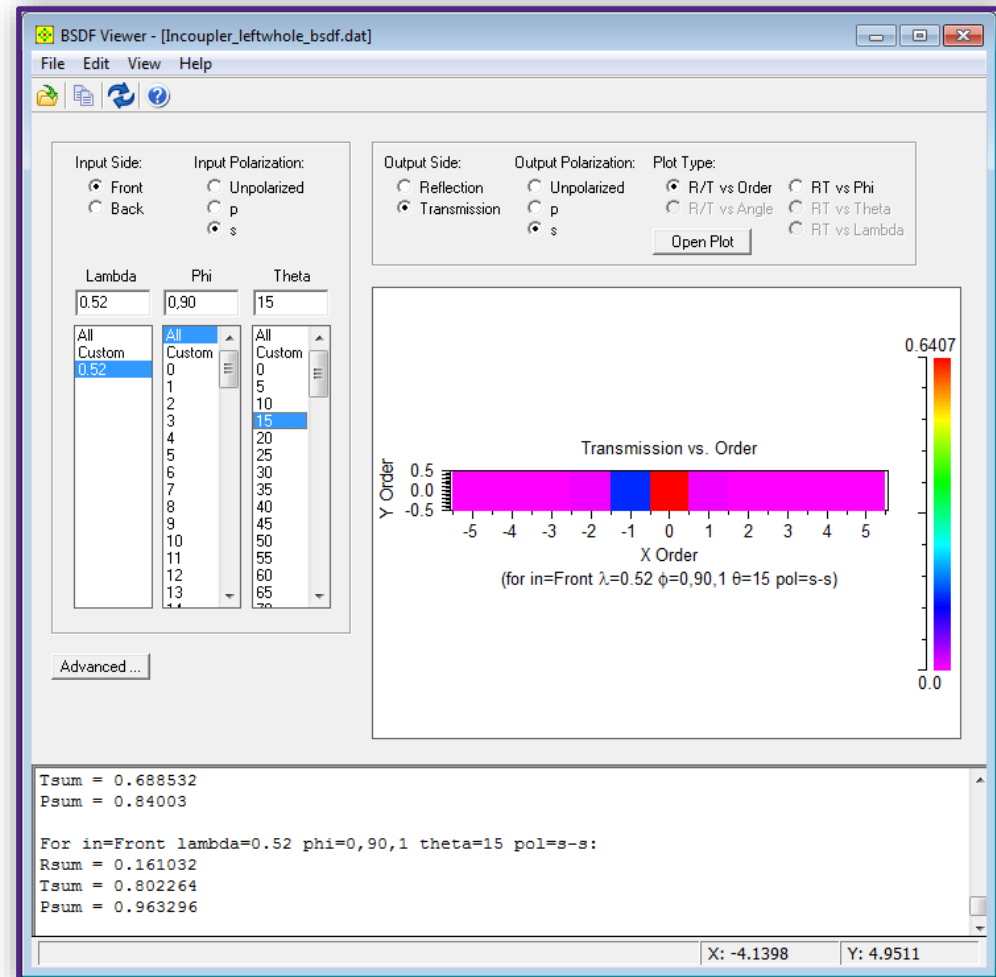
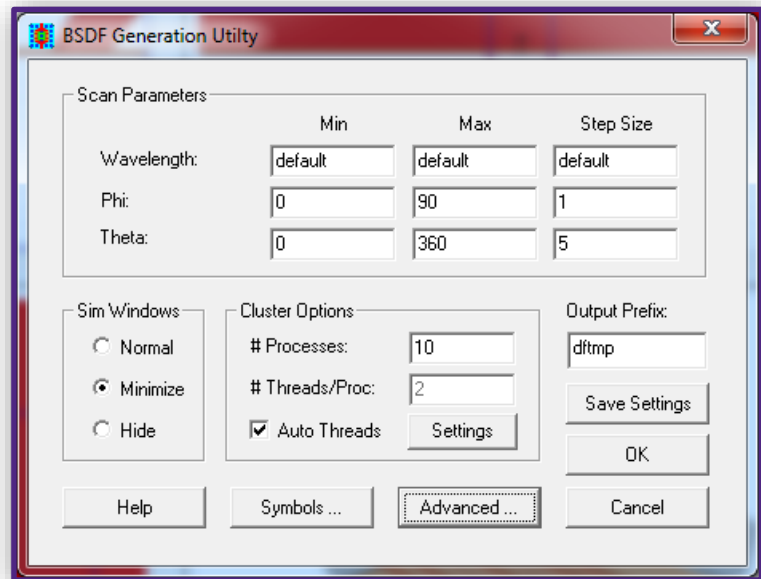
Diffraction Efficiency as a Function of Rib Height

- The plot below shows that the rib length can be used to vary the diffraction efficiency of the +1 order
- Because this is an effective parameter, we will use this to optimize the gratings to create a uniform output across the eye box



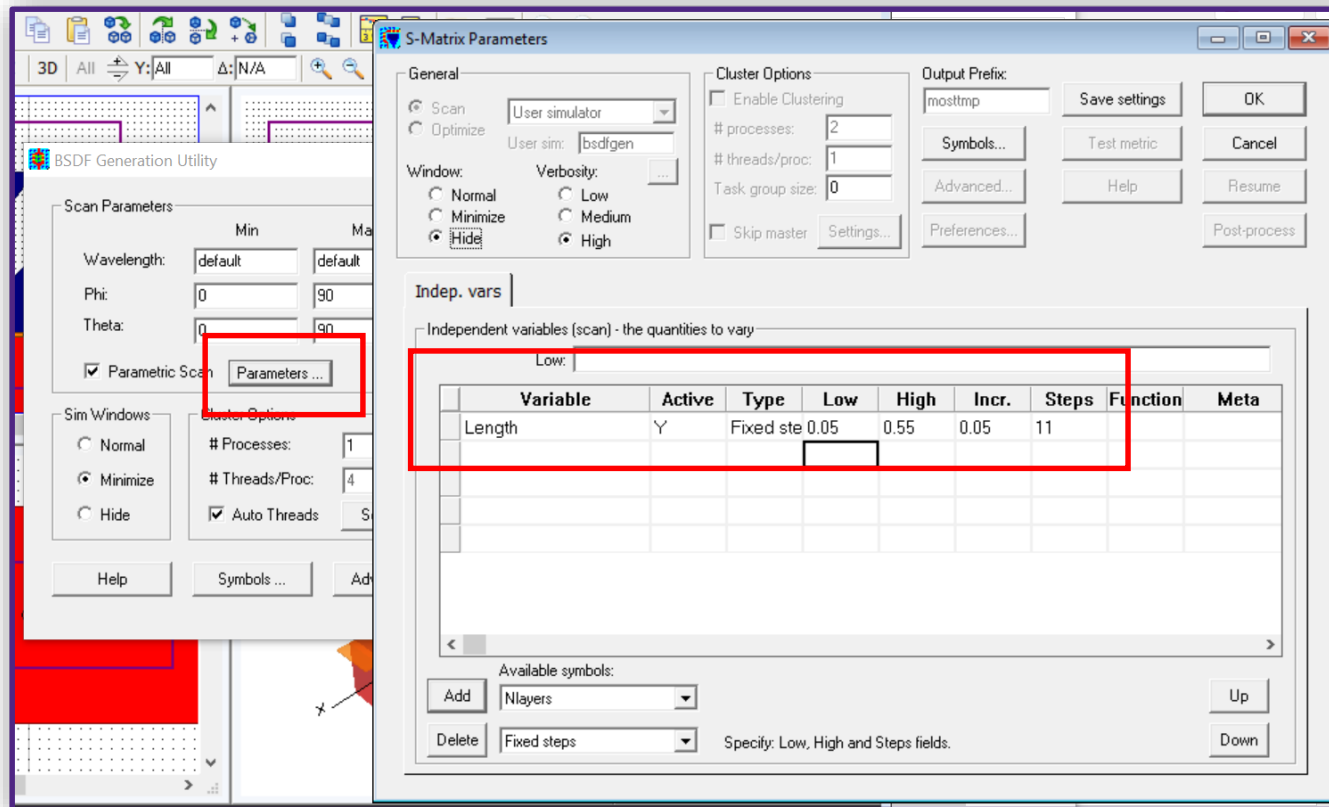
RSoft BSDF Calculation for Optimal Structure

- Angular range of RSoft BSDF file:
 - **Phi** (from normal): Range of [0,90] with 1° spacing
 - **Theta** (around normal): Range of [0,360] since the structure is anisotropic with 5° spacing
- BSDF Utility runs DiffractMOD simulations and both polarizations are automatically calculated



Parametric BSDF Database

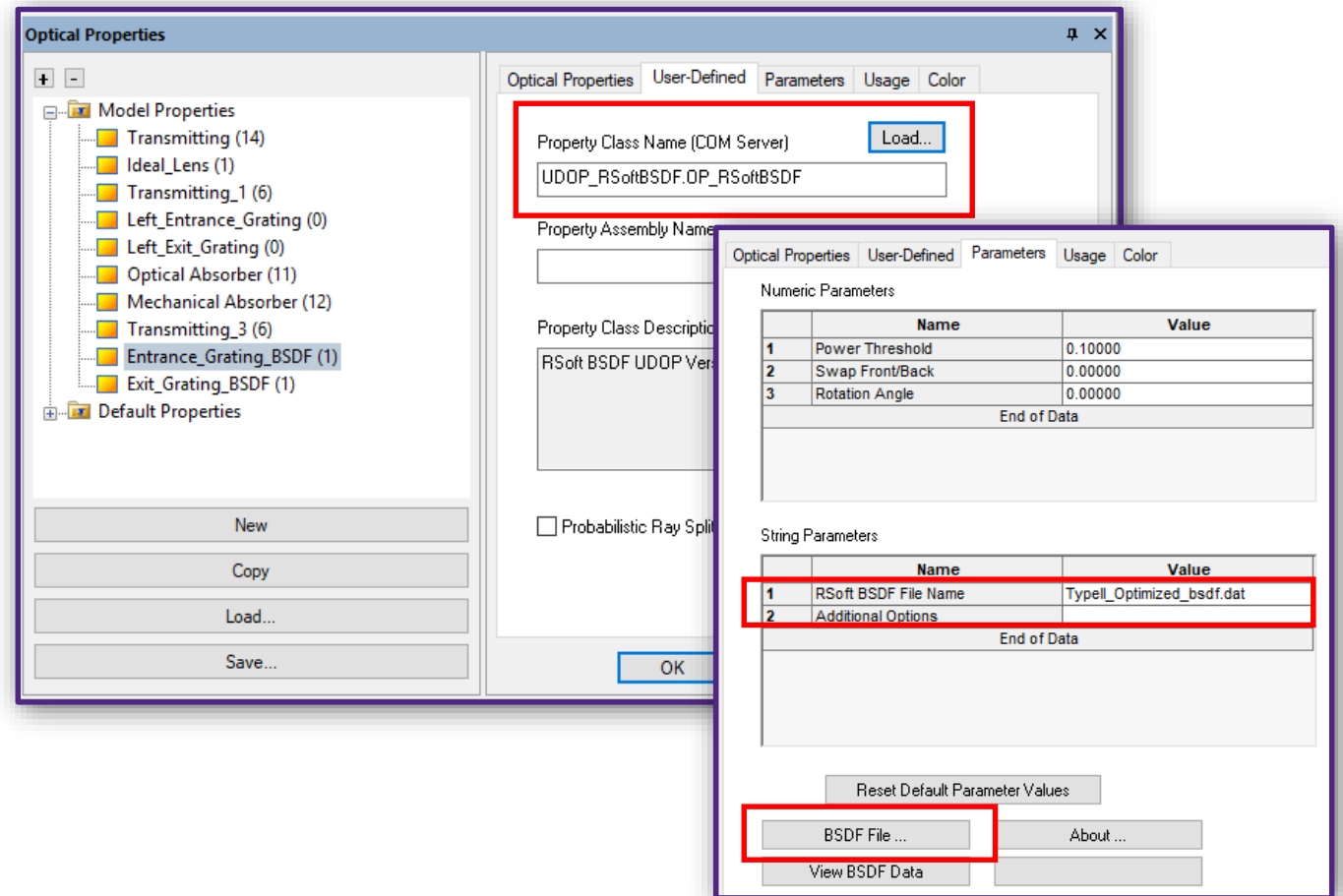
RSoft BSDF Generation Utility with FullWAVE FDTD or DiffractMOD
RCWA



- In BSDF Generation Utility, parametric BSDF data is supported
 - Any variables defined in RSoft CAD can be selected
 - Multi-variables parametric BSDF is supported as well

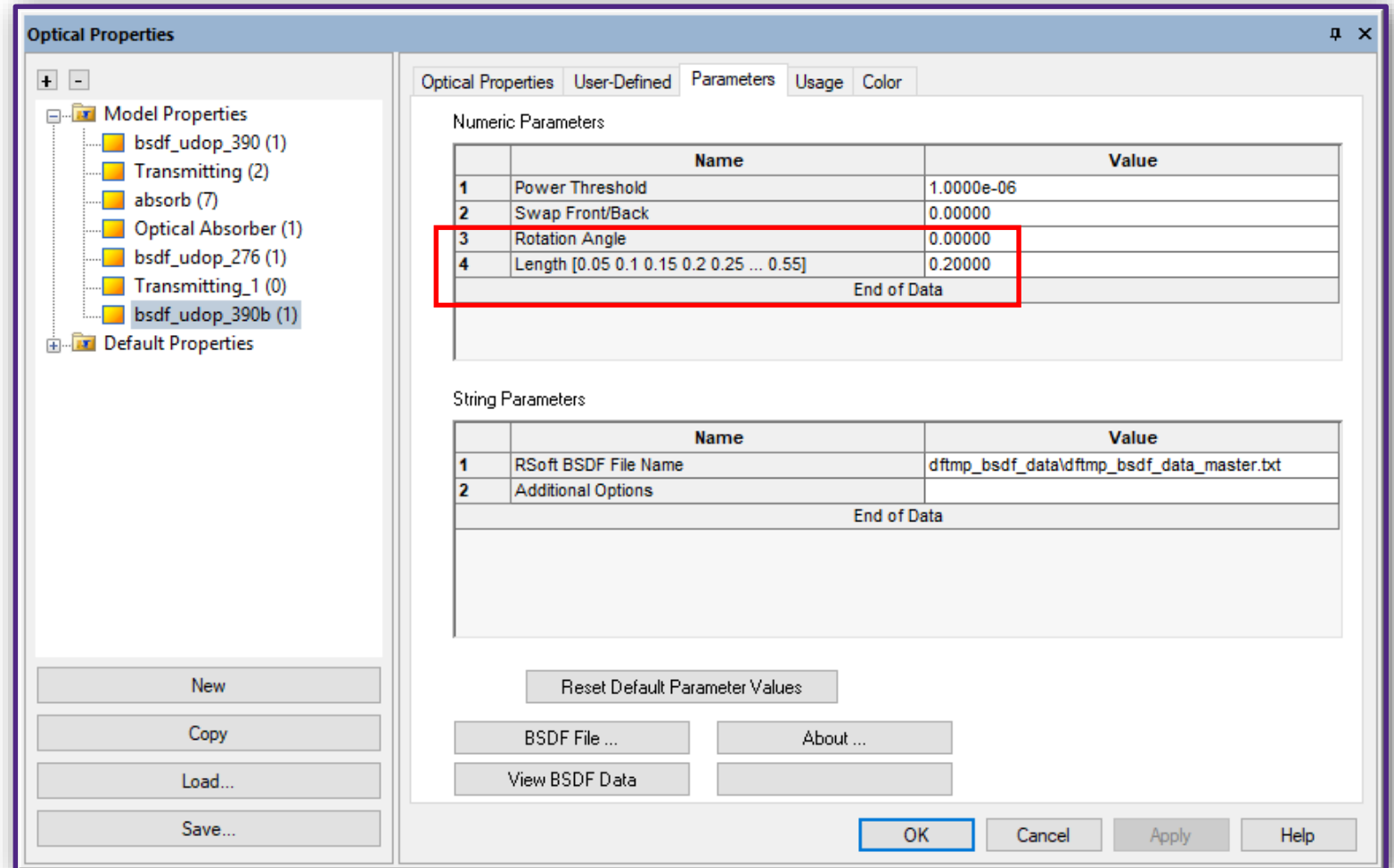
Using the BSDF File in LightTools

- Once the BSDF data has been generated in RSoft, it is a simple matter to integrate the data into the LightTools Model
- Simply create an optical property for each grating
 - Set the Type to User-Defined
 - Select the UDOP_RSofBSDF.dll, installed with RSoft Design Tools
 - Select the imported BSDF data file
- Then assign the new optical property in place of the existing nominal grating optical property
 - You may need to rotate the zone 180 degrees to get the proper orientation



Parametric BSDF Database

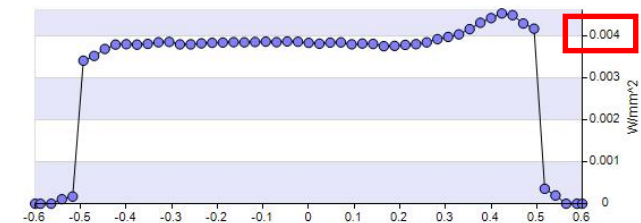
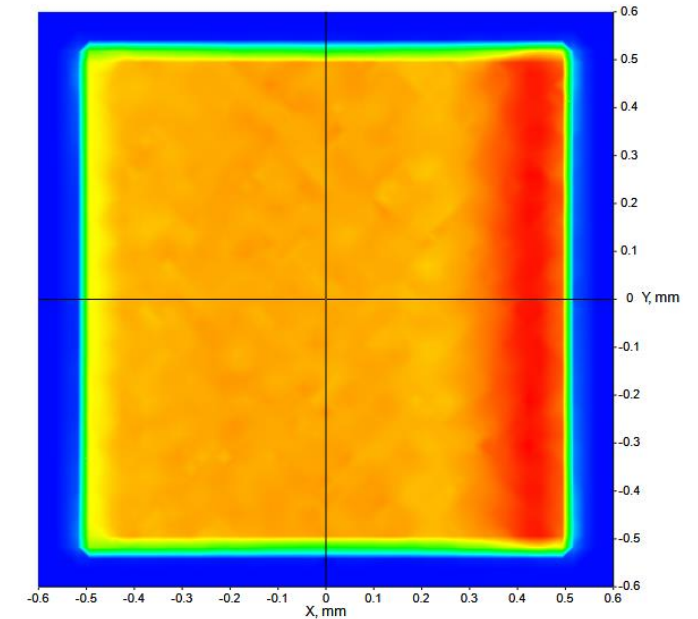
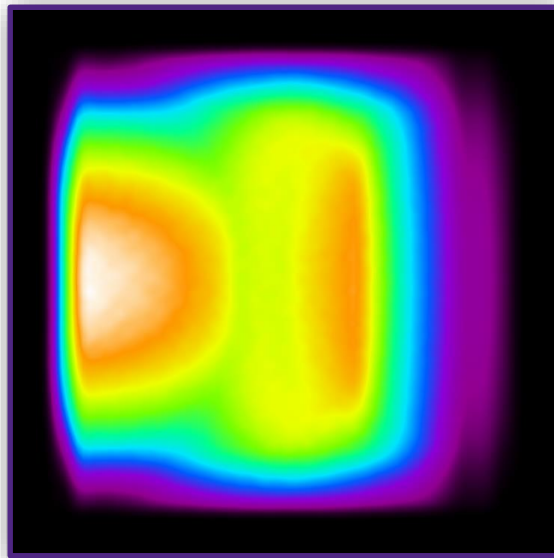
- In the optical properties with RSoft UDOP interface, the parameters calculated in RSoft are shown as variables, which can be defined as variables in optimization



Initial Results with RSoft Gratings

- Here we show the initial results from our previous system but using an initial grating design from RSoft
 - There are some differences in the eye box, and the image field is slightly less uniform horizontally
 - Also notice that the image intensity has dropped from 0.006 W/mm^2 to 0.004 W/mm^2 because of the actual rather than perfect grating efficiency

Eye box
illuminance
map

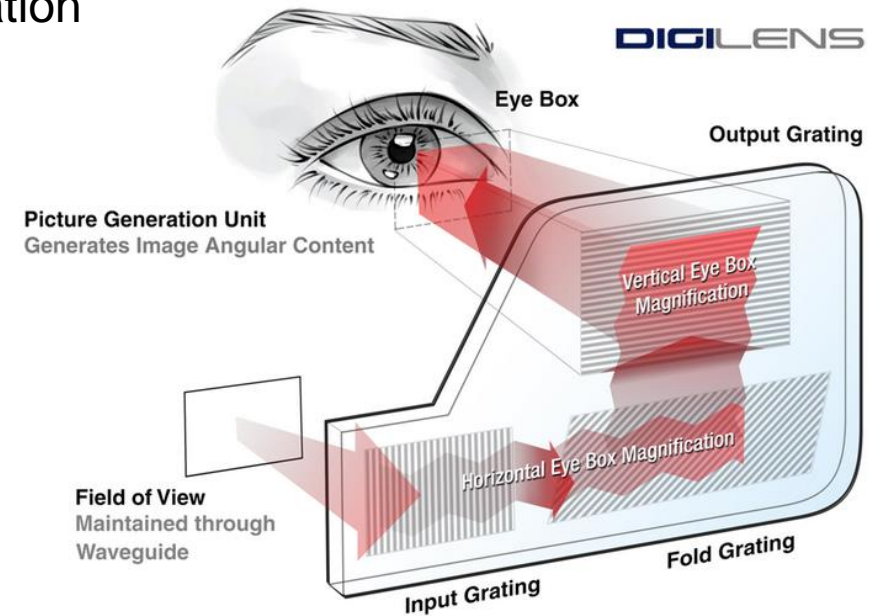


Expanding the Eye Box



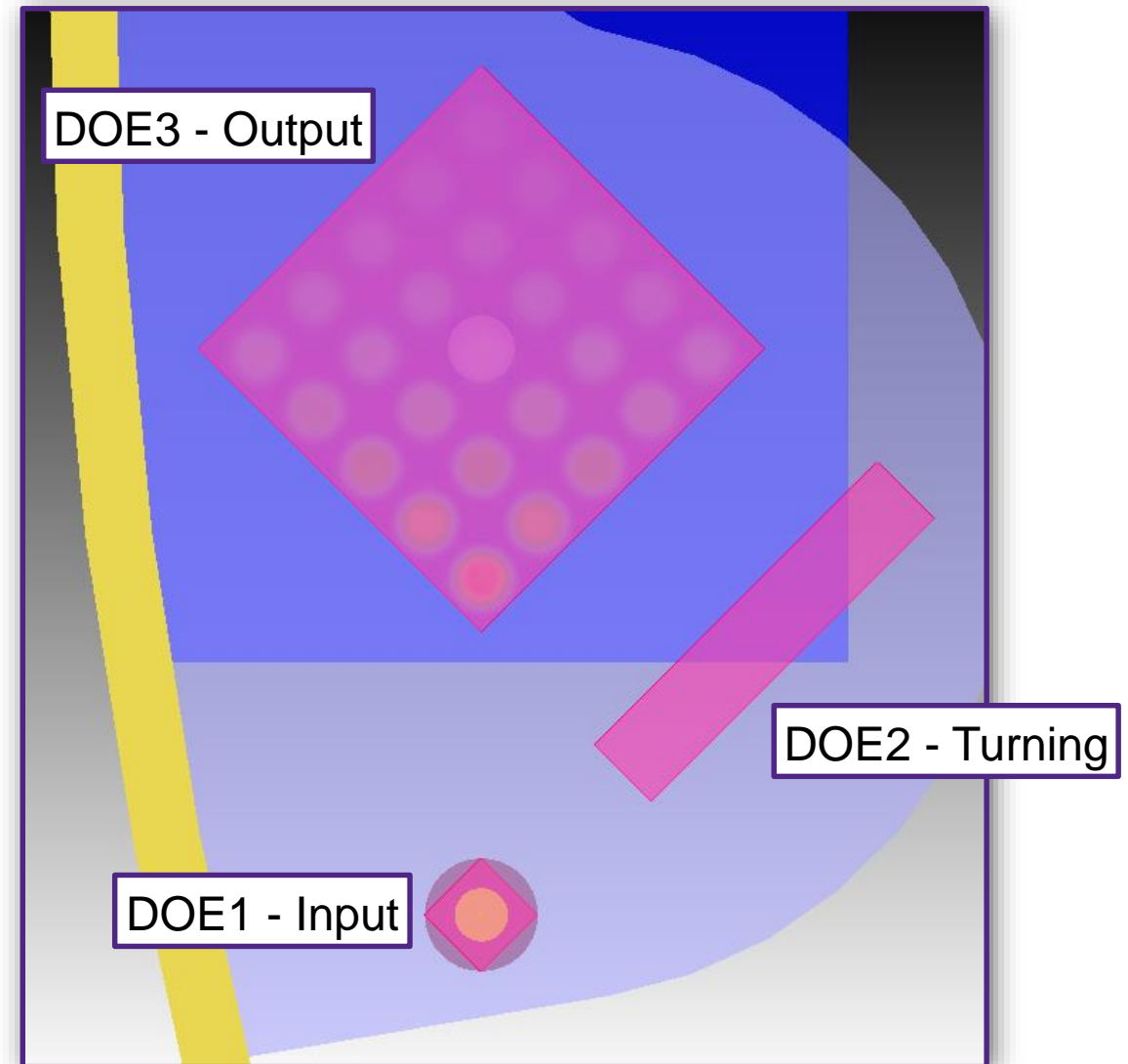
Optics Size

- As you may have noticed in the previous example, the imaging optics are quite large with respect to the device as a whole
 - This is undesirable because of the bulky size and excess weight
 - Driven by the field size and the need for the exit pupil to be a considerable distance in front of the lens
 - Without expanding the pupil, there is no way around this limitation
- We can use an extra grating to expand the eye box and therefor allow us to greatly reduce the size and weight of the imaging optics



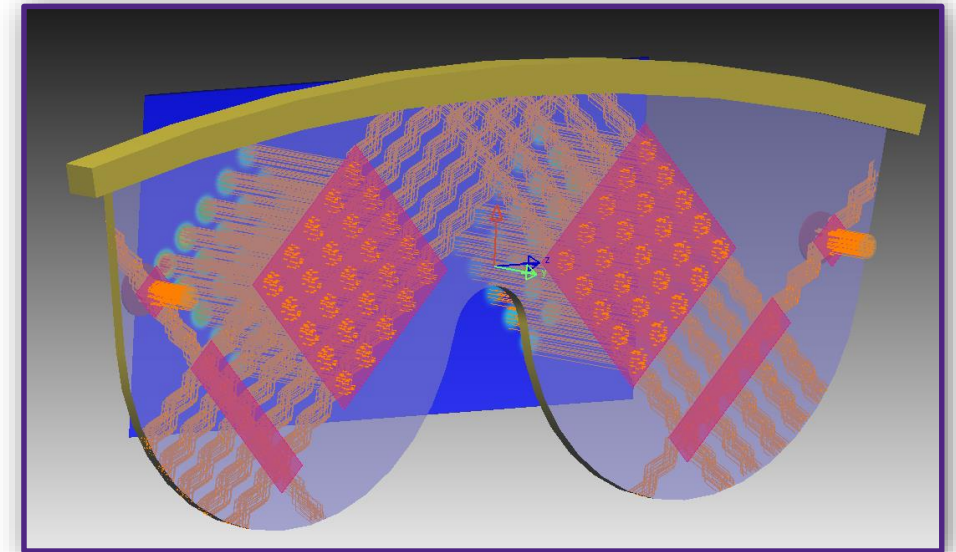
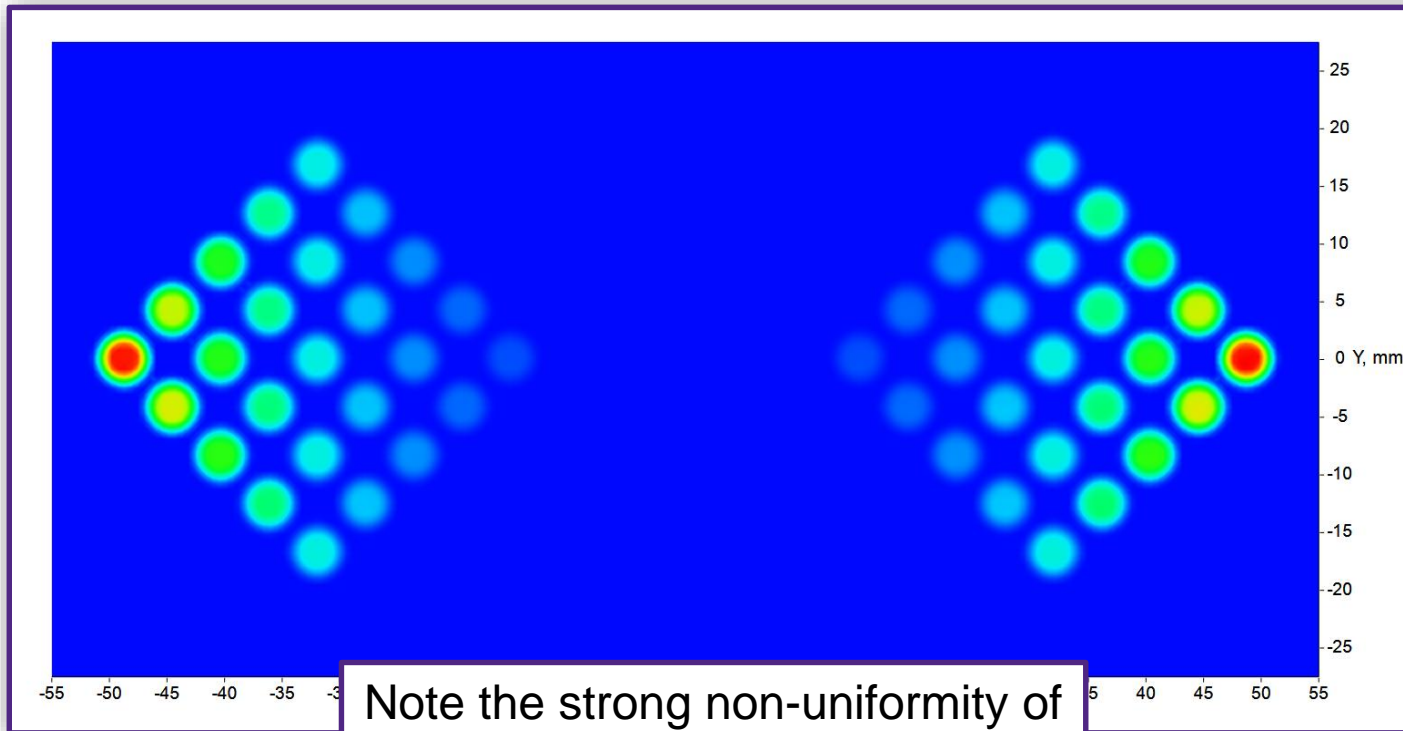
Beam Expander Example

- In this figure, DOE2 and DOE3 are shown as continuous regions
- You can see that the output from DOE3 is far from uniform
- To address this, we will sub-divide DOE2 and DOE3 into multiple zones and then use LightTools optimization to obtain a uniform output
- The beams emerging from the DOE3 would be diverging and would overlap each other at the eye position, creating a large and relatively uniform eye box



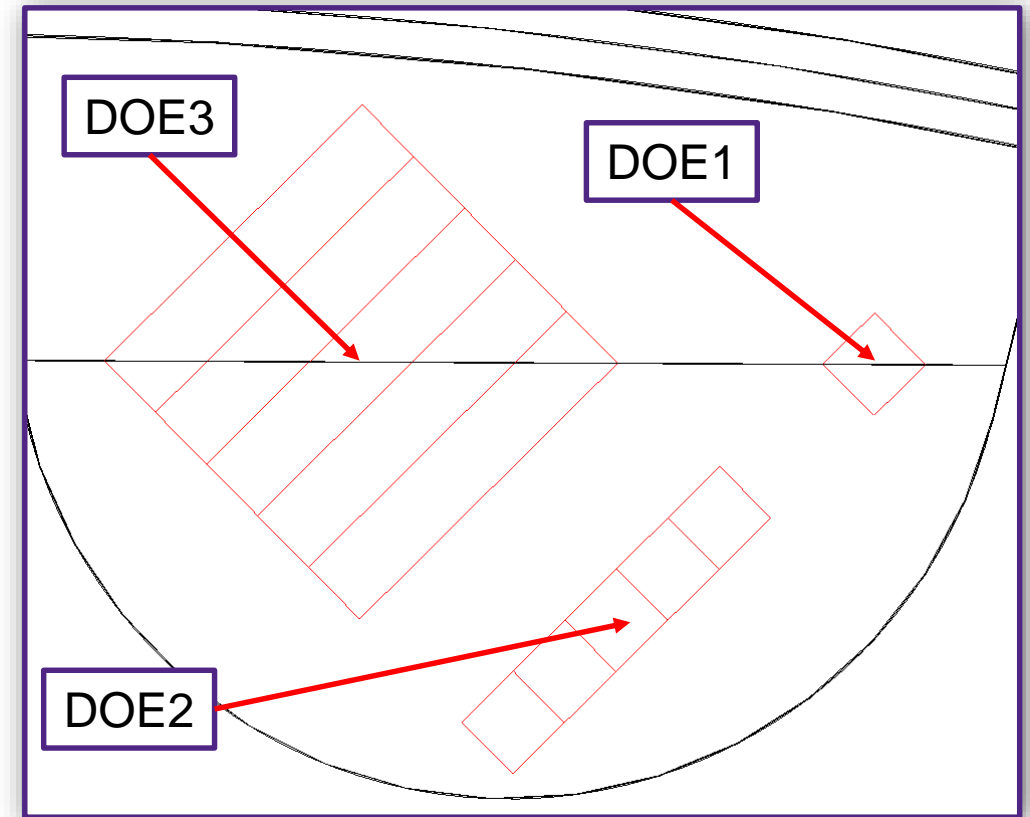
Ray Trace in LightTools

- Here we see the ray trace of the demonstration system
- DOEs 2 and 3 have not yet been sub-divided into zones



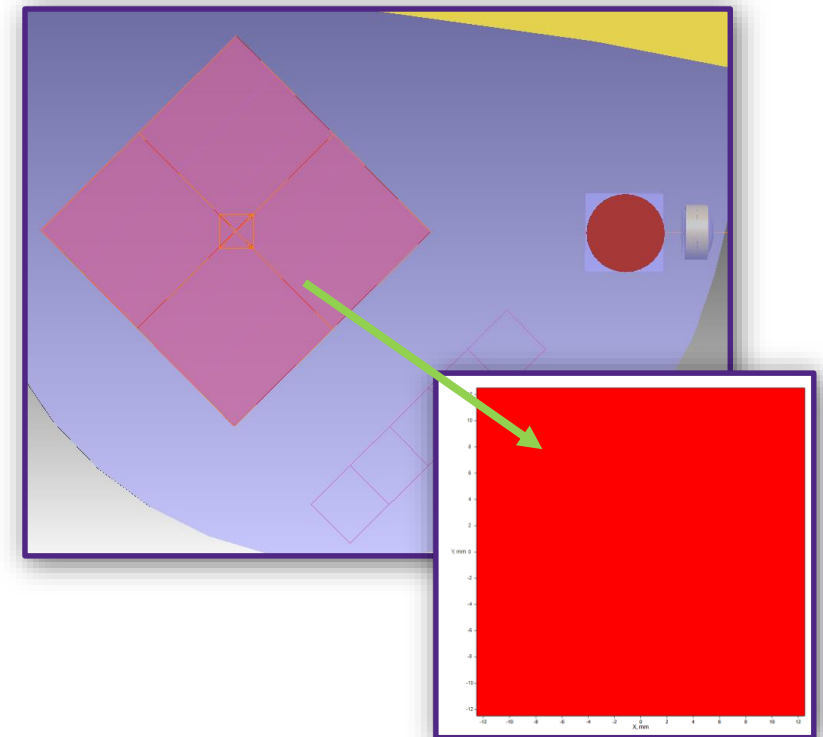
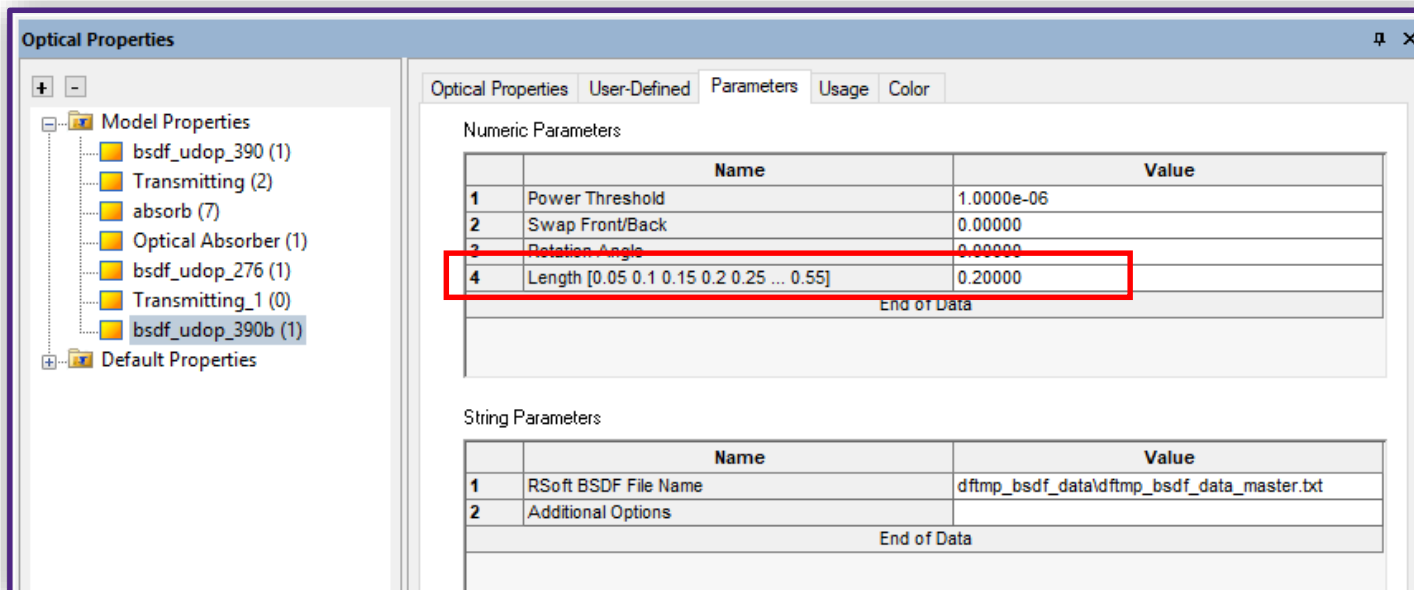
Sub-divide the Grating Zones

- DOE2 and DOE3 are now sub-divided into 5 zones each
- Each zone has its own optical property
- Each grating property can then be optimized separately
- To maximize the efficiency of the optimization the DOE2 was optimized first with the subzone furthest from DOE1 fixed for maximum extraction
- Then DOE3 was optimized independently in a similar manner



Optimizing Grating Rib Height

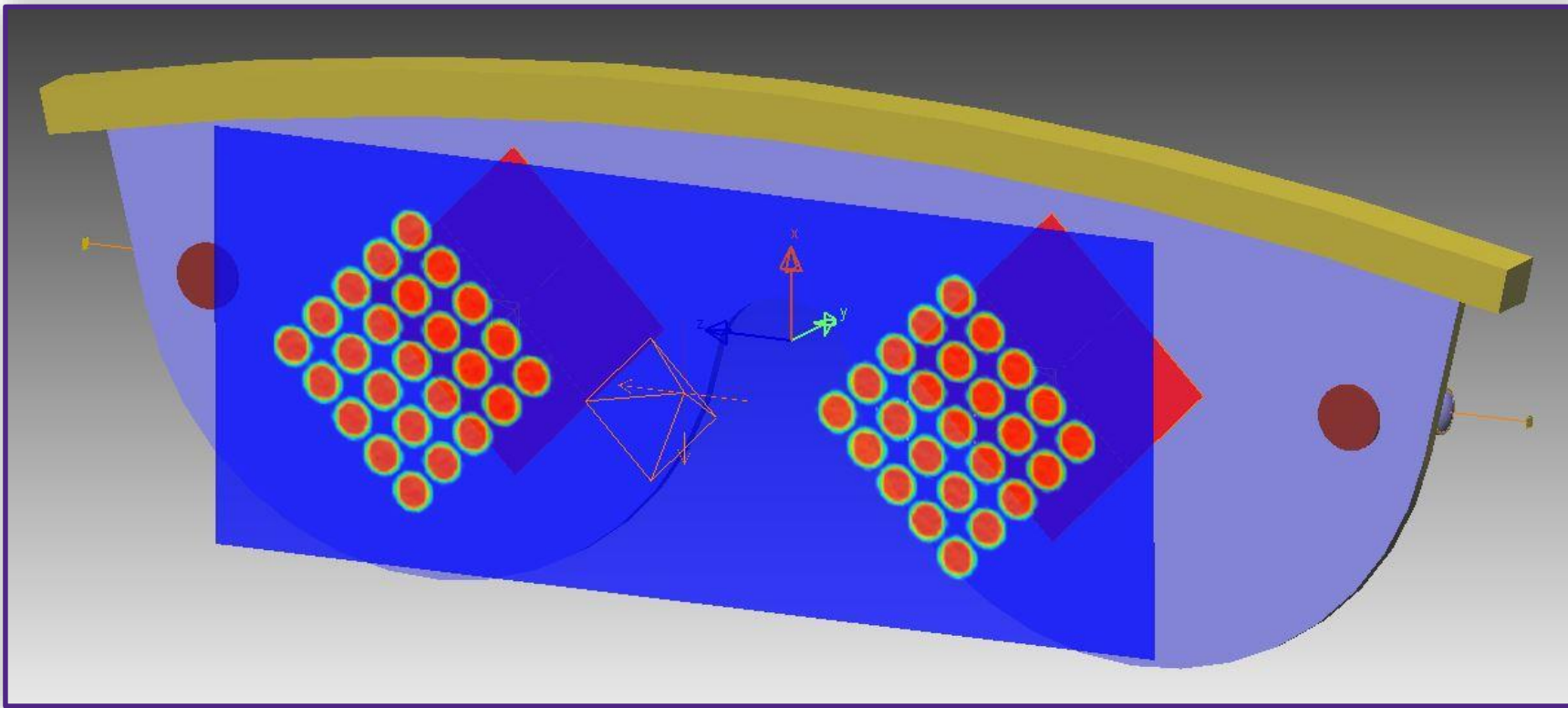
- The grating rib height was optimized in LightTools using the standard optimizer
 - Parameter appears in the UDOP UI and can be made an independent variable for each zone optical property
 - A 5 x 5 output grid was used to optimize for uniform output



Receiver grid used for optimization

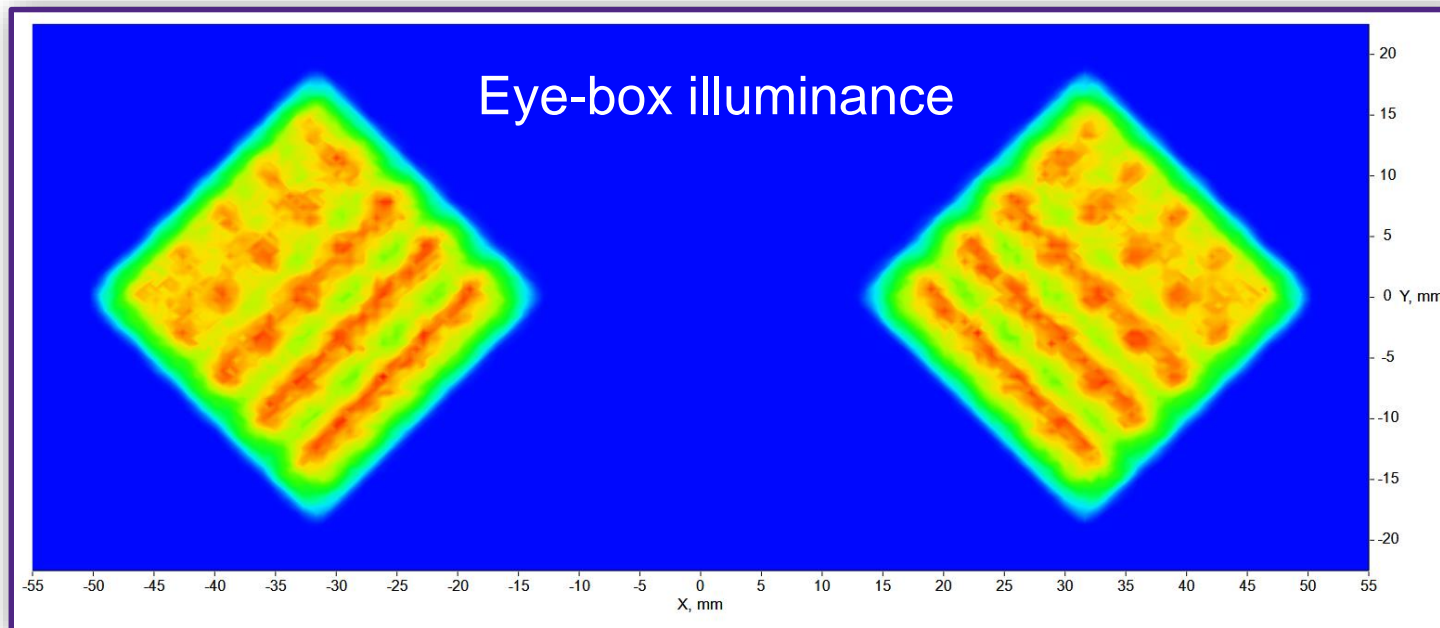
Optimized Result

- Here we see the emerging collimated spots at the eye box after optimization
 - Note the uniformity across the entire eye box

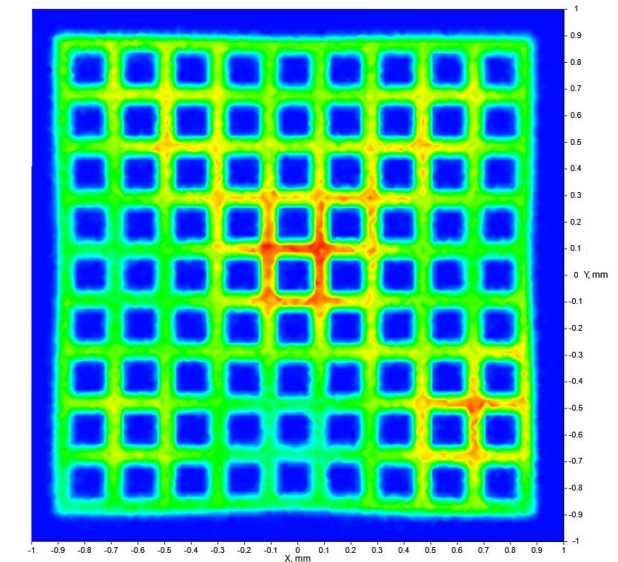


Eye Boxes with Non-Collimated Source

- We will now add an actual source and collimating optics and look at the eye box uniformity and image result
- Here we have put in a source with a field of view of ± 4 degrees
 - This blurs out the individual segments so that they overlap

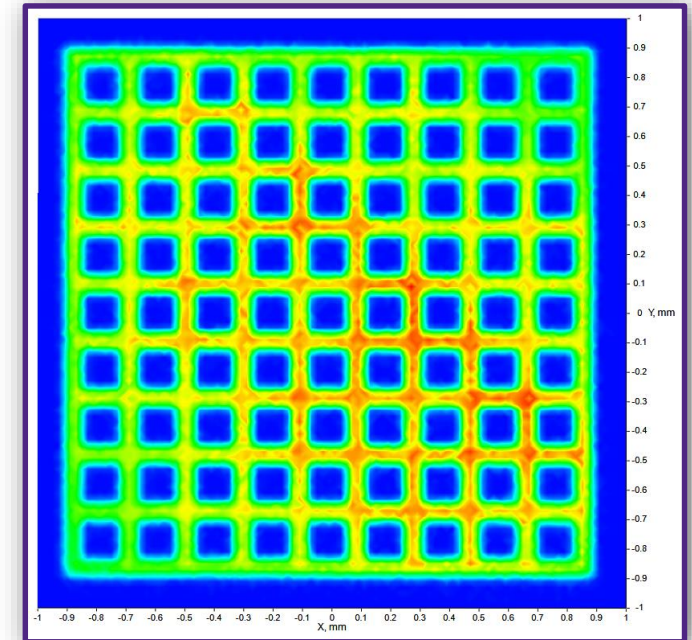
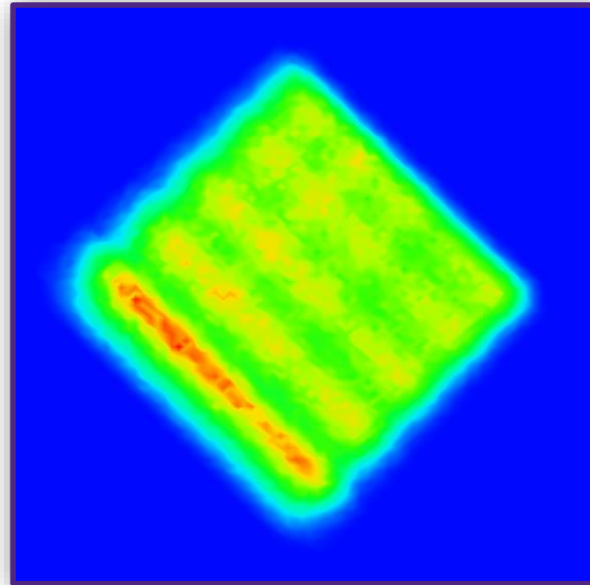
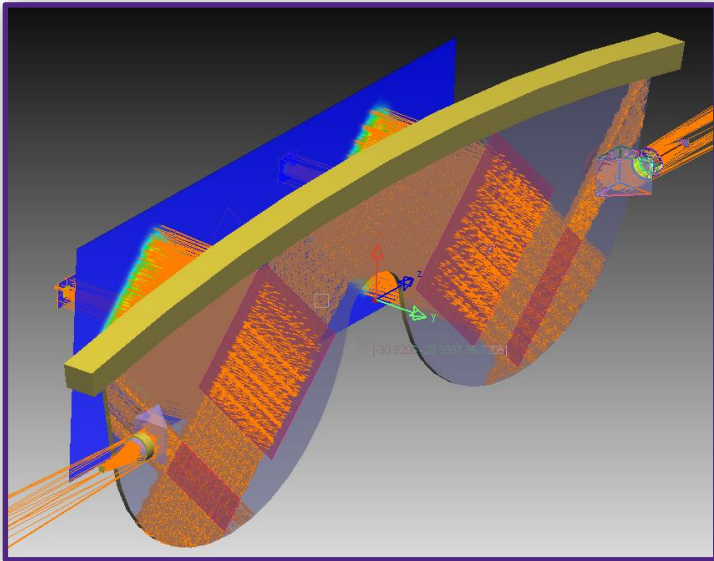


- 8° projected grid pattern
- Backward ray trace to improve ray trace efficiency
- Some non-uniformity and residual distortion can be seen



Thinning Down the Plate

- The original DOE spacing and plate thickness was chosen to give one ray bundle transmission per grating zone on the output grating
 - For a total of 25 exiting ray bundles
- By thinning the plate down from 1.667mm to 1mm and adjusting the DOE spacing and size parameters then re-optimizing we were able to improve eye-box uniformity as well as image quality



Conclusion



Conclusion

- Augmented Reality and Virtual Reality systems are complex devices requiring careful design of the imaging, illumination and photonics portions of the system
- All of these aspects need to work together
- Synopsys Optical Solutions Group along with Photonics Optical Solutions Group provides an integrated solution with CODE V, LightTools and RSoft Device Tools to meet this challenge not just in simulating performance but to optimize to the best solution

Thank You

