Polarization Controlled Bifocal Lens System

Based on Nanofin Metalens

Part of the Meta Optics Solution Guide

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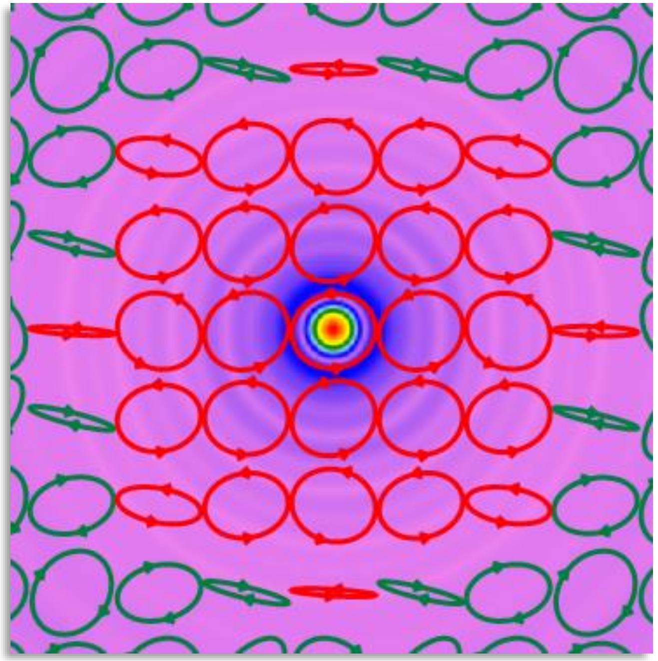
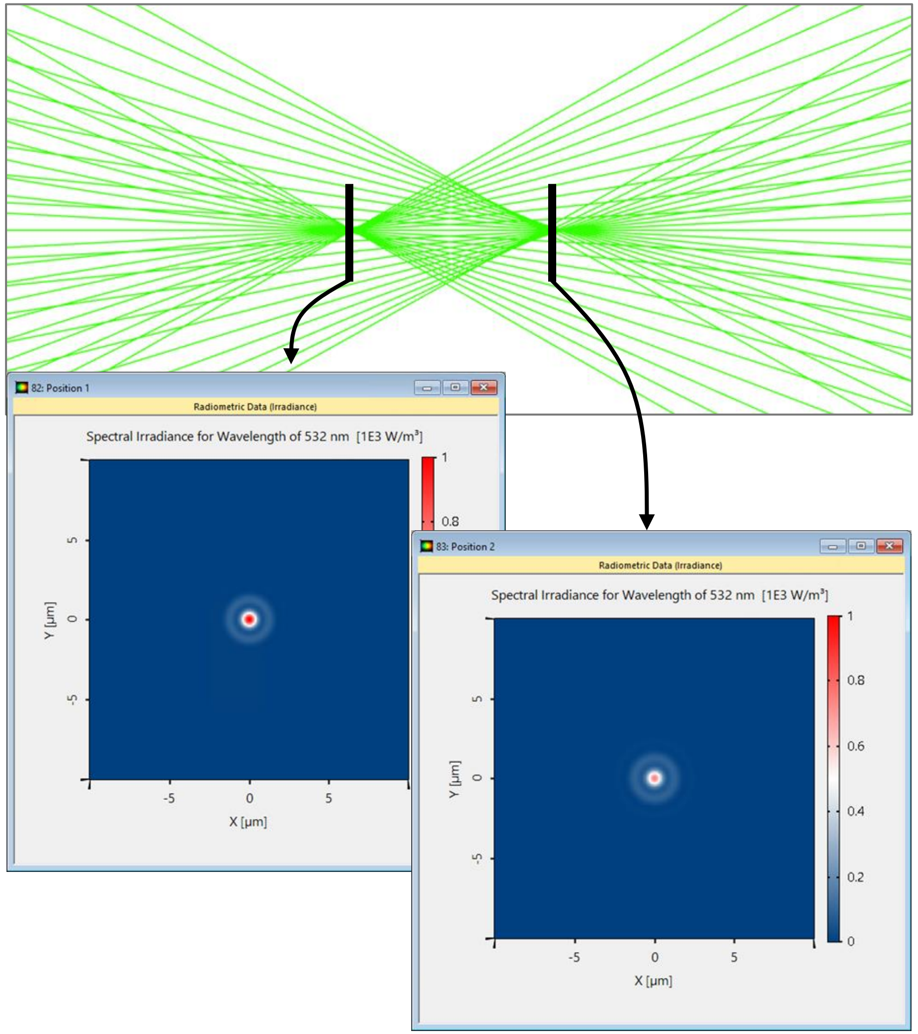


Executive Summary

Polarization-controlled bifocal system using a nanofin metalens with two opposite phase modes.

Key Achievements

- The nanofin metalens provides two opposite phase responses (design and conjugated), selected by incident polarization.
- Depending on input polarization either the focal length of the asphere is elongated or shortened, producing two distinct foci.



Application Scenario

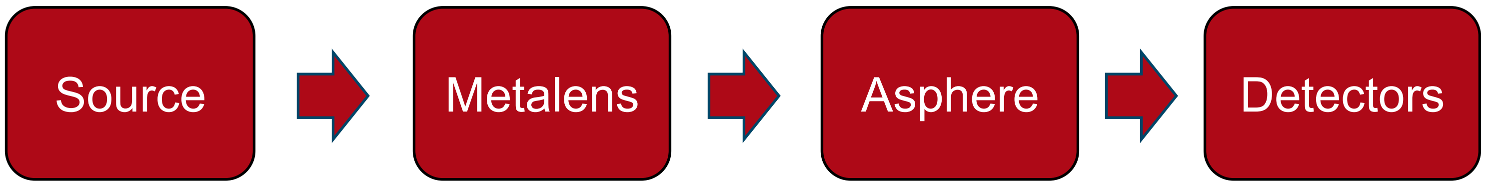
The Scenario A polarization-controlled bifocal system was designed using a nanofin-based metalens placed in front of an aspheric lens. The metalens applies a weak spherical phase whose sign depends on the incident polarization, thereby shifting the effective focal length of the combined system.

Parameters Aspherical Lens

Parameter	Value
Radius of Curvature	1.38 mm
Conical Constant	-0.56
A_4	-0.00032
A_6	$3.49E-06$
A_8	$4.76E-8$

Physical Lab Setup

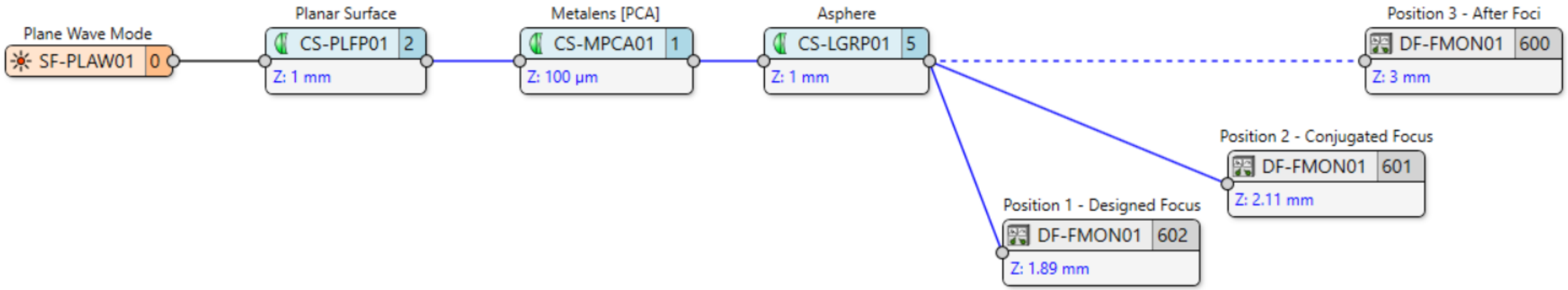
Component	Specification
Source	Plane wave, 532 nm, variable polarization
Nanofin metalens	Diameter 2 mm, f = 60 mm, nanofin meta-atoms
Nanofin meta-atom	Height 465 nm, period 400 nm × 400 nm
Aspherical lens	f = 2 mm, N-BK7, aspheric/planar
Detector 1	Irradiance at focal spot 1 (design mode)
Detector 2	Irradiance at focal spot 2 (conjugate mode)
Detector 3	EM-field after foci



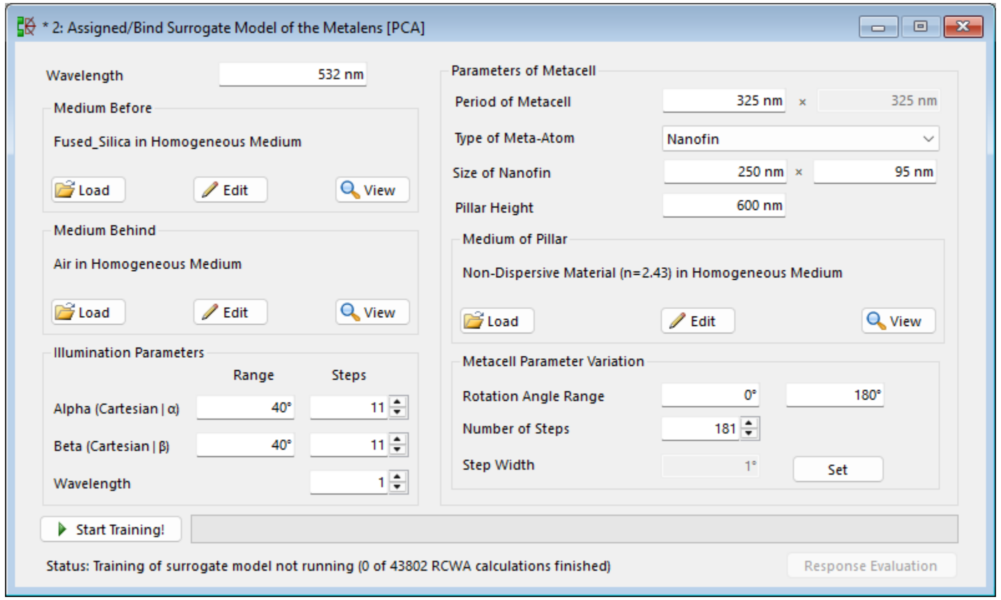
From Real Asset to Digital Twin

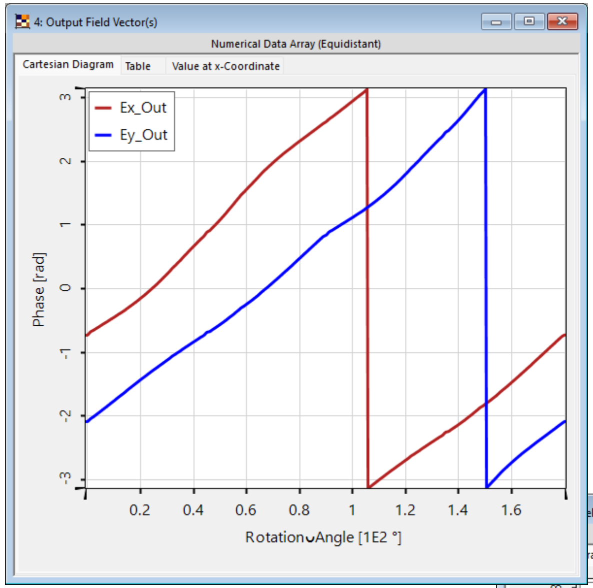
Digital Twin Mapping

Real Asset	Digital Twin	Description
Laser source	SF-PLAW01	Plane wave, 532 nm, variable polarization
Nanofin metalens	CS-MPCA01	Metalens [PCA], nanofin model, design & conjugate mode
Substrate	CS-PLFP01	Planar surface, fused silica
Aspherical lens	CS-LGRP01	Aspherical lens, f = 2 mm, N-BK7
Detector 1	DF-FMON01	Irradiance & polarization ellipses
Detector 2	DF-FMON01	Irradiance & polarization ellipses
Detector 3	DF-FMON01	EM field (visualization purpose)



Nanofin Surrogate Model





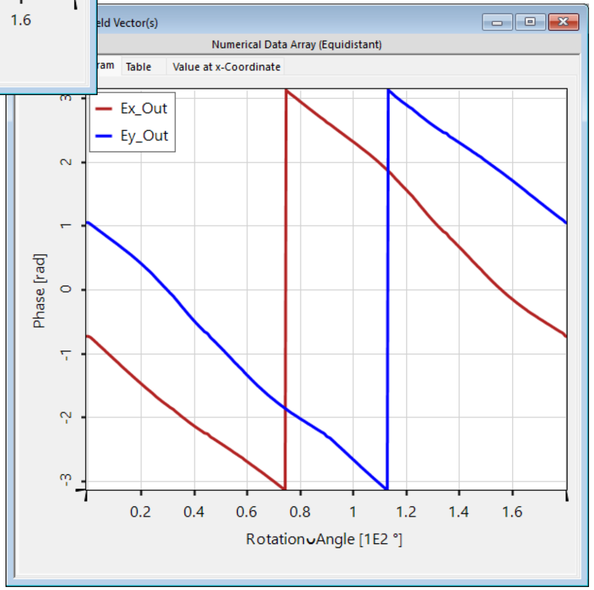
Phase component (design mode)

Phase Response vs. Polarization

The surrogate model of the nanofin metastructure was trained to predict the phase response for incident circular polarizations.

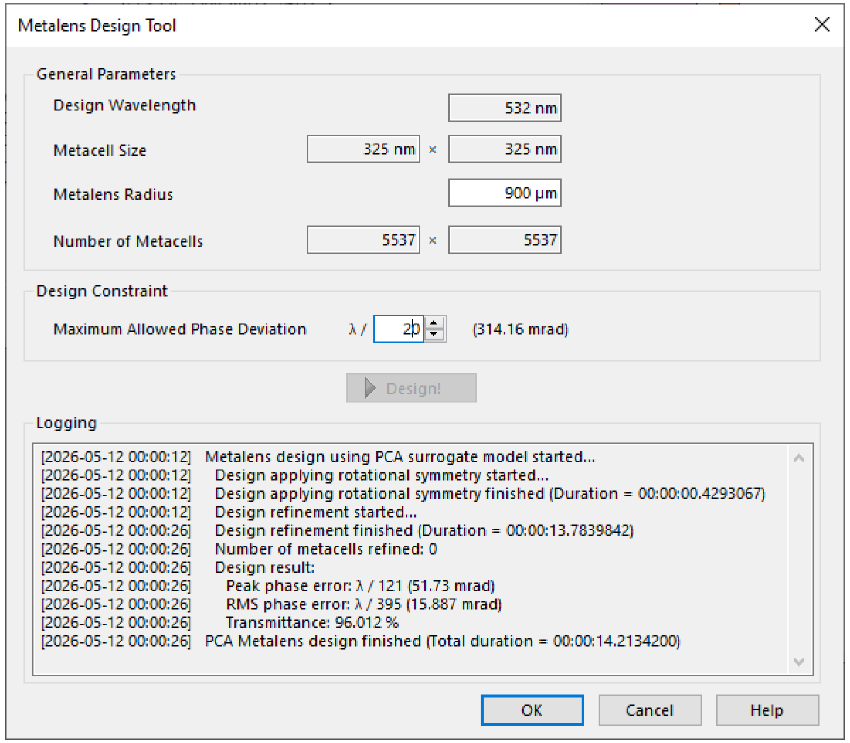
Design mode (LCP): The phase response is a increasing linear ramp.

Conjugated mode (RCP): The phase response is a decreasing linear ramp.

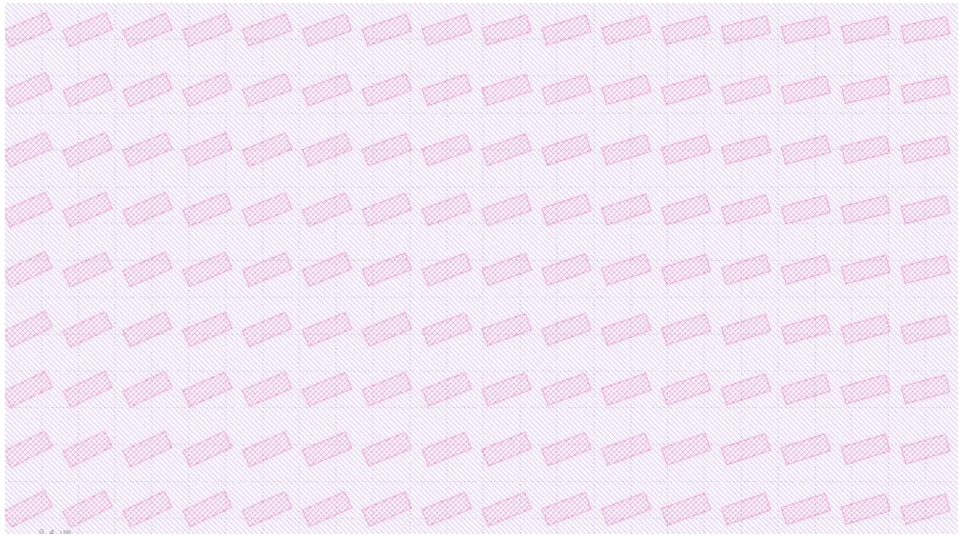


Phase component (conjugated mode)

Metalens Design



Detail view of designed metalens



Design Results

Parameter	Value
Peak phase error	$\lambda/121$
RMS phase error	$\lambda/395$

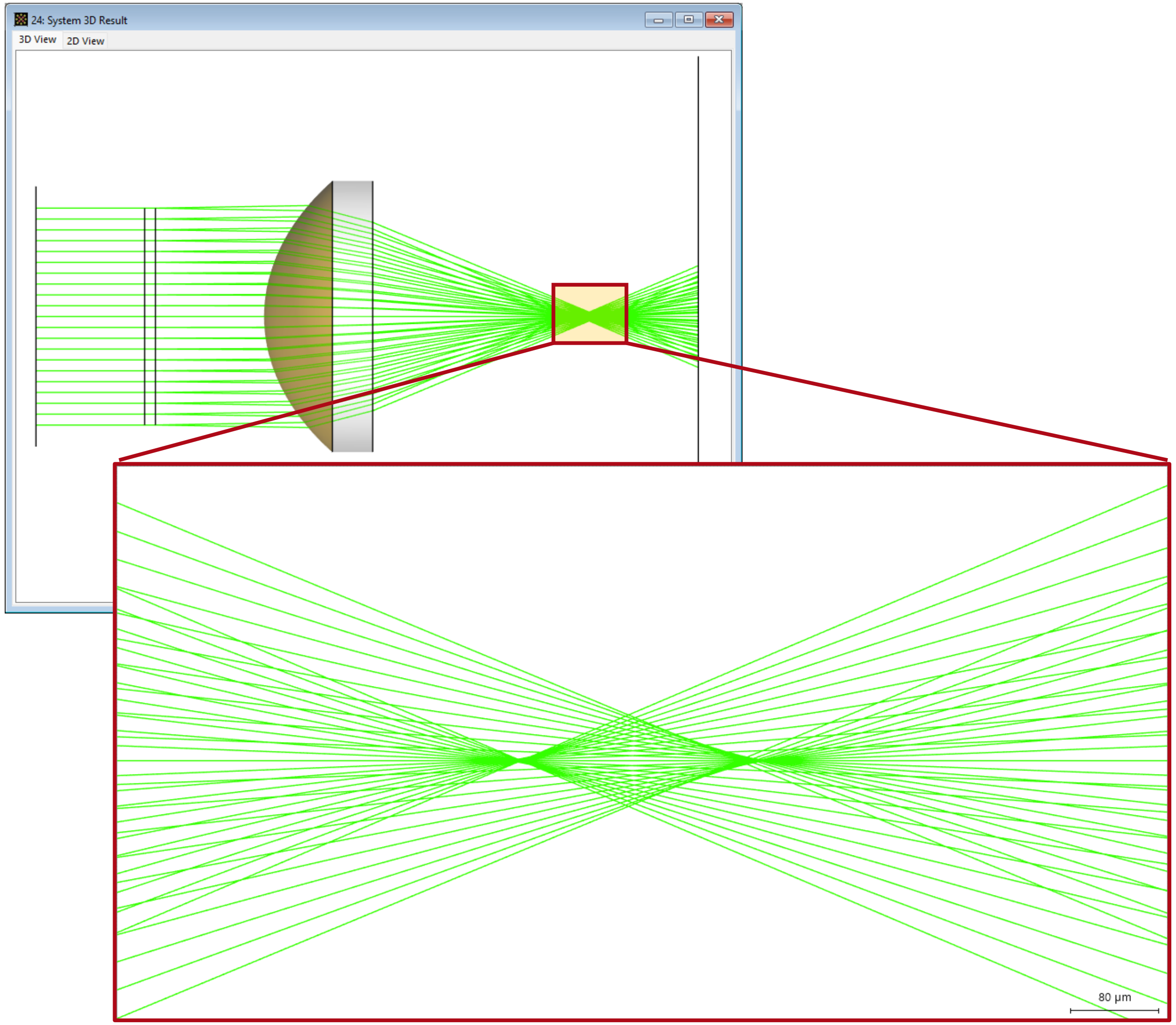
Hardware & Performance

- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Design time: 14 s for > 30 million meta-atoms

Result – System Visualization

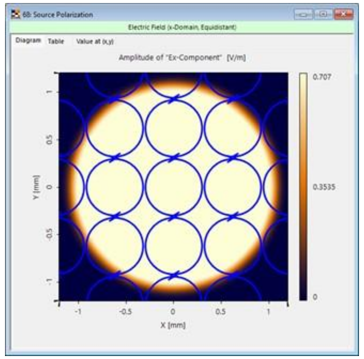
Physics Insight

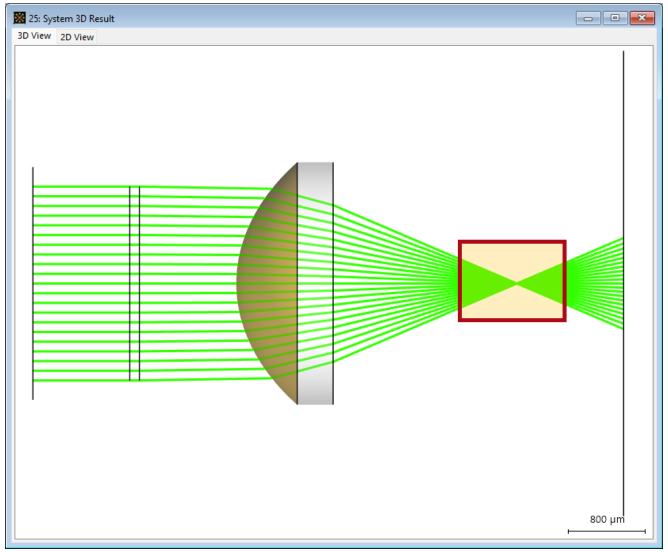
- The nanofin metalens encodes two opposite phase responses ($+\phi_0$ and $-\phi_0$) as orthogonal eigenmodes.
- Circular polarization selects a single eigenmode; linear polarization excites both.
- A positive spherical phase shortens the focal length; a negative phase lengthens it.
- With both modes present, two wavefront curvatures coexist, producing two distinct foci.
- The out-of-focus contribution of the orthogonal mode will generate a halo of opposite polarization around each focus.

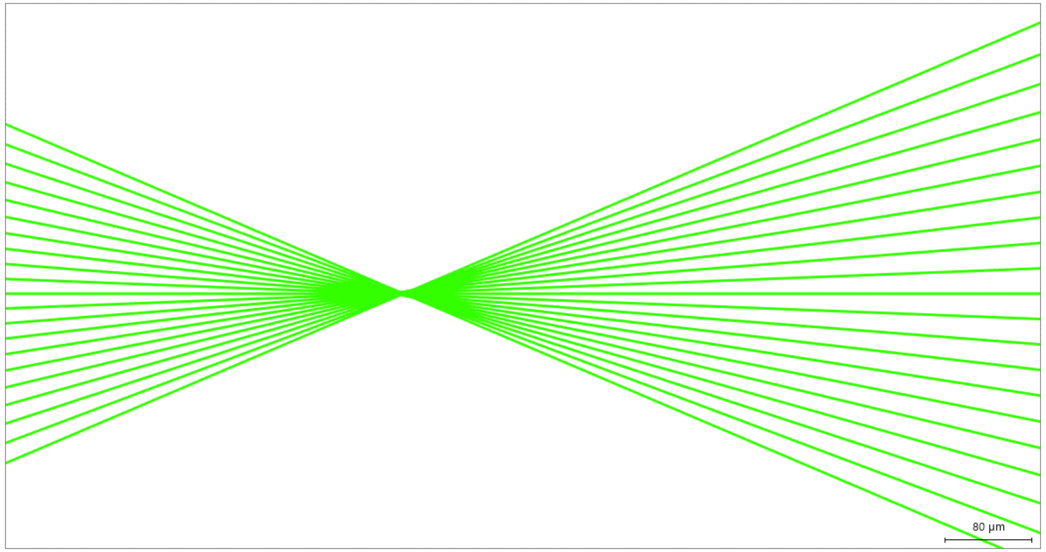


System Visualization of Design and Conjugated Mode

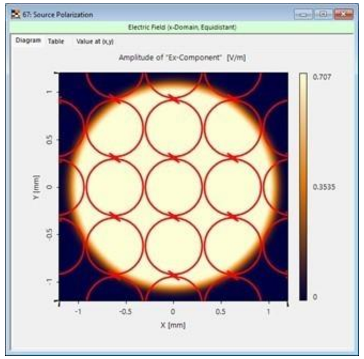
Design mode

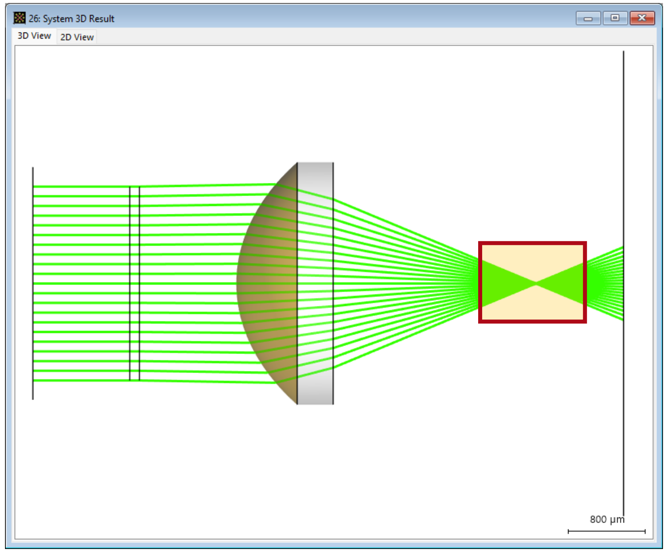


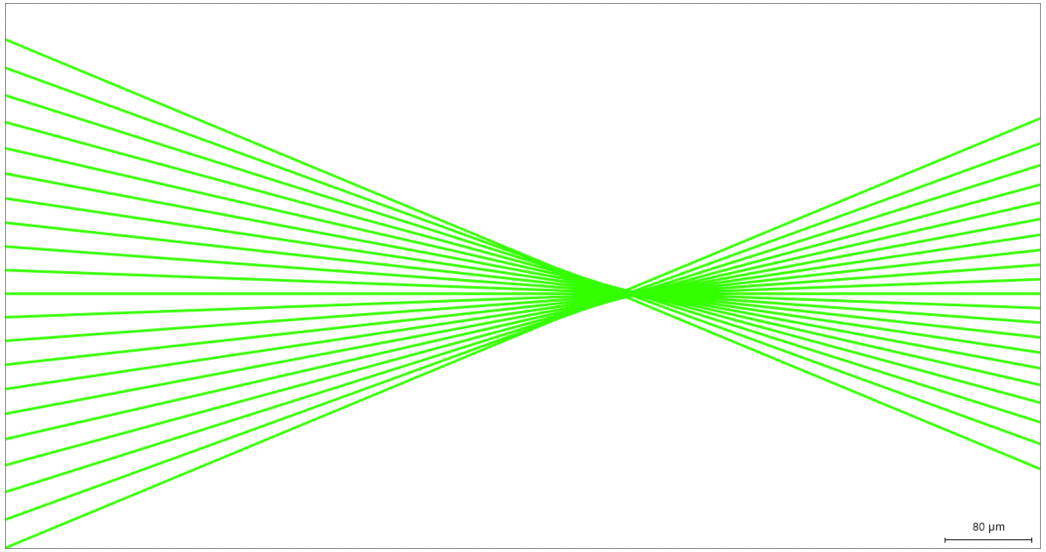




Conjugated mode

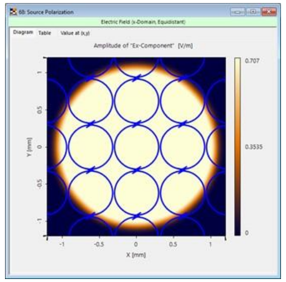


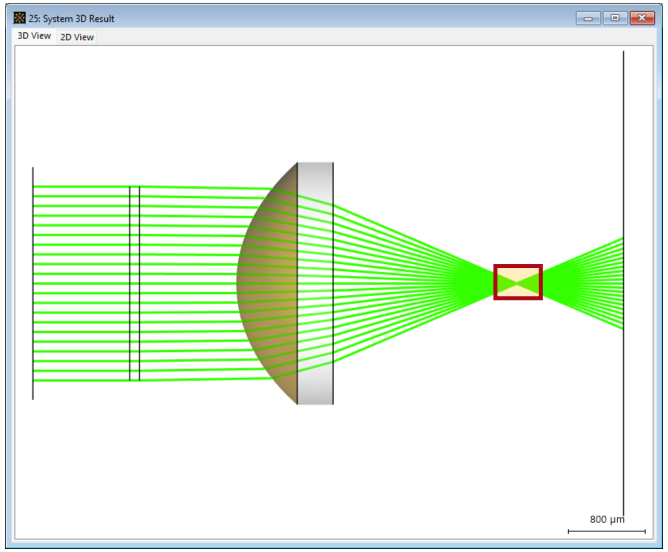


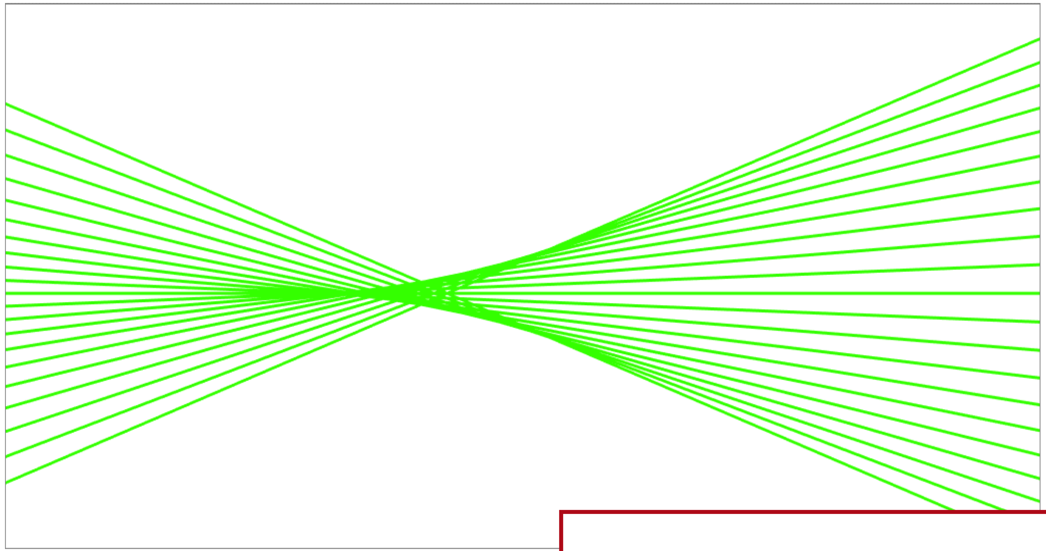


System Visualization of Design and Conjugated Mode (Zoom)

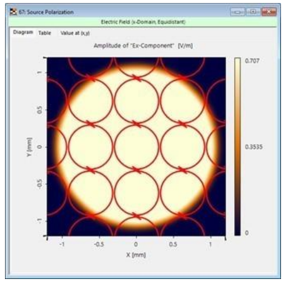
Design mode

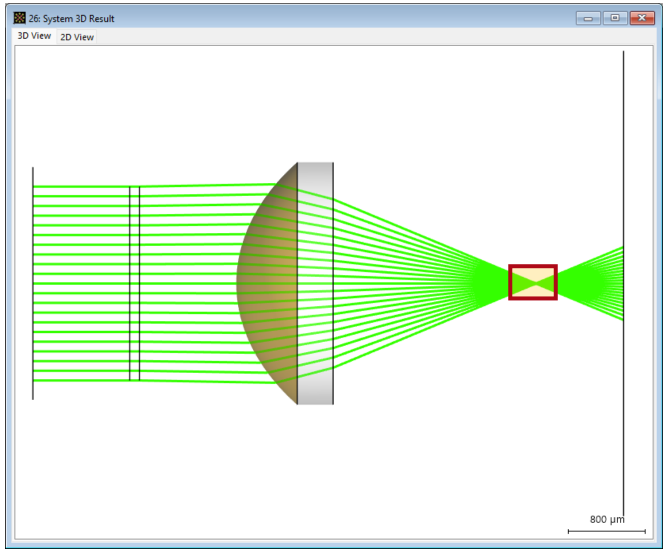


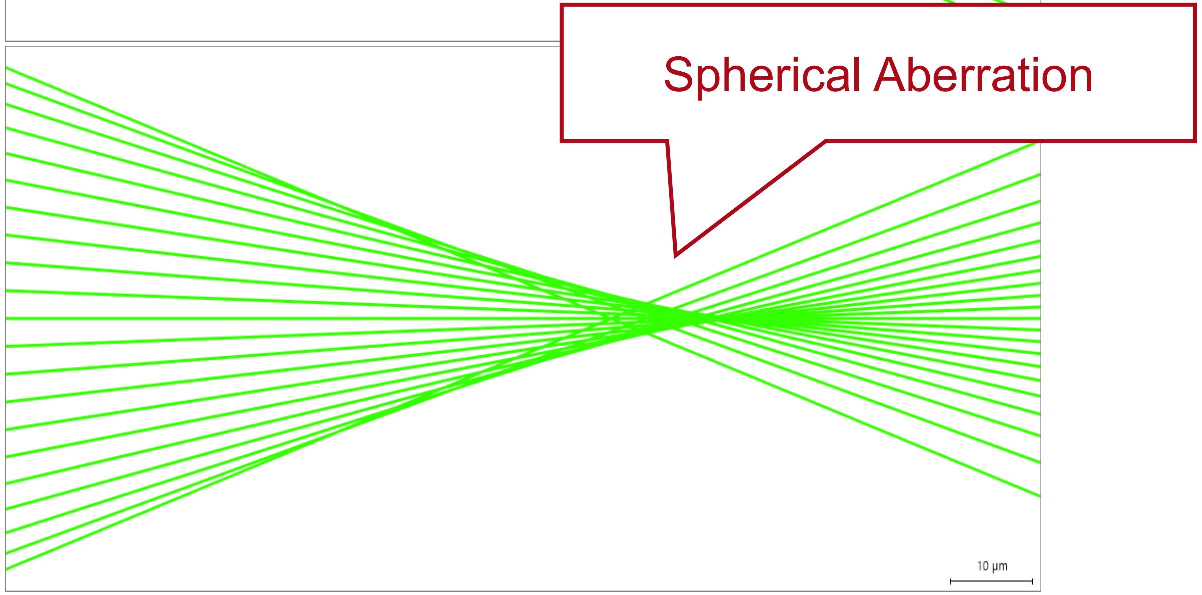




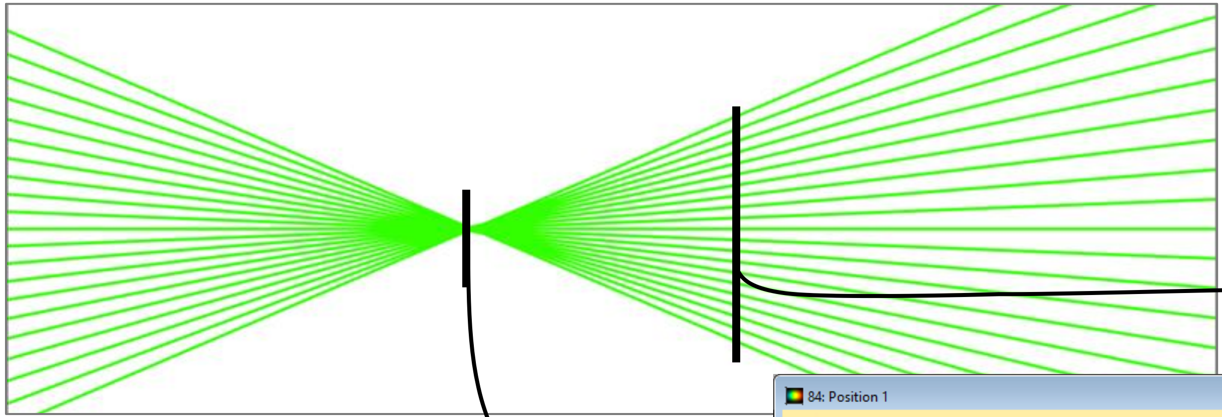
Conjugated mode







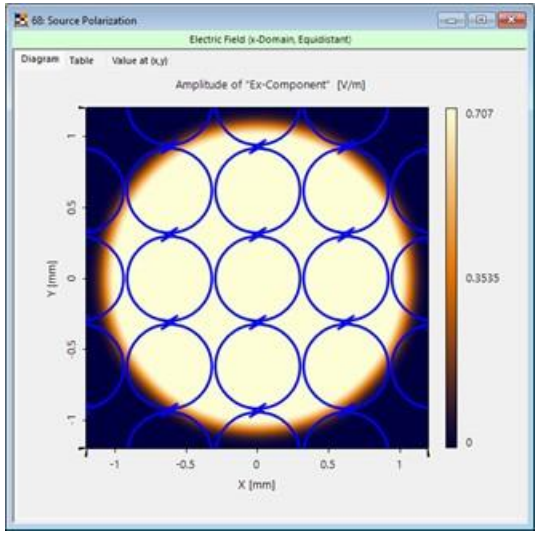
Result – Focal Spot for Right Circular Polarization

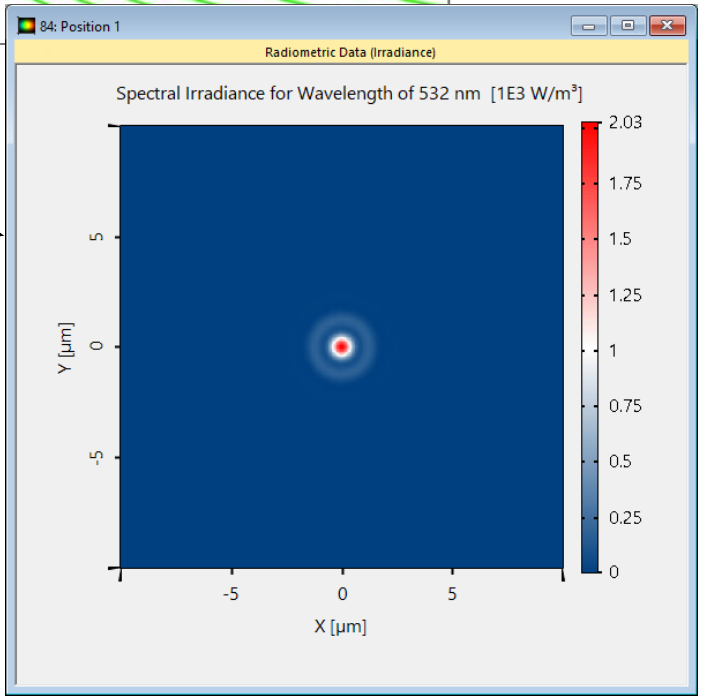


Hardware & Performance

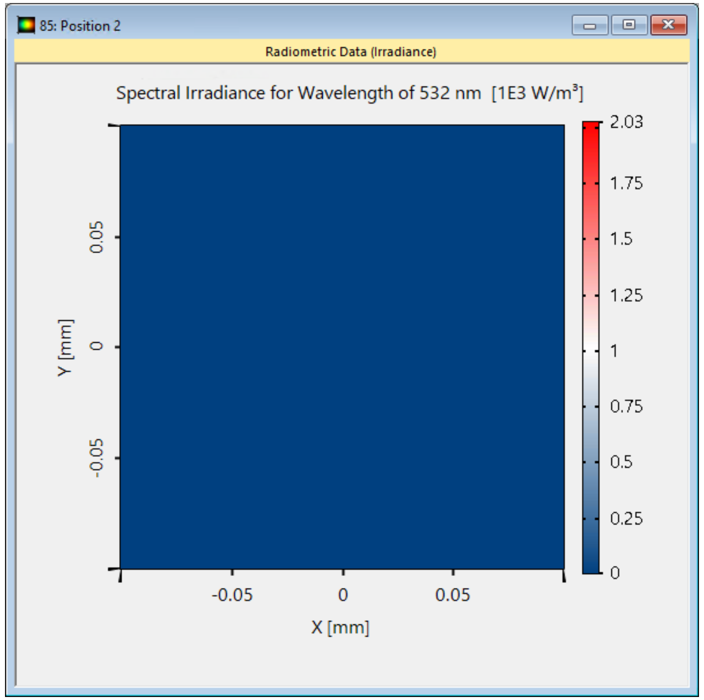
- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Simulation time: 13 s

Right Circular Polarization



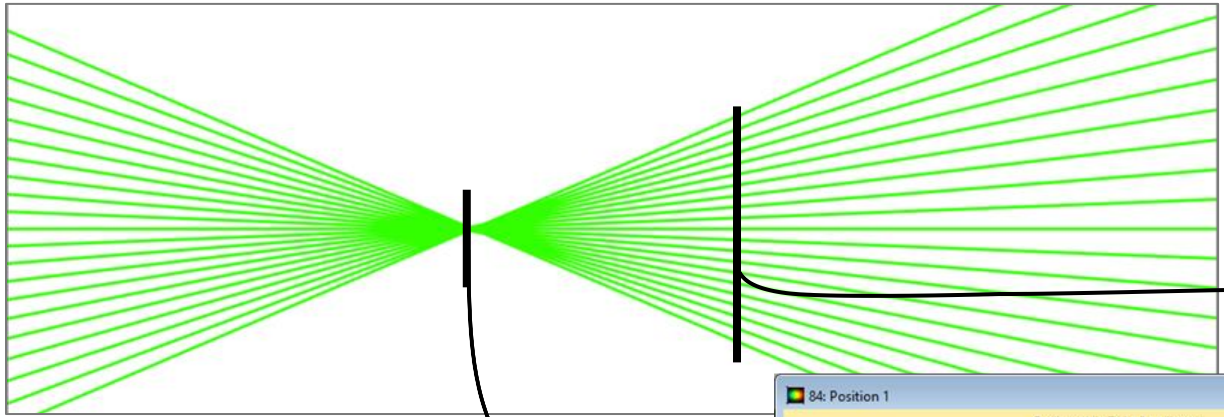


Irradiance of Detector 1



Irradiance of Detector 2

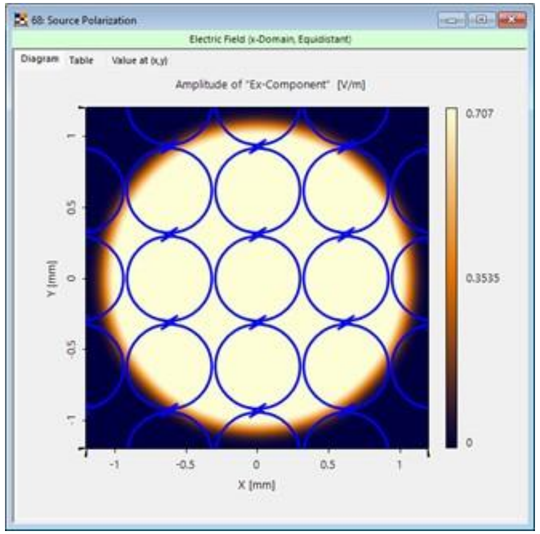
Result – Focal Spot for Right Circular Polarization

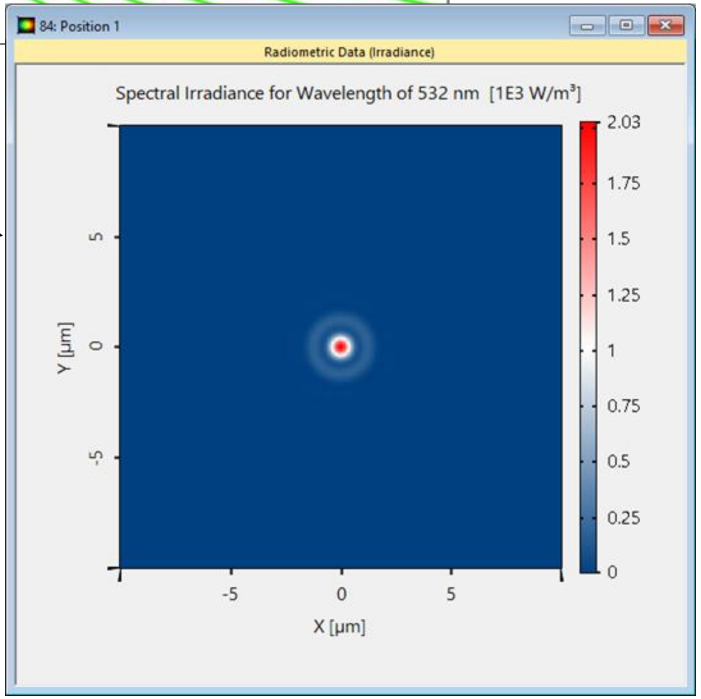


Hardware & Performance

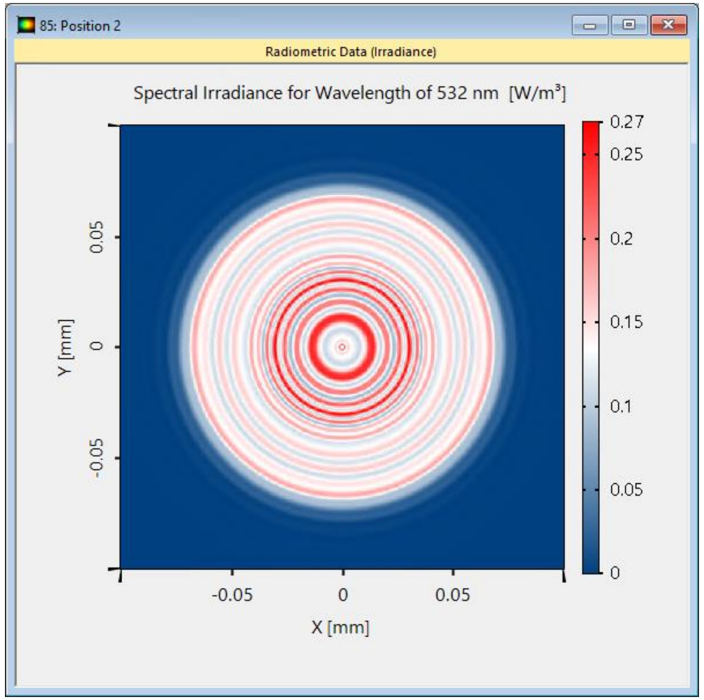
- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Simulation time: 13 s

Right Circular Polarization



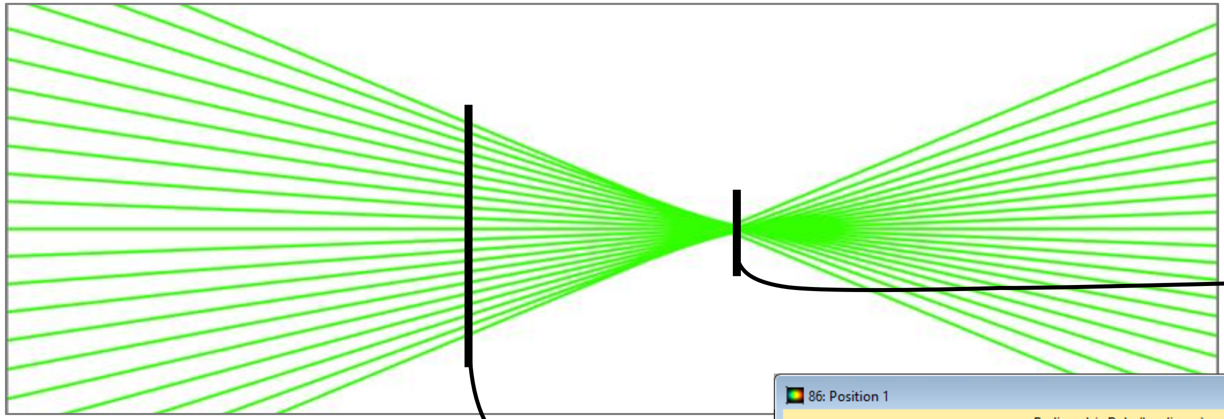


Irradiance of Detector 1



Irradiance of Detector 2

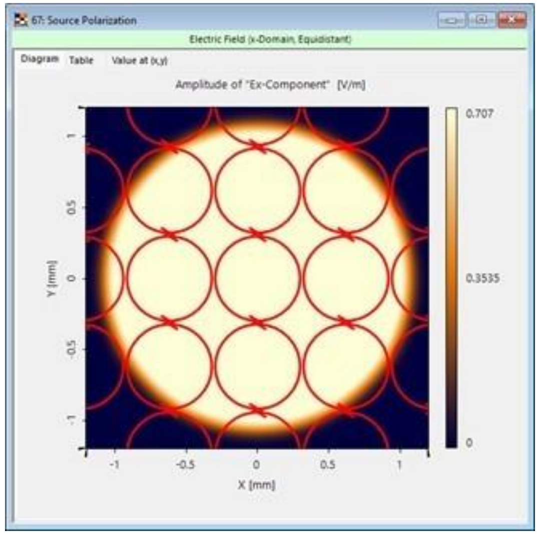
Result – Focal Spot for Left Circular Polarization

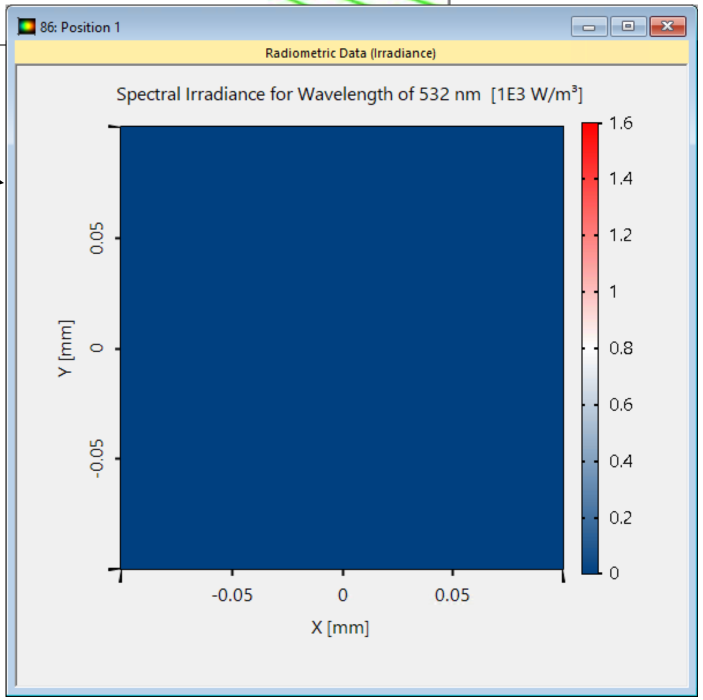


Hardware & Performance

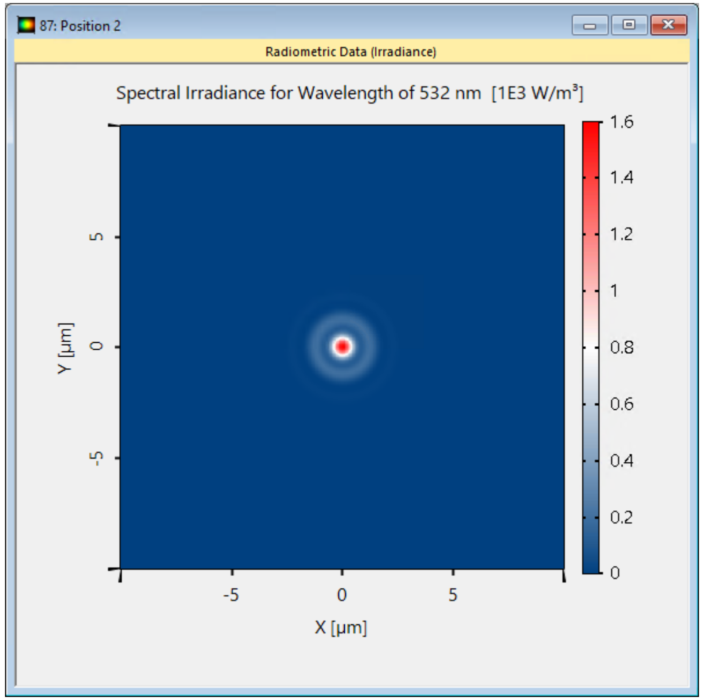
- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Simulation time: 19 s

Left Circular Polarization



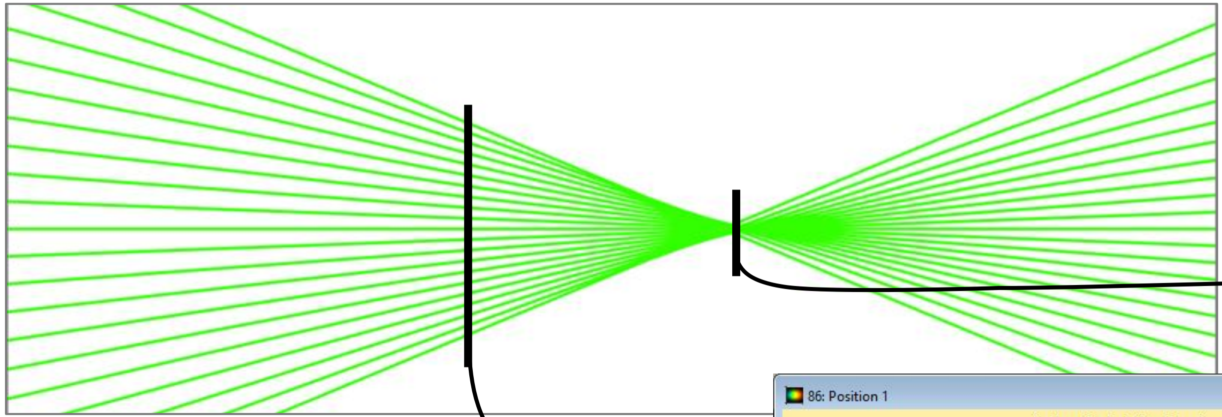


Irradiance of Detector 1



Irradiance of Detector 2

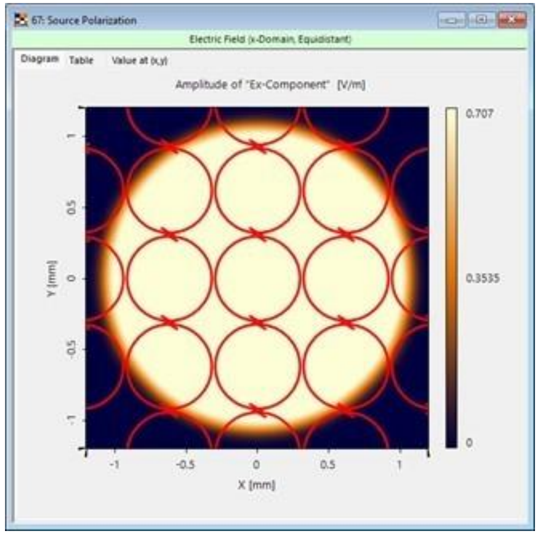
Result – Focal Spot for Left Circular Polarization

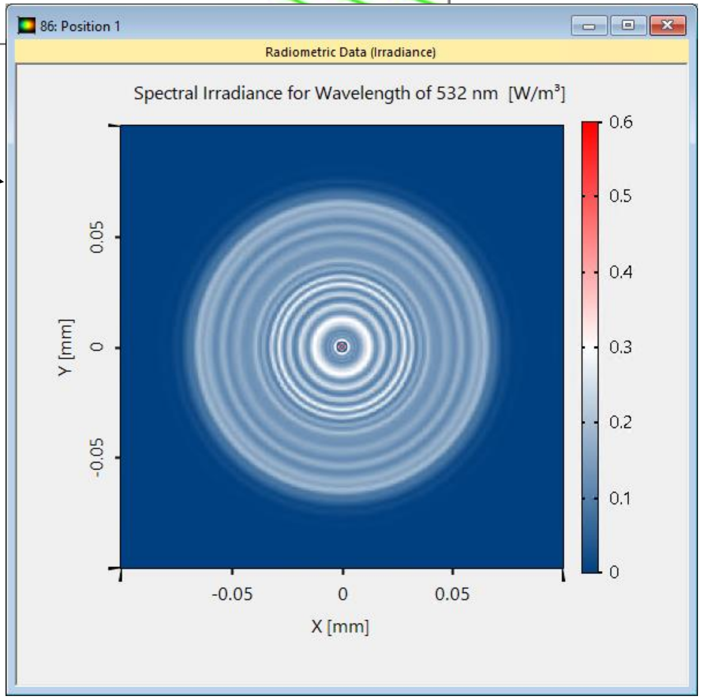


Hardware & Performance

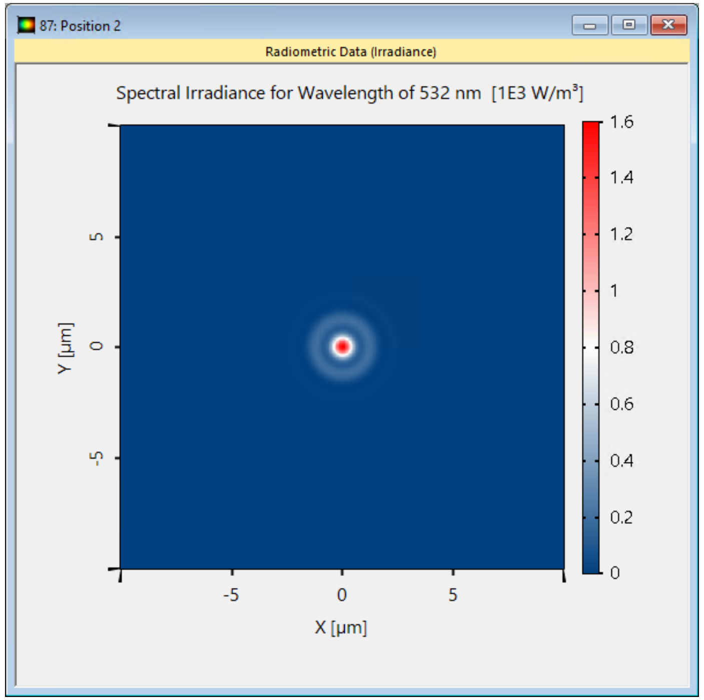
- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Simulation time: 19 s

Left Circular Polarization



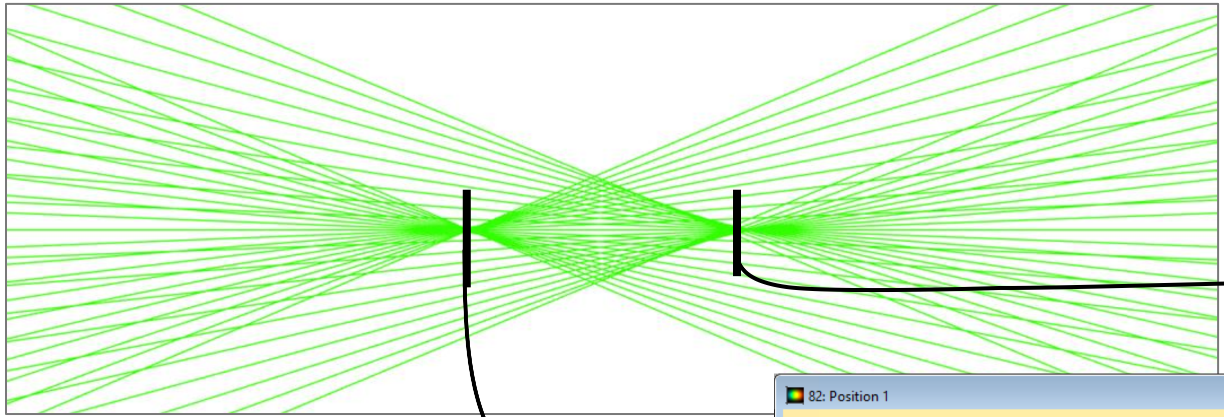


Irradiance of Detector 1



Irradiance of Detector 2

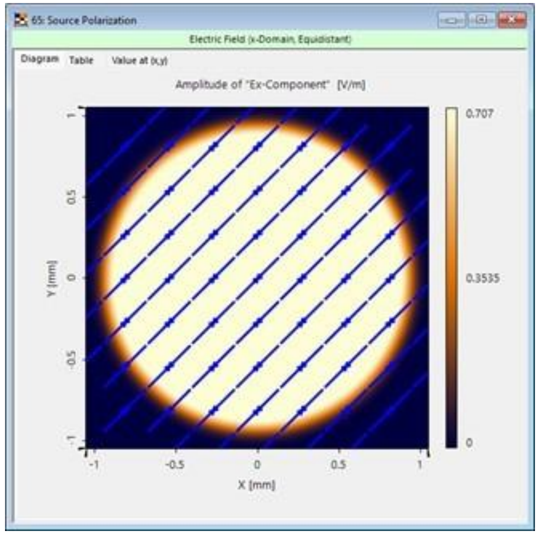
Result – Focal Spots for Linear Polarization

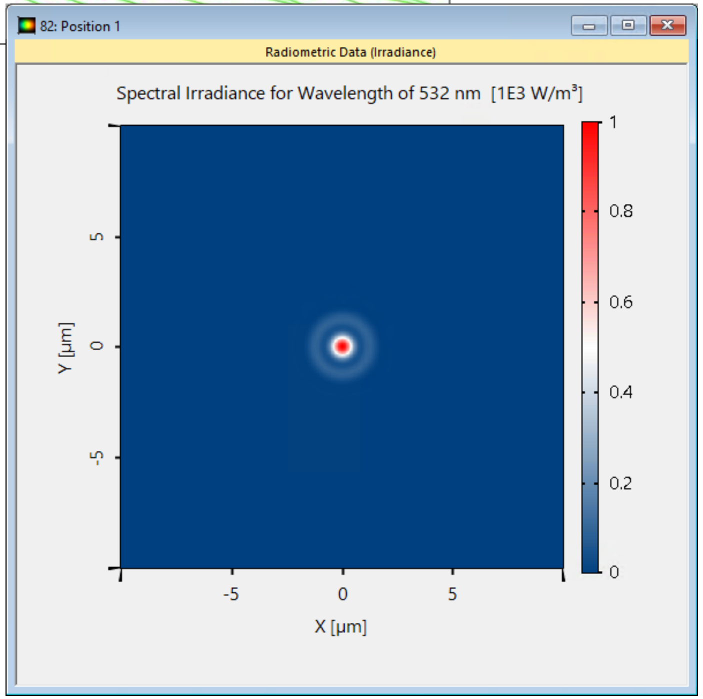


Hardware & Performance

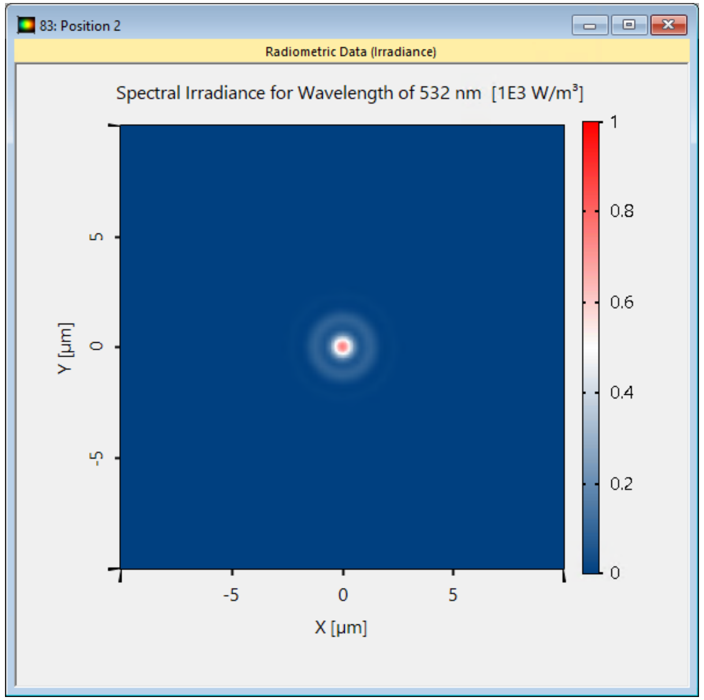
- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Simulation time: 33 s

Linear Polarization





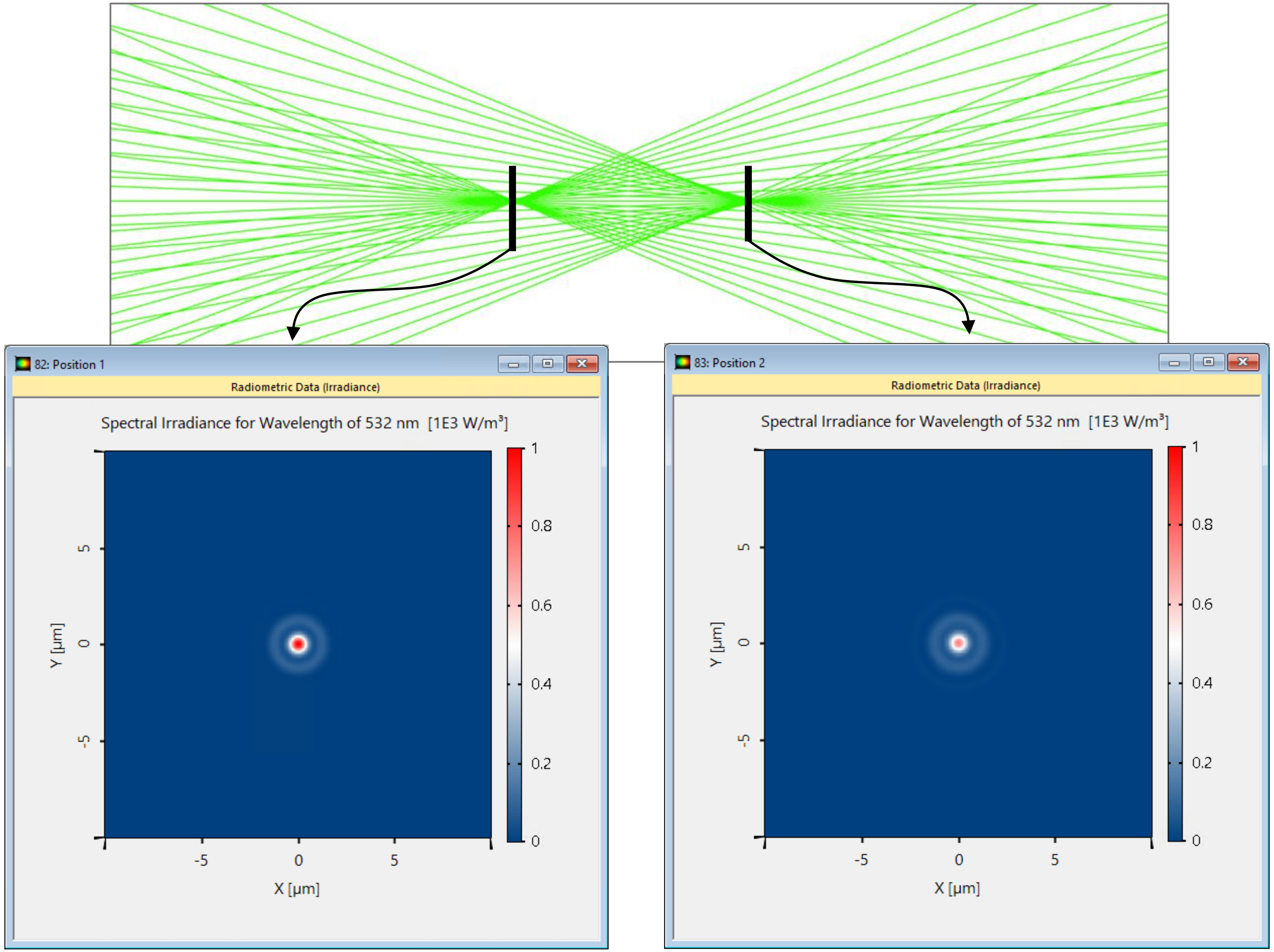
Irradiance of Detector 1



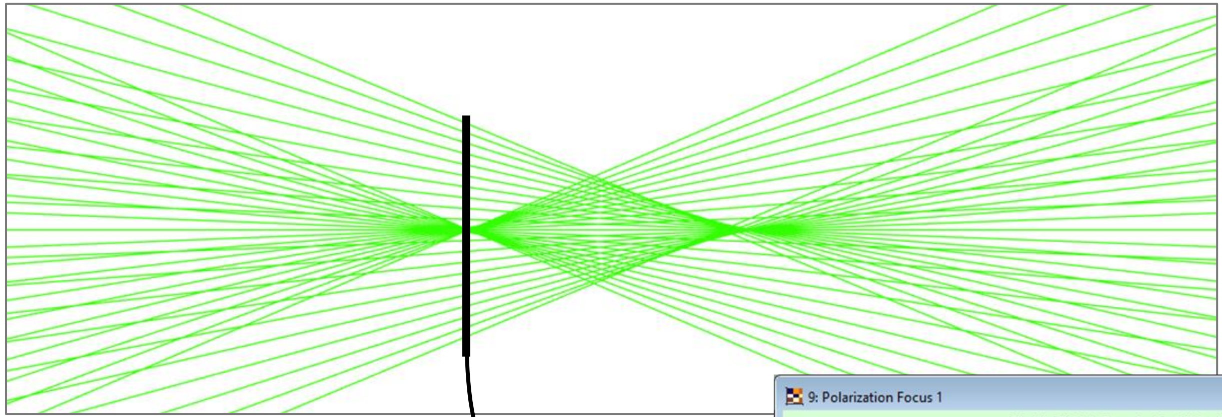
Irradiance of Detector 2

Results – Polarization of the Modes

❓ If linear polarization excites both design and conjugated modes equally, how does the polarization look like in the two focal planes?”

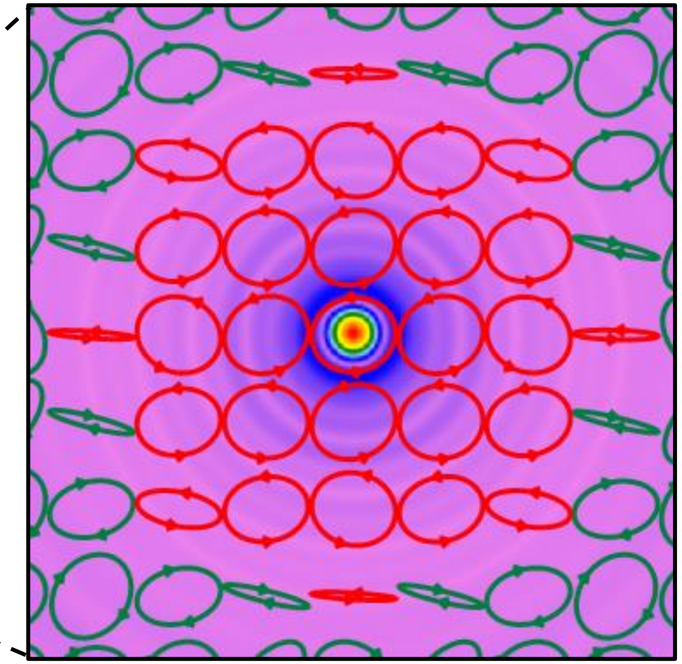


Result – Polarization Ellipses for Linear Polarization

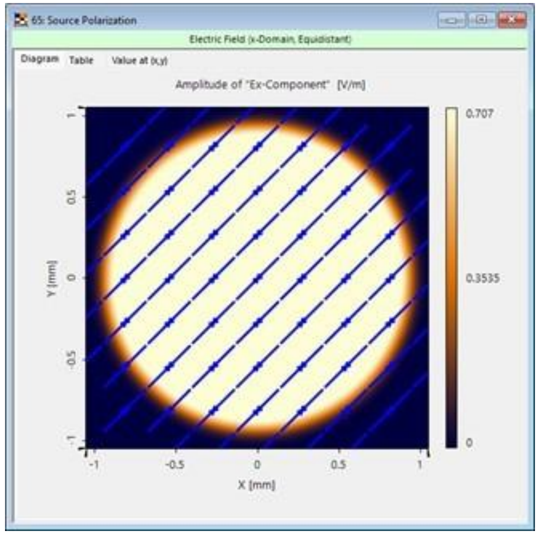


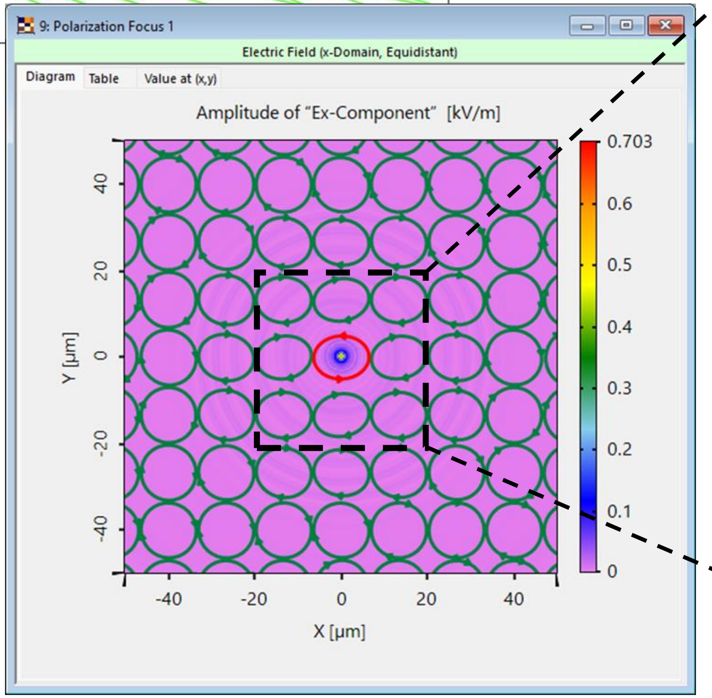
Hardware & Performance

- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Simulation time: 33 s



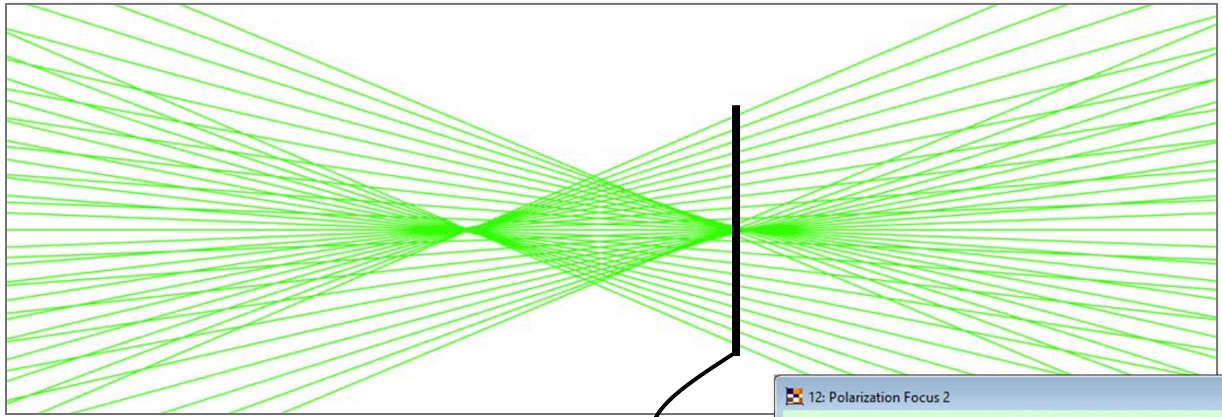
Linear Polarization





Amplitude of Detector 1

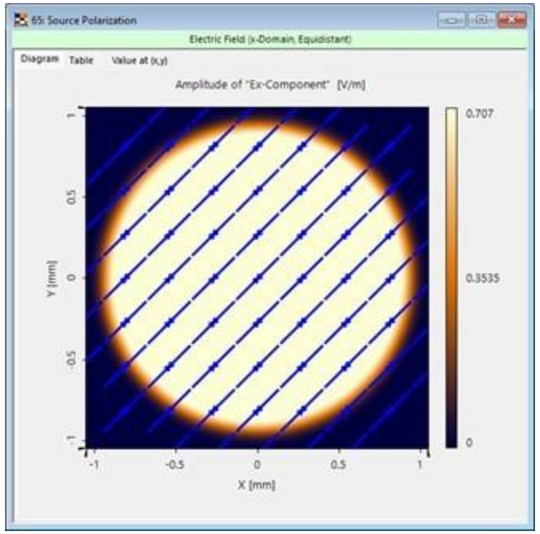
Result – Polarization Ellipses for Linear Polarization

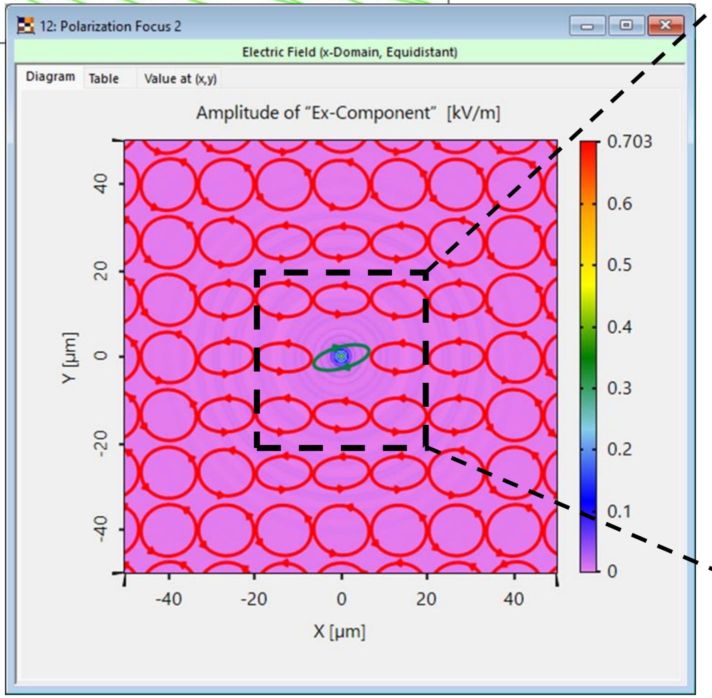


Hardware & Performance

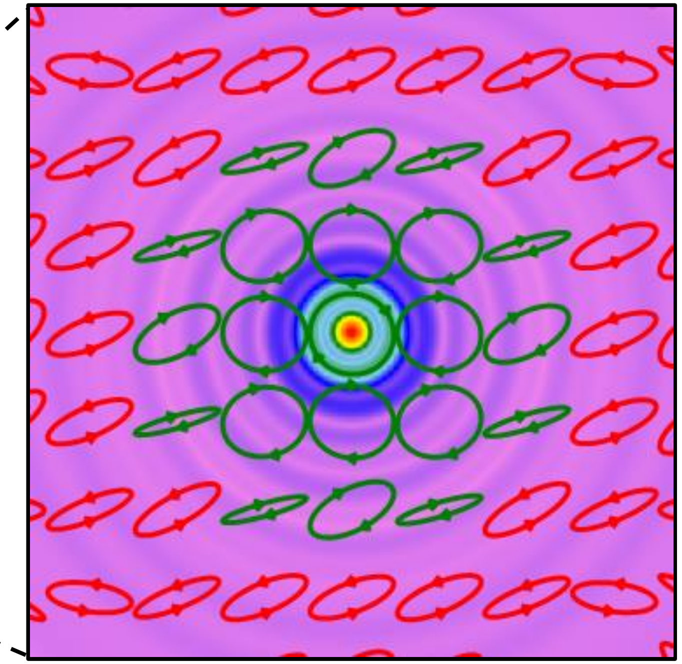
- Hardware: AMD Ryzen Threadripper 3970X 32-Core Processor, 256 GB DDR4 SDRAM
- Simulation time: 33 s

Linear Polarization





Amplitude of Detector 2



Demonstrated Workflow

Step-by-Step Workflow

1. **Train surrogate model:** Load the provided sample file — preset parameters are included and training has been performed.

2. **System setup:** Add digital twins — *Plane Wave Mode*, *Metalens [PCA]*, *Planar Surface*, *Field Monitor [2D]* and *Lens Group*. Set parameters and connect them according to the *Application Scenario* page. Additionally include the *Poynting-Vector* and *Irradiance* detector add-on for detector 1 and 2.

3. **Bind surrogate model:** In the *Metalens [PCA]* component, navigate to the *Simulation Model* page and click *Bind*. Select the trained surrogate model.

4. **Define wavefront phase profile:** Use *Even Order Radial Polynomial*. Set the first coefficient to 100.

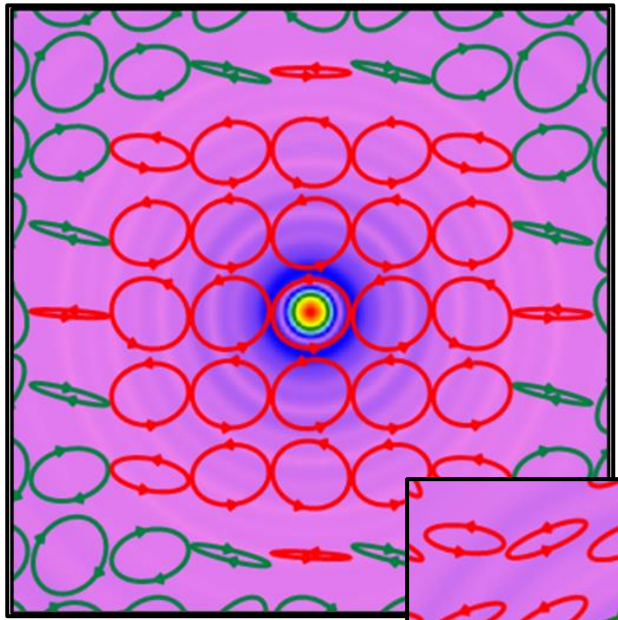
5. **Set up asphere:** Include *Aspherical Surface* and *Plane Surface* in the *Lens Group* twin. Take parameters from *Application Scenario* page. Set medium to N-BK7.

6. **Simulation:** Simulate with Field and Ray Tracing. In the options of the *Metalens [PCA]* component you can deactivate design or conjugated mode.

Conclusion

Key Takeaways

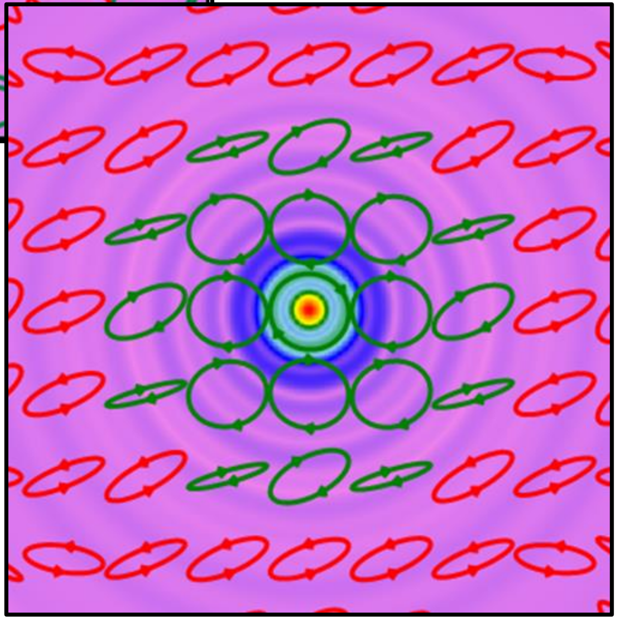
- Nanofin metalens supports design mode (focusing) and conjugate mode (diverging) — a fundamental property of Pancharatnam–Berry phase metastructures.
- Polarization controls mode excitation: RCP $\rightarrow$ design mode, LCP $\rightarrow$ conjugate mode, linear $\rightarrow$ both.
- Bifocal operation is achieved by combining the metalens with a conventional aspherical lens.



Polarization ellipses of first focal spot

Next Steps

- Download the sample files and reproduce the results.
- Export the designed metastructure for manufacturing.



Polarization ellipses of second focal spot

Resources Used

White Papers

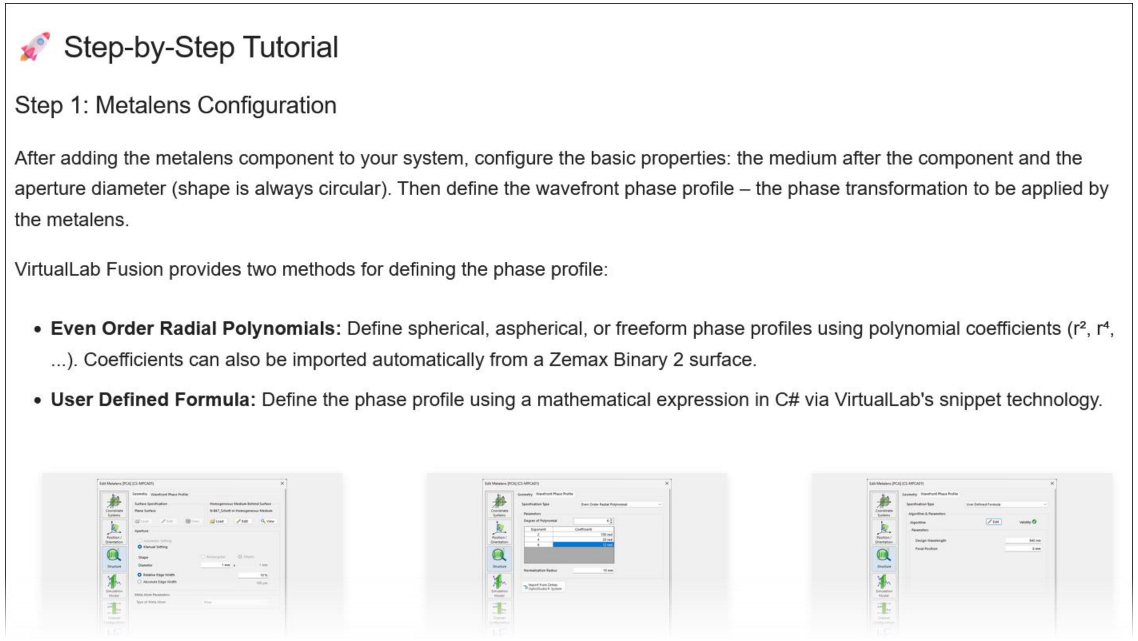
- WP-META-SURROGATE — Surrogate Modeling: Enabling Practical Metalens Design and Simulation
- WP-META-PHASE - Designing and Analyzing the Phase Response of Metasurfaces

Tutorials

- Define Metalens Functionality
- Designing a Metalens in VirtualLab Fusion
- Set Detector Add-ons into a Field Monitor

Related Use Cases

- Surrogate Model Training for Nanopillars
- Focusing Metalens Based on Nanopillars


Step-by-Step Tutorial

Step 1: Metalens Configuration

After adding the metalens component to your system, configure the basic properties: the medium after the component and the aperture diameter (shape is always circular). Then define the wavefront phase profile – the phase transformation to be applied by the metalens.

VirtualLab Fusion provides two methods for defining the phase profile:

- **Even Order Radial Polynomials:** Define spherical, aspherical, or freeform phase profiles using polynomial coefficients (r^2, r^4, ...). Coefficients can also be imported automatically from a Zemax Binary 2 surface.
- **User Defined Formula:** Define the phase profile using a mathematical expression in C# via VirtualLab's snippet technology.