Digitally Designed Meta-atom for Holographic Wavefront Shaping

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Motivation

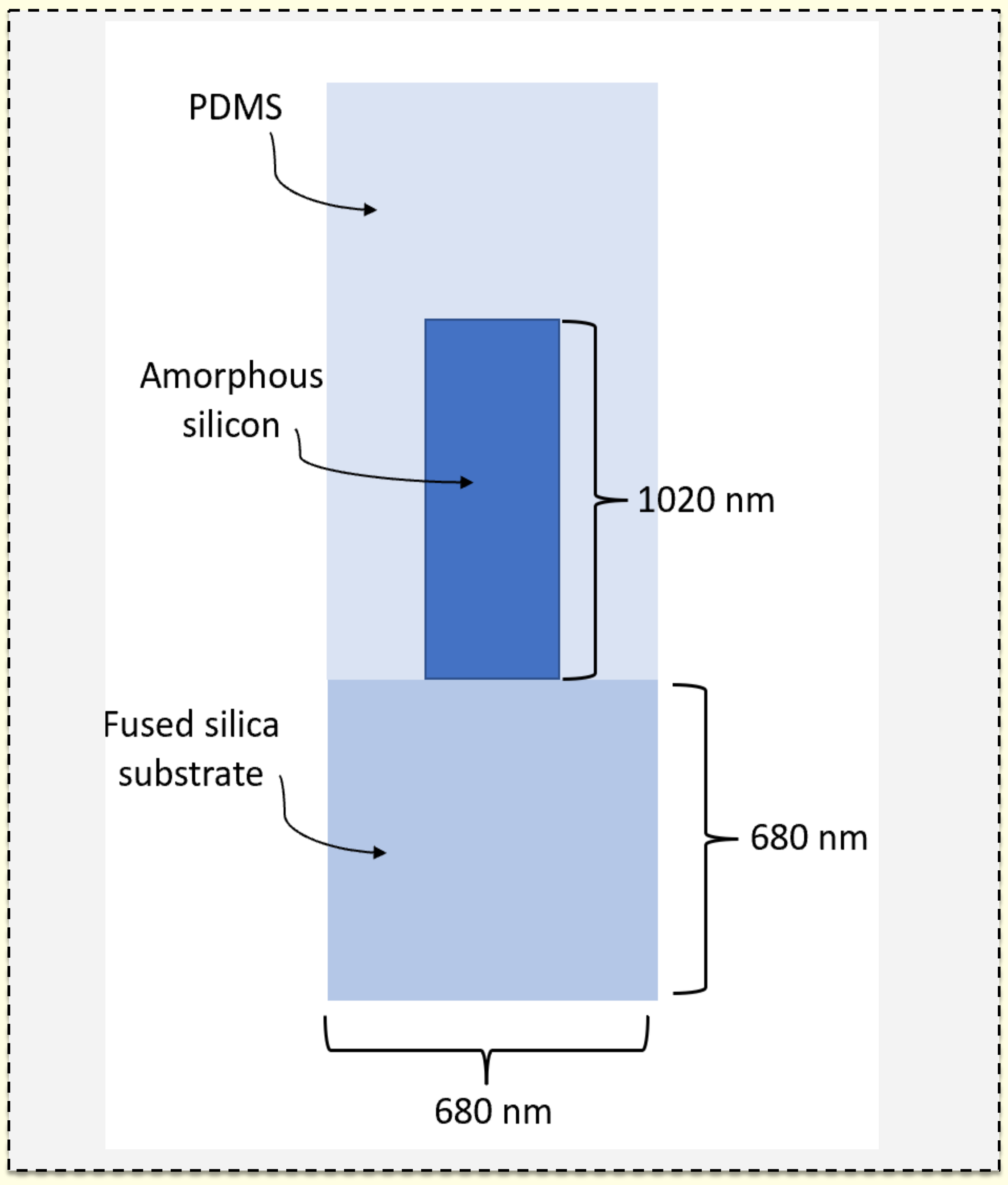
- There is interest in exploiting the properties of metasurfaces to generate physical volumetric holograms.
- A metasurface is a two-dimensional structure composed of unit elements called meta-atoms.
- Computer simulations provide a starting place for understanding the optical field distribution of a single meta-atom.
- In this poster we simulate a single meta-atom using finite-difference time-domain (FDTD) analysis. We study the transmission and phase shift resulting from a plane wave incident on a meta-atom with a fixed length and varying radius.
- We would like to know the effect of meta-atom geometry on transmission and phase shift of a plane wave through the meta-atom.

MEEP

MIT Electromagnetic Equation Propagation

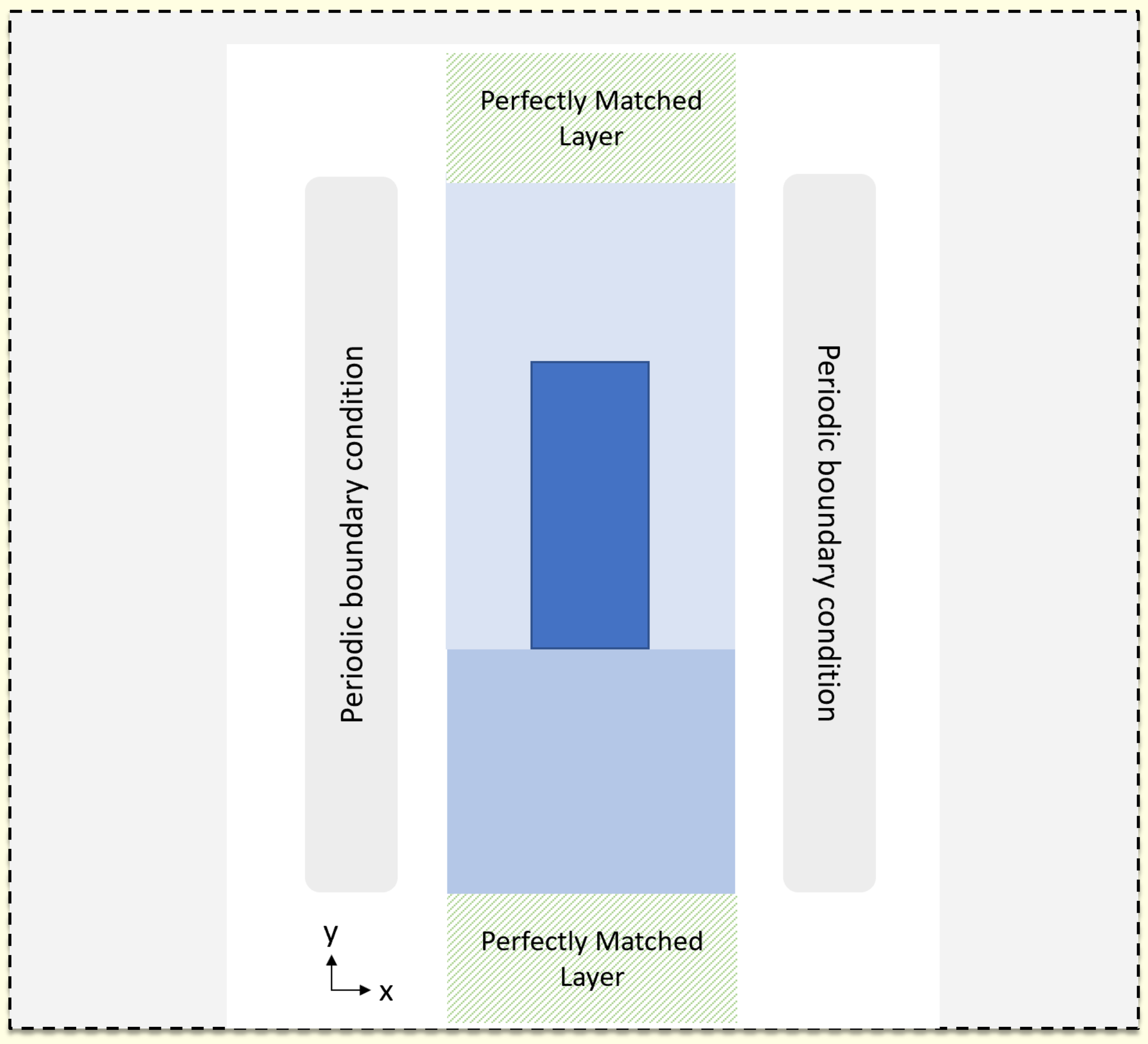
- MEEP is a free, open-source, Python-based software package that implements finite-difference time-domain (FDTD) modeling method for computational electromagnetics.
- FDTD is a computational modeling method based on the numerical solution of Maxwell's equations of classical electrodynamics.
- A normally incident planar wavefront is simulated using MEEP's continuous EigenModeSource.
- Phase and transmission information are collected from a flux region. The Fourier transforms of the fields in this region are accumulated as the simulation runs.
- Public code: **github.com/agkgd4/Meta-atom-Project**

The Meta-atom



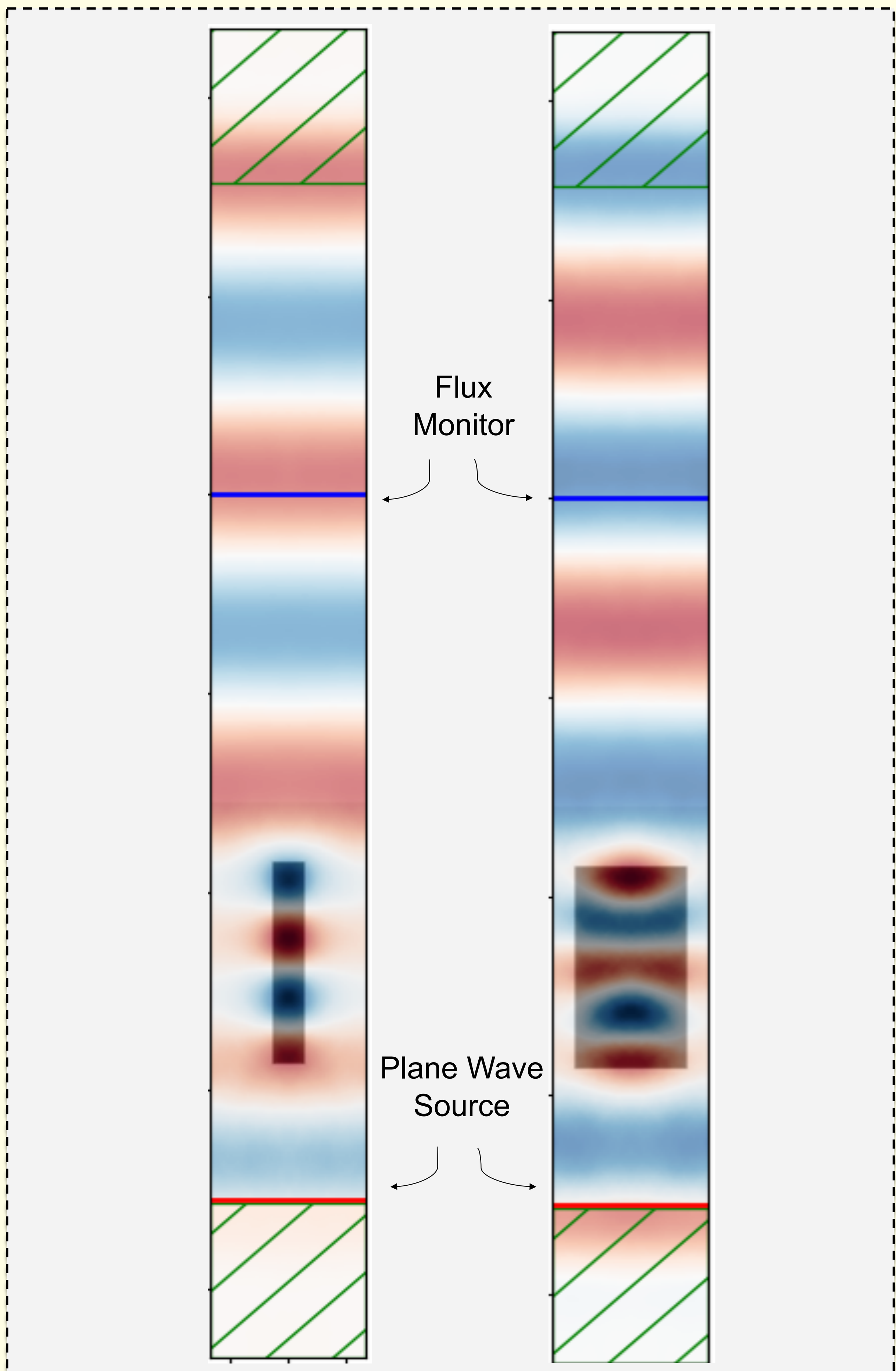
- The amorphous silicon scatterer sits on top of a fused silica substrate and is encased by a layer of polydimethylsiloxane (PDMS)
- The length of the cylinder, about 60% of the length of the source wavelength (λ = 1.55µm), is fixed.
- Cylinder radius varies between 75 and 250 nm

Boundary Conditions



- The simulation uses periodic boundary conditions along the ±y direction, which assumes the meta-atom is one element in an infinite array of identical, equidistant meta-atoms.
- This lets us make the local periodicity approximation, also known as the local phase approximation: the transmission properties of the meta-atom are independent from those of the surrounding meta-atoms and can be estimated locally.
- Perfectly matched layers along the ±x direction absorb electromagnetic waves without reflection.

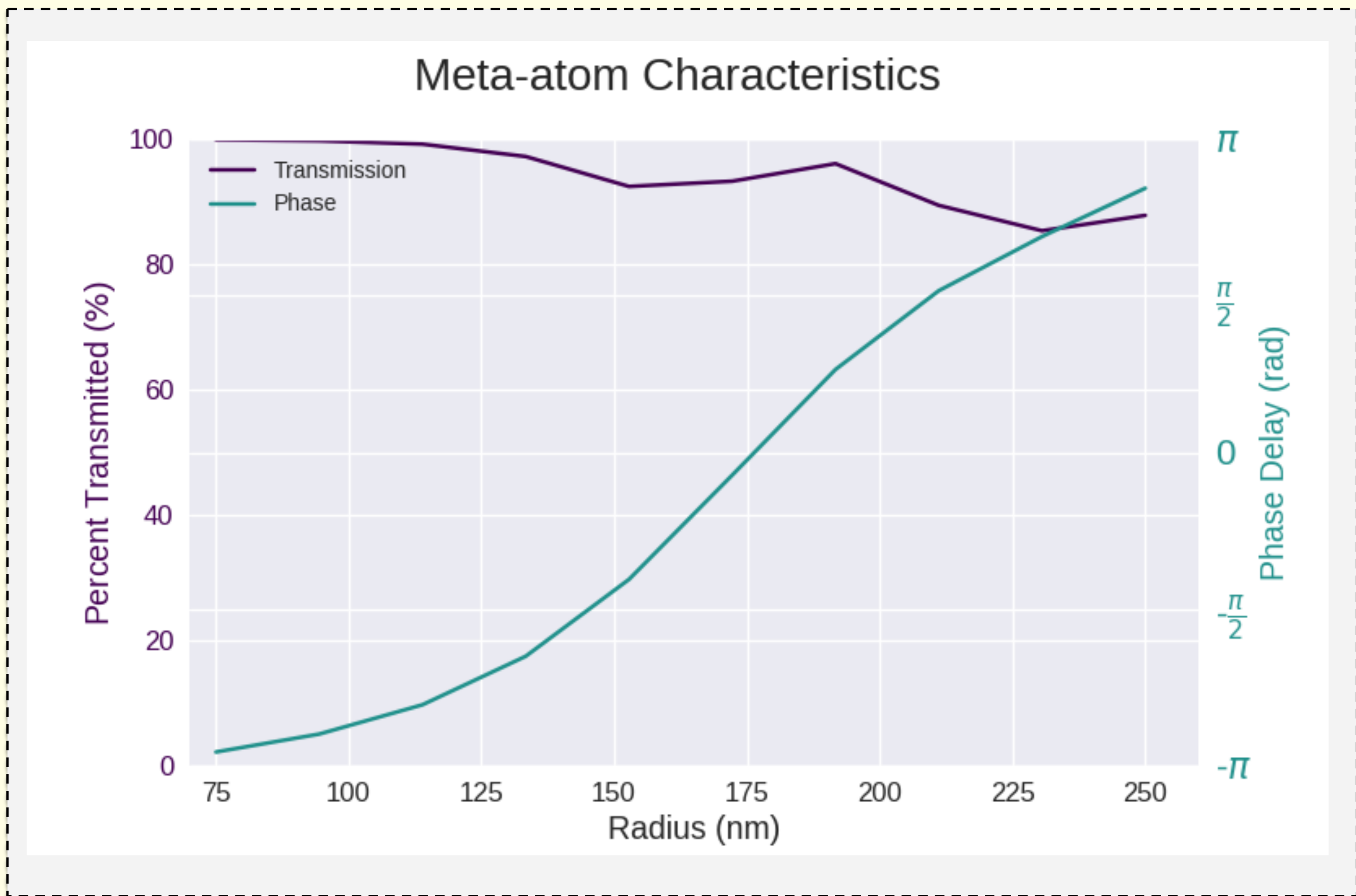
Electric Field Propagation



75 nm cylinder radius | **150 nm cylinder radius**

- The red and blue regions represent the electric field propagating sinusoidally from the source. The field is negative where the colormap is red, zero where it is white, and positive where it is blue.
- As the wave propagates through the sub-wavelength meta-atom, optical path length is increased. This increase in optical path length shortens wavelength locally, meaning the wave has to travel farther inside the meta-atom.
- The result is a local phase shift. This phase delay can locally add texture to a planar wavefront.
- We can design and build a metasurface composed of an array of meta-atoms with varying cylinder radii to get a textured wavefront across an entire surface with a desired pattern. This could form the foundation of a holographic image.

Simulated Transmission and Phase Delay



- The simulation achieves high transmission with continuous phase delay with respect to radius. These results are comparable to those achieved with the commercial electromagnetic solver, Ansys HFSS, in [1].

References

[1] B. Raeker and A. Grbic. "Lossless Complex-Valued Optical-Field Control with Compound Metaoptics," *Physical Review Applied*, 15, 054039 (2021).
[2] A. Taflove, A. Oskooi, and S.G. Johnson. *Advances in FDTD Computational Electrodynamics,* Boston: Artech House, 2013.
[3] M.V. Zhelyeznyakov, S.L. Brunton, A. Majumdar. "Deep Learning to Accelerate Maxwell's Equations for Inverse Design of Dielectric Metasurfaces," arXiv:2008.10632[physics.optics], 2020
[4] MEEP Documentation, https://meep.readthedocs.io/en/latest/ Accessed: Apr. 12, 2022