COMSOL Multiphysics® Implementation Of A Genetic Algorithm Routine For Optimization Of Flat Optics

B. Adomanis[1], M. Marciniak[1]

[1]Air Force Institute of Technology, Wright-Patterson AFB, OH, USA

Abstract

Introduction: In recent years, metasurfaces have been demonstrated to control the phase and amplitude of light across a planar interface and implemented for optical functions such as beam-steering, focusing, and polarization rotation. Initial efforts using plasmonic-based scatterers proved successful in achieving the desired functionality; however, these designs exhibited limitations in efficiency that stifled further vigor, as researchers shifted interest to higher-efficiency dielectric-based designs. A key limitation is strong backscatter; this keeps the theoretical maximum efficiency of a single-layer lens to around 30%. This comes from the inherent behavior of an in-plane, electrically-small scatterer, producing a far-field radiation pattern like that of a Hertzian electrical dipole, with nearly equal parts forward and backward scattering. Thus, if the building block of a metasurface lens is a scatterer which exhibits both low backscatter and preferential forward scattering along the optical axis, this will be a positive step towards achieving efficiencies comparable to commercial lenses. This work utilizes COMSOL Multiphysics® with LiveLink™ for MATLAB® to address this issue, deriving a genetic algorithm (GA) optimization routine to identify such a scatterer.
Use of COMSOL: COMSOL's application programming interface (API) was used to derive a binary-coded GA optimization routine, which begins with an initial population of voxels in an N x M grid populated either with a dielectric (air, representing '0') or a metal (gold, representing '1'). Each binary value represents the 'genes' of the 'parent' populations. Using COMSOL's Wave Optics module and the Far-Field Domain feature, the voxels are illuminated by a 10µm background field and the scattered far-field is extracted. The results of Far-Field Domain Point Probes are fed into MATLAB® via LiveLink™ and mutually compared against a dual-objective cost function which seeks maximum forward scatter while minimizing backscatter. A down-selection of the best candidate parents and subsequent mutation/crossover of genes is performed to create 'child' populations, which are fed back into COMSOL to form a new generation. The routine repeats for each new generation until a desired threshold is achieved.
Results: Final designs were selected based on their conformity to ideal radiation patterns of a Huygens source (suppressed side/backlobes) and feasibility of fabrication. When referenced to the intensity of the V-antenna baseline (dBv), the intensity of optimized designs reached upwards of 20+ dBv in forward scatter, while the backscatter was suppressed by -10+ dBv. These designs will be used to fabricate lenses and measured to compare against the baseline efficiencies. Additionally, the GA implementation significantly reduces computation time, as it identifies global extrema without having to sample the entire multi-dimensional parameter space.
Conclusion: COMSOL Multiphysics® and the LiveLink™ for MATLAB® module were used to successfully implement a genetic algorithm optimization routine which identified a superior scatterer for improved focusing efficiency in a plasmonic-based metasurface flat lens. This first step in optimization will be followed up with a robust expansion of the optimization space, to include multiple layers for impedance-matching and a fully 3D space for development of

independently-controlled magnetic and electric dipole responses.

Figures used in the abstract

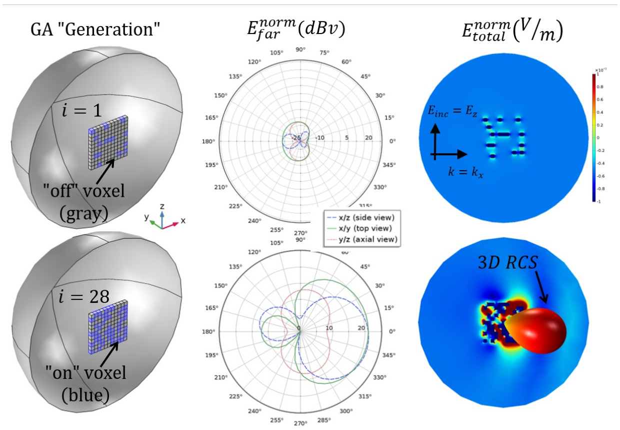

Figure 1 : Figure 2. COMSOL model of sample initial binary ‘parent’ population (top,left), with blue voxels representing “1”/“on” metallic elements and grey air voxels representing “0”/”off” dielectric. Far-field radiation pattern is extremely weak for the initial population (center), as supported by the lack of near-field coupling seen in the normalized E-field (right). The 1st individual of the 28th “generation” (bottom, left) demonstrated the highest fit, out of 30 generations. Improvements of 21.5dB over the original V-antenna and -9dB backscatter can be seen (center), as well as strong localized field interactions (right).