Lightweight Negative GRIN Lens Fabrication via Rapid Prototyping for Radio Applications

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In this paper, we report on the design, rapid fabrication, and evaluation of a flat lens with a negative gradient refractive index consisting of self-supporting 3D metamaterial elements. Recent work has shown that metamaterial structures with self-supporting architectures suffer from minimal losses compared to planar metamaterial elements that require extraneous dielectric material substrates. Low loss characteristics make multilayer devices with quality performance parameters possible. This was exemplified in a recent report on rapidly fabricated plano-concave lenses using negative refractive index 3D metamaterial. Both simulations and experiments showed that the lightweight lens benefitted from low loss and high gain in the focal region across the 10-12 GHz band. More importantly, it highlighted the fabrication flexibility afforded by rapid prototyping technology, which suggests that complex geometries and devices are readily accessible, which portends to the further actualization of metamaterial performance benefits.

In order to transition from a curved lens profile of a homogenous medium to a planar lens with a graded index, the following steps were taken. First, a gradient refractive index profile was derived using geometric optics for a flat lens with a focal distance similar to other homogenous lenses. The refractive index profile was then discretized so it could be populated with metamaterial elements with matching refractive index parameters. To build a library of metamaterial geometries and their corresponding material parameters, a parametric sweep of different S-ring unit cell dimensions was performed. The refractive indices of the varied structured were retrieved using standard procedures. By arranging the S-ring structures accordingly, the gradient index profile was well approximated. Care was taken to ensure the overall structure was mechanically viable to avoid complications during fabrication.

The performance of the lens was studied using geometric optics and physical optics. It was found that for an aperture of small electrical size, the focal points that result from geometric and physical optics appear at different locations. The discrepancy between these two methods was found to be different for lenses made from positive index materials and negative index materials.