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A Broadband Zoned Fishnet Metamaterial Lens

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Lenses, as optical instruments, have been known for centuries. With the appearance of Kock's metallic lenses, and later metamaterials, which allow tailoring both permittivity and permeability, the lenses have gained a renewed look. This great deal of effort has paid off resulting in perfect lenses, superlenses, hyperbolic lenses, chiral lenses, transformation optics lenses, epsilon-near-zero lenses, etc. One of the promising practical realizations of a metamaterial lens is the fishnet metamaterial lens. Consisting of stacked subwavelength hole arrays and working in the realm of the extraordinary transmission, the fishnet metamaterial offers lower losses and frequency-robust magnetic response. Although showing a good performance, plano- and bi-concave fishnet lenses are relatively voluminous. This problem can be solved by applying the well-known zoning technique, whereby the redundant material is removed when one wavelength phase shift in it is reached. Such a technique was successfully applied in the previous works and demonstrated the reduction of the weight and absorption losses, but for single-frequency operation (V. Pacheco-Peña *et al.*, Appl. Phys. Lett., 103, 183507, 2013; V. Pacheco-Peña *et al.*, J. Appl. Phys., 115, 124902, 2014).

The operational band can be broadened by applying an improved zoning technique, which exploits a strong dispersion of the fishnet. A best fitting procedure, which minimizes the root-mean-square-error between the smooth analytical profile and its staircase approximation (defined by the fishnet unit cell) for the whole band, is applied to the conventional zoning technique. As a result, the optimal zoned lens profile is obtained. It should be noticed that the resulting profile is completely different from that used in previous works, where it was obtained only for a single frequency.

In this communication, we present a broadband zoned fishnet lens designed by using the smart optimization procedure described above. The lens was fabricated and its performance was investigated experimentally at frequencies f_1 = 54 GHz and f_2 = 55.5 GHz. The results were compared against analytical calculations based on the Huygens-Fresnel principle, and full-wave numerical simulations. The results demonstrate a good agreement with the design parameters and an enhancement above 9 dB in the frequency range 54-58 GHz, while the zoned lens optimized for single-band operation achieves enhancement values above 9 dB only at the design frequency range, 55 - 56.5 GHz. The numerical and experimental results of a proposed lens antenna show directivities above 15 dB for both frequency bands.