Zoning Technique for a Broadband Fishnet Metamaterial Lens

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Abstract—**The profile of any lens can be reduced by applying a zoning technique, at the expense of narrower frequency range. Here, using an optimized zoning technique, a slim broadband zoned fishnet metamaterial lens with fractional bandwidth of 8.5% is designed, fabricated and measured at millimeter waves. Measurements are in good accordance with simulation results and demonstrate good performance of the zoned fishnet metamaterial lens. A high directivity of 16.6 dBi is experimentally achieved in the lens antenna system.**

I. Introduction

THE control of the light propagation continues to be one of the most popular research field in electromagnetism. Historically this mission was entrusted to metals and natural dielectrics. However the use of conventional dielectrics to tailor the shape of the electromagnetic wave is limited by the natural available permittivity and permeability values. Also their impedance mismatch and absorption losses make them less attractive for practical applications in the millimeter-wave and terahertz ranges. With appearance of the artificial dielectrics [1], and more recently metamaterials [2], researchers have gained more possibilities of designing classical beam shaping devices, such as lenses [3], beam steerers [4] and even cloaking devices [5]. A fishnet metamaterial is one of such promising metamaterials, which is suitable for microwave-to-terahertz frequencies, with low absorption losses, frequency-robust magnetic response and good impedance matching with air.

As a practical demonstration of its potential for millimeter-waves applications, fishnet-based lenses have been designed and experimentally analyzed at ~60 GHz [6], [7]. Subsequently a zoning technique, well-known for centuries and used at the beginning primarily in optics, has been successfully applied for such metamaterial lenses [8]. It makes possible to reduce significantly the volume and, therefore, minimize losses and weight of the lens, at the cost of narrowing the frequency operation band.

Here we demonstrate that the frequency span of zoned fishnet lenses can be broadened without affecting their performance, by applying a smart combination of the zoning technique and lens profile optimization [9]. The designed and fabricated fishnet metamaterial was measured at two frequencies demonstrating a subwavelength transverse resolution for both foci. A lens antenna configuration showed directivity above 15 dB for both frequencies.

II. Results

The profile of the zoned fishnet metamaterial lens was obtained using an improved zoning technique, which exploits a strong dispersion of the fishnet and 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. The performance of the obtained optimized lens design has been analyzed in lens and lens-antenna configurations. To this end, the zoned fishnet metamaterial lens has been fabricated, measured, analytically and numerically studied at frequencies f_1 = 54 GHz and f_2 = 55.5 GHz. All results demonstrate a good agreement with the design parameters. The broadband performance of the lens has been numerically confirmed for the frequency range 53.5-58.25 GHz (fractional bandwidth FBW = 8.5%), where the enhancement is above the -3dB level (from the peak value). The zoned lens presented in Ref. 8 achieved FBW = 4.9%. The experimental study showed a focal length of 48.5 mm and 51.5 mm for the first and second frequency, respectively, and a full width at half maximum of $0.7\lambda_1$ and $0.9\lambda_2$ for the first and second frequency respectively. Also the lens performance was experimentally examined in antenna configuration. Side lobes of 6.7 dB below the main lobe were found at ±7 deg for both frequencies. The beamwidth for the first and second band was 3.5 and 4.3 deg respectively. Both numerical and experimental results show directivities of the lens antenna above 15 dB for both frequencies in accordance with full-wave simulations.

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