V-band reference-phase-based zoned fishnet metalens

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DOI:
10.1109/USNC-URSI.2016.7588515

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***Abstract*—Here the reference phase technique is used in the design of all metallic zoned lenses based on the fishnet metamaterial. Several metalenses are designed and evaluated both numerically and experimentally. It is shown that the radiation gain is experimentally increased in 1.8 dB when the reference phase is applied to the design.**

Keywords—Metamaterial; Fishnet metamaterial; Zoned lens.

I. INTRODUCTION

Diffractive and refractive lenses have been widely studied within the entire frequency spectrum [1], [2]. Their design has been revitalized recently by the introduction of metamaterial concepts that enable arbitrary control of the electromagnetic material parameters [3], [4]. Within this context, the fishnet metamaterial with double in-plane periodicity has been proposed in the design of all metallic lenses due to its impedance matching with free-space and almost negligible cross-polarization [5]–[7].

In this work, the reference phase concept, which was first proposed for diffractive lenses [8], is applied in the design of several zoned fishnet metalenses at millimeter waves [9]. An improvement of the lens performance is obtained in terms of side lobe level and gain at the design frequency of 56.7 GHz, at the expense of increasing slightly the thickness of the lens.

II. DESIGN AND RESULTS

The unit cell used for the fishnet metamaterial consists of an aluminum slab perforated with a circular aperture and embedded in air, with the dimensions shown in Fig. 1(a). The metalenses are designed at the millimeter wave frequency of 56.7 GHz. At this frequency, the effective refractive index of the fishnet metamaterial is close to zero with a value of n = –0.25. With these parameters, we design several metalenses with a focal length of $4.5\lambda_0$ by applying the zoning technique [6] along with the reference phase concept [9]. The schematic representation of two metalenses is shown in Fig. 1(b, c) for the cases with and without reference phase, respectively. Here, q = 0 and q = 0.35 represent a reference phase of 0 and 0.7π, respectively [9]. As it is shown, the thickness of the metalens increases when reference phase is used due to the influence of the extra phase added to the case without reference phase.

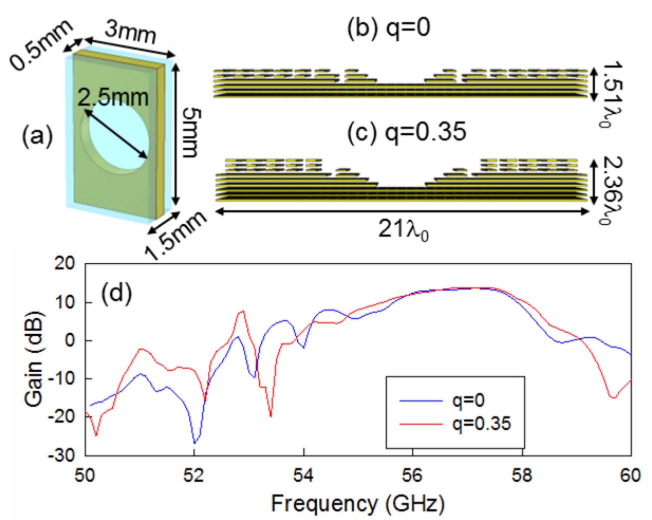

Fig. 1. (a) Unit cell used for the fishnet metamaterial. Schematic representation of the zoned lens profile when no reference phase is used q = 0 (a) and a reference phase of q = 0.35 (b). (c) Numerical results of the gain as a function of frequency for the designs with a reference phase of q = 0 (blue line) and q = 0.35 (red line).

The focusing properties of the metalenses were evaluated both numerically and experimentally demonstrating that the

This work was sponsored by the Spanish Government under contract TEC2014-51902-C2-2-R and by the Mendeleev scientific fund of Tomsk State University N8.2.48.2015. V.P.-P. is sponsored by Spanish Ministerio de Educación, Cultura y Deporte under grant FPU AP-2012-3796. B. O. is sponsored by Spanish Ministerio de Economía y Competitividad under grant FPI BES-2012-054909. M. B. is sponsored by the Spanish Government via RYC-2011-08221. M. N.-C. is supported by the Birmingham Fellowship.

side lobe level at each focal length is reduced 2.2 dB and 2.5 dB, respectively, when a reference phase of $q = 0.35$ is used, corroborating that this technique can be used also for refractive lenses in order to improve the performance of the lens.

The radiation performance was also evaluated by placing the transmitter at each focal length and evaluating the gain. The numerical results are shown in Fig. 1(d) as a function of frequency. It is shown that the radiation performance is not deteriorated when the reference phase is introduced. Numerical results demonstrate that a high gain of 13.2 dB and 13.5 dB is obtained for the case without and with reference phase, respectively. The experimental results demonstrate a very good agreement with the numerical values with an increased gain from 9.5 dB ($q = 0$, i.e., no reference phase) to 11.3 dB for $q = 0.35$. These results demonstrate that the performance of the metalenses is also improved when they are used as lens-antenna system.

III. Conclusions

The reference phase concept has been applied in the design of several zoned metalenses based on the fishnet metamaterial. Several metalenses have been designed, fabricated and evaluated both numerically and experimentally. It has been demonstrated that that the overall performance of the metalens is improved when the reference phase technique is used. It has been shown experimentally that, when the metalenses are used as lens-antenna system, the farfield gain is increased 1.8 dB for the case of the metalens with reference phase.

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