Broadband Metasurface Luneburg Lens Antenna Based on Glide-Symmetric Bed of Nails

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***Abstract*—A broadband metasurface Luneburg lens based on glide-symmetric bed of nails is designed. First, the Luneburg lens was re-shaped using quasi-conformal transformation optics. With this technique, the original circular focal curve of the lens is changed to a straight line. Afterwards, the refractive index distribution of the optically transformed lens is realized by changing the height of the pins in a bed of nails configuration. The complete Luneburg lens is simulated in *CST Microwave Studio* and the results demonstrate that the lens has 8-16 GHz bandwidth.**

***Index Terms*—Luneburg lens, planar lenses, metasurfaces, glide symmetry, transformation optics.**

I. Introduction

Luneburg lenses have excellent characteristics for antenna design, since they can be employed to create steerable directive beams. Additionally, they have no reflections at their edges, resulting in good radiation efficiency. However, the manufacturing of Luneburg lenses may be complicated and expensive. In the recent years, metasurfaces have been proposed to produce low cost planar Luneburg lenses [1], [2]. These lenses have low profile and are easy to manufacture when compared to standard dielectric lenses. These solutions are attractive for wireless communications at high frequency, such as 5G, where arrays and phase shifters are expensive solutions.

Nevertheless, there were two limitations for those first implementations of metasurface lenses. The first one is their feeding configuration has a circular shape. In this sense, they cannot be well matched to a planar feeding source or detector array. Using transformation optics, this difficulty can be eliminated since the circular focal curve may be changed to a flattened focal line [3], [4]. The second limitation is their dispersive behaviour. This dispersion appears in all the conventional configurations: arrays of patches [5], holey metallic surfaces placed over a dielectric slab [6], and the bed of nails [7]. This is a drawback when compared to conventional dielectric Luneburg lenses, which are not limited in bandwidth. Recently, glide-symmetric metasurfaces have been proposed to increase the bandwidth of a metasurface Luneburg lens [8]. It has been demonstrated in [8] that these glide-symmetric metasurfaces present a very low dispersion.

In this paper, we show the design and realization of a metasurface Luneburg lens antenna based on a glide-symmetric bed of nails. In the design, quasi-conformal mapping is used to flatten a part of the circular surface of the Luneburg lens. Afterwards, using a glide-symmetric bed of nails, a broadband flat Luneburg lens is realized. *CST Microwave Studio* simulations demonstrate that the lens that the lens performs as designed from 8 GHz to 16 GHz.

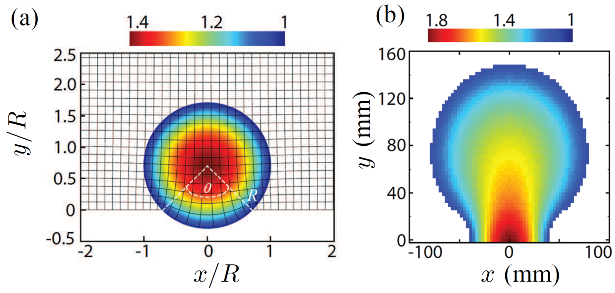

Fig. 1: Quasi-conformal mapping of a Luneburg lens. (a) Refractive index distribution of a 2D Luneburg lens in the virtual space when $\theta = 90°$. (b) Refractive index distribution of the 2D flattened Luneburg lens in the physical space.

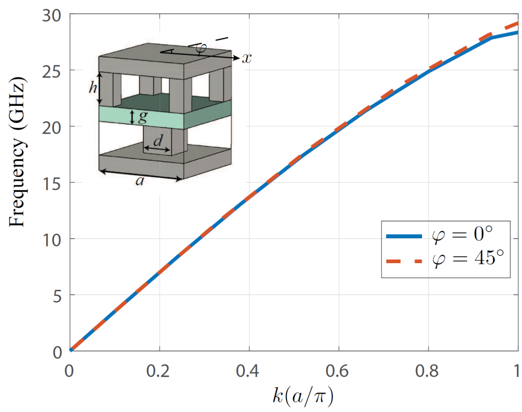

Fig. 2: Dispersion diagram of glide-symmetric bed of nails metasurface under periodic conditions for two directions of propagation ($\varphi = 0°$ and $\varphi = 45°$). The simulations correspond to the following values: $a = 2$ mm, $d = 1$ mm, $h = 1.5$ mm, and $g = 0.508$ mm.

II. Lens Design

The first step of the lens design consists of using transformation optics to convert the circularly focal curve of a

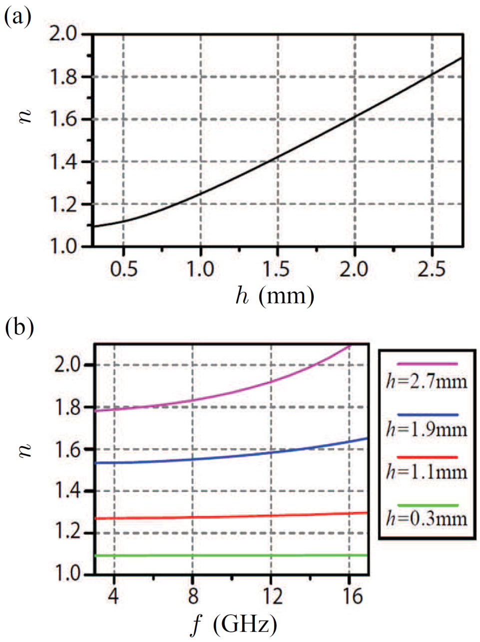

Fig. 3: Equivalent refractive index of a glide symmetric bed of nails metasurface under periodic conditions (a) at 12 GHz for different values of the height of the pins, (b) as a function of frequency for different values of the height of the pins. In both cases, the dimensions of the unit cell are $a = 2$ mm, $d = 1$ mm, and $g = 0.508$ mm.

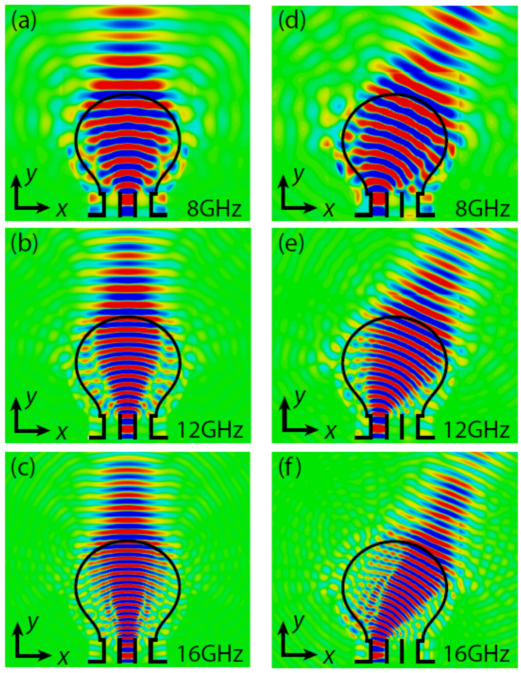

Fig. 4: Simulated electric fields for the designed lens at $f =$ 8, 12, 16 GHz. (a), (b), (c) when the feeding source is located at the centre of the focal line. (d), (e), (f) when the feeding source is 20 mm off the centre of the focal line.

conventional Luneburg lens to a flattened focal line. In the virtual space, we assume a Luneburg lens of radius R and refractive index distribution $n = \sqrt{2-(r/R)^2}$ (see Fig. 1(a)). Quasi-conformal mapping is used to flatten a part of the circular curve with an open angle $\theta = 90°$. The physical space is shown in Fig. 1(b).

The next step is to realize this lens using a glide-symmetric bed of nails. The geometry of the unit cell is shown in the inset of Fig. 2. The selected parameters are $d = 1$ mm, $a = 2$ mm and $h = 1.5$ mm. A dielectric slab of RT5880 is employed between the lower and upper plate. The dielectric constant of RT5880 is $\epsilon_r = 2.2$ and a thickness $g = 0.508$ mm is chosen. The dispersion diagram for the first mode of this glide-symmetric bed of nails is shown in Fig. 2, for two directions ($\varphi = 0°$ and $\varphi = 45°$). The result demonstrates that the dispersion diagram of the first mode is almost linear over a wide range of frequencies. Therefore, this unit cell is an appropriate choice for realizing ultra-wideband lenses.

In Fig. 3(a), we represent the equivalent refractive index at 12 GHz, for the propagation direction of $\varphi = 0°$, when changing the height of the pin. In Fig. 3(b), the equivalent refractive index of the unit cell for different values of h, and for propagation direction of $\varphi = 0°$, is plotted. These results demonstrate that the refractive index is almost constant in the frequency range from 4 to 16 GHz for $h < 2$ mm. Using this unit cell with parameters $a = 2$ mm, $d = 1$ mm, and h changes from 0.3 mm to 2.5 mm, we can realize the planar optically transformed Luneburg lens represented in Fig. 1(b). The lens is designed taken as a reference the refractive index represented in Fig. 3(a).

III. Results

The designed lens is simulated for two points of excitation. First, when the feeding source is located at the centre of the focal line, and second, when the feeding source is 20 mm off from the centre of the focal line. In Fig. 4, we show the electric fields for these two cases. These fields are extracted at the center of the RT5880 slab at $f = 8$, 12, and 16 GHz. The results show the accurate performance of the designed lens in the frequency range from 8 GHz to 16 GHz.

IV. Conclusion

Glide-symmetric metasurfaces have been recently demonstrated to have a ultra-wideband response. They are less dispersive than conventional metasurfaces due to the existence of higher symmetries [9]. Here, we have implemented a glide-symmetric bed of nails to realize a 2D broadband Luneburg lens that operates in the frequency range of 8-12 GHz. We have also used transformation optics to convert the circularly focal curve of a conventional Luneburg lens to a flattened focal line to simplify the feeding network and compress the dimensions of the lens.

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