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Wideband Substrate Integrated Luneburg Lens Using Glide-Symmetric Technology

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***Abstract*—With a glide-symmetric mushroom unit cell, a wideband Luneburg lens is integrated into print circuit boards (PCBs). Due to the low dispersion of such a unit cell of the metallic via in glide-symmetric technology, the equivalent refraction index of the unit cell remains stable versus a wide frequency range, which is a good candidate for the design of wideband Luneburg lenses. Electric fields in simulation has validated the proposed technology in a wide frequency band. Such Luneburg lens can be easily integrated with other microwave components in PCB technology, promising for applications as beamforming network and multibeam antennas.**

***Index Terms*—Glide symmetry; low dispersion; Luneburg lens; mushroom unit cell; metasurfaces; printed circuit boards (PCBs).**

I. Introduction

With the development of telecommunication technologies, e.g. the fifth-generation telecommunication (5G), demands as beam scanning and beam switching are intensively increasing. There are several methods to implement such a goal, such as phased arrays with beamforming networks, leaky-wave antennas, lens antennas and so on. Luneburg lens in microwave domain is one of the good candidates, such as designs using steps of foam glass [1], transformation optics [2], [3], metamaterials [4] and metasurfaces [5]. Aiming for compact geometry and integration, flat Luneburg lenses have been introduced by controlling the permitivity using air holes [6], [7] in dielectrics and in parallel-plate waveguides [8], meandering crossed microstrip lines [9], complementary nonresonant metamaterial [10], [11], and stacked printed circuit boards (PCBs) [12]. In order to reduce the dispersion of unit cells of metasurfaces and metamaterials, a glide symmetric technology is proposed and applied in fully metallic Luneburg lenses [13], [14], achieving wide frequency band performances. In this paper, a glide symmetric mushroom-like [15] structure is constructed as unit cells for a wideband Luneburg lens integrated in PCBs. The dispersion diagram and equivalent refractive indexes are investigated with comparison to traditional mushroom unit cells. Based on the analysis, a Luneburg lens is designed in a 0.508 mm PCB. The lens performance from 5 GHz to 30 GHz is shown in terms of electric field distributions.

II. Analysis and Design of Luneburg Lens

A. Analysis of Unit Cell

To design a Luneburg lens, the concept of metasurface is used to implement the lens in microwave domain. Mushroom-like structure constructed by printed patches and metallic vias

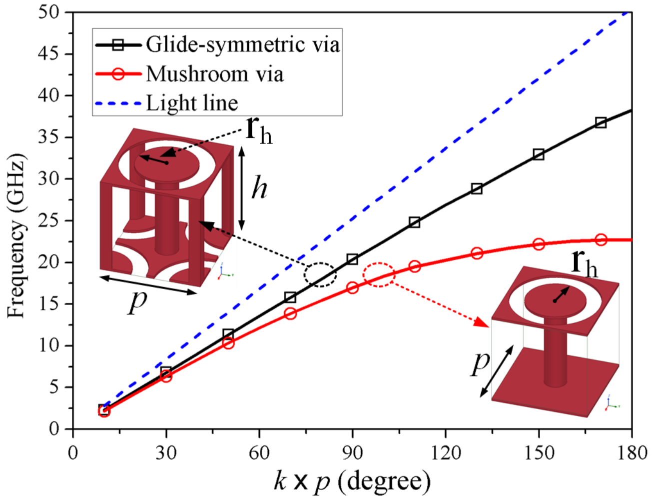

Fig. 1. Dispersion diagram of traditional mushroom and glide-symmetric mushroom.

is very widely used in metasurface designs. However, due to its dispersion characteristic, the equivalent refractive index of mushroom unit cells is usually varying dramatically with the operating frequency, which will lead to narrow operating frequency. In this paper, a glide-symmetric mushroom unit cell is proposed as shown in Fig. 1. The red curve with circles is the dispersion of a traditional mushroom unit cell, whereas the black curve with squares is the dispersion of a glide-symmetric mushroom unit cell. Both unit cells have the same circular patch radius (r_h), metallic via radius r_v, isolation circle radius r_{iso}, PCB thickness (h) and periodicity (p). It is found that the glide-symmetric mushroom is much less dispersive than the traditional one.

Furthermore, the equivalent refractive indexes (n) of both unit cells are extracted from the dispersion diagram and plotted in Fig. 2. The equivalent refractive index is tuned varying with the radius of the circular patch r_h from 0.20 mm to 0.45 mm, whereas the other parameters remain constant as h=0.508 mm, r_v=0.15 mm, r_{iso}=0.70 mm, p=2 mm, and dielectric constant ε_r=2.2. The solid lines are the equivalent refractive indexes for the proposed glide-symmetric mushroom and the dash lines are for the traditional mushroom. Fig. 2 demonstrates that the normalized refractive index $n/\sqrt{\varepsilon_r}$ of the glide-symmetric mushroom of r_h=0.20 mm remains 1.11 from 5 GHz to 30 GHz. However, the corresponding $n/\sqrt{\varepsilon_r}$ of

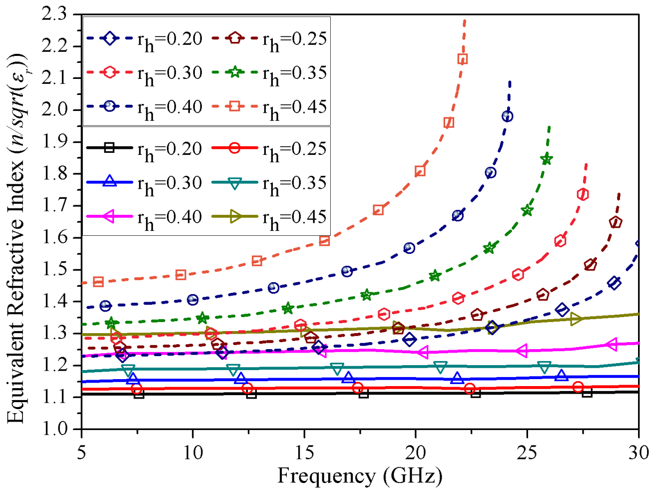

Fig. 2. Comparison of normalized Equivalent refractive index of the unit cells.

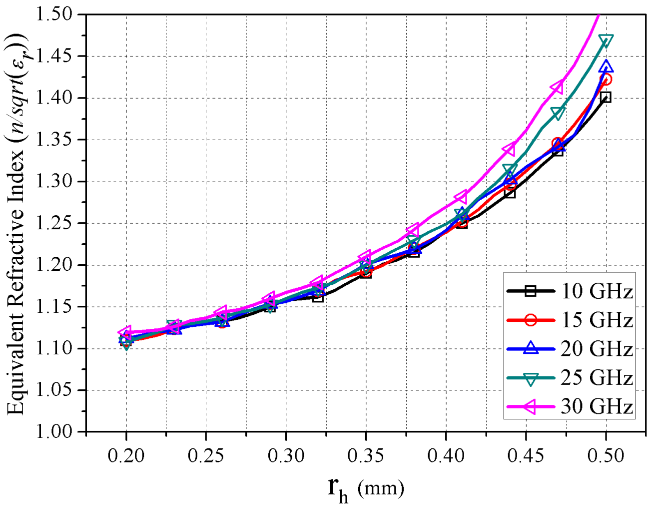

Fig. 3. Normalized Equivalent refractive index of the unit cells versus r_h.

the traditional mushroom varies from 1.23 to 1.6 from 5 GHz to 30 GHz. Moreover, the minimum $n/\sqrt{\varepsilon_r}$ of the traditional mushroom cannot reach very low values. For instance, its minimum $n/\sqrt{\varepsilon_r}$ obtained in Fig. 2 is 1.23 when r_h=0.20 mm, which is not sufficient for the design of Luneburg lens, whose equivalent refractive index varies from 1 to $\sqrt{2}$.

B. Design of the Lens

Fig. 2 has proved the advantages of the proposed glide-symmetric mushroom unit cell. Hence, the glide-symmetric mushroom unit cell is further utilized to design a flat Luneburg lens in this section.

By varying the radius of the circular patch r_h, normalized refractive indexes with respect to different frequencies are obtained and depicted in Fig. 3. The curve of the center frequency 20 GHz is chosen to design the Luneburg lens. In

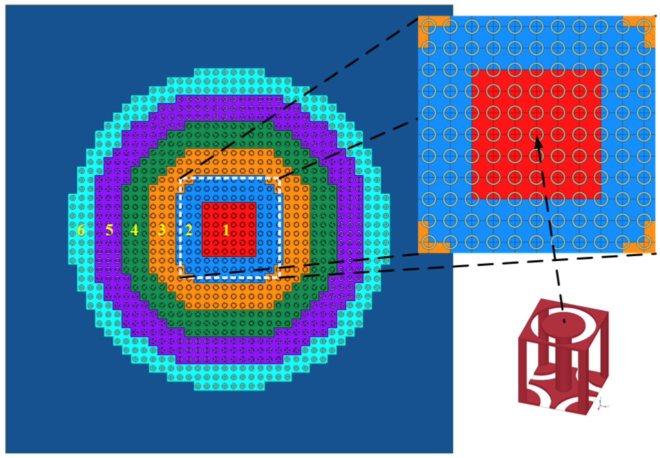

Fig. 4. Full structure of the proposed Luneburg lens in simulation.

order to achieve a Luneburg lens with geometry radius of R_0= 36 mm with 7 gradient index layers, r_h is computed by

$$n = \sqrt{2 - (r/R_0)^2}, \tag{1}$$

where r is the distance from the lens center. The width of each layer is uniform that consisting of three periodicity p. Detail dimension of each glide symmetric via is depicted in Table I, in which r_i is the radius of each layer-ring, whereas r_{hi} is the circular patch radius of each glide-symmetric via.

TABLE I
DETAILED DIMENSIONS OF EACH LAYERS IN LUNEBURG LENS.

Layers	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**
r_i (mm)	r_1=0	r_2=6	r_3=12	r_4=18
$n_i/\sqrt{\varepsilon_r}$	n_1=1.414	n_2=1.404	n_3=1.374	n_4=1.323
r_{hi} (mm)	r_{h1}=0.54	r_{h2}=0.52	r_{h3}=0.50	r_{h4}=0.47

Layers	**Layer 5**	**Layer 6**	**Layer 7**
r_i (mm)	r_5=24	r_6=30	r_7=36
$n_i/\sqrt{\varepsilon_r}$	n_5=1.247	n_6=1.143	n_7=1
r_{hi} (mm)	r_{h5}=0.41	r_{h6}=0.26	-

III. SIMULATION RESULTS

The full structure of the designed Luneburg lens is illustrated in Fig. 4, where each layer is colored differently. Full-wave simulator Ansys HFSS is used to conduct the electromagnetic simulation. A PCB in size of 100×100 mm^2 covered with printed copper except the lens is simulated. A wave port generating TE_{10} mode is excited at left PCB edge, whereas the other PCB edges are set to perfect matching layers, to avoid reflections from between PCB edges and air.

The electric fields inside the Luneburg lens at 5 GHz, 15 GHz, 20 GHz, 25 GHz and 30 GHz are computed and shown in Fig. 5. The electric field distributions imply that the designed Luneburg lens works well in a very wide frequency band except at 5 GHz, because the wavelength in dielectric is around 40 mm.

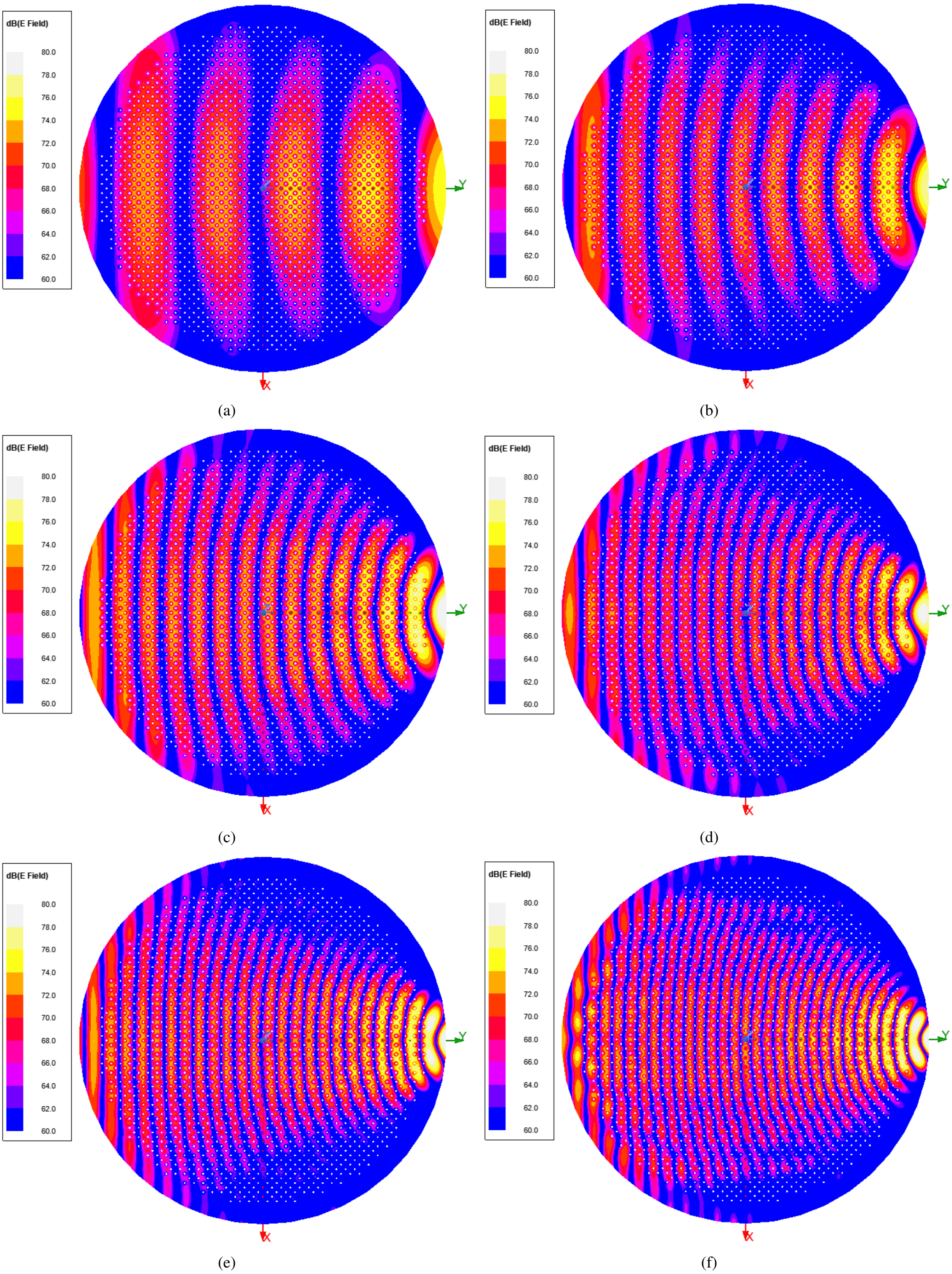

Fig. 5. Electric field distributions in the designed Luneburg lens at different frequencies: (a) 5 GHz, (b) 10 GHz,(c) 15 GHz, (d) 20 GHz, (e) 25 GHz, (f) 30 GHz.

IV. Conclusion

This paper presents a wideband substrate integrated Luneburg lens. The flat Luneburg lens is implemented using a glide-symmetric mushroom unit cell, which has very low dispersion. As a result, stable equivalent refractive index is achieved to realize the wide frequency bandwidth. The proposed Luneburg lens is in compact size and fully integrated in PCBs, which is very promising for applications as feeding network or antennas in 5G and other communication systems.

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