2023 IEEE 11th Asia-Pacific Conference on Antennas and Propagation (APCAP) | 979-8-3503-2627-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/APCAP59480.2023.10470135

A Miniaturized Fan Beam Antenna Based on Spherical Luneburg Lens

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***Abstract-* A beamforming antenna based on a spherical Luneburg lens operating at 3-4 GHz is proposed. The antenna consists of a spherical lens with a radius of 0.8λ_0 (free-space wavelength of the central operating frequency) and five double-ridged waveguides. An approximation to an ideal Luneburg lens is realized by controlling the air-filling rate of a series of hollow dielectric cones with common vertices. By adopting the double ridge waveguide as the feed source, the requirement of the fan beam for the smaller aperture feed source is realized. The simulation results show that the aperture efficiency of the designed lens can reach 60%, the synthetic beam is a fan beam with a width of 145°, and the gain flatness is better than 0.5 dB within ±60°. The antenna has the advantages of small lens size, high aperture efficiency, and wide synthetic beam, and can be used for the deployment of 5G communication base stations.**

***Keywords*-5G communication; Luneburg lens; Fan beam; Aperture efficiency; Double-ridged waveguides**

I. INTRODUCTION

With the development of mobile communication technology, the deployment of mobile communication base stations is increasingly characterized by densification, miniaturization, and wide beam coverage. This puts forward corresponding requirements for the design of terminal antennas, namely miniaturization and wide beam. Literature [1-2] respectively proposed two kinds of Luneburg lens antennas for 5G base stations, which can achieve high gain in the working frequency band, but the radius size reaches 2.5λ_0 and 1.2λ_0, respectively. Literature [3-4] used the antenna array to realize the fan beam, but the lateral dimensions reached 2.9λ_0 and 7.2λ_0, respectively. The candidates for the feed source of the lens are generally low profile microstrip antennas [5] or waveguides.

In this paper, a small-volume spherical Luneburg lens with a fan beam is proposed. The lens radius size is only 0.8λ_0. Five double-ridge waveguide feeds are used to realize a wide-angle fan beam with a fan width of 145° and a gain flatness of better than 0.5 dB within ±60°.

II. STRUCTURE OF THE ANTENNA

The proposed antenna consists of a spherical Luneburg lens and five double-ridged waveguide feeds, as shown in Figure 1. The center of the spherical lens is a dielectric sphere, and a series of hollow dielectric cones are evenly distributed on the surface of the sphere. Fitting to an ideal Luneburg lens can be achieved by adjusting the air-filling rate in the cone. The relative permittivity of the medium is 4.4. The lens can be processed by 3D printing technology. The feed antenna uses 5 WRD250 double-ridge waveguides, and uses coaxial probes to feed. Bevels are cut on the ridge near the aperture of the waveguide to achieve a better match between the waveguide and air. Compared with the rectangular waveguide, under the same working frequency band, the double-ridge waveguide has a smaller aperture, which provides the feasibility to generate a wide-angle beam with good gain flatness.

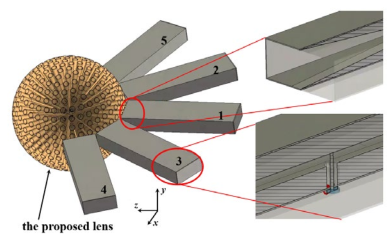


Figure 1. Schematic of the proposed lens antenna.

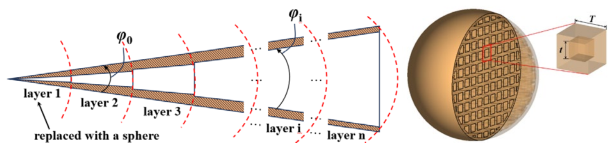
III. ANALYSIS OF STRUCTURE AND MATERIAL PARAMETERS OF LUNEBURG LENS

The basic structure of the proposed lens is a hollow dielectric cone with an apex angle φ_0. As shown in Figure 2 (a), the hollow part of this cone is composed of a series of air cones with common vertices. According to the position of the truncated cone, they are numbered in sequence from the center of the sphere to the surface, and the corresponding vertex angle is recorded as φ_i (i=1,2,…,n). By changing φ_i, the equivalent relative permittivity of the spherical shell where the truncated cone is located can be controlled. If the number of cones is recorded as N, and the relative permittivity of the material used is ε_{r1}, then the equivalent relative permittivity of the i-th spherical shell is:

$$\varepsilon_{ri} = \varepsilon_{r0} - \frac{N(\varepsilon_{r1}-1)}{4}\tan^2\varphi_i, i=1,2,...,n \quad (1)$$

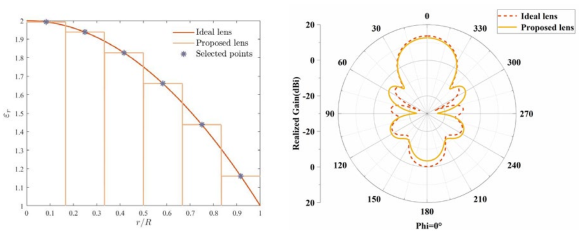
Where, $\varepsilon_{r0} = N(\varepsilon_{r1}-1)/4 \cdot \tan^2\varphi_0 + 1$ .In addition, considering the stability of the lens structure, a series of orthogonal dielectric thin plates are used as the supporting structure inside the spherical shell of the first layer, as shown in Figure 2 (b).

According to the research of Schrank and John Sanford, for lenses with a radius of 10λ_0 or less, when the number of layers is n≥6, increasing the number of layers can only improve the performance of the lens to a very limited extent [6]. Therefore, the number of layers of the proposed lens is chosen to be n=6. Figure 3 shows the comparison between the equivalent relative permittivity distribution of the lens and the ideal Luneburg lens and the radiation pattern of the two when using WR284 waveguide to feed power. It can be seen that the patterns of the two are in good agreement.



(a) (b)

Figure 2. (a) The hollow medium cone. (b) Dielectric sphere.



(a) (b)

Figure 3. (a) The comparison between the equivalent relative permittivity distribution of the lens and the ideal Luneburg lens. (b) The radiation pattern of the proposed and the ideal lens.

IV. Simulation Analysis

Model the antenna using CST Microwave Studio®. Figure 4 shows the gain and aperture efficiency versus frequency for a single WR284 waveguide loading the designed lens. It can be seen that the aperture efficiency of the lens is about 60% at 3-4 GHz. It can be seen from the simulation that the waveguide of the same type loaded with an ideal Luneburg lens has a gain of 13.6 dBi at 3.5 GHz. Whereas the proposed lens can reach 12.6 dB, with only 1 dB difference.

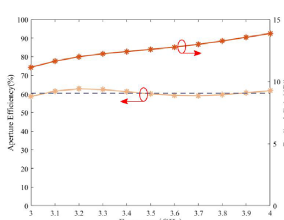
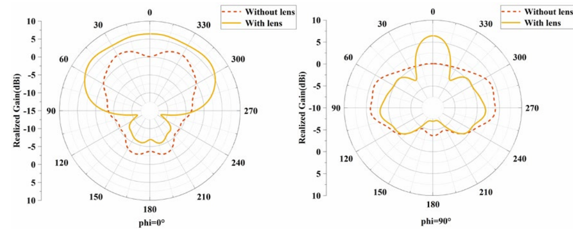


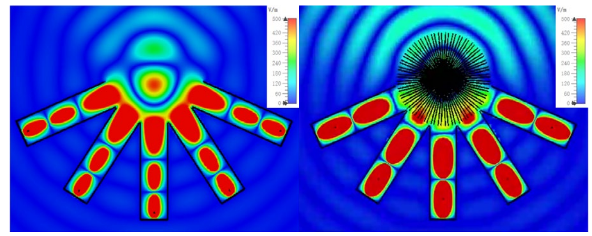
Figure 4. The gain and aperture efficiency versus frequency.

Five WRD250 waveguides are placed on the edge of the lens, and the angle between the main radiation directions of two adjacent waveguides is controlled not to be greater than the main lobe width (37°) in the case of a single feed. Figures 5 and 6 show the resultant radiation pattern and electric field distribution with/without lens, respectively. It can be seen that the lens effectively "corrects" the phase of the electromagnetic wave, so that the approximate plane wave is output in the main radiation direction of each feed source. Therefore, the beam width of the φ=0° plane reaches 140°, and the beam width of the φ=90° plane is maintained at 32°, that is, the main beam is a fan beam. The gain flatness of the main beam is better than 0.5 dB within ±60°.



(a) φ=0° (b) φ=90°

Figure 5. The resultant radiation pattern.



(a) Without lens (b) With lens

Figure 6. The electric field.

V. Conclusion

A small-volume antenna based on a spherical Luneburg lens with a fan beam is proposed. The proposed lens radius size is $0.8\lambda_0$. Thanks to the small-aperture characteristics of the double-ridge waveguide feed, a wide-angle fan beam is realized. The fan beam width is 145°, and the gain flatness is better than 0.5 dB within ±60°. The antenna has application potential in the deployment of 5G communication base stations.

Acknowledgment

The authors would like to thank CST Ltd. Germany, for providing the CST Training Center (Northeast China Region) at our university with a free package of CST MWS software.

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