A Novel Planar Perforated Hyperbolic Secant Lens Antenna for Milli-Wave Applications

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***Abstract* - In this paper, a novel generalized hyperbolic secant (H-S) lens antenna is introduced using perforated dielectric. The simulation results show 24.7dBi of realized gain at 10 GHz with low sidelobe levels (less than -18dB) and 3-dB beamwidth of 9º can be achieved. The 3-D printing technique can be utilized to fabricate the perforated structure of proposed lens. Due to its intrinsic flat shape characteristic, this lens concept could be a potential alternative design for planar Luneburg and half Maxwell fish-eye lens for millimeter-wave application, avoiding using extremely complex conformal mapping methods.**

***Keywords* — Lens antenna; Gradient index (GRIN); 3D printing; Focusing.**

I. INTRODUCTION

Lens antennas have been widely used for many applications at millimeter waves, like imaging systems, massive MIMO systems and radar systems. Unlike traditional lens antennas, Gradient Index (GRIN) lens antennas have the advantages of compact, low profile, lightweight, competitive efficiency and easy fabrication.

There have been several well-known GRIN lens, such as Luneburg lens, half Maxwell fisheye lens, and Eaton lens, which are very attractive and useful structures in milli-wave applications. Despite many merits like the above-mentioned GRIN lens, a self-focusing cylindrical lens structure has not been exhaustively reported in the literatures of milli-wave applications, thereafter known as hyperbolic secant (H-S) lens. It is also called Mikaelian lens [1]. The main difference of the H-S lens with respect to the Luneburg and half Maxwell fish-eye lens is its intrinsic flat shape characteristic. This lens concept could be a potential alternative design for planar Luneburg and half Maxwell fish-eye lens based on extremely complex conformal mapping methods. Moreover, all previous studies [2-3] of this kind of lens antenna are mainly focused on the typical case that the source feed is placed on the lens surface as shown in Fig. 1.

In this paper, we introduce a generalized H-S lens using perforated dielectric based on effective medium theory. Compared to a typical H-S lens, it's more flexible and suitable for milli-wave application. By using full-wave simulation, the radiation performance of proposed H-S lens at 10 GHz are presented.

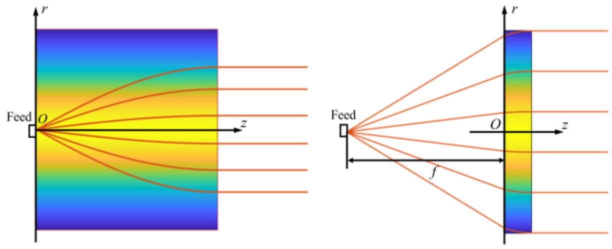


Fig. 1. The ray trajectory through the H-S lens. (a) Typical case of H-S lens. (b) Generalized H-S lens.

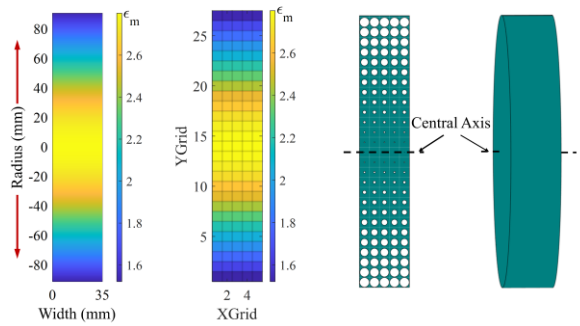
II. DESIGN OF HYPERBOLIC SECANT LENS

The refractive index profile of H-S lens is defined by the following equation [1].

$$n(r) = n_0 \operatorname{sech}\left(\frac{2\pi p}{w} r\right) \tag{1}$$

where n_0 is the refractive index along the z-axis. w is the width of the lens. Based on the effective medium theory, the perforated structure is utilized to achieve the relative permittivity distribution of H-S lens as shown in Fig. 2. The two-dimensional (2-D) relative permittivity distribution need to be discretized into different layers by staircase approximation. Then, the discrete 2-D profile is rotated along central axis to create a three-dimensional (3-D) H-S lens.

In our case, the diameter of the H-S lens is 189mm and thickness is 35mm. The focal length is 204.9mm, and the focal length to lens diameter ratio (F/D) is 1.08. The dielectric substrate has a thickness of 35 mm and a relative permittivity of 2.75 and loss tangent $\tan\delta \approx 0.011$ at 10GHz.



(a) (b) (c) (d)

Fig. 2. The discretization of 2-D relative permittivity distribution of H-S lens. (a) Continuous distribution. (b) Discrete distribution. (c) Perforated dielectric structure. (d) Three-dimensional H-S lens

III. RADIATION PERFORMANCE

To illustrate the H-S lens operation performance at 10 GHz, the printed antipodal fermi antenna (APFA) [4] with corrugation structure is placed at the focal point of H-S lens as a feed source, as shown in Fig. 3.

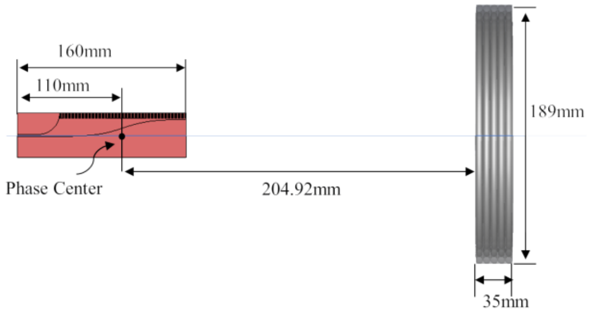
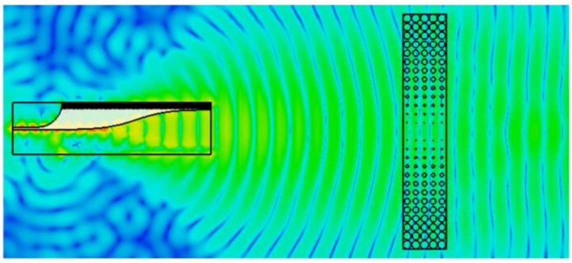
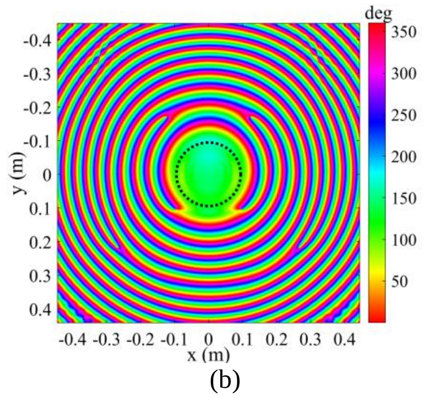


Fig. 3. The schematic of proposed H-S lens antenna at 10GHz composed of feeding source (APFA) and H-S lens.

Fig. 4(a) illustrates the 2-D electric field distribution through the H-S lens. The aperture phase distribution at the exit aperture plane of the lens is given in Fig. 4(b). Obviously, proposed H-S lens can be a phase transformer to convert a spherical wave into a plane wave.



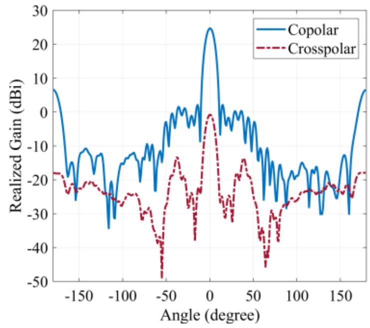
(a)



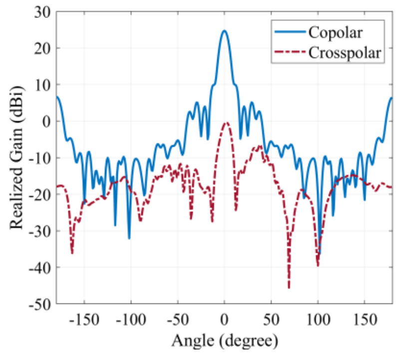
(b)

Fig. 4. (a). Simulated 2-D electric field distribution with APFA as source feed. (b). The aperture phase distribution at exit aperture plane. The black dot circle represents the actual physical aperture (0.189m diameter) of lens

Fig. 5(a) and (b) illustrates the simulated radiation patterns for both Co- and Cross-polar in the E- and H-plane at 10GHz respectively. The simulated realized gain of the H-S lens antenna is 24.7 dBi, which is 10.5 dBi higher than the feeding source of APFA itself. The side lobe levels remain lower than -18dB, and the 3-dB beamwidths of E- and H-plane is about 9 degree.



(a)



(b)

Fig. 5. Simulated co- and cross-polar radiation patterns in E-plane and H-plane respectively at 10GHz. (a) E-plane. (b) H-plane.

IV. CONCLUSION

A novel generalized hyperbolic secant (H-S) lens antenna using perforated dielectric was present in this paper. The simulation results show 24.7dBi of realized gain at 10 GHz with low sidelobe levels (less than -18dB) and 3-dB beamwidth of 9^{o} can be achieved. The 3-D printing technique can be utilized to fabricate the perforated structure of proposed lens. Due to its intrinsic flat shape characteristic, this lens concept could be a potential alternative design for planar Luneburg and half Maxwell fish-eye lens based on extremely complex conformal mapping methods for millimeter-wave applications.

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