# *Design of quaternary layer high-efficiency transimitting phase-gradient metasurface*

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***Abstract*—We introduce a quaternary layer element which can achieve 360° transmission phase shift with very low transmission loss at 28 GHz. Both 1-D anomalous refractive phase-gradient metasurface and 2-D planar lens based on the proposed element are designed and simulated. The designed metasurface have advantage of thin thickness, high efficiency and light weight, and will have important application in high gain antennas and beam control.**

***Keywords—anomalous refraction ;planar lens;phase-gradient***

## I. Introduction

In recent years, the research and application of phase -gradient metasurface have become hotspots[1-7].Based on generalized snell's law anomalous reflection and refraction of electromanetic waves are realized using phase-gradient metasurface[4] . Furthermore, planar lens are realized by taking advantage of metasurface to compensate phase difference based on Fermat's principle[1-3].In this paper, a quaternary layer cascaded metasurface particle that can cover transmission phase 360° with low transmission loss are proposed. Then the 1-D anomalous refractive phase-gradient metasurface and 2-D phase focusing metasurface are designed by using this element. The designed quad-layer metasurface will have important application prospects in high gain antennas and beam control[5-7].

## II. Design and Analysis

As shown in figure 1(b), a quaternary layer cascaded metasurface particle is proposed, which consists of double square loop metal elements integrated on ROGERS RO4003C substrate ($\varepsilon_r$=3.38, tanδ=0.0027) on each layer. As shown in figure 1(a), the length of outer square loop is Lout , the length of inner square loop is Lin($L_{in}$=0.58× $L_{out}$), the width of the metal strip is W(W=0.2mm),the quaternary layers of elements are separated by air with a distance of 2.17mm. The unit cell of this element is simulated at 28GHz with half-wavelength periodicity(P=5.6mm≈$\lambda_0$/2) using CST Microwave Studio. The quaternary layer metasurface improve transmission phase range and avoid the higher-order mode coupling between layer due to the high substrate permittivity. As shown in figure 2, transmission magnitude and phase shift vary with different length of outer square loop under a normal incident planar wave excitation. By increasing Lout from 2.9 to 4.5 , a maximum phase shift of 360° can be achieved with a maximum transmission loss of -1.3 dB, which makes the designed transmitting metasurface very high efficient.

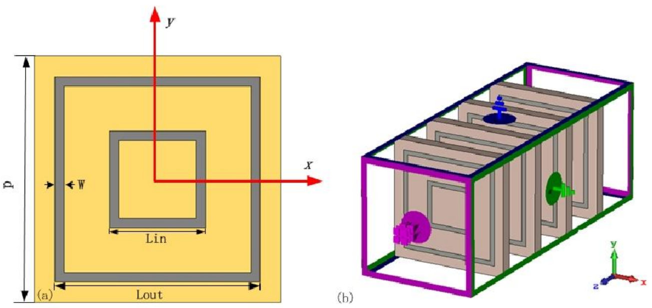


Fig. 1. (a) Front view of the metasurface element. (b) Perspective view of the metasurface element

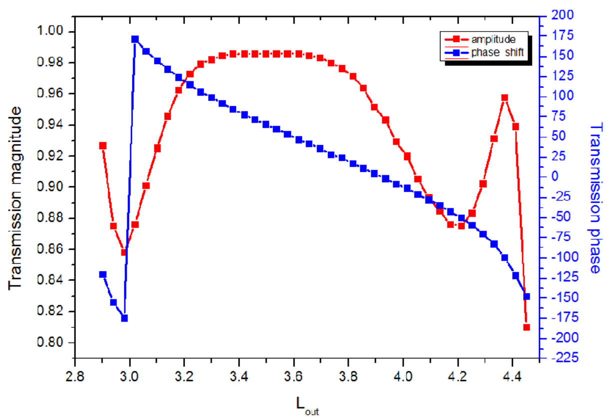


Fig. 2. Simulated performance of the proposed quaternary layer metasurface : transmission magnitude and phase with different square length $L_{out}$.

As shown in figure 4, a 1-D phase-gradient metasurface is proposed, the transmission phase difference of adjacent cells is 45° with a transmission magnitude over 0.9. According to generalized Snell's law, when electromagnetic waves operating at 28GHz are incident perpendicularly to the phase-gradient metasurface , the refraction angle $\theta_t$=12.5°

$$n_t \cdot \sin(\theta_t) - n_i \sin(\theta_i) = \frac{\lambda}{2\pi} \cdot \frac{d\phi}{dX} \qquad (1)$$

where $n_t$ and $n_i$ are the refractive index of the refractive layer and the incident layer, respectively. λ is operating wavelength and dΦ/dx denotes the phase-gradient along x axis.

In order to verify the correctness of the design theory, the refraction phenomenon of 1-D metasurface is simulated. As shown in figure 3, the incident electromagnetic waves emerge an anomalous refraction significantly.

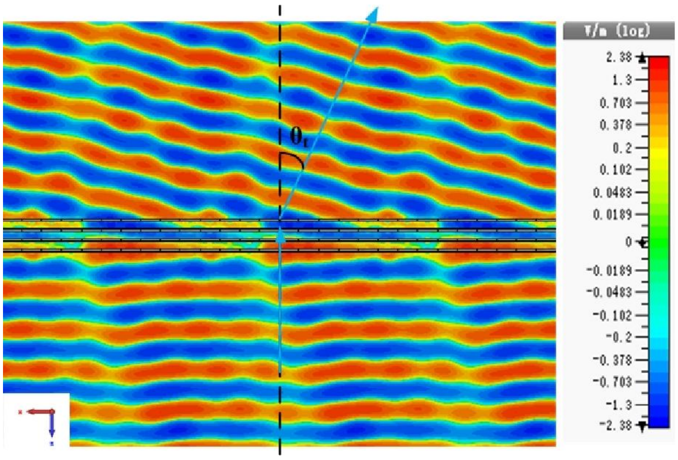


Fig. 3. The electric field density distribution in xoz plane.

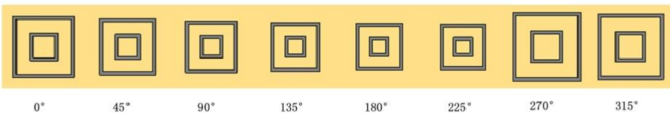


Fig. 4. Diagram of 1D phase-gradient metasurface.

Based on Fermat's principle, figure 5(b) shows the operation mechanism of the proposed planar lens, where quaternary layer metasurface are used to compensate for the zoned phase shift caused by ray path difference. The phase compensation of the planar lens can be calculated by

$$\varphi_c = -\frac{2\pi f}{\lambda_0}\cdot\frac{1-\cos(\theta)}{\cos(\theta)}, \theta = tan^{-1}(r/f) \tag{2}$$

Where r is the distance from the lens center to center of a cell, θ is the angle of an incident ray deviated from the axis, and f is the focal length of the lens. The structure is arranged by 21×21 units array, while the designed focal length is 53mm.The operating frequency is set to 28 GHz, transmission magnitude and phase of metasurface element is shown in figure 2.As shown in figure 6(d), a normal incident electromagnetic waves focus on z=-60.7 plane, which means real focal length of planar lens is 52.16 mm. As shown in figure 6(b), the radius of focal point is 3.61mm when energy decrease to -3dB.

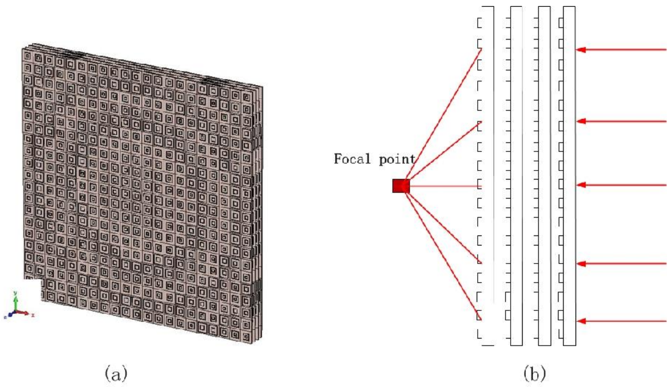


Fig. 5. Geometric structure of the proposed planar lens based on quaternary layer metasurface.

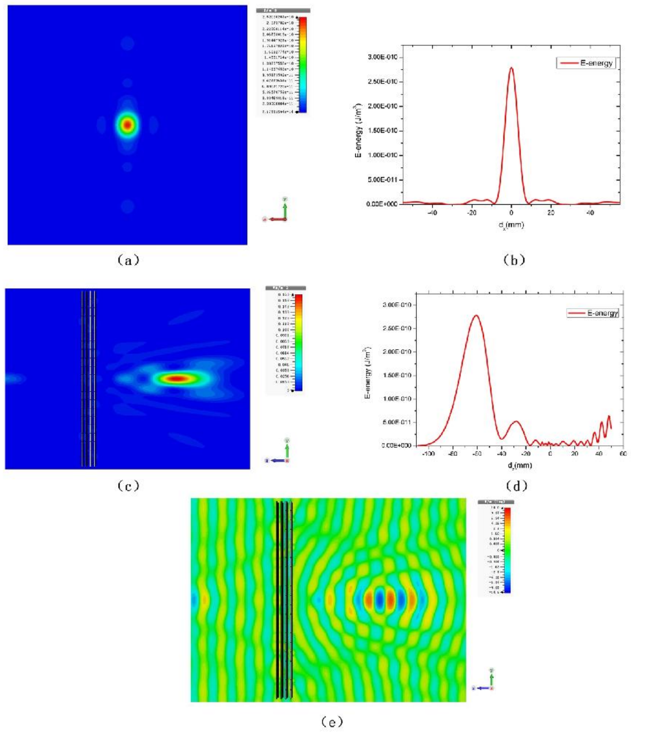


Fig. 6.Simulated performance of the proposed planar lens:(a)The electric energy distribution in z=-66.7 plane;(b) The electric energy distribution in z=-66.7 plane along x axis;(c)The electric energy distribution in yoz plane;(d) The electric energy distribution in yoz plane along z axis;(e) The electric field density distribution in yoz plane.

## III. CONCLUSION

In this article, we propose a quaternary layer metasurface particle which can achieve 360° transmission phase shift with a very low level of transmission loss. To verify the the proposed particle ,both 1-D anomalous refractive metasurface and 2-D focusing planar lens are designed and simulated.

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