Reflectarray Based on Concept of Gradient Refractive Index

Shi-Wei Qu*, Jerdvisanop Chakarothai, Qiang Chen, and Kunio Sawaya
Sawaya-Chen Lab, School of Engineering, Tohoku University
Aramaki Aza Aoba 6-6-05, Aoba-ku, Sendai 980-8579, Japan
E-mail: dyon.qu@gmail.com

Introduction

Planar reflectarrays are receiving more and more attentions since they were proposed a few decades ago due to their many advantages, such as flat and low-profile structures, low manufacturing cost, and relatively high efficiency and so on [1]-[4]. Although a few analytical formulas can reveal their operating principles, practical designs of planar reflectarrays are actually a quite complicated and troublesome process. A lot of factors should be taken into consideration, for example, there are reflection phase, reflection efficiency, beamwidth, and bandwidth just only for element itself, and several other factors for the whole arrays [2]. Metamaterials with controllable permittivity and permeability over an interesting frequency band attract efforts and attentions of many researchers [5], in spite that there are some controversies about them [6]. Planar gradient index (GRIN) lens [7] is a typical one among many applications of metamaterials, which can be made by a series of split ring resonators (SRR) with gradually increasing refractive index [8], or other structures [9]- [10]. The possibility to replace traditional curved lens by the planar GRIN lens is reported, since as it is known that the former is costly and much difficult to fabricate [11]. In [9], it is employed to realize beam steering or focusing to improve electrical performances of horn antennas. Moreover, since the particles operate in non-resonant mode in the GRIN lens, the loss inherent in metamaterials is also quite small. In this paper, a type of novel reflectarray based on the GRIN lens is proposed. Basic idea about the new reflectarray is carefully addressed in next section, and then initial simulated results are given in the following part.

Basic Idea about Reflectarray Based on Gradient Refractive Index

Basic operating principles of the proposed reflectarray, composed of a GRIN lens and a metal plate, are described in Fig. 1. The lens, denoted by a rectangular box, is discretized into m segments with a side length of p along x and z directions, and the refractive index is n_i for the ith segment. Meanwhile, there are q layers along z direction with identical n_i for each segment. A deeper color in the box represents a larger refractive index. Here the lens functions as a beam-steering component, shifting the wave-propagating direction by an angle of θ to +x direction. A metal plate is placed behind the GRIN lens with a proper distance of d. When plane waves are incident from +z direction, they firstly pass through the GRIN lens with a shifted propagating direction [9]. Then the waves hit the

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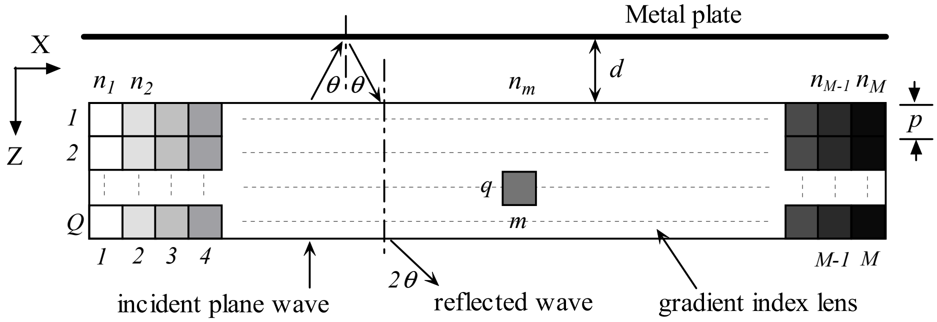

Fig. 1. Simplified model of the proposed reflectarray fed by a plane wave.

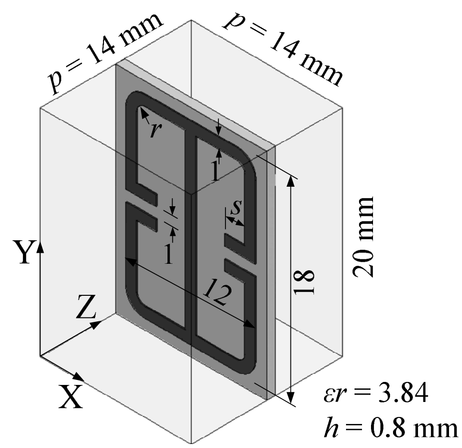

Fig. 2. HFSS model of the employed metamaterial particle (in mm).

metal plate and are reflected back with a reflection angle equal to the incident angle, and finally pass through the GRIN lens again with a further shifted angle of 2θ to +x direction. For this arrangement, the required $\Delta n = n_i - n_i - 1$ is only a half of its original value in [8]- [11] for the same deflection angle, so much better impedance matching between the GRIN lens and free space can also be achieved.

Initial Practical Model, Simulated Results and Discussions

Actually, there are other commercial softwares that can more effectively simulate the proposed reflectarray, after the effective permittivity and permeability of each particle with different parameters are extracted by the finite element method (FEM), because full-wave simulations, especially for metamaterials with fine structures, need amount of resources, i.e. CPU time and memory. However, our initial investigations of the simplified model in Fig. 1, to verify our basic ideas about reflectarray realized by the GRIN lens, are still based on full-wave simulations by the FEM in this paper.

Fig. 2 shows the FEM model of the employed metamaterial particle in this design, which is also given in ch.4 of [5] as a rapid design example, but the center frequency of our design is 2.6 GHz, instead of 10 GHz. The total dimensions of one particle are 14 × 20 × 14 mm^3 in x, y, and z directions, respectively, and the employed substrate has a relative permittivity ε_r = 3.84 and a thickness h = 0.8 mm. The other parameters are given in Fig. 2 in millimeter (mm). For this kind of

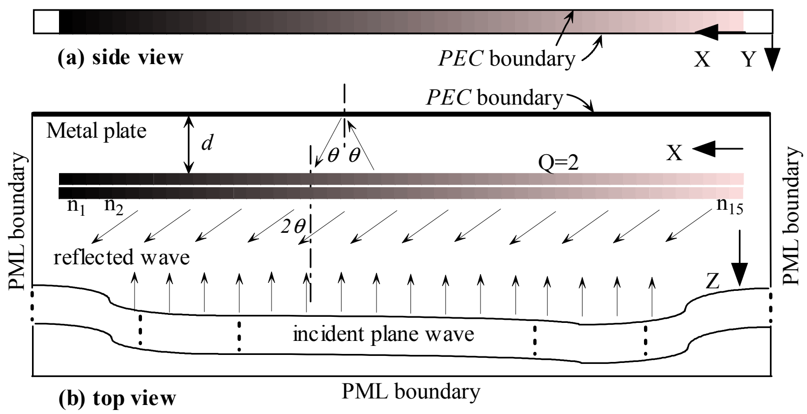

Fig. 3. HFSS model of plane-wave fed reflectarray realized by the GRIN lens.

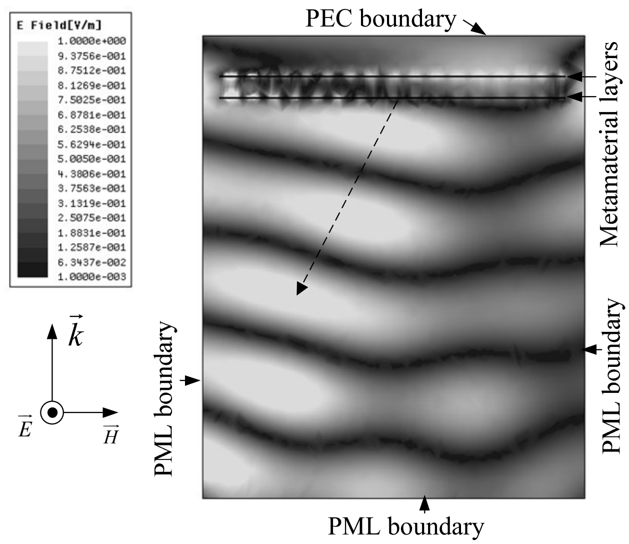

Fig. 4. Simulated distributions of scattered electric fields on top surface.

particles, its refractive index n and equivalent wave impedance η are functions of r and s, i.e. $n = n(r, s)$ and $\eta = \eta(r, s)$. The desired value n_i in Fig. 1 can be achieved by tuning r and s, keeping η close to unity at the same time for better impedance matching.

Simplified model in the FEM simulations is given in Fig. 3. There are 2 slabs along z direction, i.e. $q = 2$, and particle number along x and y directions are 15 and 1, respectively. The boundary condition in each plane is given in the figure, and there are 3 perfect electric conductor (PEC) and 3 perfectly matched layer (PML) boundaries, so it operates as an infinite array along y axis. The optimized value of d is 26 mm (0.23 λ_o), among discrete parametric studies of 0.1λ_o, 0.23λ_o, and 0.5 λ_o, where λ_o is the free-space wavelength at the designed frequency 2.6 GHz. Fig. 4 shows simulated distributions of the scattered electric fields on the top PEC surface at 2.6 GHz, with excitation of plane waves propagating along –z axis. It is clear from the figure that the reflection angle 2θ is about 25^o~30^o, and the PML boundary still has some influences on the reflected waves. It is also obvious that only the middle part of the GRIN lens can work well, and end effects make the particles in the two ends disfuntional. Generally speaking, the number of particles should be much larger than what is employed in this design, for example, over 30 particles are used in [8]- [9] across its apertures, however, even 15 particles in our design can prove validity of the idea to construct a novel reflectarray with the GRIN lens. Experimentally verifications and design of the proposed reflectarray fed by an offset source are under progress.

Conclusion

A novel reflectarray realized by the metamaterial GRIN lens has been proposed and investigated in this paper. Its operating principles and how to make this model into reality are carefully addressed, and simulated results by the FEM validate the simplified model. It is definitely sure that there are other plans to replace conventional reflectarray by a new one made of metamaterials.

Acknowledgement

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