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Metasurface Augmented Lens Antennas

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***Abstract*—In this paper the theoretical methodology of lens antennas augmented with metasurfaces is proposed and demonstrated with 28 GHz 2D Luneburg lens. The paper performs details an approach based on method of images to design a metasurface augmenting a lens antenna. The cases of PEC reflector and metasurface reflector are considered and 28 GHz Luneburg lens simulated in CST Microwave Studio. The simulated results demonstrate successful beamsteering of a lens antenna radiation by an engineered metasurface.**

***Keywords*—5G Communication, Luneburg Lens Antenna, Metasurface.**

I. INTRODUCTION

High data throughput demands for wireless communication systems create new challenges for the hardware design. The 5 and beyond wireless communication networks are aiming at higher frequencies as millimetre and sub-millimetre become more and more attractive offering wide bandwidth necessary to adequately respond to high data rate demands. However, the high path loss associated with propagation at these frequencies requires antenna engineers to propose high gain antenna designs to compensate for the extra loss incurred.

Phased arrays, lens and metasurface antennas are popular designs for mm-wave frequencies. As a high gain beamformers the lens antennas can be used[1], [2]. The gradient lens antennas are alternative to the traditional homogeneous lens antennas and can provide broadband operation, beam-steering capability within wide angle of view and reduced scan loss. The gradient index lens can be implemented using additive manufacturing [3], [4] or being all-metal support artificial dielectric approach [5], [6].

The metasurface antennas employ planar design with wither incorporated feed with leaky wave radiation mechanism or separate spatial feed as in reflectarray[7] or transmittarray structures [8] .The other way is to use antenna arrays with spatial feed. The transmit or reflectarray can provide beam steering capability by incorporation tunable component into each unit cell of the metasurface [7], [9]. For simplifying biasing networks and decreasing power supply the unit cell with 1-bit quantization are often used [10]. In its turn only two-phase states leads to the gain drop for scanning angles and decreasing the angle of view of antenna array.

The classical advantages of diffractive lenses can be augmented with 2 dimensional metasurfaces to achieve novel properties, especially in spatial beam control. In this paper the theoretical methodology of lens antennas augmented with metasurfaces is proposed and demonstrated with 28 GHz Luneburg lens.

II. THEORY

A metasurface can be designed as a thin layer of scatterers placed in a boundary between two media in such a way that induced electric and magnetic currents correspond to the necessary change in the electric and magnetic fields above (+) and below (-) the boundary [11], as shown in Figure 1,

$$\vec{J}_s = \vec{n}\times\left(\vec{H}_2^{+} - \vec{H}_1^{-}\right), \vec{M}_s = -\vec{n}\times\left(E_2^{+} - \vec{E}_1^{-}\right)$$

There exists a multitude of different implementations of the metasurfaces exploiting either electric or magnetic current boundary conditions or both. The key design parameters for the metasurfaces would be either impedance Zs or admittance Ys tensor. In some simpler cases a phase-only relation is considered as in classical reflectarray theory [12].

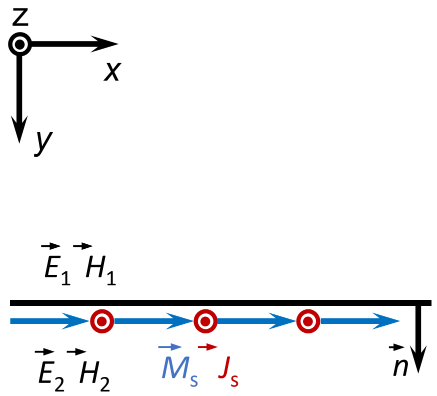

Figure 1. Fields on engineered metasurface.

III. METASURFACE AUGMENTED LUNEBURG LENS

Let us consider as an example a Lunenburg lens [13] with a dielectric permittivity profile as follows

$$\epsilon_r = 2 - \left(\frac{r}{a}\right)^2 \qquad (1)$$

The lens is centrally symmetric and can be analyzed in 2D and 3D forms using (1). The lens presents an optical system that transforms a point source placed on the circumference of the lens into a plane wave emanating from the lens in an opposite direction and follows the ray distribution shown in Figure 2.

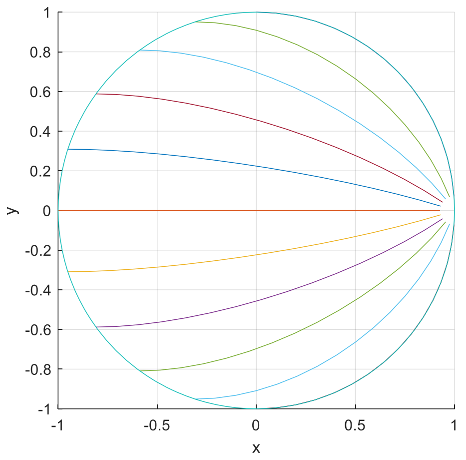

Figure 2 Ray distribution in a Luneburg Lens.

Let us consider a simple case of half a lens backed with a ground plane. In order to understand the direction of the reflected wave one can employ the method of images. Namely, one can place a virtual source at a position mirrored with respect to the ground plane as shown in Figure 4.

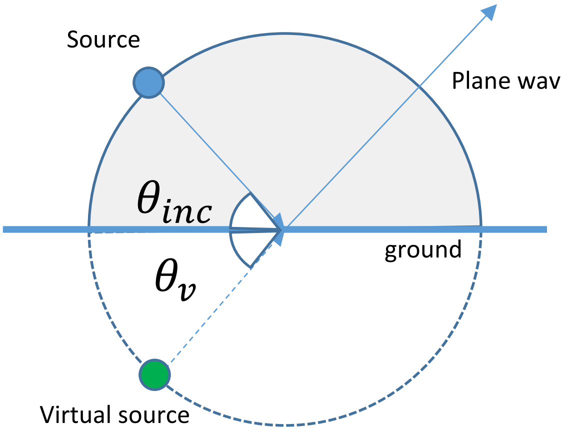

Figure 3. Half of the Luneburg lens above a ground plane.

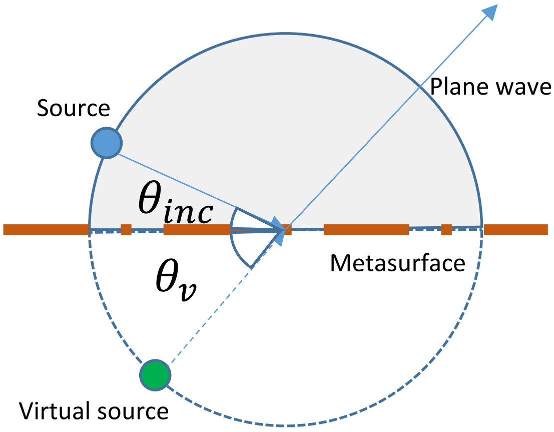

Figure 4. Half of the Luneburg lens above an engineered metasurface.

By developing this analysis further one can place a virtual source that corresponds to a desired radiation direction and design the metasurface that realise the field difference induced by real and virtual sources as shown in Figure 4.

IV. SIMULATIONS

In order to demonstrate this principle a 2D Lunenburg lens with 100 mm radius and thickness of 6mm and covered with metallic plates was simulated in CST Microwave studio. The permittivity distribution is approximated by 5 layers of 20mm width.

There were several variations simulated and the first one was the arrangement with the half lens and the ground plane as shown in Figure 3.

The structure was excited at 28 GHz with 9dBi horn antenna rotated to form an incident angle of 30 degree. The simulation shown in Figure 5 demonstrated specular at -30 degree that confirms our analysis demonstrated in Figure 3.

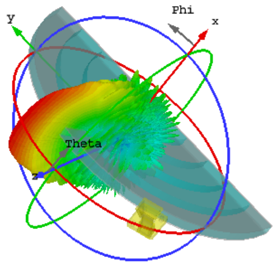

Figure 5 Simulation of half of the Luneburg lens with a PEC ground plane excited at 30 degrees.

In order to engineer the metasurface that steers the beam in different direction, we employ the fact that by simulating the virtual source in different positions one can find necessary field distribution for both incident and induced fields.

Here, the full lens is simulated as shown in Figure 6. The virtual straight lines are drawn to sample the electric field in the different planes passing through the centre of the lens as shown in Figure 6. Since the lens is centrally symmetric this exercise is identical to sampling the fields in a central cut and rotating the source. Obviously, the simulation shown here is much faster.

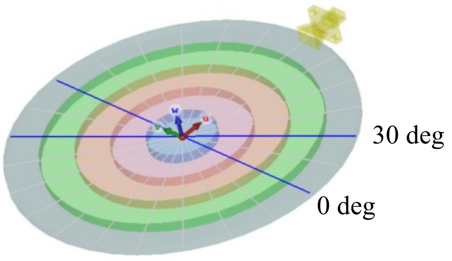

Figure 6 Simulation of full Luneburg lens and sampling field in rotated planes (0 degree and 30 degree) (top and bottom metallic plates are hidden).

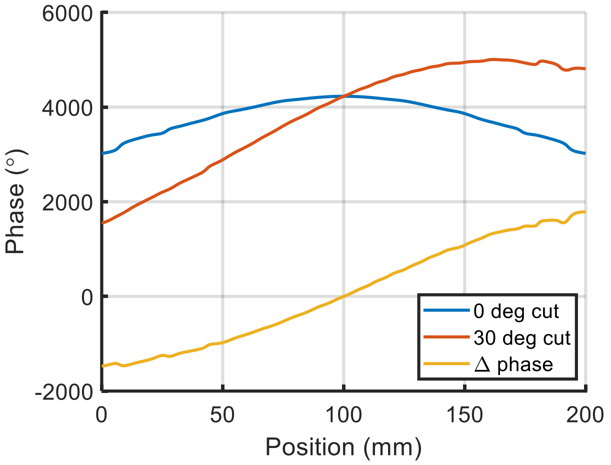

Figure 7 Phase profiled at cuts taken at 0 degree, 30 degree and the difference between them.

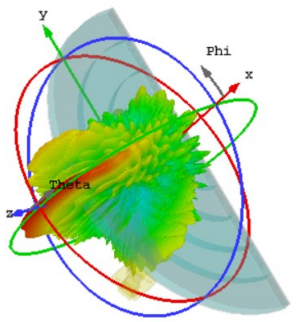

Figure 8 Simulation of half of the Luneburg lens with a metasurface engineered for radiation in normal direction and excited at 30 degrees.

The two cuts chosen for this exercise were 0 and 30 degrees rotated with respect to the VoW plane as shown in Figure 6. The phase distribution sampled at this plane is shown in Figure 7 as well as the phase difference between these profiles.

The metasurface was designed to compensate for the phase difference between the real and virtual sources, which in this case were placed at -30 degrees and 0 degrees, so that the resultant wave is reflected back at normal direction.

The details of the metasurface design are reported in [14] and not of interest in this paper. However, once the reflective metasurface as designed and the augmented lens was simulated in CST Microwave studio with excitation placed at -30 degrees, the resultant beam was pointing at normal direction as shown in Figure 8.

V. CONCLUSION

The paper presents a method for design of lens antennas augmented with metasurfaces in order to steer the radiation pattern of the antenna. As an example, a 5-layer parallel plate waveguide Luneburg lens is simulated. The lens with PEC reflector has demonstrated specular reflection with 30 degree beam direction. In turn the antenna with engineered metasurface steered the beam to normal direction with the same position of the exciting source. Thus simulated results demonstrate successful beamsteering of a lens antenna radiation by an engineered metasurface.

In further work, a transmission case as well as reconfigurable structures will be explored.

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