Luneburg Antenna

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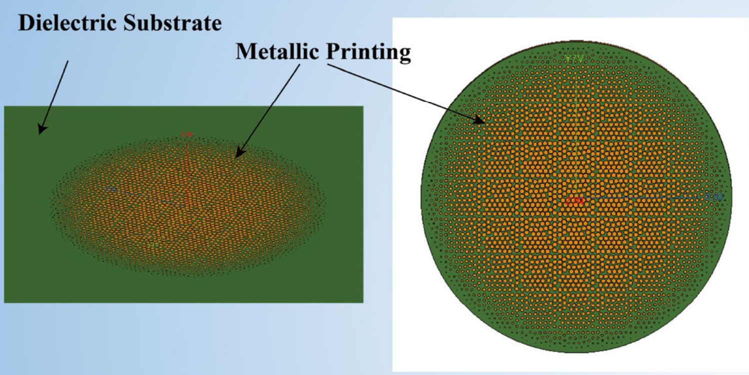
Introduction

Luneburg lens antennas operating in microwave band is drawing increasing attention in recent years because of its almost unlimited spatial reuse property and potential to replace expensive transceiver components in MIMO systems for next generation communication systems. Traditionally, Luneburg lenses are designed and fabricated by changing the effective refractive index of dielectric composites with 2D or 3D inclusion particles. However, the dielectric lenses with multiple layers are very expensive due to the complex fabrication process. A more flexible solution to achieve Luneburg lenses is using metasurface because it allows a large number of layers or pixels to better approximate the refractive index profile of the Luneburg lens. The variant impedance corresponding to the refractive index of a metasurface is obtained by changing the geometrical parameter of the metallic printings on a dielectric substrate gradually. The metallic printings on substrate are arranged in crystal or quasi-crystal in order to obtain the effective refractive index of a unitcell analytically or numerically. However, this leads the lenses essentially anisotropic and its radiation patterns from different spatial angels different, which directly limits the wireless communication quality of MIMO systems with Luneburg lens antennas.

Our Work



(a) (b)

Fig.1 A hyperuniform disorder metallization pattern for Luneburg lens.
(a) Perspective view, (b) top view.

THEORY AND METHODS

The refractive index of a Luneburg lens is given by the Luneburg law

$$n_{eq} = \sqrt{2-(\rho/R)^2} \quad (1)$$

where ρ is the radial coordinate and R is the radius of the Luneburg lens. With this refractive index profile, the lens focus a plane wave into a cylindrical wave (2D) or a spherical wave (3D) at its rim, or reciprocally, transforms the wave from a point source into a plane wave. Therefore, the Luneburg lens can be used as a highly directive antenna with scanning property to receive signals from different directions.

The concept of "hyperuniform" is used to describe a point distribution pattern whose number variance $\sigma(R)$ within a spherical (3D) or a cylindrical (2D) sample region with radius R of increases at a rate slower than the increase rate of the region volume. Therefore, the hyperuniformity can be regarded as a constrained random pattern and greatly suppresses the variation of particle density, like a crystal. On the other hand, within a short distance, the hyperuniformly distributed particles have identical physical properties seeing from all directions, like a liquid. Comparing to complete random dielectric composites, hyperuniform composites are more isotropic at low frequencies, i.e. sizes of inclusion particles are much smaller than the wavelengths. At higher frequencies, similar to crystals, the hyperuniform disordered composites also have photonic bandgaps but suppress the Bragg scattering because of the disordered arrangement, as show in Fig. 1. To obtain the gradient index of surface impedance according to equation (1), the radius of circular patches are adjusted according to the fitted curve shown in Fig.2.

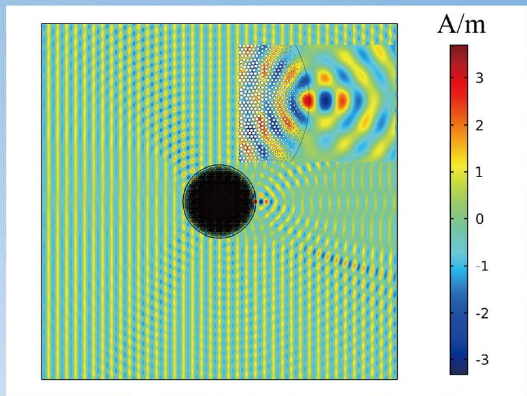


Fig.3. Snapshot of the simulated Magnetic field (Hz) at the designed frequency (Inset: local field profile inside the Luneburg lens and near the focus point.

Simulation Results

To design a metasurface for a Luneburg lens antenna with radius of 4 cm, the hyperuniform unitcell is first extended periodically along x and y directions, and patches outside region of the lens are discarded. The local refractive index of each patch can be determined by (1) based on its position, and the size of each printing patch is determined by the fitted curve shown in Fig2. Finally, the designed metasurface consist of 2819 circular patches and radiuses of these patches range from0.02 mm (at lens rim) to 0.606 mm (at lens center) as shown in Fig.1. To verify the functionality of the proposed metasurface, we illuminate it with a plane wave traveling in the XY plane from different directions. The design is then tested through full wave simulation with the commercial finite-element solver COMSOL, and the resultant magnetic fieldprofile is shown in Fig. 3. The plane wave is incident from the x direction to the $+x$direction, and the metasurface produces a focus right behind the lens rim. Although there are some backscattering at around 60°, the field profile shows a very good focusing function.

The field profiles along the Luneburg lens rim for plane wave excitations from different angles are shown in this figure, and the incident angles are $-30^\circ, -10^\circ, 0^\circ, 10^\circ\ 30^\circ$, where 0° refers to the position along the x-axis direction. Based on Fig.3, the focusing points precisely locate at the incident angles on the lens rim and the intensities are almost identical. Reciprocally, if place a point source at the rim of this Luneburg lens, a perfect plane wave on the other side of the lens will be produced. Moreover, the radiation pattern and directivity remain stable when the source moves along the lens rim by $\mp 10^\circ$ and $\mp 30^\circ$, as verified in Fig. 4.

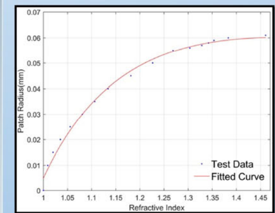


Fig.2 Relation between the radius of the printed circular patch and the refractive index.

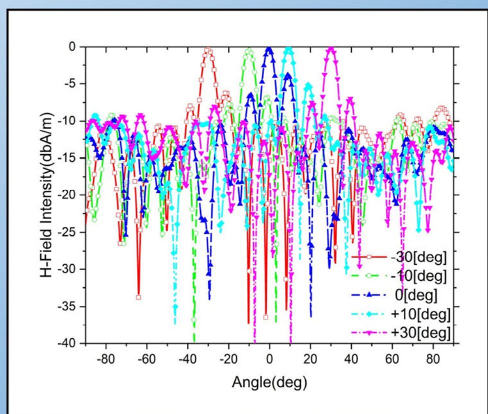


Fig.4 Magnetic field intensity along the lens rim for different angles.

CONCLULSIONS

In this letter, an alternative non-uniform metasurface design for planar Luneburg lens antennas is presented.The lens is realized through a metasurface with variable metallic printings: by modulating the size of circular patches printed on a dielectric slab, a gradient effective refractive index profile is achieved to approximate the Luneburg law.Then the circular patches are hyperuniformly disordered arranged to suppress anisotropy of the lens.Numerical results show that this metasurface is more circularly symmetric and provides more stable scanning properties than previous