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Metal-only Reflecting Luneburg Lens Design for Sub-THz Applications

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***Abstract*—This paper presents a metasurface (MTS) beam-former based on Reflecting Luneburg Lenses (RLLs) operating in the sub-THz range. RLLs consist of two circular parallel plate waveguides (PPWs) vertically stacked. The bottom wall of the lower PPW is loaded with a MTS with an axially symmetric modulation. The wave launched by a primary feed in the bottom PPW is collimated in the top one, so that a plane wave is identically generated for any azimuthal position of the source. The proposed solution uses a bed of nails, well-suited to fabrication by Si micromachining, to implement the RLL refractive index profile. Simulation results yield a 30% -3dB directivity bandwidth around the center frequency (280 GHz). This device can be used as a beam-former for multi-beam antennas for Earth observation or for front- and back-hauling in beyond 5G wireless.**

***Keywords*—Metasurface, Reflecting Luneburg Lens, beam-forming, flat optics, sub-millimeter waves.**

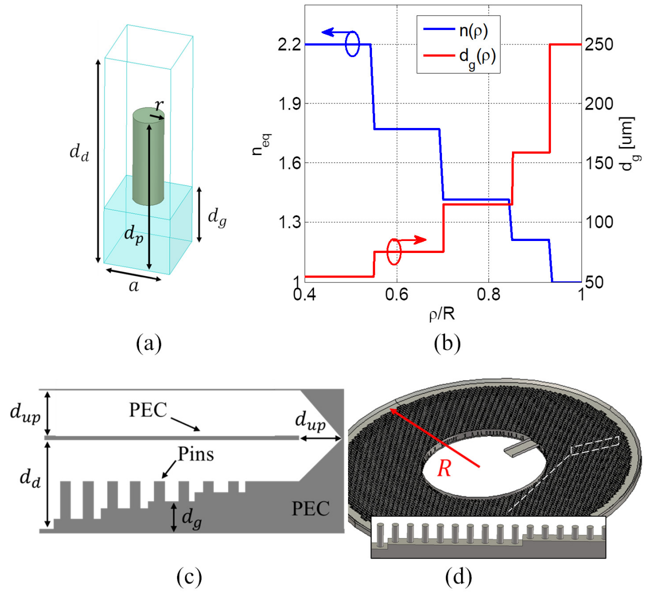
I. INTRODUCTION

Larger bandwidths are necessary to deal with the steady increase in wireless data traffic over the last decade, and it is an accepted fact that beyond 5G wireless will have to access the sub-THz range (above 100 GHz). Applications include switched point-to-point links in data centers and wireless backhaul/fronthaul [1]. More specifically, the IEEE has already published a standard [2] that allocates the 253-325 GHz frequency band.

To work at the aforementioned frequency range one has to select accurate fabrication processes that also guarantee low losses. To this end, Si wafers can be micro-machined with micrometer accuracy by deep reactive ion etching (DRIE) and then metallized by sputtering Au to avoid dielectric losses [3]. On the other hand, beam-steering is pivotal at these bands to ensure an accurate beam alignment in long-range point-to-point scenarios. Besides, multi-beam architectures are also crucial for user tracking in point-to-multipoint configurations.

Reflecting Luneburg Lenses (RLLs) have been proposed as effective beam-formers for multi-beam antennas at mm-waves [4]. They provide total azimuthal scanning, without suffering from feed blockage effects, and present a low-profile, while efficiently using real-estate with the beam-forming network and the radiating aperture within the same horizontal area. RLLs comprise two vertically stacked circular parallel plate waveguides (PPWs). The beam launched by a primary source in the lower PPW is transformed into a plane wave in the top PPW, thanks to a proper radial modulation of the equivalent refractive index. RLLs can be implemented by modulated metasurfaces (MTSs) [4] that impose the required impedance boundary conditions to control the curvilinear wavefront of a surface wave.

This work presents a RLL design by a metal-only MTS that operates in the sub-THz range from 240 GHz to 320 GHz.



(a) (b)

(c) (d)

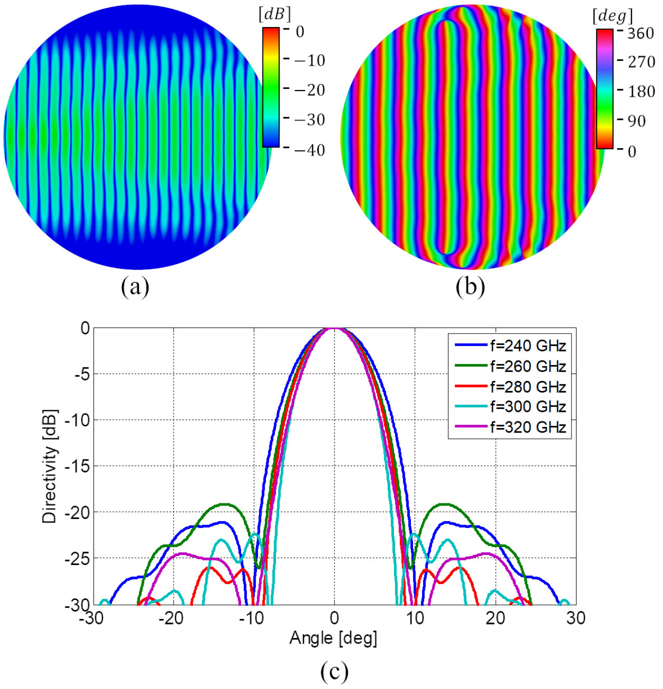
Fig. 1. (a) Unit-cell containing the metallic pin and base, with $r = 25$ μm, $d_d = 375$ μm, $d_p = 250$ μm and $a = 110$ μm. (b) Piecewise refractive index profile (blue line) and the d_g (red line) as a function of the radial distance. (c) Side view of the lens, with $d_{up} = 125$ μm. (d) Perspective view of the structure.

II. DESIGN OF RLLS AT SUB-THZ REGIME

The MTS lens is implemented by a bed of nails [5] with constant height d_p for the pin-air interface and pins grown on a pedestal with varying height $d_g(\rho)$. Fig. 1a depicts the unit-cell constitutive element. In essence, the base height for each unit-cell is linked with the local equivalent refractive index $n_{eq}(\rho)$. Since we envisage a future fabrication by DRIE, $n_{eq}(\rho)$ of the original model [4] has been appropriately adapted. A maximum of four etching steps is selected to avoid increasing the fabrication complexity [3]. This means that the refractive index can only take five values along the lens radius, since the final step with $n_{eq} = 1$ does not require any etching. Furthermore, a minimum difference of 20 μm between consecutive steps is imposed to keep a sufficient height difference between zones.

The system is fed by an H-plane sectoral horn placed in the internal focal circle of the bottom PPW. Thus, after sampling the original $n_{eq}(\rho)$ in five steps, we carry out an optimization to adjust the value and the position of each step to the previous fabrication constraints. Likewise, the location of the feed is optimized, being finally set at $\rho = 0.4R$, where R is the radius of the lens. Fig. 1b presents the obtained profile of $n_{eq}(\rho)$ (blue line), which results in a piecewise function starting from the source position. For the MTS, we use the unit-cell in Fig. 1a to generate a curve relating the base height d_g with the local refractive index, not shown here for the sake of space. Fixing the radius of the lens to $R = 6.5\lambda_0$, where λ_0 is the free-space wavelength at 280 GHz, we get the radial distribution of the ground depth (red line) shown in Fig. 1b. Fig. 1c depicts a schematic illustration of the side view of the lens along with the corner reflector used to couple the wave energy to the upper layer, while a perspective view of the entire structure is shown in Fig. 1d.

Fig. 2a and Fig. 2b present the simulated magnitude and phase, respectively, of the real part of the vertical E-field component in the top PPW of the structure, computed by CST [6] at 280 GHz. As observed, a plane wave is clearly generated. The consequent radiation patterns at the H-plane (xy-plane, where the lens lies) are plotted in Fig. 2c, showing an excellent behavior throughout the entire band of interest.



(a)

(b)

(c)

Fig. 2. (a) Real part of the vertical component of the E-field and (b) phase distribution in the top layer at $f = 280$ GHz. (c) Simulated radiation pattern in the band of interest.

III. CONCLUSION

A new version of the Reflecting Luneburg Lens (RLL) has been presented for operation at sub-THz frequencies. To avoid huge dielectric losses at such high frequencies, the RLL is implemented through a metal-only structure based on a bed-of-nails metasurface. Moreover, the required refractive index profile is adapted to the fabrication constraints of deep reactive ion etching by adopting a variation of the refractive index amenable for fabrication with just 4 etching steps. This adjustment results in a piecewise function of the refractive index composed of 5 values, since the last step does not need any carving process. The proposed lens is a wide-band beamformer solution, particularly interesting for multi-beam and beam-scanning antennas for beyond 5G wireless.

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