Modulated metasurface antennas and beam-formers for mm-waves and beyond

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***Abstract* – Modulated metasurfaces (MTSs) can be efficiently used to guide the propagation of surface-wave (SW) wavefronts or to gradually radiate the power carried by a SW. These two complementary mechanisms can be applied, respectively, to design beam-formers and antennas capable of addressing some of the needs in emerging millimeter wave wireless and future networks beyond 5G. More precisely, we will present the use of modulated metasurfaces for the design of high-gain antennas and broadband beam-formers. We will also show how the later can be efficiently combined with the former to provide multi-beam operation.**

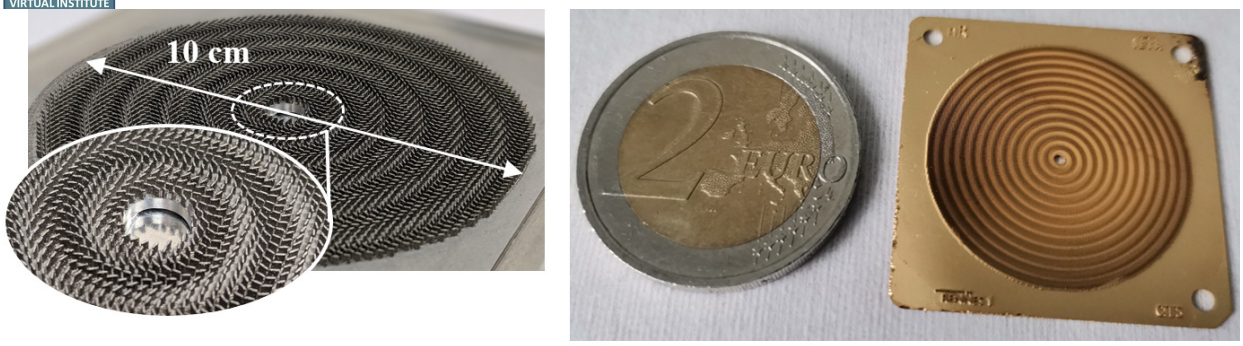
I. Introduction

Operators are currently deploying millimeter-wave 5G cellular networks for reliable and low-latency communications, enhanced mobile broadband and massive machine-type communications [1]. However, ways forward at sub-THz frequencies (above 100 GHz) are already under study to cope with the race to data rate [2] and some standards have been already proposed. One of the key challenges will be the deployment of a large number of small cells and the use of millimeter-waves and sub-THz frequencies to enable ultra-large bandwidth wireless, with seamless connectivity to the core network and to the cloud. Directive antennas with multi-beam or beam steering capabilities will be needed to compensate path-loss at these high frequencies and to increase the energy efficiency, by minimizing the amount of power radiated into directions in which it will not be received. Besides satisfying the link budget and providing broad bandwidths, antennas must be also amenable for integration on the chassis of vehicles, in smart urban furniture, and on buildings and rooms' walls. On account of their low-profile, gradient or modulated metasurfaces (MTSs) are excellent candidates to address all these challenges.

II. Modulated metasurface antennas

Aperture antennas based on modulated metasurfaces gradually radiate the power carried by a surface wave (SW), owing to the SW interaction with a periodically modulated impedance boundary condition (IBC) [3]. This mechanism enables an accurate control of the aperture fields and allows one to generate directive beams by means of low-profile and lightweight structures. Recent realizations of modulated MTS antennas have proven that they can meet challenging specifications such as high-gains, dual-polarization [4], multiple beams [5], and dual-band [6, 7] or broadband operation [8].

To date, modulated metasurface antennas have been mostly fabricated and tested in the microwave range. Such realizations consist of sub-wavelength patches printed on dielectric substrates and fabricated by standard PCB technology [3]. In this invited presentation, we will discuss some specific challenges of mm-wave and sub-THz modulated metasurface antennas. Special attention will be paid to material losses, and to the high accuracy and strict tolerances required in the sub-THz range. In order to avoid dielectric losses at such high frequencies, we have recently explored the use of metal-only metasurfaces [9, 10]. These structures can be fabricated by metal additive manufacturing [9] in the millimeter-wave range or by Deep Reactive Ion Etching (DRIE) above 100 GHz [10]. Fig.1 shows two recent realizations at IETR. Besides benefiting from reduced losses, metal-only structures can withstand harsh environments with large thermal ranges and/or high radiation levels.



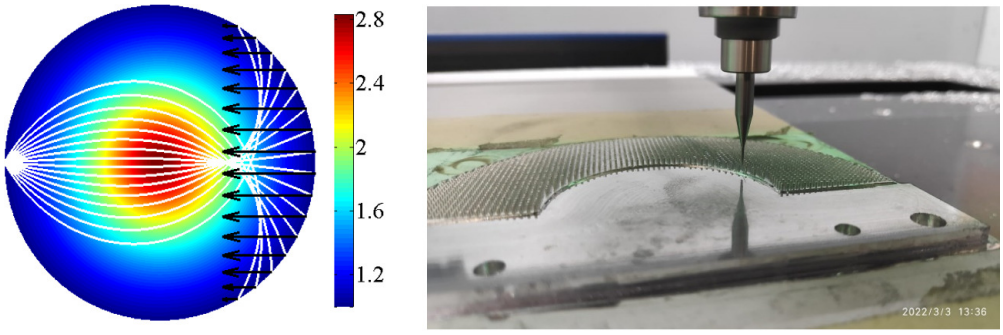
(a) (b)

Fig. 1: (a) Metal-only modulated metasurface antenna at Ka-band fabricated by metal additive manufacturing. (b) Modulated metasurface antenna at 240 GHz fabricated by DRIE and metallized sputtering Au.

III. Beamforming by modulated metasurfaces

Gradient metasurfaces can be also applied to design planar devices for guided SWs. By modulating the equivalent refractive index, one can address the SW rays along curvilinear paths in order to split an impinging SW beam [11] or to obtain planar wave-fronts. Among the latter structures, one finds Luneburg lenses (LL) [12]. LL enable the generation of multiple fan beams: one per each source in the focal circumference. Nevertheless, to provide pencil beams, an antenna should be placed after the lens and on the same plane. Therefore, the total footprint [13] will be much larger than in two-layered pillbox systems [14], where the beam-former is placed in te bottom layer and the radiating aperture in the top one.

To overcome this limitation, one can use reflecting Luneburg lenses (RLLs), which benefit from the compactness of double-layered pillbox beam-formers and the full azimuthal scanning of Luneburg lenses [15]. RLLs consist of two vertically stacked parallel plate waveguides (PPWs) of circular shape, of which the bottom one is filled with a graded index (GRIN) medium with azimuthal symmetry. The rays launched by a source in the bottom PPW follow curvilinear paths such that they emerge collimated in the top PPW after encountering a reflecting boundary. Fig. 2 shows the GRIN profile required to obtain this behavior, along with the aforementioned rays trajectories (white lines in the bottom layer, black lines in the top one). Owing to the lens' symmetry, one can generate plane waves with arbitrary directions by simply changing the azimuthal position of the source in the bottom layer. Moreover, multiple beams can be achieved by accommodating several sources in the focal circumference or the inner focal region where the rays concentrate in the bottom PPW.



(a) (b)

Fig. 2: (a) Ray trajectories in a RLL and color map with the refractive index profile of the GRIN medium. (b) Realization by CNC milling of a RLL where the GRIN medium is implemented by a bed-of-nails.

IV. Conclusion

In this paper, we will review the application of modulated metasurfaces to the design of aperture antennas and beam-formers. During the presentation, we will mainly focus on high-gain and multi-beam capabilities. Then, we will present the generation of multiple pencil beams by combining planar beam-forming lenses with modulated metasurface apertures. Such structures can provide several pencil beams with high gains and, hence, enable scanning by beam switching. Finally, fabrication and testing aspects will be presented with emphasis on structures operating above 100 GHz.

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