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Design Methodologies For Dual-band Modulated Metasurface Antennas

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Abstract – This paper presents two different design methodologies to cope with the somehow unexplored design of dual-band modulated metasurface (MTS) antennas with circular shape. In the first approach, one overlays two different modulations. Each modulation is appropriately chosen to provide a broadside beam for one of the bands and a very weak radiation for the other frequencies. The second approach builds on the active region modulated MTS concept, recently applied to broadband designs. In this case, the periodicity of the modulation at the central region of the aperture is selected to radiate at the high frequency band. In turn, a larger periodicity in the outer annular region provides the broadside beam at the low frequency band. Both approaches are compared and their advantages and drawbacks, discussed.

I. INTRODUCTION

Modulated metasurface antennas [1, 2, 3] have recently sprung up as a low-profile and low-cost solution to realize antennas with high-gains, shaped-beams, dual-polarization or multiple beams [4, 5]. The radiation effect in modulated MTS antennas stems from the interaction between a cylindrical surface wave (SW) and a sinusoidally modulated impedance boundary condition (IBC) along the radial distance. As in periodic leaky wave (LW) antennas, the period of the modulation is chosen so the -1 indexed Floquet mode in the field expansion enters in the visible region. However, despite their versatility, modulated MTS antennas are often impaired by a relatively narrow gain bandwidth. For broadside antennas, the radiation occurs at the frequency where the period of the impedance modulation is equal to the SW wavelength. As the operating frequency moves away from the central frequency the generated LW suffers from frequency scanning, which leads to a quick gain reduction.

The bandwidth of modulated MTS antennas can be improved by locally increasing the period of the modulation along the radial distance [6]. Doing so, one obtains an active region antenna, where each annular region radiates at a different frequency. In [6], an average gain of 27.5 dB between 24-29.5 GHz was experimentally obtained for a 11.1 cm radius aperture with an exponential periodicity function. It has been also shown in [7] that the in-band gain oscillation observed for exponential functions can be controlled by optimizing the periodicity function. Both in [6] and [7], the aperture efficiency was traded for bandwidth. For instance, the prototype in [6] had a peak 20% aperture efficiency at 29 GHz and lower at the rest of the in-band frequencies. In some applications, however, it is preferable to radiate at two rather distant frequencies with higher aperture efficiencies. In the following, we will discuss two different strategies to obtain a dual-frequency response, while obtaining aperture efficiencies higher than in the broadband designs reported in [6] and [7].

II. DUAL-BAND RADIATION

Next we compare two different approaches, schematically shown in Fig.1, to design dual-band modulated MTS antennas. In the first approach, depicted in Fig.1(a) and hereinafter referred to as overlaid modulations approach, two sinusoidally modulated IBCs with different periods are combined in the antenna aperture. The period of the first sinusoidal function is chosen to radiate at frequency f_1 (with $f_1 < f_2$), whereas the period of second sinusoid is shorter and it is responsible for radiating at the higher frequency band (f_2). This strategy has the advantage of using the whole aperture for both frequency bands, so the aperture efficiency can potentially be higher than in active region designs. Moreover, this method can be used to design self-diplexed antennas, as shown in [8].

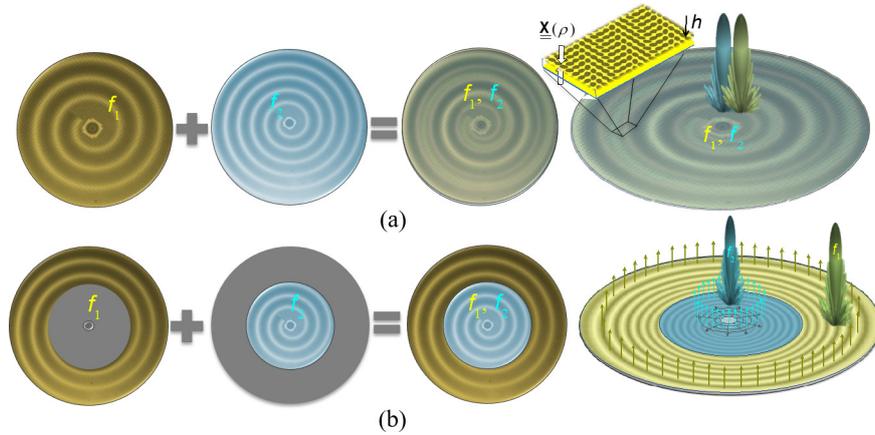


Fig. 1: Working principle of the (a) overlaid modulations approach and (b) active region approach.

The second approach, depicted in Fig.1(b), builds on the active region concept described in [6] and [7]. The circular aperture is divided into a circular region in the center and an external annular region. The period of the sinusoidal modulation for the central area is smaller than for the external ring. Hence, the antenna's central region will be responsible for radiating at frequency f_2 . Conversely, a larger period in the external annular region allows one to achieve the desired broadside beam at f_1 . Since only one sub-region of the antenna is used for each frequency band, the aperture efficiency improvement can be limited. On the other hand, one gets more flexibility than in the overlaid modulations to control the relative bandwidth in each sub-band.

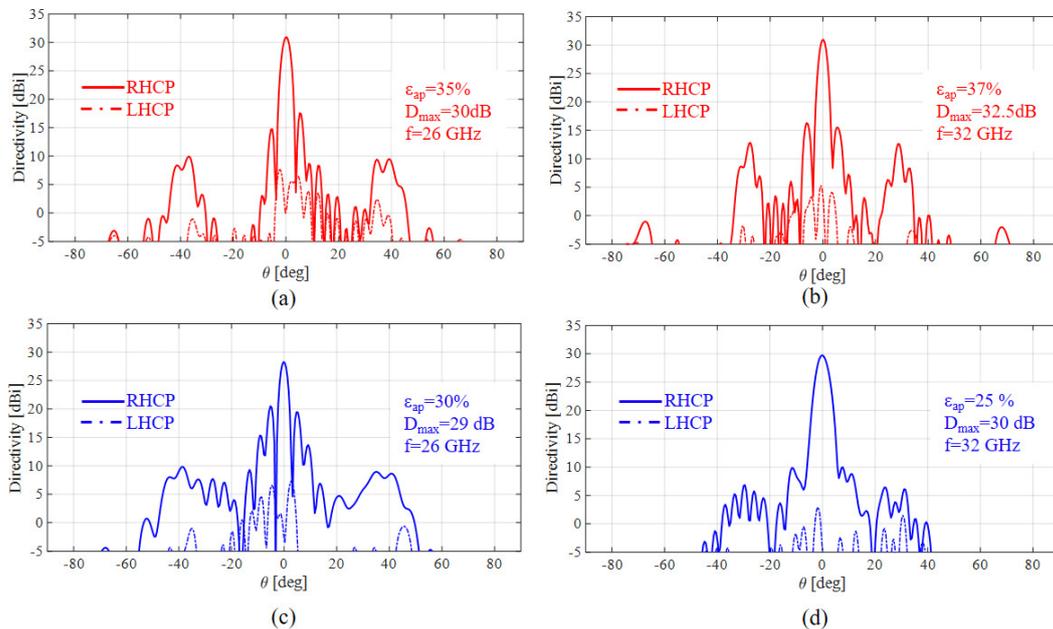


Fig. 2: Directivity patterns for the overlaid modulations method at (a) 26 GHz and (b) 32 GHz, and for the active region design at (c) 26 GHz and (d) 32 GHz. The insets report the peak directivities and the aperture efficiencies.

III. NUMERICAL RESULTS

Fig.2 shows the radiation patterns obtained for two dual-band designs that radiate in two different bands around 26 GHz and 32 GHz. Both antennas consist of circular apertures with 10 cm radius. The IBCs have been realized by

elliptical metallic patches printed on a Rogers RO3006 grounded substrate, with relative permittivity $\epsilon_r = 6.15$ and thickness $h = 0.64\text{mm}$. The resulting structures comprise more than 15000 patches and they have been simulated using a Fast Multipole Method (FMM) tool optimized for elliptical patches and described in [4]. Fig.2(a)-(b) shows the radiation patterns obtained using the overlaid modulations method, whereas Fig.2(c)-(d) presents the results for the active region approach. The desired dual-band radiation is obtained with both methods. The overlaid modulations design provides higher aperture efficiencies ($>35\%$) in both frequency bands than the active region antenna and, thus, higher directivities. Besides, the annular shape of the active region for the low frequency band leads to slightly higher side-lobe level, as one can see in Fig.2(c). On the other hand, the active region method is more flexible when one needs to control the relative bandwidth in each sub-band. It is to be observed that the aperture efficiencies obtained with both approaches are also higher than in the broadband designs in [6].

IV. CONCLUSION

We have described two different approaches to design dual-band modulated MTS antennas. In the first approach, two different modulations are superimposed on the antenna aperture. The period of each sinusoidal modulation is chosen to provide a broadside beam in one of the frequency bands. This design strategy can provide higher aperture efficiencies than active region designs. The latter use the center of the antenna to radiate at the high frequency band and an external annular region to provide a broadside beam at the low frequency band. The performance of each approach has been assessed by full-wave simulations of modulated MTS antennas based on PCB technology.

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