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Modulated metasurface antennas and arrays for millimeter wave and sub-terahertz applications

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Abstract: This summary presents the application of modulated metasurfaces in millimeter wave and sub-terahertz antenna systems. We succinctly show that by adopting metasurfaces as array element, one may mitigate some of the challenges found in large phased arrays with a limited field of view and concurrently enhance the gain bandwidth of modulated metasurfaces antennas with a single port.

The advent of future wireless networks beyond 5G has fostered the interest in millimeter and sub-terahertz (sub-THz) frequency bands, which will allow one to benefit from large unlicensed bandwidths and thus satisfy the need for higher data rates [1]. However, to make the most of such large bandwidths, one has to compensate the free space path loss (FSPL), which is proportional to the carrier's frequency and typically burdens the link budget as one approaches sub-THz bands [2]. Moreover, the generation of power at room temperature in the sub-THz gap is also challenging. Therefore, high-gain antennas radiating narrow pencil beams must be adopted. Typical architectures consist of scalar horns used as focal source for large reflector and lens systems [3]. Although efficient and wideband, such architectures are bulky and difficult to adopt in a paradigm that foresees the massive deployment of small cells. As opposed to electrically large reflectors and lenses, we target low-profile and light-weight architectures that can provide similar gains without imposing a toll on the relative bandwidth. This summary discusses the use of modulated metasurfaces (MTSs) [4]-[5] for the efficient transformation of guided modes into directive radiation in the millimeter-wave and sub-THz ranges.

In modulated MTSs, a dominantly transverse magnetic (TM) surface wave (SW) is typically excited on an inductive impedance plane. It has been shown that one can gradually radiate the SW power by periodically modulating such impedance boundary condition (IBC) [6]. This effect has been successfully exploited to design high-gain antennas capable of providing multiple beams [7], dual-polarization [8], and dual-band [9] operation [9]. Their main drawback is a relatively narrow bandwidth (BW) in gain, which has so far precluded their use for broadband applications (wideband sensing, 5G communications, etc.). The relative -3dB gain fractional BW ($\Delta f/f_0$, with f_0 being the center frequency and Δf the total BW) of modulated MTS antennas with circular shape is equal to [10],

$$B = \Delta f / f_0 = 1.2(v_g / c)(\lambda_0 / a) \quad (1)$$

where c is the speed of light in vacuum, a is the antenna radius, λ_0 is the free-space wavelength at f_0 , and v_g is the SW group velocity at f_0 . Practical values of $\Delta f/f_0$ may vary between 3.5% and 12% when the radius goes from $17\lambda_0$ to $5\lambda_0$ for $v_g/c = 0.5$. On the other hand, the aperture gain G in absence of losses (directivity) is given by

$$G = (2\pi a / \lambda_0)^2 (a / \lambda_0) / (a / \lambda_0 + 2) \quad (2)$$

Combining the latter expressions the product between fractional bandwidth and gain can be approximately written as $G \times B = 47.37(v_g/c)(a/\lambda_0)^2/(a/\lambda_0 + 2)$. On this basis, and assuming that v_g is fixed and according to (1), we

will show that one can increase the BW without impacting the gain (G) by dividing the total aperture into sub-apertures with smaller radius, each one fed by its own source. Second, grating lobes (repetitions of the main lobe related to the spacing between sources) can be avoided by the combined action of an aperiodic tiling of the aperture [11] and appropriately tailoring the element pattern of each sub-aperture. Compared to other approaches for broadband operation [12], the aperiodic tiling of the plane presents the advantage of allowing one to steer the beam over a limited field of view (FoV).

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