

Early Identification of Some Deficiencies of Rotation-Type Metasurfaces in Near-Field Beam Steering Antenna Systems

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This paper outlines a method to identify some deficiencies of the said metasurfaces prior to conducting full-scale simulations, in order to save the time and efforts of the beam-steering system designer.

Phase-gradient metasurfaces can be used to tilt or steer the beam of almost any fixed-beam antenna using the Near-Field Phase Transformation Method (M. U. Afzal and K. P. Esselle, "Steering the Beam of Medium-to-High Gain Antennas Using Near-Field Phase Transformation," in *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 4, pp. 1680-1690, April 2017). One such metasurface (MS), designed to add a spatially linear phase shift to the near field, tilts the antenna beam. The rotation of this MS enables 1D beam steering. By placing a second metasurface (MS) in the near field and independently rotating both MSs, complete continuous 2D beam steering is achieved over a wide range of directions, allowing independent control of the elevation and azimuth angles. There are two types of such metasurfaces: phase-shifting and rotation types. (P. Naseri, S. A. Matos, J. R. Costa and C. A. Fernandes, "Phase-Delay Versus Phase-Rotation Cells for Circular Polarization Transmit Arrays—Application to Satellite Ka-Band Beam Steering," in *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 3, pp. 1236-1247, March 2018). The first type can be used with any type of polarization (linear, circular, dual, etc.). The focus of this paper is on the latter, which is applicable only to circularly polarized (CP) antennas.

A unique feature of the cells of the 'Rotation' type is that the effective phase shift can be varied by simply rotating the internal inclusions. When all the internal structures of the cell are rotated by an angle of α , the phase shift of the cell changes by 2α . This allows antenna designers to produce near-field metasurfaces with variable phase distributions without changing the dimensions of the parts of the cell. Our focus in this paper is designing linear phase gradient metasurfaces using these rotation type cells. Another feature is that each cell converts the sense of incident circular polarization. If the antenna is right-handed circularly polarized (RHCP), the first MS converts it to left-handed circularly polarized (LHCP) and a second MS converts it back to RHCP.

In such a Meta-Steering system, the first step is to design a cell that converts the sense of polarization well over the required bandwidth, with high transmission of the desired polarization, low transmission of the undesired polarization and low reflection of both polarizations. This is often conducted assuming periodic boundary conditions. In far-field/Fresnel Zone transmitarrays, cell performance for all possible oblique incident angles needs to be checked. In Near-Field Meta-Steering Systems, incidence on the first MS is normal so oblique incidence is not a concern. Once the cell is optimized for the required bandwidth, the next common step is to create a full-scale model of the MS and simulate it with the base antenna (which has a fixed beam) to assess beam-steering performance. Such models of high-gain antennas are large and complex, so the simulations can take days or even weeks even in high-performance servers. Only after such exhaustive simulations that the designer will know for sure whether the designed MS will produce acceptable performance. Instead, it is more efficient to analyse a "supercell" prior to simulating the full-scale model of the MS. A supercell is the unit cell of a periodic phase-gradient MS. It consists of only several cells, and can be analyzed with lesser computing resources. Some deficiencies of metasurfaces can be identified through supercell-level analysis. Examples of very good rotation cells that have poor performance at super-cell level will be presented at the conference.