Beam Steerable Reflectarray Antennas Using Electronically-Reconfigurable, Polarization Rotating Unit Cells

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Reconfigurable reflectarray antennas (RRAs) are promising, low-cost alternatives to phased arrays in numerous wireless communication and radar applications that require adaptive beam forming and steering. Various techniques reported for RRA design incorporate different types of lumped devices (e.g. diode varactors, PIN diode and MEM switches) or tunable materials (e.g. liquid crystal, graphene) in the designs of unit cells to enable reconfigurability and produce quantized or continuous reflection phase shifts. Unit cell designs with higher phase resolutions are generally preferred as they allow the arrays to have higher gains and better beam-scanning performance. However, for many practical scenarios where large apertures are needed, 1-bit RRAs are preferable due to lower complexity, reduced cost of fabrication, more stable phase states, and larger bandwidth. Therefore, there has been great interest in design and optimization of 1-bit RRAs. In this paper, we present a reconfigurable polarization rotating (PR) unit cell that can be applied for designing wideband, 1-bit RRAs.

The building block for the proposed RRAs is the reconfigurable PR unit cell with 1-bit phase quantization ($0^o/180^o$). At both states of operation (bit-0 and bit-1 states), the unit cell rotates the polarization of the reflected wave by 90^o compared to that of the incident wave. By configuring the unit cell in bit 1 as the geometric mirror image of the unit cell in bit 0, we achieve a 180^o difference between the phases of the reflected waves in these two operating states over an extremely wide frequency range. The proposed unit cell is based on and modified from a PR unit cell consisting of a metallic double-headed arrow, which is oriented along a diagonal of the square-shaped unit cell and backed by a ground plane (Chen et al, J. Appl. Phys. 115, 2014). For reconfigurability, we used two double-headed arrows that are 90^o-rotated versions of each other within the same unit cell and deployed a switching mechanism that allows for activating one double-headed arrow while simultaneously deactivating the other. Two PIN diodes or a double-pole double-throw switch, which can be mounted below the ground plane and connected to the segmented double-headed arrows through vertical via-holes, can be used to perform the switching function to configure each unit cell corresponding to its state of operation.

We plan to initially demonstrate the design concept by using static versions of the proposed PR unit cell. The static PR unit cells were optimized for operation at X band and implemented using three layers of Rogers RO4003C bonded together by two layers of 0.1-mm thick Rogers RO4450F prepegs. Each unit cell has an aperture size of 6 mm × 6 mm and a thickness of 2.5 mm. Simulation results produced in CST Microwave Studio show a wide operating bandwidth from 7.8 to 11.9 GHz for the static 1-bit PR unit cells. We used the static PR unit cell to design three reflectarray prototypes for three different beam steering scenarios where the main beam is at (1) $\theta = 0^o$, (2) $\theta = 60^o$ with $\phi = 0^o$, and (3) $\theta = 60^o$ with $\phi = 45^o$, respectively. The static reflectarray antennas have aperture dimensions of 30 cm × 30 cm and a focal length of 30 cm. The pattern of the 1-bit phase shifting unit cell for each beam steering scenario was configured by taking into account the field distribution generated by a feed antenna, which has aperture dimensions of 4 cm × 4 cm and a directivity of 13 dBi at 10 GHz, on the plane of the reflectarray. Further simulation results and experimental characterization for the three static reflectarray prototypes as well as a follow-up study on the deployment of fully reconfigurable versions of the proposed reflectarray will be presented and discussed at the conference.