Electronically Reconfigurable, 1-Bit Reflectarray Antennas Using Polarization Rotating Unit Cells

Hung Luyen*, John H. Booske, and Nader Behdad
Department of Electrical and Computer Engineering
University of Wisconsin-Madison, Madison, WI 53706

Reconfigurable reflectarray antennas (RRAs) capable of providing high-gain, steerable beams are of great interest for various radar and wireless communication applications. Reconfiguration techniques using MEMS and PIN diode switches have been commonly used to reconfigure reflectarray elements into discrete phase states to provide beam collimation over the array's aperture. A higher number of phase states generally results in better beam collimation and pattern scanning, but also increases the complexity, losses and implementation cost of the array and control circuit. Therefore, reconfigurable reflectarrays using 1-bit phase quantization have been widely used in practical scenarios where large collimating apertures are needed. We have reported studies on using polarization rotating (PR) unit cells to achieve wideband 1-bit phase shifters (e.g., with about 40% bandwidth) for static transmitarrays and reflectarrays. In this work, we demonstrate a 1-bit reflectarray prototype that is populated with electronically reconfigurable PR unit cells and capable of providing beam steering over a wide frequency range.

The building block for the proposed RRA is an electronically reconfigurable PR unit cell with 1-bit phase quantization ($0^o/180^o$). The unit cell consists of four metallic single-headed arrows on the top surface backed by a ground plane. The four arrowheads point toward the four corners of the square unit cell. Each arrow shaft is aligned along a diagonal line of the unit cell and connected to a vertical via going through a slot in the ground plane and reaching the bottom layer, where the switching is implemented using PIN diodes. Through this approach, two electronically-controlled states of the unit cell are obtained by rotating the polarizations of reflected waves by $+90^o$ and -90^o with respect to those of incident, linearly-polarized waves. As a result, the two states of the unit cell provide a 180^o phase difference for the reflected waves over a wide operating frequency range, serving as bit-0 and bit-1 states of the reconfigurable phase shifters.

The PR unit cells were designed 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 12 mm × 12 mm and a thickness of 2.5 mm. For each unit cell, PIN diodes (MACOM MA4SPS402) were used to perform switching and lumped inductors (Coilcraft 0402DC-4N3X) were used to prevent the DC signal paths from impacting the RF performance of the unit cell. The PR unit cell was modelled and simulated with periodic boundary conditions in ANSYS HFSS. In the unit cell simulations, the PIN diodes (in forward and reverse bias) and the inductors were modeled with corresponding equivalent circuits of lumped components (inductors, resistors, and capacitors). Simulation results predict that the PR unit cell should provide a wide, 8.4 – 11.6 GHz operating bandwidth, over which a co-polarization reflection coefficient (R_{xy}) should be > -2 dB, the cross-polarization reflection coefficient (R_{yy}) should be < -10 dB, with a difference of 180^o between the phases of R_{xy} for bit-0 and bit-1 states. We plan to fabricate an electronically reconfigurable reflectarray prototype consisting of 15×15 elements and a complete control circuit for reconfiguring the PR unit cells. More details on simulation results and experimental characterization of the fully reconfigurable prototype of the proposed reflectarray will be presented at the conference.