An X-band, Mechanically Beam Steerable Lens Antenna Exploiting Risley Prism

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

Phased array antennas have been used in various applications ranging from satellite and airborne communications to radar and imaging systems. However, the high cost, complexity, and thermal engineering challenges of phased array antennas have limited their applications, especially for large, high-power, phased array antennas. This motivates research for alternative, less complex and more affordable beam steerable antennas. Recently, mechanical steerable reflectarrays and trasnmitarrays have been studied as promising alternatives to phased arrays, although the beam scanning speeds cannot be compared with the traditional electronically-reconfigured phased arrays.

In this paper, we present the design of a mechanically steerable lens antenna based on the Risley prism concept at X-band. The proposed lens antenna is composed of one feed horn and two prisms, where the main beam can be scanned by mechanically rotating the two prisms with respect to each other. In this design, unit cells of a low-pass frequency selective surface are used as spatial phase shifters to construct the Risley prism with the specific phase progression. All of the unit cells were designed to work at 10 GHz. Simulations in CST Microwave Studio predicted simulated transmission coefficients > -1 dB. The distance between the two prisms was determined by simulating together all pairs of complementary unit cells. A 2 mm gap between the two unit cells in each pair was predicted to provide the best overall performance. For experimental validation, we designed a pair of Risley prism to be able to scan the main beam from broadside direction to 60° in the upper space. The maximum 60° beam scan angle should be enough for most radar and satellite systems. A motivation for limiting the maximum scan angle to 60° was to ensure a good angle resolution. The proposed Risley prism has a circular aperture with a diameter of 345 mm, equivalent to 11.5 λ. A small, custom-made, 40 × 40 mm^2 aperture horn antenna made of aluminum was used to excite the Risley prism antenna from a focal distance of 172.5 mm. The simulation and measurement results matched well and both showed that the main beam could be scanned from broadside direction to 60° in the upper space with low gain loss. Very good agreement between the theoretical results and measurement results was obtained for beam pointing accuracy, with beam pointing errors < 1° for all measurement results. The proposed lens antenna can be a candidate for radar and satellite applications with a requirement for low-cost phased array antennas. Details of the design and the simulation and measurement results of the fabricated lens antenna in E-plane, H-plane and D-plane will be presented to demonstrate the capability of beam scanning.