A Single-Layer, Near-to-Zero Index Metasurface Superstrate for Gain-Enhanced, Circularly Polarized Antenna Designs

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Abstract

This paper presents a single-metallic-layer, near-to-zero-index metasurface (NZIM) as a superstrate for an antenna to achieve gain enhancement and circular polarization. The proposed metasurface comprises an array of split ring resonators (SRRs) rotated and aligned diagonally to provide linear-to-circular polarization conversion when placed above a linearly polarized patch antenna. Simulated and measured results show that the proposed antenna system has a 3-dB axial ratio bandwidth of 200 MHz, exhibits a right-hand circular polarization (RHCP) with a good cross polarization level, and achieves a 6-dB gain enhancement thanks to the use of the NZIM superstrate.

1. Introduction

Metasurfaces with zero or near-to-zero refractive index, permittivity, or permeability are among emerging techniques to enhance performance of antennas [1-2]. While most studies in the literature have been focusing on integrating these metasurfaces with antennas to provide radiation patterns with enhanced gains and linear polariziations, very little attention has been given to circular polarization applications. Circularly polarized (CP) antennas with high gain, however, have being widely used in satellite, radar, and space wireless communication systems [3-5]. More recently, reference [6] introduces a linear-to-circular polarization convertor using a zero-index metasurface, which is implemented by two metallic layers sandwiching a dielectric substrate. The circular polarization is obtained by tuning two parameters, which are the two slits on the two square rings of the unit cell. In this work, we propose an NZIM with a similar function as the one presented in [6] but having only one metallic layer, allowing for potentially reduced implementation cost and simpler design procedure. The proposed NZIM is used as a superstrate of a linearly polarized patch antenna to achieve gain enhancement and circularly polarized radiation. The circular polarization is achieved by rotating the SRRs, which can generate two orthogonal modes with a 90° phase difference. In what follow, the design and numerical and experimental characterization of the proposed high-gain, circularly polarized antenna are presented.

2. Proposed Superstrate-Loaded Antenna Design

Fig. 1 shows the configuration of the proposed design. It consists of a rectangular patch antenna placed below an NZIM superstrate. The patch has dimensions of 16.29×21.5 mm^2 and is printed on a grounded substrate of Rogers RT/Duroid 5880 with a permittivity of 2.2, loss tangent of 0.002 and thickness of 0.787 mm. The patch antenna is fed by a 50-Ω coaxial probe and was optimized in full-wave simulations using CST Microwave Studio to provide a low reflection coefficient as well as a linear polarization around the center frequency of 5.8 GHz. The NZIM superstrate is placed at a distance of 30 mm (about $\lambda/2$ at 5.8 GHz) above the patch antenna to convert the linear polarized wave radiated by the patch into a circularly polarized one. The metasurface is a 2-D array of 9×9 elements and has the same aperture area of 67.4 x 67.4 mm^2 as the radiating patch's substrate. Each element of the metasurface consisted of a smaller split-ring resonator (SSR) nested inside another bigger SSR. The two SSRs have opposite slot orientations: one ring has the slot at φ=135° while another ring has the slot at φ=315° (refer to Fig. 1(b)). The outer ring has a radius of 3.3 mm, the widths of the rings are 0.8 mm, the gap between inner and outer rings is 0.8 mm, and the widths of the splits are 0.4 mm. These parameters were selected to place the quasi-static resonance of the unit SRRs within the C-band of the microwave spectrum according to the theory developed in [7]. The most attractive feature of this element is its ability to exhibit a quasi-static resonant frequency at wavelengths that are much larger than its own size.

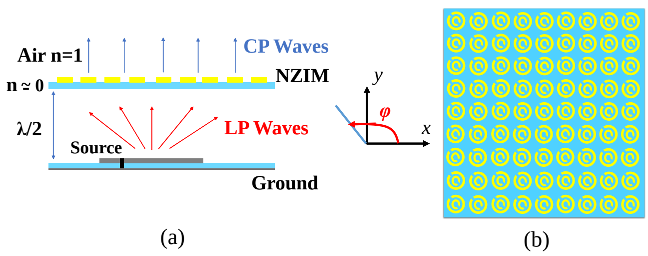

Figure 1: Proposed circular polarization High-Gain antenna with NZIM polarizer. (a) Front view (b) NZIM metasurface polarizer

3. Simulation and Measurement Results

We designed, fabricated, and measured a prototype of the proposed high-gain CP antenna. The measured and simulated reflection coefficients are presented in Figure 2(a). It can be seen that placing the NZIM above the patch antenna slightly improves the impedance matching without shifting the resonant frequency of the patch. Figure 2(b) shows the simulated and measured axial ratios (ARs) of the superstrate-loaded antenna prototype, demonstrating the effectiveness of the NZIM metasurface in providing linear-to-circular polarization conversion. The 3-dB axial-ratio bandwidths observed from the simulation and measurement are from 5.72 to 5.91 GHz (3.27 %) and from 5.83 to 6.11GHz (4.82%), respectively.

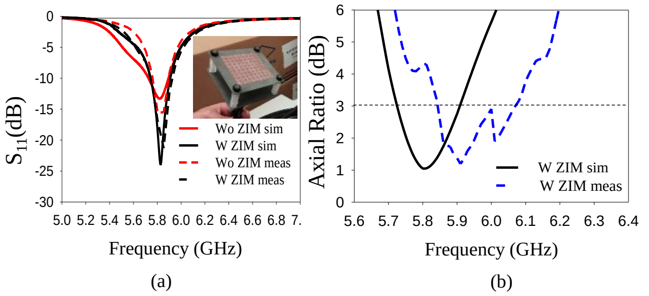

Figure 2: (a) Simulation and measurement results for the (a) reflection coefficient and (b) axial ratio of the high gain CP antenna.

The measured and simulated realized gains of the patch antenna without and with the NZIM metasurface around the resonant frequency are depicted in Fig. 3. The measurement and simulation results show good agreement. The measured peak gain of 11.8 dBic is observed for the superstrate-loaded antenna at the central operating frequency of 5.8 GHz, which is about 6 dB higher than that of the patch antenna without the superstrate. As expected, the antenna gain can be enhanced significantly in the whole operating bandwidth (5.72-5.92 GHz) when the patch antenna is loaded with the NZIM. The increase in gain can be explained by the fact that the NZIM superstrate exhibits a near-zero refractive index around the resonant frequency of the patch antenna as discussed above. According to the Snell–Descartes laws, when an incident wave radiated from the patch antenna goes from a positive medium (air) to a near-to-zero refractive index medium (the NZIM) with a grazing angle, the transmitted wave will propagates normal to the interface, producing a collimated beam, and hence the gain enhancement.

There are slight frequency shifts observed between the simulation and measurement results for the AR/realized gain of the antenna with the NZIM superstrate (as seen in Figs. 2-3). These small frequency shifts can be mainly attributed to fabrication tolerances of the NZIM substrate and uncertainties in positioning of the superstrate with respect to the patch antenna. The fact that there is no discernible frequency shift between the simulation and measurement results for the patch antenna alone (shown in Fig. 3) further supports this hypothesis.

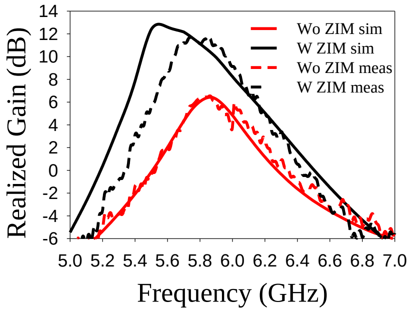

Figure 3: Simulated and measured realized gains of the antenna with and without ZIM polarizer superstrate.

4. Conclusions

A low profile, high-gain, circularly polarized antenna using a NZIM metasurface is presented. The measurement results agree well with full-wave simulations results, demonstrating the effectiveness of the NZIM in enhancing the antenna's gain and converting a liner polarization to a circular one. Future research on achieving larger AR bandwidths is being conducted by the authors.

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