Reflective Surface for Linear-to-Linear and Linear-to-Circular Polarization Conversion at Multiple Frequencies

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Abstract
In this paper, a thin multiband reflective polarization converter surface is proposed that can reflect a circularly polarized (CP) wave in the following frequency bands: 7.8-8.10 GHz, 8.32-10.04 GHz, 10.80-13.75 GHz, 14.19-14.53 GHz, 16.22-16.52 GHz, and 16.77-17.18 GHz. It can also convert a linearly polarized (LP) incident electromagnetic wave into its orthogonal LP reflection wave in these bands: 8.14-8.25 GHz, 10.23-10.60 GHz, 13.90-14.08 GHz, and 16.59-16.71 GHz. With slotted semicircles supported by a metallic ground plane, the suggested unit cell of the periodic structure has significant stability in all frequency ranges, even at oblique incidence within a 75° angle limit. Furthermore, the suggested polarizer has an easy-to-manufacture construction that only needs one substrate layer and does not include any via holes. A sample prototype consisting of 30×30 unit cells was fabricated and tested, validating our design and simulations.

Keywords: Circular-polarizer, cross-polarizer, meta-surface, polarization converter, reflective surface.

1. Introduction

In many polarization-sensitive applications in contemporary wireless communication systems, such as satellite communication systems [1], stealth [2], and cloaking targets [3], polarization manipulation of electromagnetic (EM) waves has become essential [4]. Numerous cross-polarization converters in various frequency ranges have been documented [5]. Techniques such as multilayer structures or multi-resonances have been reported [6], [7] to achieve broadband conversion. Magnetic or electric resonances are necessary for broadband performance, and multilayer devices can create these resonances by coupling the responses of multiple resonant layers. Through the use of a multilayer structure, the study accomplishes a thorough polarization conversion operation over a wide frequency range of 7–13.7 GHz [6]. An ultrawideband cross-polarization converter using a via-based surface and a superstrate was presented by Jia et al. [8]. However, these structures function as cross-polarizers only for normal incidence.

The ability of the structure to maintain functioning for oblique incidence is critical for a range of applications in the microwave and optical regimes [9], [10]. Conversely, scientists are working to create broadband and single-layer cross-polarizers. Two effective single-layer broadband cross converters are described: a square split ring resonator [12] and a double W-shaped [11]. In [13], a narrow reflecting polarizer with an oval-shaped design is suggested for wideband cross-polarization conversion (CPC) between 10.2-20.5 GHz. Nevertheless, the cross-polarization conversion is the only single action performed by these devices. It is necessary in many applications to integrate many operations into a single structural design.

Recently, a polygon-shaped linear-to-circular (LTC) converter was investigated using anisotropic impedance surfaces in reflection mode, achieving right-handed circular polarization (RHCP) and left-handed circular polarization (LHCP) with a 46% axial ratio (AR) bandwidth from 7.62-12.16 GHz [14]. A reflective multiband converter with maximal cross-polarization conversion at 13, 16, and 18 GHz is shown in an inquiry in [15]. Furthermore, a low-profile multiband, multifunctional hexagonal reflecting surface with CPC and LTC activities was shown by [16]. A triple-band polarization converter for single-band LTC and dual-band CPC conversion was published by Zheng et al. in [17]. In [18], a new reflective metasurface-based polarizer for multiband and multifunctional applications was unveiled. Nonetheless, there is still a lot of interest in creating a multiband, highly efficient cross-polarization converter with excellent angular stability for oblique incidence and simultaneous LTC conversion.

This work proposes a thin reflective multiband polarization converter for linear to circular conversion and cross-polarization conversion. With a polarization conversion ratio (PCR) of more than 85%, the cross-polarization conversion is achieved over four different frequency bands. In addition, the transition from linear to circular polarization occurs in six different frequency ranges. For both tasks, the suggested structure offers excellent angular stability up to 75◦.

2. Unit-Cell Design

A reasonably priced FR4 square substrate with a thickness of h = 0.8 mm, $\epsilon r = 4.4$, and tan $\delta = 0.02$ is the unit cell for the proposed polarization converter. It is positioned between the ground plane and the upper patterned surface. The unit cell is made up of four semicircles on each of its four sides, each having a distinct radius (R1 and R2). Resonances at lower and higher frequencies can also be impacted by two large and small circles. By forming two complete circles, the semicircles function as unit cells in a periodic array, so minimizing size and maintaining structural compactness. The entire structure of the unit cell and the stages of evolution are shown in FIGURE 1(a, b). For an incident y-polarized wave, the reflection coefficients of the co- and cross-polarizations are defined as ryy and rxy, respectively. Therefore, FIGURE 2(a, b) shows the magnitude of co-polarization (ryy) and cross-polarizations (rxy) for the evolution process, respectively.

The slotted semicircle patch structures shown in step 1 function as a cross-polarization converter in the unit cell's evolution stages at 10.8 GHz and 15.55 GHz, with rxy (ryx) magnitude values of 0.85 and 0.88, respectively. For co-polarization, an amplitude of greater than 80% or less than -10 dB (ryy < -10 dB or rxx < -10 dB) is generally regarded as efficient. Furthermore, an efficient performance criterion for cross-polarization reflection coefficient is 0 dB < ryx < -3 dB or 0 dB < rxy < -3 dB. During polarization conversion, the circular patches optimize reflection by using greater amplitudes to transfer power efficiently. The linearly polarized wave incident is partially converted into cross-polarized components by the semicircles' anisotropy. Adding small slotted semicircle patches improves the polarization conversion mechanism leading to enhanced values of rxy and ryx. To achieve a multiband response, the slot on the left semicircle is intentionally shifted in the y-direction.

3. Aim

To design a thin multiband reflective polarization converter surface capable of transforming a linearly polarized (LP) incident electromagnetic (EM) wave into its orthogonal reflection wave in different frequency bands.

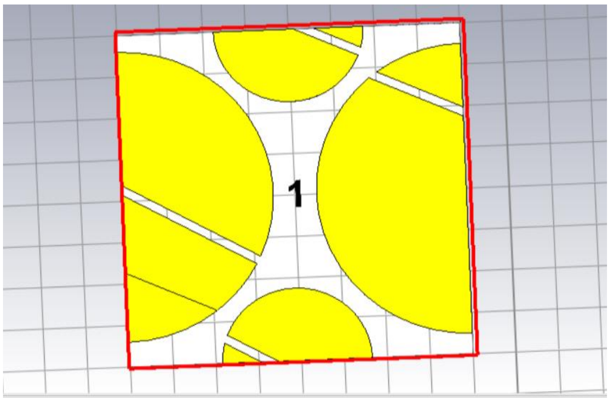
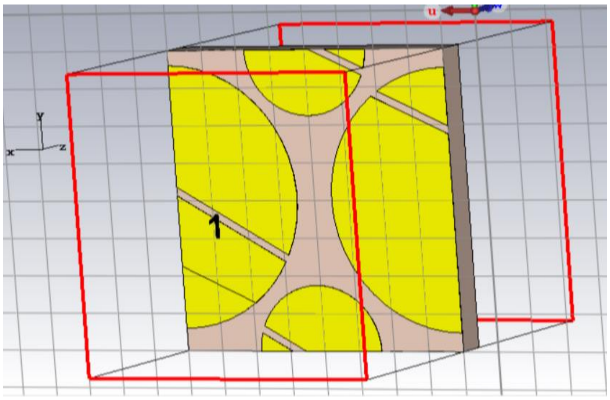


Fig.1 Design of Antenna: . (a) Proposed unit cell with electric field decomposition (total length=8 mm, big radii=3.5 mm, small radii=1.8 mm, length1=1.6 mm, length2=1.06 mm, cuts width=0.2 mm)



(b) Evolution of the unit cell with an excitation source

Source Excitation

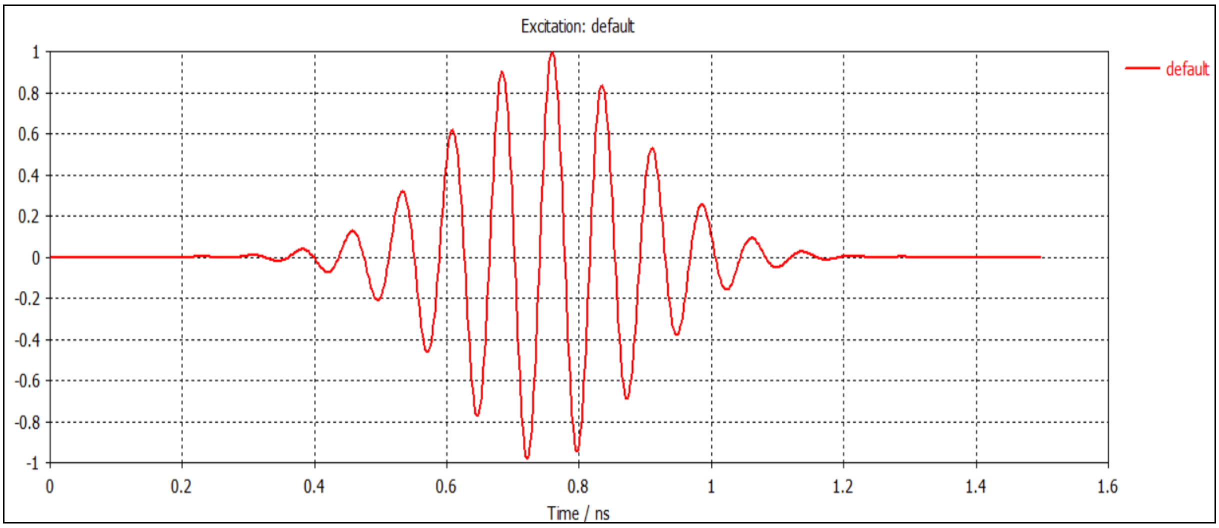


Fig.2 Excitation sources (default)

4. 1D-Results

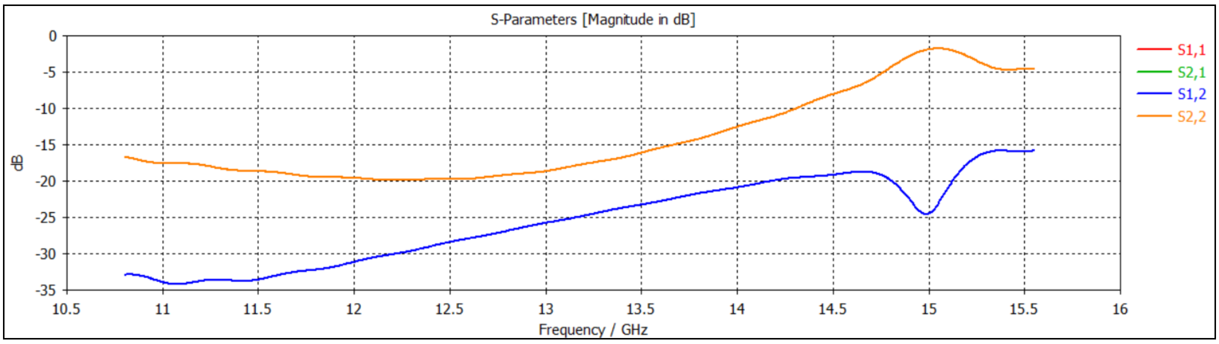


Fig.3 S-Parameters (Magnitude in dB)

S-parameters are a way of expressing things with general **waves** instead of voltages and currents. It describes how much the waves are reflected or transmitted from/through a device. With a device like an antenna, there's not only 1 but 4 S-parameters. The first one S_11 is also known as the reflection coefficient.

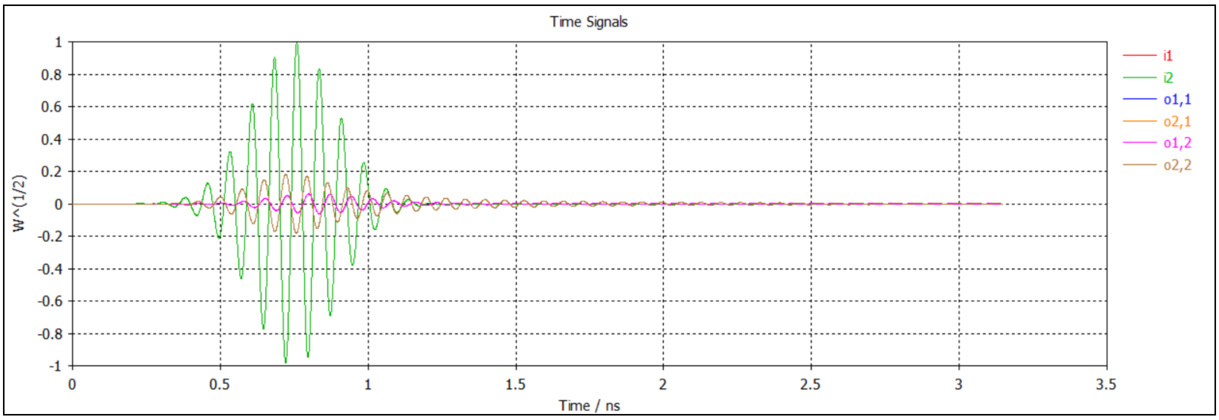


Fig.4 Port Signals

Port Signal gives you the incident (i1) and reflected signal (o1,1) on given port (1) with respect to time. For your antenna to show strong resonance the port signal should start at zero and after some resonance should tend towards zero. Something like shown below.

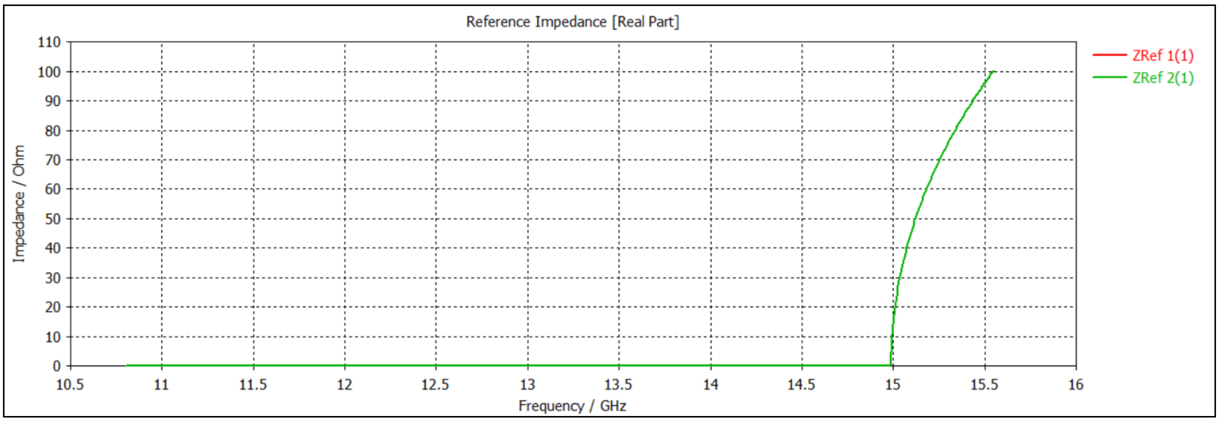


Fig.5 Reference Impedance

Then the reference impedance is just an impedance that S matrices are referred to (transmission line impedance, port impedance and other names). In physical experiment, you usually take it as VNA port impedance, which is normally a very good reference.

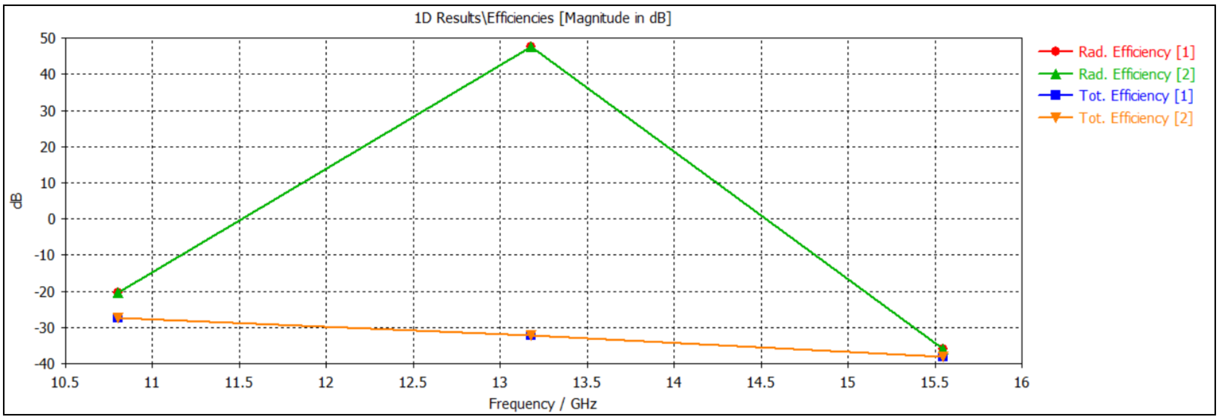


Fig.6 Efficiencies (Magnitude in dB)

The radiation efficiency of an antenna is defined as the ratio of the power radiated by an antenna to the power fed to the excitation port of the antenna.

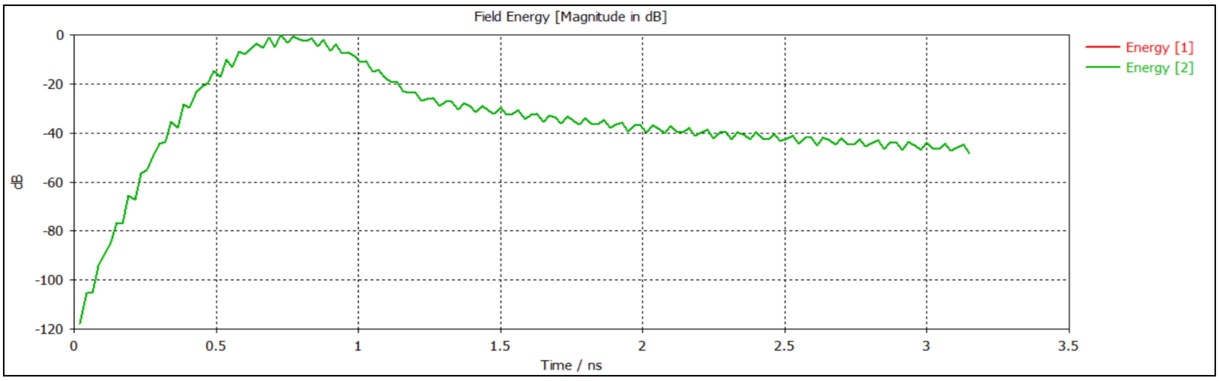


Fig.7 Field Energy (magnitude in dB)

It records the data at the specified frequencies. It is recommended to use the proprietary FSM nearfield data format in software products of *CST*.

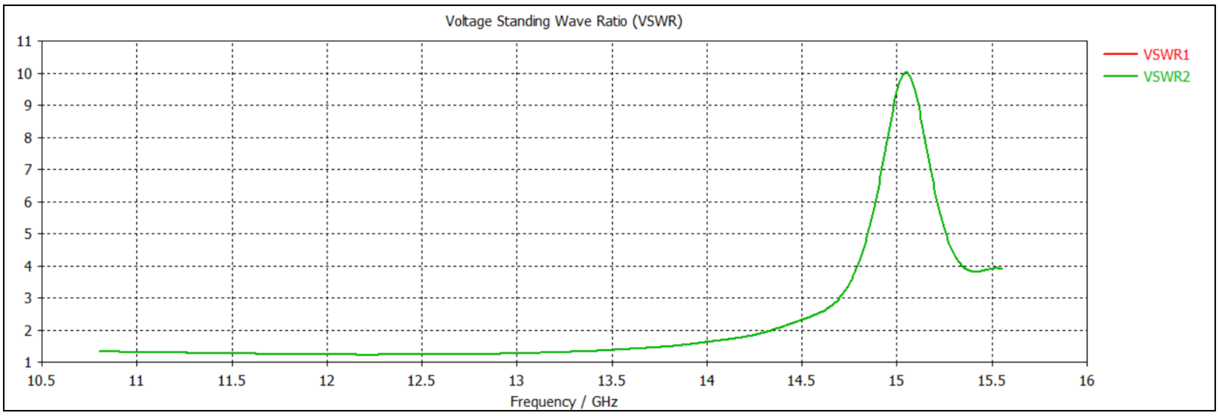


Fig.8 Voltage Standing Wave Ratio (VSWR)

VSWR (Voltage Standing Wave Ratio) is a measure of how efficiently radio-frequency power is transmitted from a power source, through a transmission line, into a load (for example, from a power amplifier through a transmission line, to an antenna).

3D-Results:

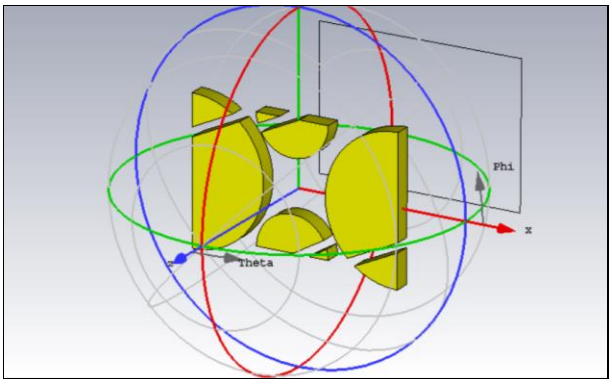


Fig.9 Unit cell shows the Farfields

It's defined as the ratio between radiated power from the antenna and delivered power into it. So, if efficency is equal 1 all delivered power is radiated from antenna. It's an ideal condition, but it's represent the ideal antenna. Farfield is related with the gain of the antenna.

4. Conclusion

In summary, a single-layer, multiband reflective polarizer was designed in this paper. The design principle of the proposed polarizer based on simple slotted semicircles was investigated and analyzed in detail. The proposed thin, multiband, and multifunctional polarization converter exhibits CPC at four and LTC conversion at six frequency bands with high efficiency. Additionally, the proposed structure provides suitable stability to oblique incident waves up to 75◦. Simulation results were validated by experimental measurements. Moreover, a comprehensive comparison was made with recently reported single-layer polarization converters to highlight the advantages of the proposed structure.

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