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Broadband Cross Polarization Rotator on a Single-layer Ultrathin Anisotropic Metasurface

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Abstract— In this article, we present the reflective cross-polarization conversion metasurface operating in the X and Ku band of microwave frequencies. We have numerically calculated and showed that the proposed metasurface manifests 90% PCR in the operating band from 8.8-15.5 GHz. Furthermore, it can also be scalable to other operating bands by carefully selecting the materials and optimizing the design parameters. This kind of reflective meta-device would be prudent for the applications of beam reflectors, antennas, and holography.

Keywords—Absorber, microwave frequency, polarization insensitive, dual band

I. INTRODUCTION

Since the premier work of Landy [1] and his team mates on narrow-band and single layer metamaterial absorber for microwave band, a huge focus has been aroused in the research community towards this exciting field [2-4]. Thereafter, a different class of meta-devices has been implemented including dual-band, triple-band, multiband, wideband, single-layer and multi-layer etc. ranging from the microwave to infrared spectrum [5, 6]. In addition to meta-absorbers, polarization converters have also gained huge significance owing to their many applications in antennas, holograms, transmissive surfaces, beam splitters, wireless communication and imaging etc. [7-10].

Previously, polarization conversion phenomena can be obtained by using the conventional approaches of optical grating, dichroic crystals and birefringence effect etc. [11-13]. These methods limit the practicality in real applications due to the bulky weight, narrow bandwidth and costly fabrication process [14, 16]. In recent years, a new class of two dimensional (2D) surfaces also called metasurfaces have been broadly employed to model various microwave and optical components including sensors, antennas, waveguides, absorbers and polarization converters etc. These 2D planar surfaces are composed of man-made artificially fashioned meta-molecules possessing different rotation, shapes, size and materials etc. Through these metasurfaces, electromagnetic (EM) waves can be manipulated by altering their periodic

elements and design parameters to achieve exotic and unusual features which cannot be realized with natural materials [5, 15, 17].

Polarization conversion metasurfaces can be modeled in two different operation modes, reflection mode and transmission mode [8]. In reflection mode, anisotropic resonators play a role to control the EM reflection of the incident waves and to rotate into its orthogonal component [18]. A lot of research has also been conducted in anisotropic reflective metasurfaces to attain cross- and circular polarization conversion. In transmission mode, chiral structures are used to alter the transmission of incoming EM waves and to use them in achieving the polarization transformation. Similarly, people also implemented chiral metasurfaces in different configurations including single- and multi-layer etc. Most of the implemented devices rely on multi-layer and multi-faceted arrangements [20]. Advanced and modern communication systems demand highly efficient, broadband and single-layer polarization conversion metasurfaces.

In this paper, authors' motive is to investigate highly efficient wideband metasurfaces which can transform the linearly polarized EM waves into their counter orthogonal component. Our reported meta-device converts the linearly polarized waves into their cross component over a broad spectrum of 8.8 to 15.5 GHz. The proposed metasurface operates in the reflection mode having an efficiency of more than 90%. The designed configuration possesses a three-layer scheme, i.e. top anisotropic metasurface, middle lossy dielectric spacer and bottom ground film. Furthermore, the proposed architecture can also be scalable to mm-wave and terahertz bands. This kind of reflective meta-device would be prudent for the applications of antennas, imaging and beam generations.

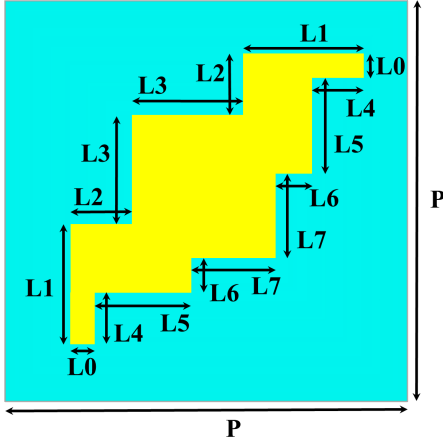


Fig. 1. . Schematic diagram of the designed meta-unit cell, where $P = 5.5$ mm, $L_0 = 0.6$ mm, $L_1 = 2.25$ mm, $L_2 = 1$ mm, $L_3 = 1.5$ mm, $L_4 = 0.8$ mm, $L_5 = 1.4$ mm, $L_6 = 0.7$ mm, $L_7 = 1.3$ mm.

II. DESIGN TECHNIQUE

The metasurface unit cell is designed and simulated to explore its EM characteristics, as shown in Fig. 1. The proposed design is simulated by using EM solver, CST Microwave Studio employing unit cell boundary conditions along x and y direction and open add space boundary conditions in z -axis. The linearly x -polarized electromagnetic wave (EM) is taken as an input source to excite the metasurface. The co- and cross-polarized reflection components are computed and depicted in Fig. 2. It has been observed in Fig. 2 that the cross-polarized parameter is approaching to its maximum value for the operating frequency from 8.8 GHz to 15.5 GHz, whereas the co-polarized reflection component attains its minimum value (ref. Fig. 2).

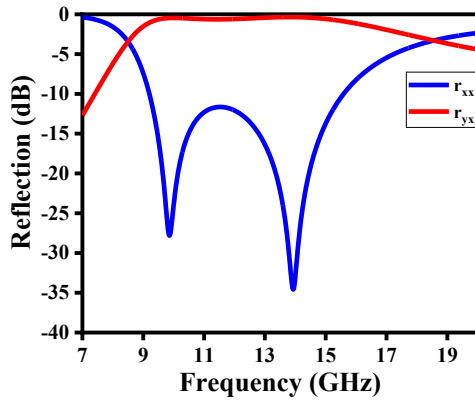


Fig.2. Frequency-dependent reflection components of the proposed metasurface

III. RESULT AND DISCUSSION

When an EM wave falls on the top surface of the metamaterial, its overall absorption is determined from the following equation [1].

$$A(\omega) = 1 - T(\omega) - R(\omega) \quad (1)$$

Where,

$T(\omega) = |t_{xx}(\omega)|^2 + |t_{yx}(\omega)|^2$ and $R(\omega) = |r_{xx}(\omega)|^2 + |r_{yx}(\omega)|^2$ are the transmitted and reflected energies of the designed metasurface. The subscript 'xx' and 'yx' corresponds to the co- and cross components. The transmitted energy becomes zero due to the presence of the bottom metallic sheet, as mentioned in [1]. So, the total absorption is mainly depends on the reflection component of the proposed metasurface. The actual absorption of the designed metasurface is below 10% because the designed has large cross-reflection component as depicted in Fig. 2. The actual absorption of the metasurface is below 10% from 8.8-15.5 GHz.

Cross-polarization converter can be measured in terms of its polarization conversion ratio (PCR), stated as [8].

$$PCR = \frac{|R_{yx}|^2}{|R_{yx}|^2 + |R_{xx}|^2} \quad (2)$$

Figure 3 demonstrates the PCR of the proposed metasurface as above 90% over the operating band (8.5-15.5 GHz). Therefore, the proposed device can be treated as a wideband cross-polarization converter. Further, the anisotropic geometry of the designed metasurface device is suitable for the polarization conversion phenomenon and it shows a very poor absorption results because the cross-polarized reflection component is very high.

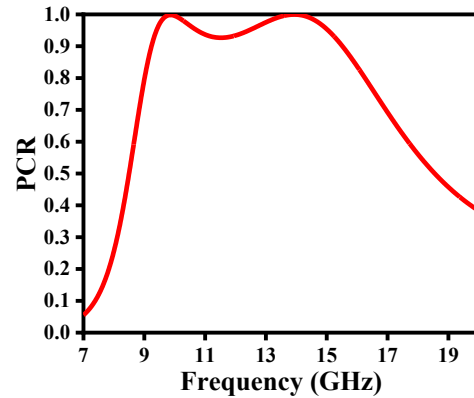


Fig. 3. Frequency-dependent PCR of the proposed metasurface.

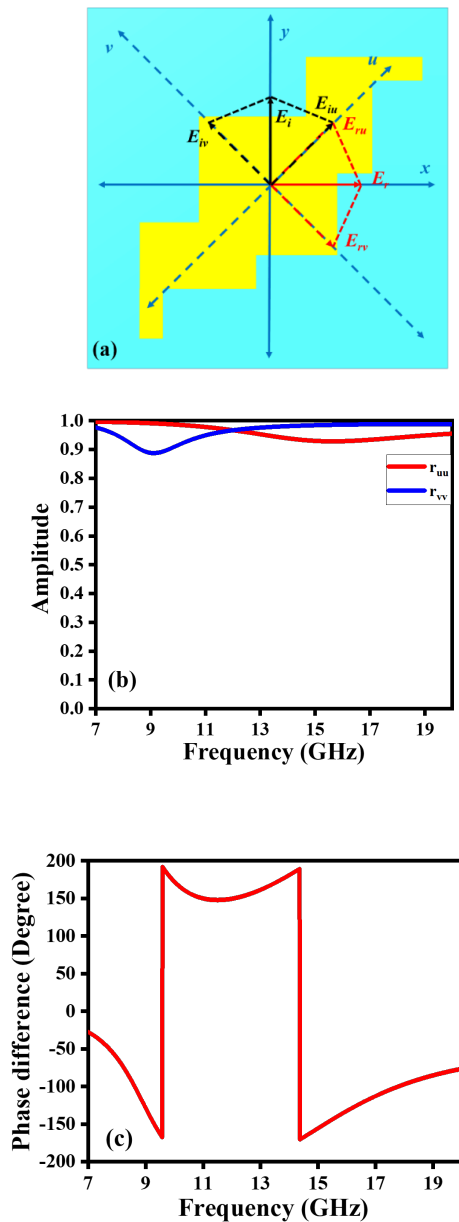


Fig. 4. Representation of the u- and v- components of the proposed metasurface (a) illustration of the incident and reflected electric field for u- and v- polarized wave (b) amplitude and (c) phase difference.

IV. CONCLUSION

In summary, a highly efficient wideband linear reflective polarization rotator was investigated in this study. This meta-device possesses three-layer device configuration, top and bottom metallic layers and middle lossy dielectric spacer. The aforementioned PCM illustrated more than 90% efficiency over a broad spectral range ranging from 8.5-15.5 GHz. Moreover, the proposed reflective meta-device can also be extended for other operating regime, i.e. THz and IR, if we carefully chose the constitutive materials and geometric parameters.

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