An Efficient Anisotropic Metasurface for Polarization Conversion Applications

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Abstract—**This paper presents an anisotropic metasurface that can work as linear and circular polarizer simultaneously. The proposed design has the ability to achieve linear-to-linear polarization (LTL) within two frequency bands ranging from 7.2-10.51 GHz and 15.81-17.48 GHz. The linear-to-circular (LTC) polarization is also accomplished within the frequency ranges between 6.78-6.89 GHz, 12.54-13.76 GHz and 18.39-18.82 GHz. The proposed design provides stable response against incidence angles up to 30°. The investigated metasurface with the multi-band and multi-polarization capabilities, the compact size and the angular stability can be suitable for several applications related to satellite communications.**

Index Terms—**anisotropic metasurface, angular stability, polarization conversion.**

I. INTRODUCTION

The polarization state of electromagnetic (EM) waves is an essential feature which is dictated by the radiator and the propagation path. The EM waves polarization control has attracted the attention of several researchers throughout the years since it has a vital role in microwave or optical communications [1]. Conventional techniques like Faraday Effect and birefringence in anisotropic crystals, have been used for polarization conversion. However, these techniques have the two main disadvantages, the narrow bandwidth and the bulky volume which impose several restrictions for several applications.

One way to achieve polarization control is the use of two-dimensional artificial structures known as metasurfaces [2]. Due to the compact size, low cost, wide bandwidth and substrate flexibility that allows conformal shapes, metasurfaces have been considered repeatedly as polarization control devices.

Several metasurfaces designs for polarization conversion can be found in literature [3]. Polarization conversion can be applied in both transmission [4] and reflection [5] modes. Other anisotropic metasurfaces achieving only cross polarization conversion have also been reported [6-7]. In [8], a symmetric anisotropic metasurface performing both (LTL and LTC) conversions in reflection mode was reported however the used frequency bands were rather narrowband.

Although, various structures performing either LTL or LTC conversion have been introduced the achievement of both conversions using a single layer design remains a research challenge. In [9], an anisotropic metasurface achieving both LTL and LTC conversion was proposed. The cross conversion was realized in the frequency range of 8-11 GHz with a fractional bandwidth 31.6% [9]. Recently, a metasurface was reported achieving both conversions (LTL and LTC) but the band achieved for cross conversion is narrow [10].

In this work, a design of an anisotropic metasurface is presented that can achieve both linear (cross) polarization and circular polarization conversions. The cross conversion is accomplished in the two frequency bands of 7.2-10.51 GHz and 15.81-17.48 GHz. The fractional bandwidth for the first band of LTL (7.2-10.51 GHz) is 37.38 %. Moreover, the axial ratio remains below 2 dB for the three frequency bands (6.78-6.89 GHz, 12.54-13.76 GHz and 18.39-18.82 GHz) achieving LTC conversion. The proposed multi-band and multi-polarization metasurface can be used in a variety of satellite communications.

II. UNIT CELL CONFIGURATION

The perspective view, the front view and the periodic array of the unit cell are illustrated in Fig. 1 (a)-(c), respectively. FR-4 substrate having permittivity of 4.30 and loss tangent of 0.0250 is used to design this metasurface. The copper annealed is used for the metallic design with a thickness of 35µm. The optimized dimensions of the metasurface are as follow: w1= w2= 7mm, r= 2.9mm, x1= 3.3mm, x2= 2.9mm, a= 1mm, b= 1.3mm, g= 1mm and t= 2.4mm. From Fig. 1 (d), it can be observed that there is a symmetry in the structure along v-axis due to which the responses for the x-polarization and y-polarization are the same.

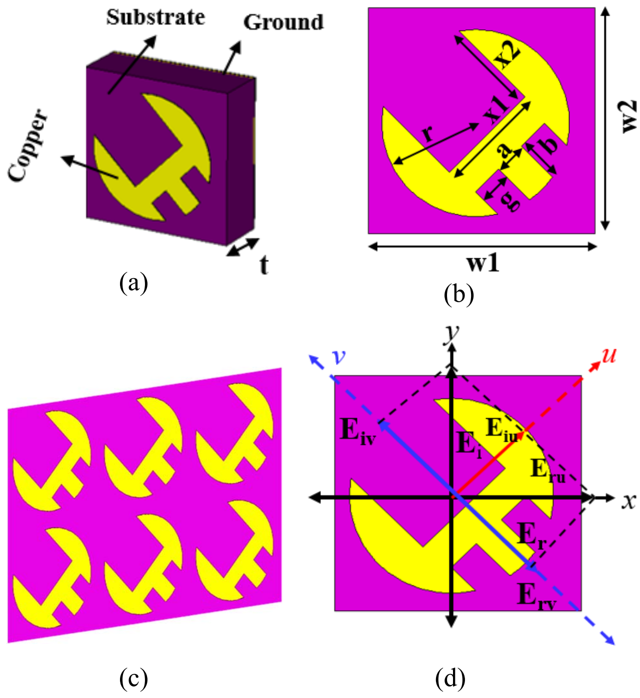

Fig. 1 Geometry of the unit cell (a) Perspective view (b) Front view (c) Periodic arrangement (d) UV-diagram

III. Results and Discussion

For the linear polarization conversion, the incident y-polarized wave must be converted into x-polarized wave upon reflection or vice versa. The co- (R_{yy}) and cross- (R_{xy}) components for the y-polarized wave are written as:

$$R_{yy} = \left|\frac{E_{ry}}{E_{iy}}\right| \tag{1}$$

$$R_{xy} = \left|\frac{E_{rx}}{E_{iy}}\right| \tag{2}$$

The anisotropic design is simulated using CST Microwave Studio®. The cross-component of the y-polarized wave should remain above -3 dB while the co-component of y-polarized should remain below -10 dB in order to realize cross conversion. The simulated cross- and co- reflection coefficients vs. frequency for both y- and x-polarizations are shown in Fig. 2 (a-b), respectively. The behavior of both y- and x-polarizations is same due to the symmetry along the v-axis of the unit cell, as can be seen in Fig. 1 (d).

In Fig. 2, it can be seen that the cross conversion has been achieved over two frequency bands: 7.2-10.51GHz and 15.81-17.48GHz. A highly efficient and stable metasurface is realized through this design as the three resonances are forced below -20 dB at 7.56 GHz, 9.52 GHz and 16.72 GHz.

To achieve LTC polarization conversion, the incident y- or x-polarized wave has to be transformed into circularly polarized wave. For LTC conversion, the co- and cross- reflection coefficients must assure that the ratio between them is 1±0.15 while the phase difference between them is $90^0 \pm 5^0$

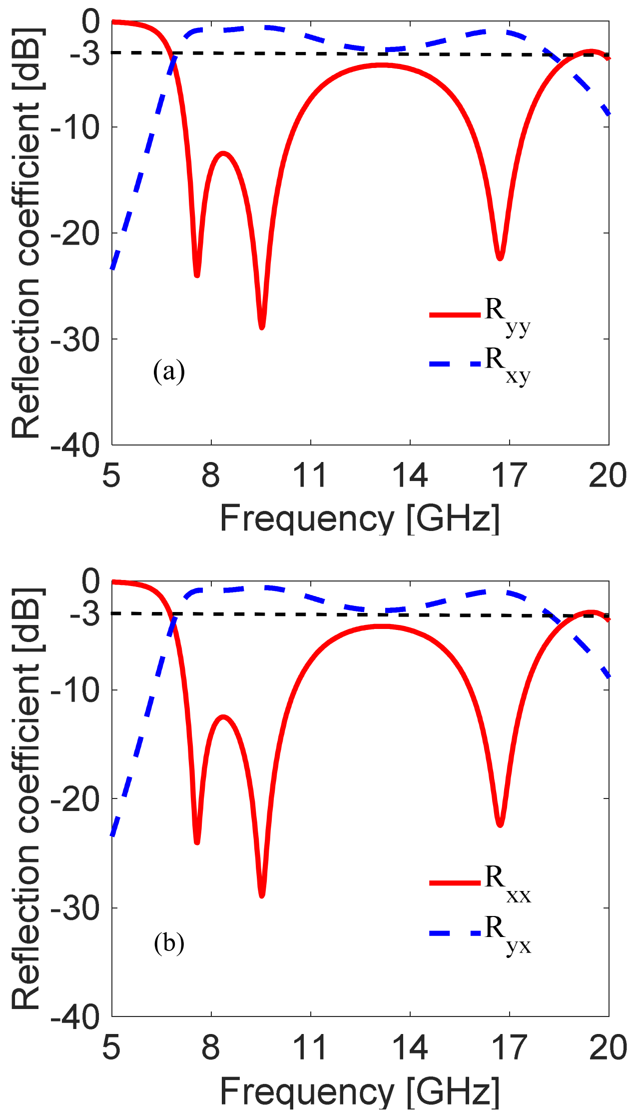

Fig. 2 Co- and cross- reflection coefficients (a) For y-polarized wave (b) For x-polarized wave

[10]. Using these criteria of magnitude and phase difference, it can be stated that the LTC conversion is realized within the three frequency bands of 6.78-6.89 GHz, 12.54-13.76 GHz and 18.39-18.82 GHz.

A. *Polarization Conversion Ratio*

Polarization conversion ratio (PCR) is a parameter which gives the LTL conversion efficiency. PCR is defined by:

$$PCR = \frac{|R_{xy}|^2}{|R_{xy}|^2 + |R_{yy}|^2} \tag{3}$$

Fig. 3 showed that the PCR graph remains more than 0.9 over the whole claimed frequency bands of 7.2-10.51GHz and 15.81-17.48GHz. Therefore, it can be stated that the efficiency remains more than 90% for these two bands.

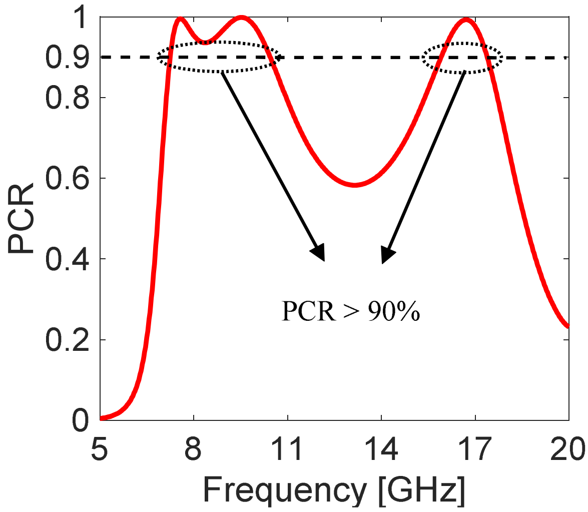

Fig. 3 Polarization Conversion Ratio

B. Axial Ratio

Axial ratio (AR) is used to indicate the circular polarization's quality. Axial ratio can be written as:

$$AR = 20 * \log\left|\frac{R_{xy}}{R_{yy}}\right| \quad (4)$$

Often the 3 dB threshold is used to define the bandwidth where circular polarization occurs. In this work, the less strict 2 dB axial ratio criterion was used. The AR vs. frequency simulation is shown in Fig. 4 where the horizontal dashed line indicates the 2 dB level. Using the 2 dB threshold for the AR, it can be stated that the circularly polarized wave can be achieved within the frequency bands of 6.78-6.89 GHz, 12.54-13.76 GHz and 18.39-18.82 GHz.

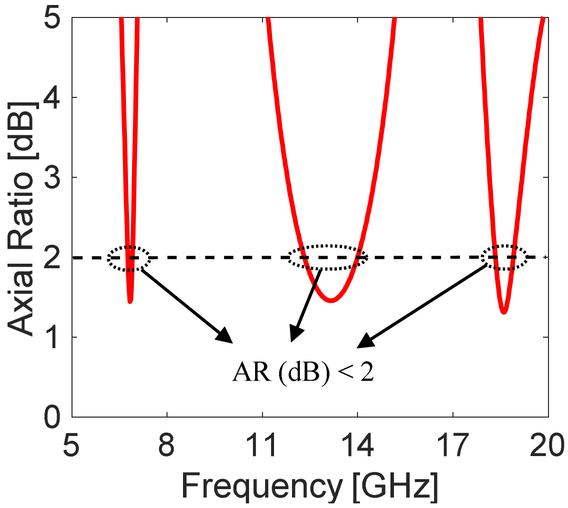

Fig. 4 Axial Ratio (in dB)

C. Angular Stability

There are many applications which require the angular stability of the design. Therefore, the behavior of the proposed metasurface is investigated under different EM wave incidence angles. The proposed structure has angular stability up to 30^0 which is verified in Figs. 5 (a) and (b) for the LTL and the LTC bands, respectively.

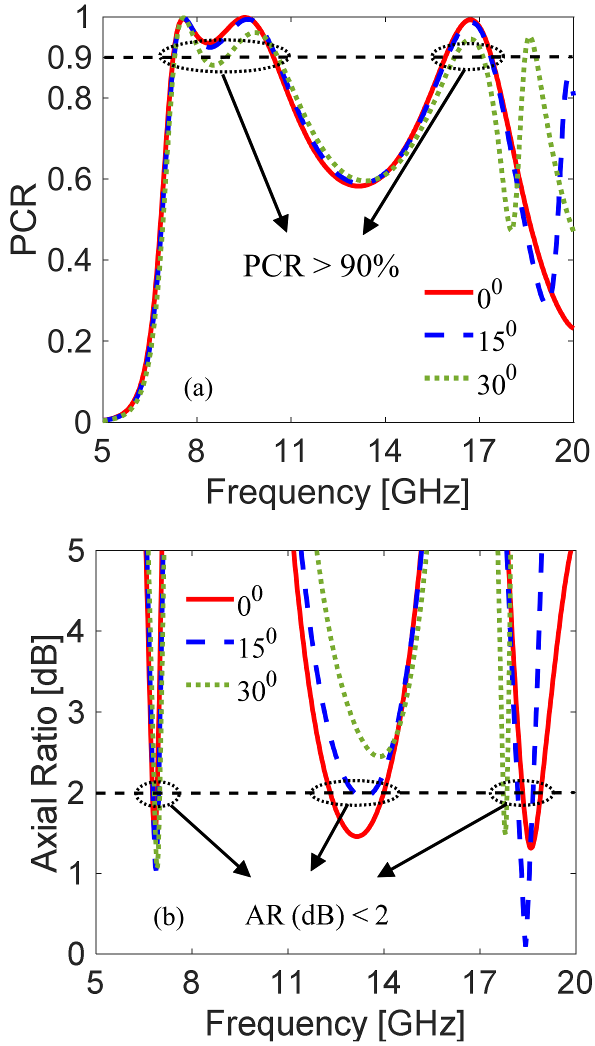

Fig. 5 Oblique incidence (a) PCR (b) Axial Ratio

IV. Conclusion

A single-layer metasurface is presented with multi-band and multi-polarization characteristics. The proposed metasurface remains angularly stable up to 30^0 for both LTL and LTC conversions. The cross polarization has been realized over two frequency bands (7.2-10.51 GHz and 15.81-17.48 GHz) with high efficiency because of the design anisotropy. Moreover, linear polarization is also converted to circular polarization over three frequency bands (6.78-6.89 GHz, 12.54-13.76 GHz and 18.39-18.82 GHz) through this anisotropic structure. The proposed metasurface can be used for various applications in satellite communications.

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REFERENCES

[1] M. I. Khan, F. A. Tahir, "Simultaneous quarter-wave plate and half-mirror operation through a highly flexible single layer anisotropic metasurface," *Sci Rep*, vol. 7, p. 16059, 2017.

[2] M.I Khan, Q. Fraz, and F.A Tahir, "Ultra-wideband cross polarization conversion metasurface insensitive to incidence angle*," Jour. of Phys.*, 121(4), p.045103, 2017.

[3] S. Bhattacharyya, S. Ghosh and K.V. Srivastava, "A wideband cross polarization conversion using metasurface," *Radio Science*, vol. 52, pp.1395-1404, 2017.

[4] S. H. A. Bokhari, H. M. Cheema, "Broadband asymmetric transmission via angle-induced chirality enhancement in split ring resonators," *Jour. of Appl. Phys.*, vol. 128, p. 063102, 2020.

[5] H. F. Ma, G. Z. Wang, G. S. Kong, and T. J. Cui, "Broadband circular and linear polarization conversions realized by thin birefringent reflective metasurfaces," *Opt. Mater. Exp.,* vol. 4, no. 8, pp. 1717–1724, 2014.

[6] M. I. Khan, Q. Fraz, and F.A Tahir, "Ultra-wideband cross polarization conversion metasurface insensitive to incidence angle," *Jour. Of Appl. Phys.*, vol. 121, p.045103, 2017.

[7] M.I Khan and F.A Tahir, "A broadband cross-polarization conversion anisotropic metasurface based on multiple plasmon resonances," *Chin. Phys. B*, vol. 27, p. 014101, 2018.

[8] Bao-Qin Lin., et al., "Multiple-Band Linear-Polarization Conversion and Circular Polarization in Reflection Mode Using a Symmetric Anisotropic Metasurface," *Phys. Rev. Appl.,* vol.9, 024038, 2018.

[9] M.I Khan, Z. Khalid, and F.A Tahir, "Linear and Circular Polarization Conversion in X-band Using Anisotropic Metasurface," *Sci. Rep.*, vol. 9, p. 4552, 2019.

[10] S. M. Q. A. Shah, F. Ahmed and N. Shoaib, "A Highly Efficient Multifunctional Metasurface for C-and X-Band Applications," *2020 14th European Conference on Antennas and Propagation (EuCAP)*, Copenhagen, Denmark, 2020.