A Wideband Linear-to-Circular Polarizer based on Hexagonal FSS on PDMS Substrate for CubeSats

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Abstract— **A novel flexible single-layered and single-sided linear to-circular polarizer is proposed in this work. The proposed polarizer is designed for a deployable format for application in a 3U Cube Satellites. It features a near-zero 3 dB AR, with a size of $0.22\,\lambda_0 \times 0.27\lambda_0 \times 0.03\lambda_0$ and a 3dB AR fractional bandwidth of 34.39 %, starting from 1.95 GHz to 2.76 GHz. It performs with a conversion efficiency bandwidth covering 90% of 43.47 %, starting from 1.8 GHz to 2.8 GHz. This indicates the polarizer's wideband CP performance, with a pure CP centered at 2.41 GHz.**

Keywords— Polarizers, frequency selective surfaces, metamaterials, CubeSats.

I. INTRODUCTION

Polydimethylsiloxane (PDMS) is a polymer which has found vast applications in electronic devices when used as a substrate. This is due to its versatile properties such as: lightweight, flexible nature, antistatic and have resistant against abrasion and chemicals, making it a safe option [1]. More recently, PDMS has been used in applications such as a reconfigurable frequency selective surface (FSS) for a Fabry-Perot cavity antenna system [2], bendable and switchable FSS for wearable applications [3], stretchable FSS for high power applications, radomes with mechanical tuning (stretching), electrical tuning for X-band [4] and microfluidic channel based transmit array for linearly-to-circularly-polarized waves using split-ring resonator (SRR) with unit cell rotational capabilities [5].

Satellites are classified based on the distance between the Earth and satellite in space. They are broadly put into strata of the distance a) geostationary earth orbit (GEO), b) medium earth orbit (MEO), and c) low earth orbit (LEO). One of the most widely used LEO satellite systems in recent years is the pico-satellites, which are miniature in size and light in weight (from 0.1 to 1.33 kg). The drastic decrease in satellite sizes is spurred by nanotechnology, which decreased the size of the electronic components. The simultaneous increase in launching costs and the need for smaller satellite volume and minimized power consumption has given birth to Cube-satellites (CubeSats). CubeSats are the most common type of pico-satellites [9], [10], and are designed for dedicated tasks such as imaging, wireless body area network (WBAN) localization, remote sensing and deep space communication etc. [6]–[8]; CubeSats can be used for off-body WBAN communications to exchange data from on-body network to PDA then to CubeSat due to its tiny sized $10 \times 10 \times 10\ cm^3$ [9]. A comparison of the mission counts (MC) from the last decade indicates that there is about 80 MC for commercial purposes [11].

Polarization is pivotal when two or more CubeSats need to connect wirelessly with each other, or for the CubeSat to send downlink data to Earth [12]. This is to optimize the limited power on board. The transmitter and receiver should be of the same polarization, otherwise, half of the power will be lost [13], [14]. Most satellites use circular polarization (CP) for this purpose as CP is capable of penetrating through the earth's atmosphere and has less effect when signals are reflected from the buildings and other natural structures [15], [16]. The design of CP antennas for CubeSat is more complex. Their sizes are typically small, resulting in a low realized gain. This must be compensated using power amplifying circuits on board, which is an unrealistic option for a CubeSat.

An alternative solution to achieving broadband CP is by employing a linear-to-circular polarizer for use in combination with a LP antenna. Available polarizers consist of multi-layered rigid substrates, which makes them unsuitable to meet the stringent dimension requirements for CubeSats. A few S-band flexible polarizers exist presently based on textile or PDMS as a substrate, but the size of the unit cell is relatively large [17], [18]. In this paper, a flexible, simple and single-layered S-Band linear-to-circular polarizing surface is designed and presented. It uses PDMS and compact-sized unit-cells, which maintains ease of fabrication and ease of deployment.

II. LINEAR TO CIRCULAR POLARIZATION

A. Conditions

It is assumed that when an LP wave is impinged on the polarizer with an angle 45º and travels in the *-z* direction as shown in Figure 1 and Figure 2, the incident electric field will be decomposed into two electric fields, namely E_x^i in x-direction and E_y^i in y-direction. The ratio of q (between E_x^i and E_y^i) [18], [19]. To simplify analysis, the electric vectors can be rewritten in terms of transmission signals as T_x in x-direction and T_y in y-direction, as shown in equation (1) and in Figure 3. To obtain CP wave at the other side of the

polarizer in -z direction, both electric fields should have equal magnitude but 90° phase difference between them as shown in (2) and in Figure 4.
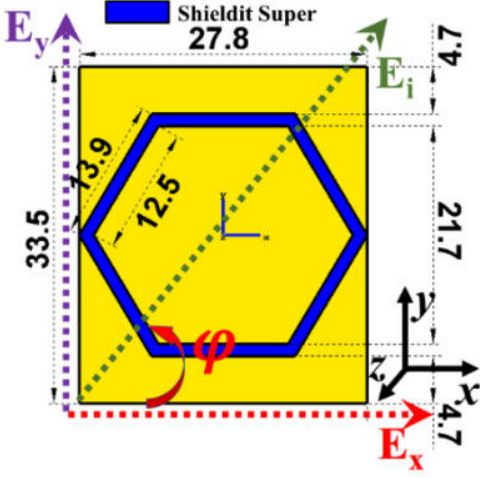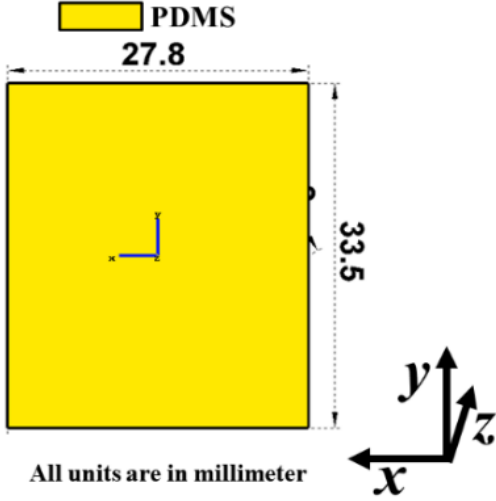

Fig. 1. Front view of the unit cell

Fig. 2. Back view of the unit cell

$$|E_x^i|.|T_x| = q|E_y^i|.|T_y| \qquad (1)$$

$$\Phi(T_x) - \Phi(T_y) = 90^0 \qquad (2)$$

B. Parameters used for Circular Polarization

Upon achieving conditions (1) and (2), the value of q will be unity. The 3 dB axial ratio (AR) is widely accepted in the scientific community to indicate the condition of CP, where a 0 dB value indicates pure CP. The AR can be calculated using (3), based on the transmission coefficients for x and y polarized waves, respectively. In the figures, the recommended band from FCC [20] is highlighted in blue. The simulated near-zero AR is shown in Figure 5.

To further assess the polarizer, two more parameters are used besides AR: a) conversion efficiency and b) conversion coefficients, which are calculated in (4) and (5), respectively. Parameters C_- and C_+ are the right-handed circular polarization coefficient and left-handed circular polarization coefficient, as shown in Figure 6 [19], [21].

$$AR = \sqrt{\frac{|T_y|^2 + |T_x|^2 + |T_y^2 + T_x^2|}{|T_y|^2 + |T_x|^2 - |T_y^2 + T_x^2|}} \qquad (3)$$

$$\eta_{conv} = \frac{(abs(C_-)^2 - abs(C_+)^2)}{(abs(C_-)^2 + abs(C_+)^2)} \times 100 \qquad (4)$$

$$C_+ = E_x^i T_x - jE_y^i T_y \qquad (5)$$

$$C_- = E_x^i T_x + jE_y^i T_y$$

III. UNIT CELL DESIGN AND RESULTS

A hexagonal-shaped unit cell is designed and optimized in an electromagnetic simulator. The unit cell boundary condition is defined at the $Xmin, Xman, Ymin,$ and $Ymax$ borders.

The inductive and capacitive creates a phase difference of 90° between Φ_{T_x} and Φ_{T_y}, as shown in Figure 4.

On the other hand, for $Zmin$ and $Zmax$, an open boundary and a Floquet port have been defined, respectively. Shieldit Super conductive fabric is used in place of conventional copper, whereas pure 3mm-thick PDMS with a dielectric constant (ε_r) of 2.7 and loss tangent (tanδ) of 0.02 is used as its flexible substrate, as shown in Figures 1 and 2. When an LP wave passes through the polarizing surface, the unit cells connections in the $x-$ direction create an inductive effect in the E_i^x direction. The gap between the two rows of unit cells creates a capacitive effect for E_y^i in the y direction, as shown in Figure 7. This is also supported by the high value of surface current which can be observed in between the two adjacent unit cells.
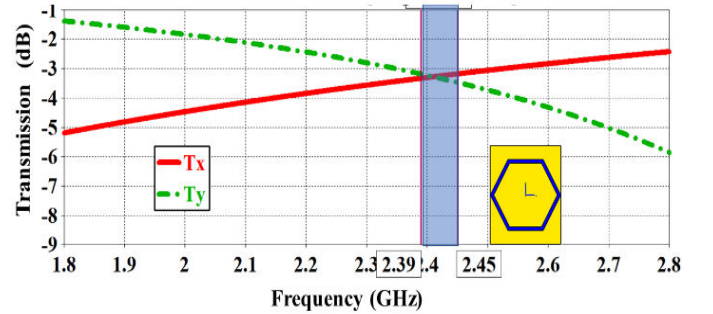

Fig. 3. The transmission coefficient of the two orthogonal components
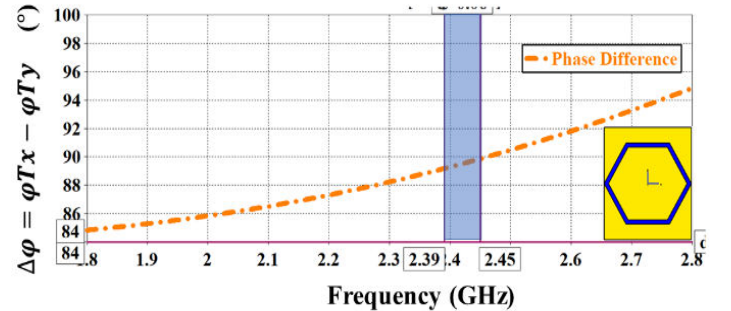

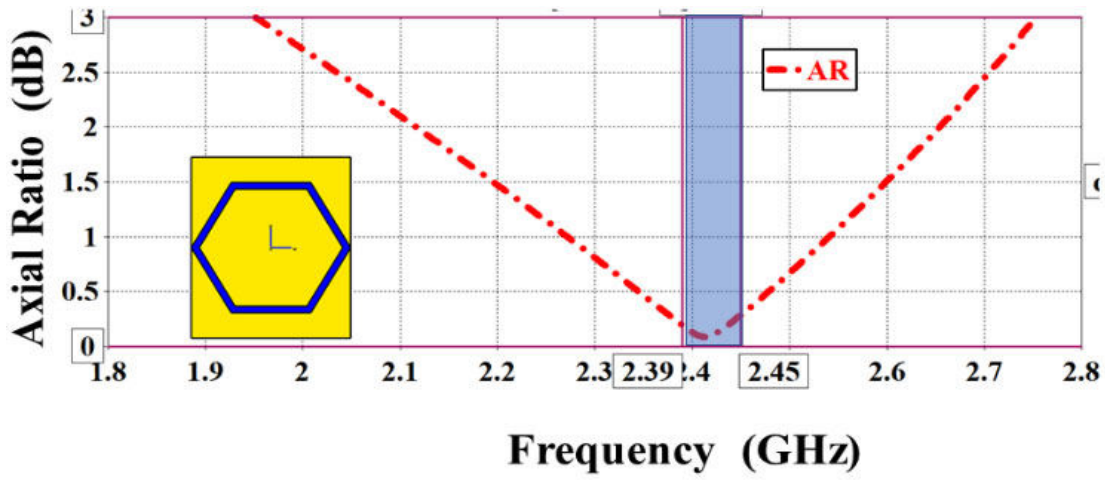Fig. 4. The phase difference between the two orthogonal components
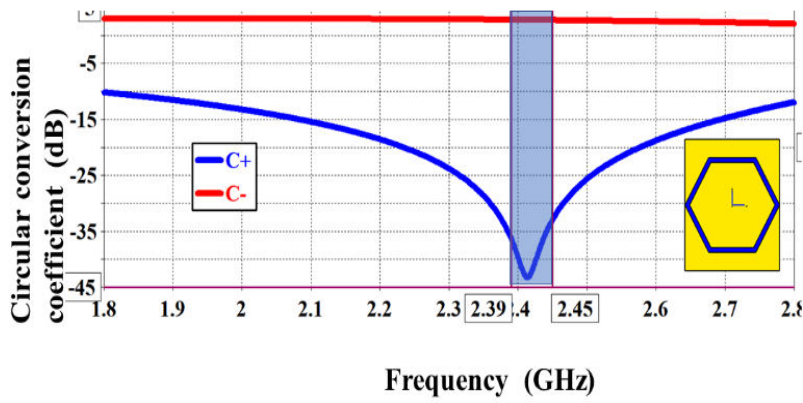
Fig. 5.   Axial Ratio
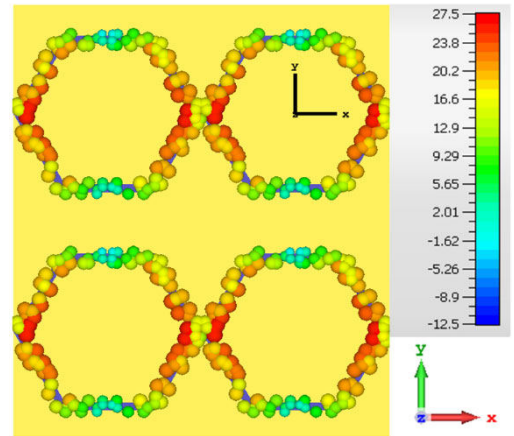

Fig. 6.   Conversion coefficient

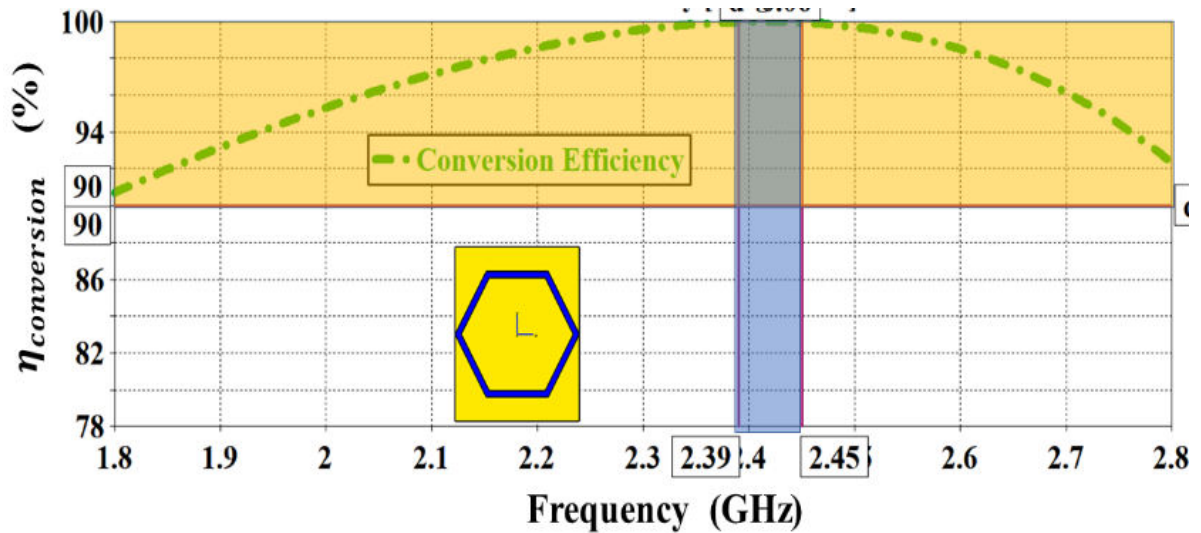Fig. 7.   The surface current distribution of the unit cells

Fig. 8.   Conversion efficiency

The 3dB AR of the proposed polarizing surface is shown in Figure 5. Its frequency range starts from 1.95 GHz to 2.76 GHz, with a near-zero minimum value at the center of the FCC recommended S-Band (from 2.39 to 2.45 GHz) for CubeSat. Finally, the conversion efficiency is shown in Figure 8, with the yellow-highlighted region indicating an efficiency range of 90 %. The conversion efficiency above 90 % is from 1.8 GHz to 2.8 GHz, which provides a 43.47 % fractional conversion efficiency bandwidth.

IV. CONCLUSION

A flexible single-layered and single-sided linear to-circular polarizer has been designed for application in a 3U CubeSat. Hexagonal-shaped unit cells have been selected for this polarizing surface unit cells to yield the maximum 3dB AR fractional bandwidth, besides enabling ease of fabrication. The proposed polarizer has a near-zero axial ratio (0.08 dB), and its performance assessed using two different approaches (axial ratio and conversion efficiency) resulted in: a) a 3dB AR bandwidth of 34.39 % and, b) fractional bandwidth of conversion efficiency (which is 90 % of the maximum value of conversion efficiency) of 43.47 %. These values indicate that the polarizer is wideband and can be integrated in CubeSat application in the S-Band for off-body WBAN applications.

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