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HIGH-PERFORMANCE LINEAR TO LINEAR POLARIZATION CONVERTER EXHIBITING 30° ANGULAR STABILITY

Haneef Hamza[*1], **Arbab Talha**[2], **Dr. Sadiq Ullah**[3]

[*1,2]*Ms Telecommunication Engineering, University of Engineering and Technology, Mardan*
[3]*Chairman of Telecommunication Engineering department, UET, Mardan*

[*1]haneefhamza@ymail.com, [2]arbabtalhah@gmail.com, [3]sadiqullah@uetmardan.edu.pk

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Corresponding Author: *
Haneef Hamza

Abstract
A thin linear polarization converting metasurface has been proposed with better efficiency and performance. The proposed surface is etched on 3mm thick dielectric substrate. It has the ability to convert linear to orthogonal equivalent in the 10.5-21.5GHz band with polarization conversion ratio above 90%.along with this, parametric analyses has also been conduct to monitor the effect of various parameter on the performance of surface. Moreover, for deeper insight into polarization conversion mechanism the surface current distribution is carried out.

INTRODUCTION

Metamaterial are artificially custom design periodic or aperiodic micro structures that give new properties and behavior that is not found in the natural state of the material from which they are derived. Because of such exotic properties from last couple of year it gained much interest in the optics research community and widely used in many new applications [1-3]. Metasurface, is the two dimensional version of metamaterial having sub wavelength structure, diameter is less than wavelength, is utilized for controlling the propagation of electromagnetic waves because of its un-parallel ability of controlling the electromagnetic wave Phase, polarization and amplitude. The metasurface is used for constructing different meta-device i.e., absorber, lenses, holograms, quarter and half wave plates and sensors [4-10]. The geometric structure of metasurface alter the amplitude, phase or polarization of the electromagnetic wave and have potential application in various field like radar cross section reduction[11], antenna designing[12], absorber[13,14]. In addition to this, they are also widely utilized for polarization converter of the electromagnetic waves.

Polarization is the main feature of transverse wave. In transverse wave the particle vibrate along the direction of propagation [15]. Electromagnetic wave (EM) is transverse wave and like many other transverse wave the EM wave also held the polarization characteristic. Polarization is the direction of electric$(\vec{E})$ and magnetic$(\vec{H})$ field when it radiate away from the source, while polarization conversion is the process in which the wave is manipulated according to one desired to utilize it for specific application. In polarization conversion mainly the phase and amplitude of the incident wave is change. Polarization conversion take place in two mode either transmission or reflection mode. The majority of work takes place in reflective mode because of its high efficiency and larger bandwidth.

For polarization conversion, some traditional method were used that were birefringence and Faraday Effect [15]. In former, the incident wave with different phase factor. The wave having polarization perpendicular to the propagation axis is called ordinary wave (n_o), while the wave polarization is along the direction of propagation is called extra ordinary wave (n_e). The difference between ordinary and extraordinary wave is called birefringence ($\Delta n = n_o - n_e$). In latter, half wave plate and quarter wave plate were used as a polarization converter. The half wave plate performs cross polarization and the quarter wave plate performed circular polarization of incident wave. However, with the passage of time new advancement took and technological evolution the used of traditional technique were gradually decline and replaced by new ones because of their bulkier volume and narrow bandwidth.

To overcome these limitation the researcher strive better polarization converter that are compact, less bulkier, large bandwidth and more efficient than previous ones[16]. Therefore, many polarization converters had been proposed [17, 18, 19], but they suffer from limited bandwidth and large unit–cell thickness. Several methods can be employed to increase the polarization conversion bandwidth among these methods the two main and popular methods are unit–cell optimization and stack method. A number of paper has been proposed on unit-cell optimization method that increase the bandwidth by properly designing the structure to resonate it at wide plasmonic resonance i.e., H-shape [20], Centre disk shape[21], crescent shape[22], oval shape[23]. Xu et al.prosped a H-shape ultra-broadband reflective cross polarization converter which attained PCR>90% and relative bandwidth of 94%in 7-19.65 GHz band. Zhao et al. presented a split ring with center disk resonator for 5.7 to 10.3 GHz band. The proposed surface successfully achieved PCR above 90% with the relative bandwidth of 57.5%. Recently, Neuygen et al. designed a crescent shape wide band and wide angle linear polarization converter for ku-band(12-18 GHz) applications, The PCR of crescent shape is over 90% with relative bandwidth of 40%.Karamirad et al. presented an oval pattern multiple plasmoic resonator for 10.2 to 20.5GHz having angular stability 30^0 and bandwidth 67%. Another [24] increase the angular stability at the cost of bandwidth which is only 61%. It is noted that for the polarization converter there is give and take between bandwidth, angular stability and efficiency. Therefore, polarization converter with less complex structure having wideband and having more angular stability is still of great interest.

In this paper a scared-crow shape structure is proposed that successfully transform linearly or circularly incident EM wave into its orthogonal counterpart. The PCR of the proposed surface, which define the efficiency of the unit-cell is also plotted which is more than 90%. Also, the assessment range of the surface is from 10.5 to 21.5 GHz. The bandwidth of the surface is 68% with angular stability 40^0.The metallic ground is added to the substrate that reduces the scattering of wave and makes transmission zero. The mechanism of PCR is comprehensively explained. In this paper the proposed unit-cell has advantage of simplest structure, high PCR, and less complexity in fabrication as the structure is simple one. Therefore, it can be used in various applications in communication technology, remote sensing, radar cross section reduction and satellite communication etc.

Parameter and design steps of the unit cell

The metasurface that has symmetric structure has low co and cross polarization and widely used for absorption of EM wave, but if the symmetry of the unit-cell is break in specialized manner its cross polarized coefficient increase, while the co polarized coefficient decrease. It signifies that the structure successful convert the x-polarized wave in to y-polarized or y-polarized to x-polarized.

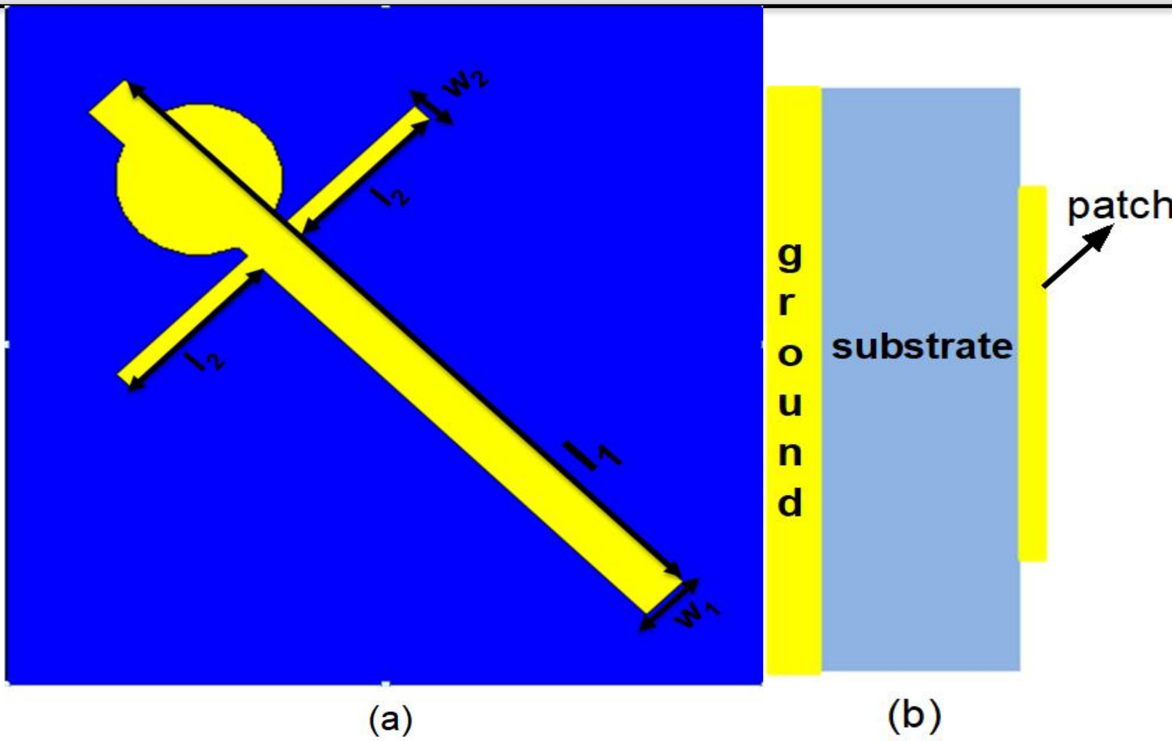

Figure 1: a and b; figure (a) show parameter of the patch, figure (b) show the unit cell

Following same principle, we proposed a wideband and highly efficient reflective metasurface based on a scared–crow shaped unit cell as depicted in figure-1-a and the different layer combination that result in unit-cell in figure-1-b.

The detail description of physical dimension of the unit-cell is as follow. The F4B is used as a dielectric medium having thickness 3and over all unit-cell size $7 \times 7 \times 3$ mm². The electrical permittivity of the substrate is $\varepsilon_r = 2.2$ and loss tangent $(\sigma) = 0.001$. The metallic ground is introduced to restrict the incident wave scattering. The conductivity of the ground $\sigma = 5.8 \times 10^7 s/m$ having thickness t=0.035. The ground and top patch is of similar thickness (t). The parameter of the top patch is following: P=7, length l1 =7.5 and l2=e and width w1= 0.5 and w2=0.2.thr radius r of the top circular is 0.8

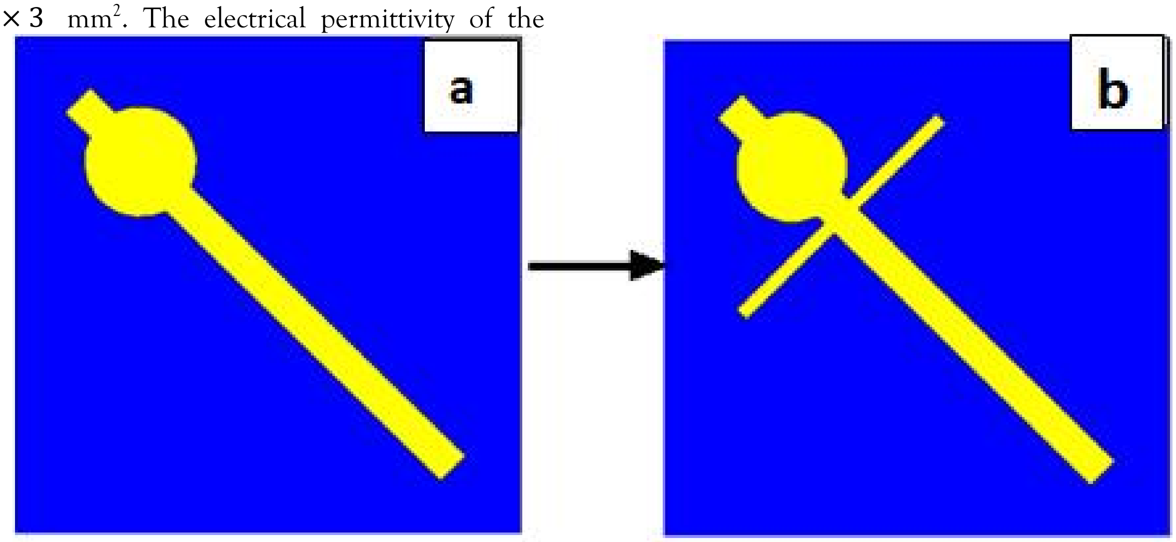

Figure 2: Design steps of the patch

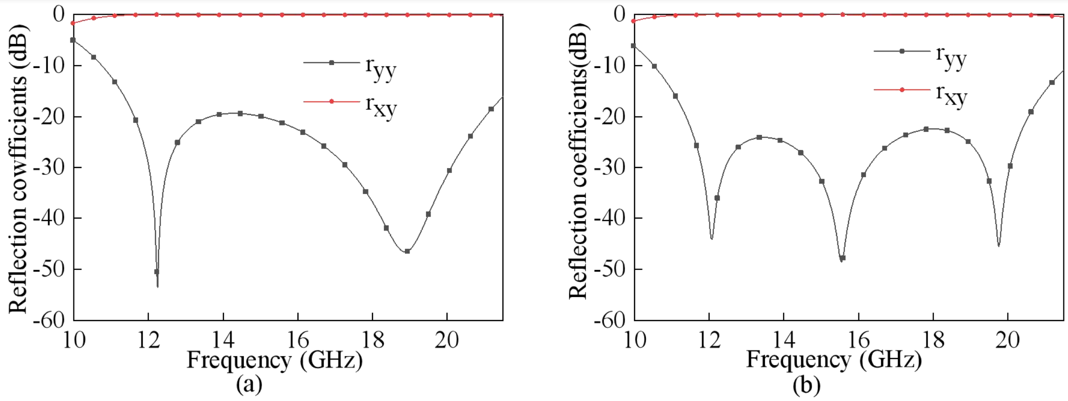

Figure 3: co and cross reflection co-efficient of design steps

The proposed design is obtain after performing two steps procedure. In primary step, a drum stick patch of length l1 and width w1 in erected as show in figure-2-a. The drum stick shows two resonances in the assessment frequency band which is shown in figure -3-a. In second step, a rod of length l2 and width w2 is inserted to the patch that gives it a shape of scared crow as shown in figure-2-b. This provide us three resonance in the frequency band which is display in figure 3-b.

Simulation and result discussion/performance analysis and simulation result:

The CST Microwave Studio, which is commercially available and the result show good agreement to the experimental result was used in optimizing and analyzing the proposed metasurface unit-cell design. Before performing the simulation the boundaries was applied is x and y plane, while floquent port in z direction. The surface is simulated in frequency domain solver. Whenever, the incoming electromagnetic waves strike the surface it decomposed in to two components: co polarized field and cross polarized field components. The former is represented by, r_{xx} and r_{yy}, while the latter is represented by r_{xy} and r_{yx}. In co-polarization the incident and reflected wave has same polarization and in cross polarization the incident wave is reflected into its orthogonal counterpart means x incident y reflected vice versa. The co and cross polarized reflection coefficient of x and y can be define as [25]:

$$|r_{yy}| = \frac{\vec{E}_{yr}}{\vec{E}_{yi}} \text{ and } |r_{xy}| = \frac{\vec{E}_{xr}}{\vec{E}_{yi}}$$

$$|r_{xx}| = \frac{\vec{E}_{xr}}{\vec{E}_{xi}} \text{ and } |r_{yx}| = \frac{\vec{E}_{yr}}{\vec{E}_{xi}}$$

Here, the x and y represent the path of electromagnetic waves. Because of, diagonal symmetry of the surface the refection amplitude is similar and create identical response for polarization transformation of the incident x and y polarized wave. Polarization conversion occurs, when the cross polarized coefficient increase and the co polarized coefficient decrease. The criteria for achieving cross polarization conversion greater than 90% the co-polarized coefficients should be less than -10dB $(r_{xx} \text{ and } r_{yy} < -10\text{dB})$, while the cross –polarization coefficient should be greater than -1dB $(r_{xy} \text{ and } r_{yx} > -1\text{dB})$ [23]. The proposed polarization conversion metasurface fulfills the aforementioned condition. The co-polarized coefficient is small than -10dB and the cross-polarized coefficient in near to zero in assessment frequency range from 10.5 to 21.5 GHz.

To further elaborate the performance of the proposed unit-cell; polarization conversion ratio (PCR) is calculated from the co and cross polarized reflection coefficients. Cross polarized coefficient square divide by cross square plus co polarized coefficient square. The PCR can be mathematically expressed as [26]:

$$PCR_{x \text{ or } y} = \frac{|r_{xy}|^2}{|r_{xy}|^2 + |r_{xx}|^2}$$

PCR of the proposed polarization converter metasurface is greater than 90% and the fractional bandwidth of the surface is 68%.

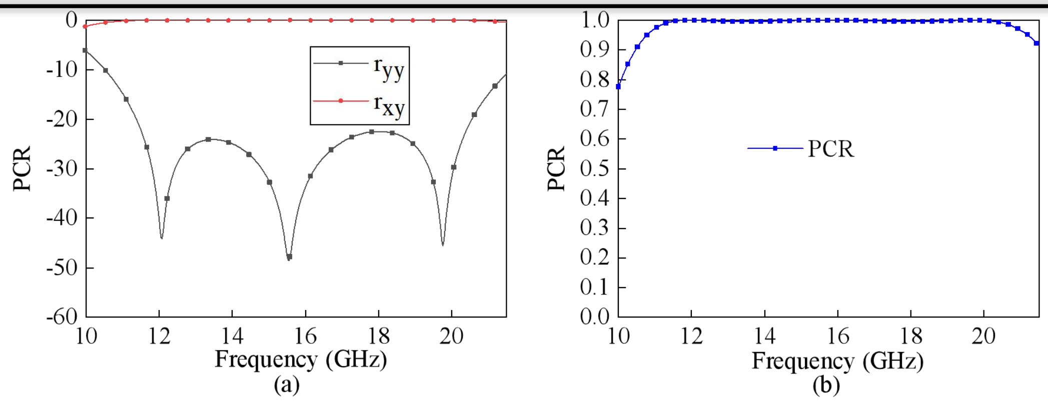

Figure 4: magnitude and PCR of unit cell: figure (a) show co and cross-refection co-efficient and figure (b) show PCR

Working Mechanism

For understanding the mechanism of linear to linear polarization conversion of polarization conversion metasurface (PCM); the linearly polarized EM wave that incident the surface has been fragmented into two orthogonal components E_{iu} and E_{iv}, respectively that are along u and v –axis as illustrated in fig-15. The two orthogonal components u and v axis are 45^0 and 135^0 degree apart from x –axis. The incident electromagnetic can be described as [25].

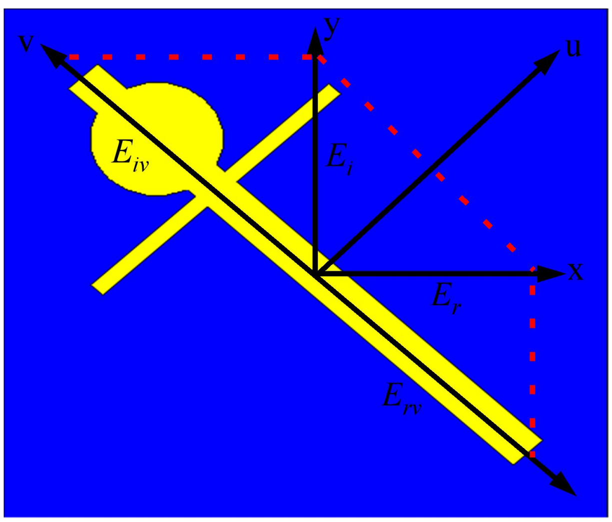

Figure 5: u and v decomposition of unit cell

$$\vec{E} = u\vec{E}_{iv} + v\vec{E}_{iu}$$
$$\vec{E} = u\vec{E}_{ru} + v\vec{E}_{rv} = u r_u \vec{E}_{iu} + v r_v u\vec{E}_{iv}$$

The r_u and r_v are the reflection coefficients along u and v- axis and $\Delta\varphi$ represent their phase difference. Polarization conversion occur, when the amplitude of r_u and r_v is equal to one and their phase difference is $180^0 (r_u \approx r_v$ and $\Delta\varphi = 180^0 \pm 37^0)$. The plotted result in fig16-a and b shows that the PCM is achieving the ability to transform a specific polarization to its orthogonal counterpart.

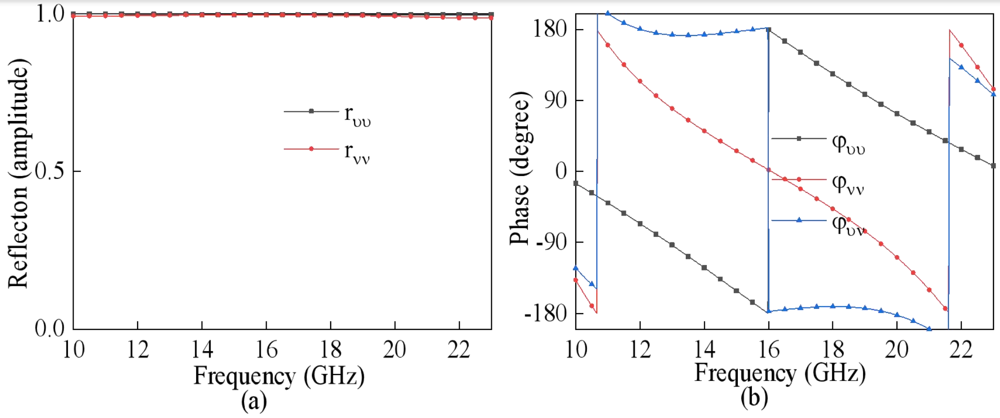

Figure 6: Simulated reflection coefficient of the proposed polarization converter under u and v polarized normal incidences (a) amplitude and (b) phase

In order to further explain the polarization conversion working principle the surface current distribution at the ground and top metallic patch. If the surface current distribution at top and bottom is parallel the resonance will be termed as electric resonance. Contrary to this, if top and bottom surface current flowing in opposite direction the resonance will be termed as magnetic resonance. These resonances are also known as plasmonic resonances. The exciting unit-cell show three plasmonic resonances in frequency band 10.5 to 21.5 GHz. As shown in figure-7-a, c the current flow anti-parallel on top and bottom and the resonance are magnetic resonances, while figure-7-b is electric resonances because the current flow parallel at top and bottom metallic.

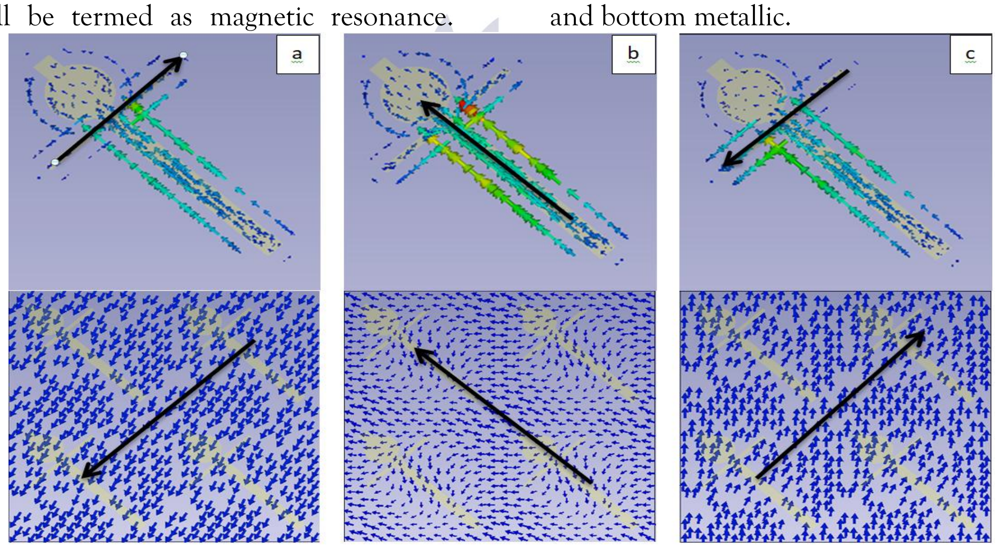

Figure 7: surface current distribution at top and bottom metallic layer

Parametric Analysis

There are several important parameter that has great impact on the PCR result obtained from the proposed scared –crow surface. Using CST software, keeping the step width 0.5 several simulations performed and compare their results. The important parameter: length, width and incident angle greatly affect the PCR of proposed surface. When the length s of square patch7*7 unit cell is small the PCR in higher in lower frequencies, while increase in length the PCR gradually shifted to higher frequencies as shown in figure 8- a. In addition to this, the height of substrate also effect the PCR and suitable height is necessary to attain higher PCR. As shown in figure 8 –b, the change in the height has great impact on the PCR. Moreover, both the length of top patch l1 and l2 change the PCR of the proposed surface when the length is small the PCR is higher in lower frequencies. Conversely, when the length is increase the PCR of the surface is shifted to higher frequencies as demonstrated in figure-8 c and d.

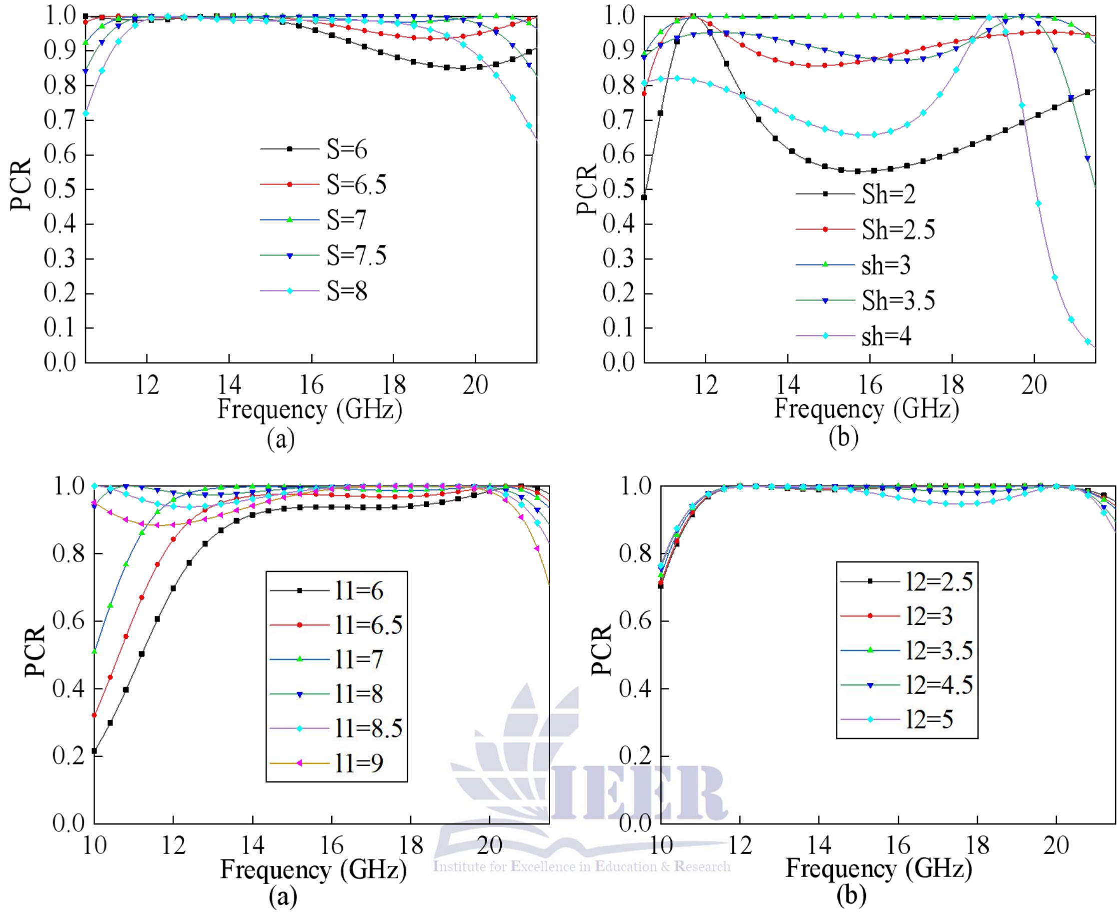

Figure 8: Parametric analysis (a) s (b) Sh (c) l1 (d) L2

Immunity of the surface to oblique incident EW is also important in modern wireless technologies. Increase the incident angle impact the overall PCR of the proposed surface. The PCR of the proposed surface remain over 90% for a wave incident from 0-30^0. Above 30^0, increase in incident angle significantly affects the PCR of the proposed surface as illustrated in figure-9. At incident angle 40^0 the PCR of the surface is less than 90%

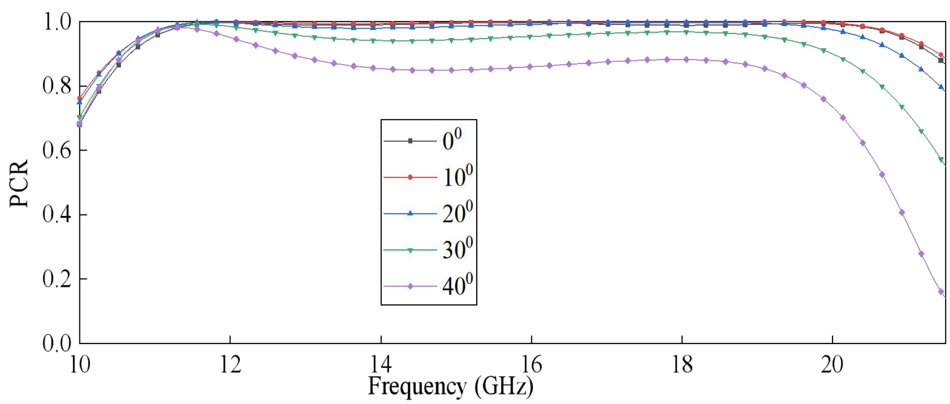

Figure 9: PCR at different incident angles

Conclusion

This paper, a sacred crow shape polarization converter was proposed for frequency band 10.5 to 21.5 GHz. The proposed reflective polarization converter metasurface is highly efficient having PCR greater than 90% for entire band. The simulation and parametric sweep were performed and displayed in figure to justify the claim of high PCR and bandwidth. Furthermore, the working mechanism is also explained with help of surface current distribution at the top and bottom and a dielectric layer is placed between them, in addition to this, the proposed surface is angular stable up to 30^0. Hence, the prosed structure can be utilized in many applications that demand high PCR along with some angular stability. For example, remote sensing, GPS and communication etc.

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