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Metasurface based Circularly Polarized Reconfigurable Antenna

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Abstract

Objective: The polarization reconfigurable elliptical slot antenna using corner truncated square Metasurface (MS) is proposed. **Methods/Statistical Analysis:** The proposed antenna has an elliptical slot radiator with aperture coupled microstrip feed and Metasurface is placed just above the slot antenna. The antenna reconfigures to LP, RHCP and LHCP using Metasurface. The antenna performance is observed in its three polarization states. The Metasurface antenna is designed and numerical simulation is presented using HFSS. **Findings:** The investigation reveals that the antenna resonates at 3.5 GHz and it has an impedance bandwidth of 370 MHz. The linear and circular polarization is obtained when the Metasurface is rotated at different angles with relative to the slot antenna. Additionally, due to the Metasurface structure, the wide axial ratio bandwidth of about 350 MHz is obtained. The gain of about 7.5 dB is obtained for both LHCP and RHCP and that for LP is 6.8 dB. **Applications:** The Metasurface loaded antenna exhibit characteristics that can meet the requirements of WiMAX (3.5 GHz) applications.

Keywords: Metasurface, Microstrip Patch, Polarization Reconfigurability, Slot Antenna

1. Introduction

The attention of tunable antenna is increasing since there is a demand for incorporating multiple wireless standards into a single platform. The position of several mobile devices are often dynamically changing which creates problems to achieve polarization matching for antennas which have single polarization and is desirable to have antenna able to function in different polarization. Polarization reconfiguration can occur between different kinds of Linear Polarization (LP) and Circular Polarizations[1] (CP). Reconfiguration of antenna provides the possibility of designing antennas of more compact size whilst operating in several frequency bands. Reconfiguration of an antenna is attained through changing its frequency, polarization[2] and radiation characteristics. Most common methods used for reconfiguration of antenna are optical switches[3], PIN diode, MEMS switch[4–6], RF switches[7], mechanical change[8] and material changes.

Metamaterials is an artificial material with periodic structure. Such materials possess of both effective permeability ($\mu < 0$) and effective permittivity ($\varepsilon < 0$) are concurrently negative in a given frequency band. Metasurface (MS) is two dimensional version of metamaterial with repeated array of scatters to get engineered properties that arenot present in nature[9]. Recently, Metasurface are extensively used to improve the efficiency of an antenna and also to acquire novel function. Zero index and dual negative properties of the metamaterial are used to enhance the antenna's directivity[10,11]. The Metasurface is used for beam steering applications[12] with p-n diode switches. The effective anisotropic property of the Metasurface causes electromagnetic wave to bend around the objective covered by it. The electromagnetic

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waves are neither scattered nor absorbed. The physical property of Metasurface utilized for cloaking applications[13] and also reduces the Radar Cross Section (RCS) of an antenna[14,15] without modifying its radiation properties. The Metasurface lower the out-band RCS[16] and in-band RCS of the antenna[17]. An anisotropic Metasurface is used to convert the linear polarized waves into circular polarized waves by placing the metasurface on smooth slot antenna[18]. Very recently, a corner cut patch-based Metasurface has been used to reconfigure the polarization of a planar antenna[19].

In this work, the antenna reconfigured to Linear Polarization (LP), Right-Hand Circular Polarization (RHCP) and Left-Hand Circular Polarization (LHCP) by spinning the Metasurface relative to the slot antenna[20,21]. The radiation property of an antenna also depends on the shape of the aperture and the feed line. The coupling between the Metasurface and the patch is very low because the slot is placed behind the feed line. As the coupling mechanism determines the radiation characteristics, we modify the shape of the feed line to get greater coupling effect between the feed line and the Metasurface and which in turn improves the bandwidth and gain.

2. Analysis of Metasurface

The Metasurface used is considered to reconfigure the polarization states and to enhance the radiation characteristics of the unit cell[17]. It is a corner truncated square structure as shown in Figure 1. The Metasurface unit cell have a conducting copper square patch is placed above the substrate where the edges of the patch are truncated to convert the Linear Polarized (LP) waves to Circular Polarized (CP) waves. The Metasurface structure is simulated in HFSS tool to test its electromagnetic properties.

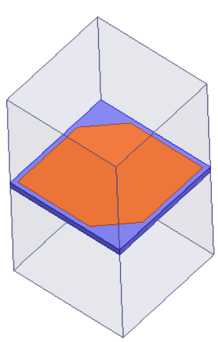


Figure 1. Unit cell model.

The reflection phase versus frequency is shown in Figure 2. It is observed that the reflection phase is zero at 3.5 GHz. The simulated reflection and transmission coefficient is shown in Figure 3. The reflection coefficient and the transmission coefficient for the resonant frequency will be nearer to zero and one when measured in terms of magnitude. This resembles that the Metasurface behaves as band pass filter.

In order to extract the material parameters (ε and μ), unit cell of the Metasurface with lattice vector is considered. Boundary conditions (Master, Slave and Perfect E) and Excitations (Floquet Port) are appropriately set to different face of the three dimensional unit. S11 and S21 parameters are extracted from the simulation and the electromagnetic parameters are derived using MATLAB Script. The S parameters extracted from the HFSS are in .csv format. The equivalent permittivity and equivalent permeability are obtained from the following Equations:

$$Z = \sqrt{\frac{(1+S_{11})^2 + S_{21}^2}{(1-S_{11})^2 + S_{21}^2}} \quad (1)$$

$$e^{jnkd} = X \pm \sqrt{1 - X^2} \quad (2)$$

$$X = \frac{(S_{11}^2 + S_{21}^2)}{2S_{21}} \quad (3)$$

Where, Z is the equivalent impedance, n is the refractive index, k is the wave number and d is the thickness of the Metasurface. Z and n are in complex form. effective permittivity and permeability can be obtained by the following mathematical expressions:

$$\varepsilon_R = \frac{n}{Z} \quad (4)$$

$$\mu_R = n{*}Z \quad (5)$$

After calculating the effective permittivity and effective permeability from the Equation (4) and (5), the curves are shown in Figure 4 and

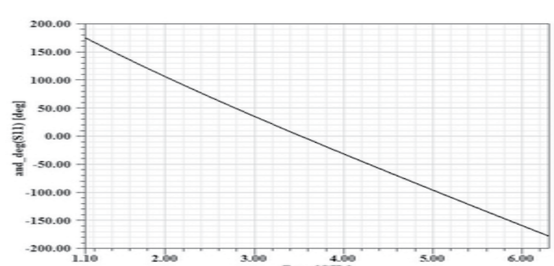


Figure 2. Reflection phase vs. Frequency.

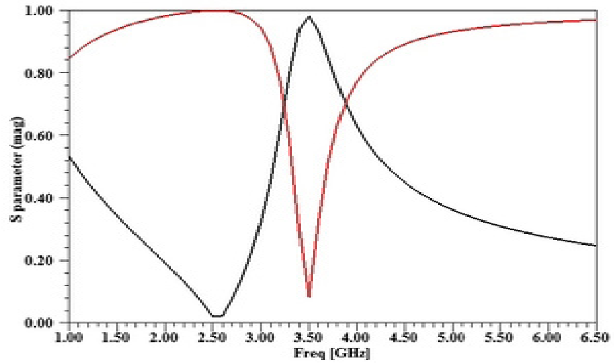


Figure 3. Transmission and reflection co-efficient vs, frequency.

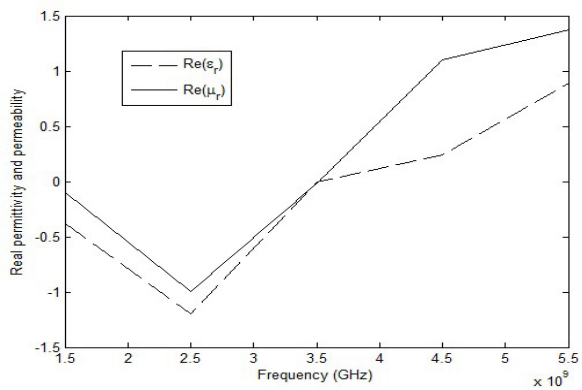


Figure 4. Real part of permeability and permittivity vs. frequency.

Figure 5. It is noted that electrical parameters curves are negative in the frequency range of 1.5 GHz to 5.5 GHz, which showed the metamaterial behaviour in the region of interest.

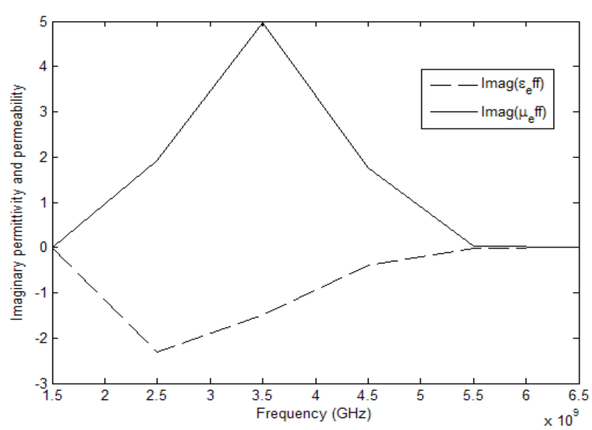
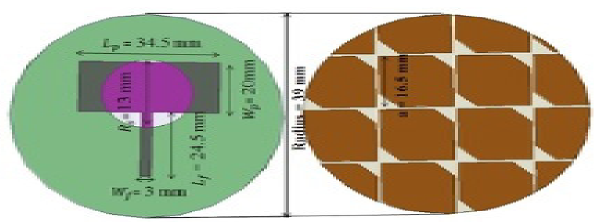


Figure 5. Imaginary part of permeability and permittivity vs. frequency.

3. Antenna Geometry

The proposed Metasurface antenna structure is composed of microstrip line fed elliptical antenna and the square corner truncated Metasurface is shown in Figure 6. The elliptical slot antenna is designed with a Rogers substrate of dielectric constant ε_r = 3.8 and loss tangent (tanδ = 0.004) and thickness of 1.524 mm. A 50 Ω microstrip line is imprinted upon the substrate and the elliptical slot is cut on the bottom of the substrate, as shown in Figure 6(a) and Figure 6(b). A vacuum is present between the elliptical slot antenna and the Metasurface antenna with a thickness of 1 mm.



(a) (b)

Figure 6. Structure of (a) Elliptical slot antenna with microstrip patch feed and (b) Metasurface.

4. Analysis of Antenna

4.1 Reconfiguration Mechanism

The Metasurface can reconfigure the polarization of elliptical slot antenna into LHCP, RHCP and LP as shown in Figure 7. When the elliptical slot antenna energizes the Metasurface oriented in the direction, the incident electric field can be split into two orthogonal components with phase difference of $90°$, the resultant E-field through the Metasurface will be of Left-Hand Circular Polarization (LHCP) wave. When $\theta_R = 90°$, the Right-Hand Circular Polarization (RHCP) wave is radiated from the Metasurface. When $\theta_R = 45°$ 0r $\theta_R = 135°$, the E-field can be split into two components with same amplitude and phase. The resultant field through the Metasurface is Linear Polarization (LP).

In constructing the Metasurface antenna, the radiator side is placed above the Metasurface substrate and the bottom layer is kept on the vacuum layer, which directly makes contact with the elliptical slot antenna with microstrip line feed in the top layer of the source antenna. An aperture coupled feed is used to feed the microstrip patch feed via the ground is shown in Figure 8.

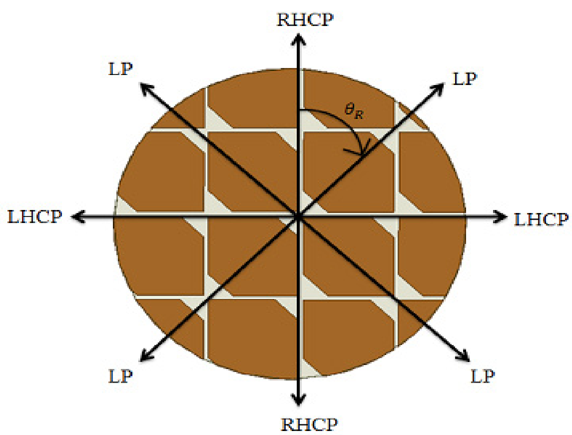


Figure 7. Polarization for different rotation angles.

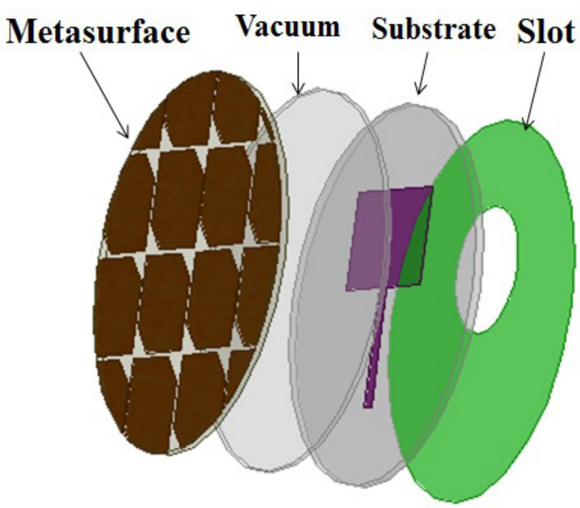


Figure 8. Diagrammatic representation of Metasurface antenna.

4.2 Effect of Coupling

In the aperture coupled microstrip feed line, the coupling between aperture and radiating element determines the radiation properties of an antenna. The coupling mainly depends on the shape of the patch and feed line. The impedance bandwidth of an antenna can be proposed by changing the antenna shape and feed line shape. The antenna performance is studied by changing the shape of the feed line. At the end of the feed line a stub is connected with a length of 34.5 mm and width of 20 mm. If we change the length and width of the stub, it is noted that the variations in return loss and resonant frequency is observed is shown in the Figure 9. It is also observed that gain of the antenna as shown in Figure 10, varies when the stub length and width is changed as tabulated in Table 1. From above analysis, the radiation properties of an antenna depend on the coupling effect between the feed line and the radiator.

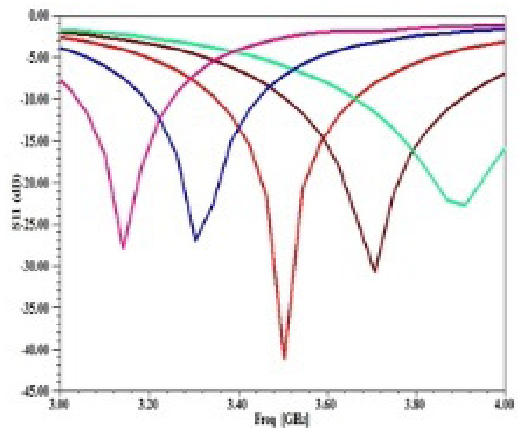


Figure 9. Return loss vs. frequency.

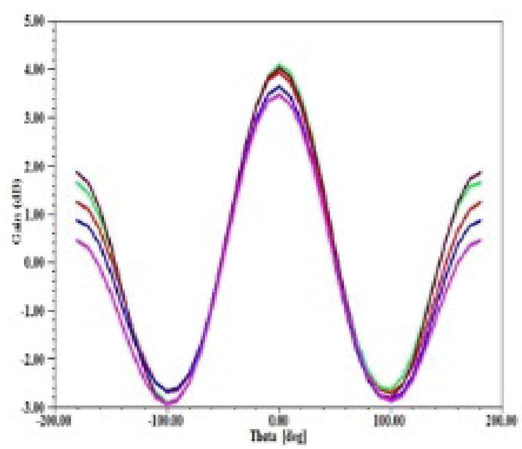


Figure 10. Gain vs. theta

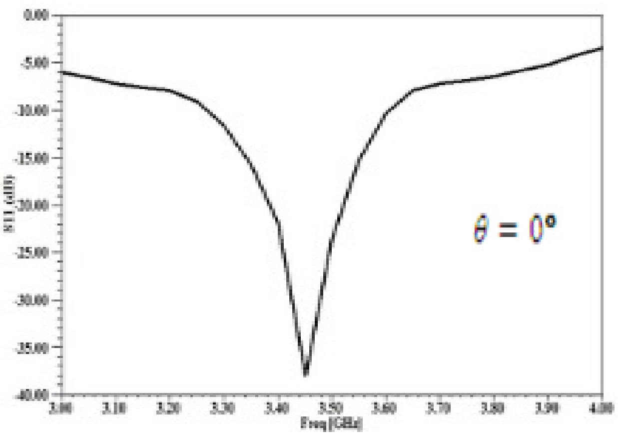
Table 1. Parametric Study

Dimensions of Stub		Centre Frequency (GHz)	Gain (dB)
Length (mm)	Width (mm)		
32.5	18	3.1414	3.46
33.5	19	3.3000	3.67
34.5	**20**	**3.5000**	**4.05**
35.5	21	3.7000	4.02
36.5	22	3.9000	4.11

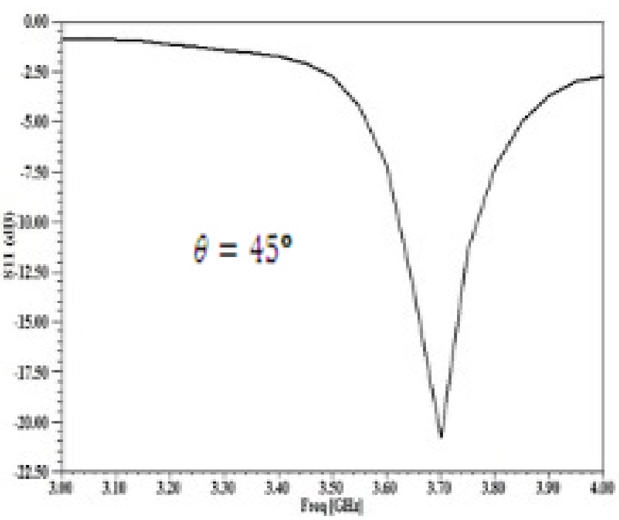
5. Simulated Results

5.1 Return Loss Bandwidth (RLBW)

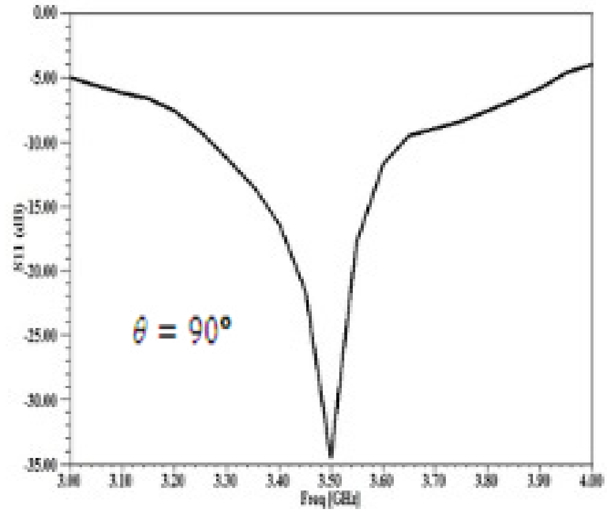
The proposed Metasurface antenna is simulated and studied using HFSS tool. For different rotation angles, the return loss bandwidth is simulated. Since the Metasurface is the mirror image for $\theta_R = 0°$ and $90°$, the results for LHCP and RHCP are same as shown in Figures 11(a) and 11(c), respectively. The return loss bandwidth (S11 < -10 dB) are from 3-4 GHz. At rotation angle $\theta_R = 45°$ for linear polarization the frequency range shifts from 3.6 GHz to 3.78 GHz as shown in Figure 11(b). And for rotation angle $\theta_R = 135°$ the return loss S11 frequency band shift from 3.46 GHz to 3.91 GHz as shown in Figure 11(d).



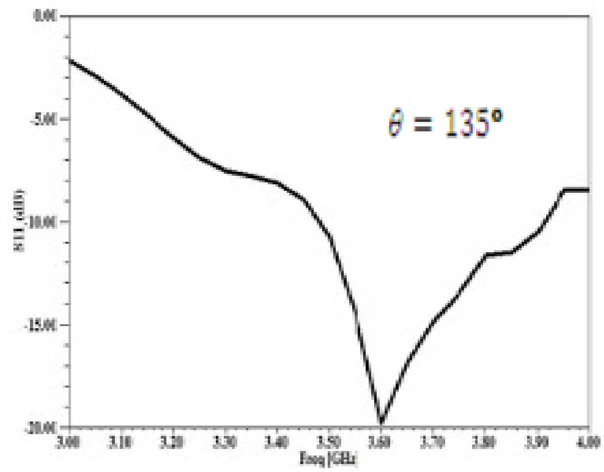
(a).



(b)



(c)

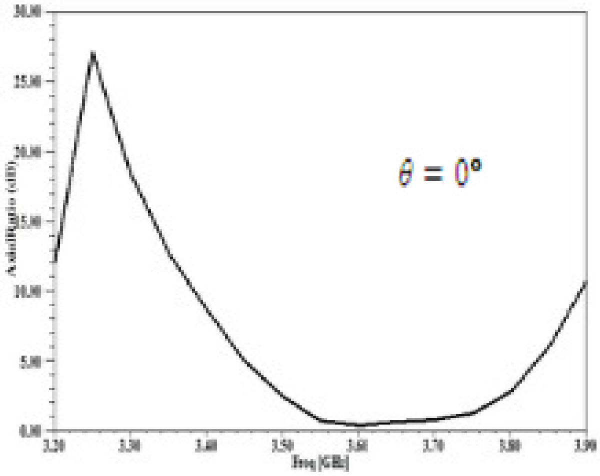


(d)

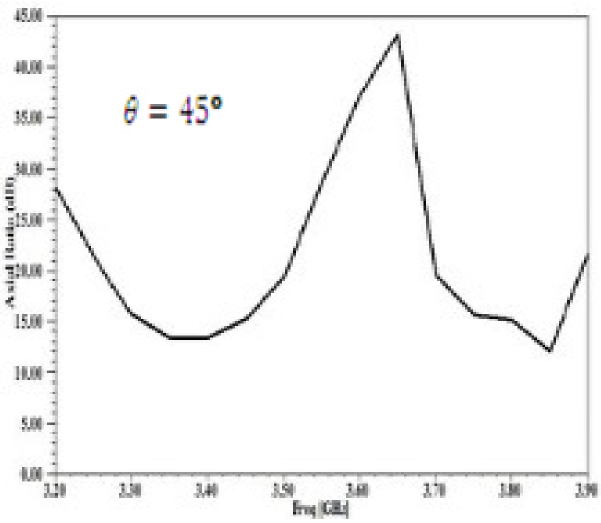
Figure 11. Simulated return loss S_{11} for(a) $\theta = 0°$, (b) $\theta = 45°$, (c) $\theta = 90°$ and (d) $\theta = 135°$.

5.1 Axial Ratio Bandwidth (ARBW)

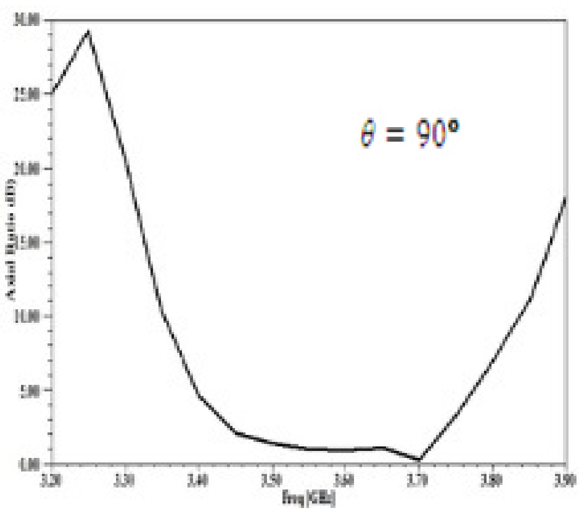
The simulated Axial Ratio (AR) of the Metasurface antenna is shown in Figure 12. Since the $\theta_R = 0°$ and $\theta_R = 90°$ are similar because of the mirror image of each other as shown in Figure 12(a) and 12(c). The simulated AR is less than 3 dB from 3.48 GHz to 3.80 GHz for LHCP with an Axial Ratio Bandwidth (ARBW) of 320 MHz. Similarly the RHCP is from 3.42 to 3.77 GHz Axial Ratio Bandwidth (ARBW) of 350 MHz. For rotation angle $\theta_R = 45°$ and $135°$, the antenna operates in Linear Polarization (LP) shown in Figure 12(b) and 12(d) shows that the Axial Ratios are larger than 10 dB from 3.2 GHz to 3.9 GHz.



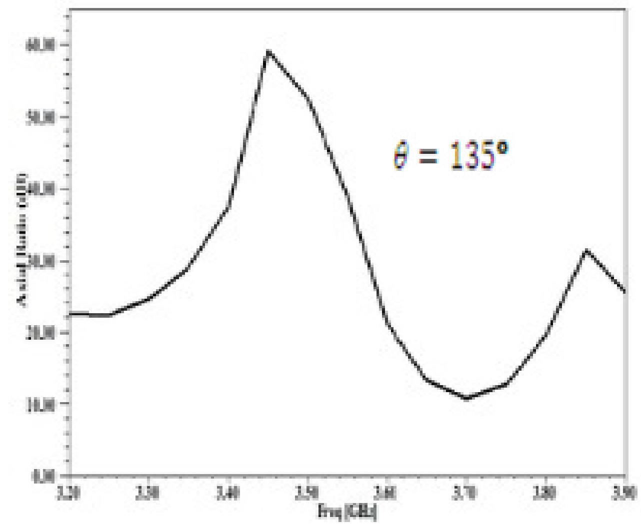
(a)



(b)



(c)

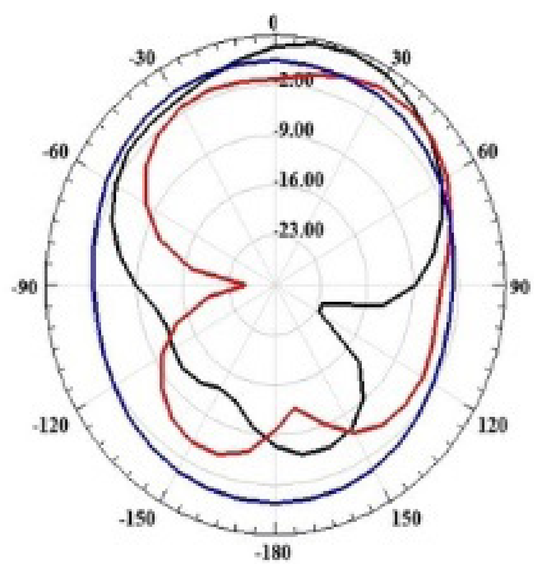


(d)

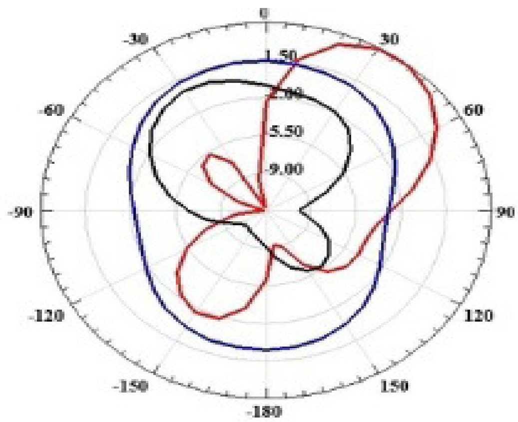
Figure 12. Simulated Axial Ratio for (a) $\theta = 0^\circ$, (b) $\theta = 45^\circ$, (c) $\theta = 90^\circ$ and (d) $\theta = 135^\circ$.

6. Radiation Pattern

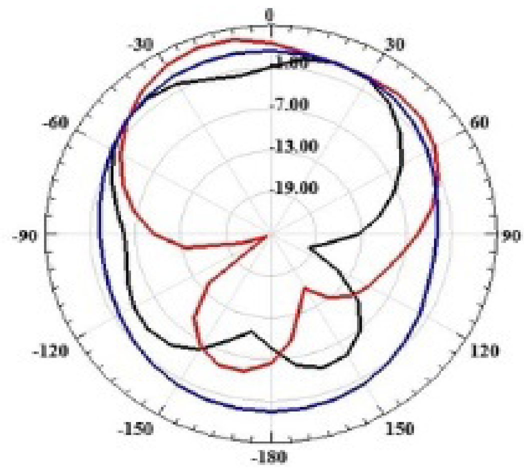
The radiation pattern of the Metasurface antenna operated at 3.5 GHz is simulated for different rotation angles as shown in Figures 13(a), 13(b), 13(c) and 13(d). From the result, it is observed that the Metasurface antenna has unidirectional radiation pattern, instead of omnidirectional pattern. At 3.5 GHz, the gain of 7.5 dBi is obtained for both LHCP and RHCP and that for LP is 6.8 dBi.



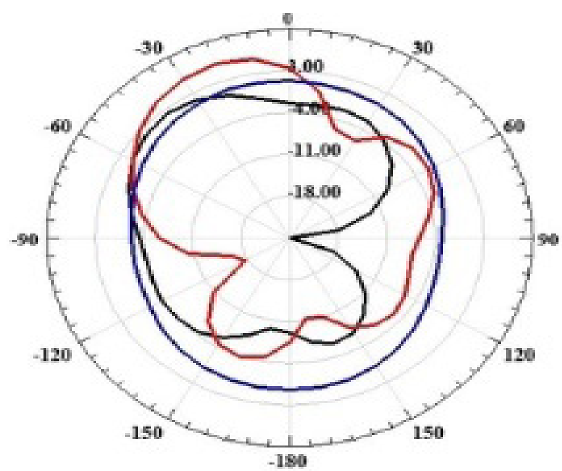
(a)



(b)



(c)



(d)

Slot only Cross-Pol Co-Pol

Figure 13. Simulated radiation pattern at 3.5 GHz for (a) θ = 0°, (b) θ = 45°, (c) θ = 90° and (d) θ = 135° °.

7. Conclusion

A Metasurface based circularly polarized reconfigurable antenna is designed and simulated. The unit cell of Metasurface is designed and characterized to have in-phase reflection at around 3.5 GHz that is used to form the Metasurface structure. The Metasurface can be reconfigured to three polarization states namely LP, RHCP and LHCP by spinning the Metasurface around the centre of the elliptical slot antenna. The impedance bandwidth of about 370 MHz is obtained for all states of polarization. The proposed antenna gives the 3 dB bandwidth of about 350 MHz for LHCP and RHCP. The work can be further improved to achieve improved ARBW in future and also study the experimental analysis to verify the simulated results.

8. Acknowledgment

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9. References

1. Jeen-Sheen R, Wang-Lin L, Tsair-Rong C. Circular Polarization and polarization reconfiguration designs for annular slot antennas. IEEE Transactions on Antennas and Propagations. 2012 Dec; 60(12):5998–6002.
2. Nisha ASA. Hybrid coupled feed circularly polarized patch antenna for military applications. Indian Journal of Science and Technology. 2015 Nov; 8 (29). DOI: 10.17485/ijst/2015/v8i29/63684.
3. Kim JM, Park JH, Baek CW, Kim YK Kwon Y. Electrostatically-driven low voltage micromechanical optical switches using robust single crystal silicon actuators. Journal of Micromechanics and Microengineering. 2010; 20(9):095007.
4. Newman HS. RF MEMS switches and their applications. Proceeding of 40th Annual International Reliability Physics Symposium; Dallas, TX. 2002. p. 111–5.
5. Kim JM, Park JH, Baek CW, Kim YK. The SiOG-based Single Crystalline Silicon (SCS) RF MEMS switch with uniform characteristics. Journal of Microelectromechanics Systems. 2004 Dec; 13(6):1036–42.
6. Jung CW, Lee MK, Li G, de Flaviis F. Reconfigurable scan-beam single-arm spiral antenna integrated with RF-MEMS switches. IEEE Transaction on Antennas Propagation. 2006 Feb; 54(2):455–63.

7. Yashchyshyn Y. Reconfigurable antennas based on the RF switch technology. Proceedings of 5th MEMSTECH International Conference; 2009 Apr. p. 155–7.
8. Rajaraman G, Anitha M, Mukerjee A, Sood K, Jyoti R. Dual-band, miniaturized, enhanced-gain patch antennas using differentially-loaded Metastructures. Indian Journal of Science and Technology. 2015 Jan; 8(1). DOI: 10.17485/ijst/2015/v8i1/53640.
9. Engheta N, Ziolkowski RW. Metamaterials: Physics and engineering explorations. Wiley-IEEE Press; 2006.
10. Zhou H. A novel high-directivity microstrip patch antenna based on zero-index metamaterials. IEEE Antennas Wireless Propagation Letter. 2009; 8:538–41.
11. Majid HA, Abdul Rahim MK, Masri T. Microstrip antennas gain enhancement using left-handed metamaterial structure. Proceedings in Electromagnetics Research. 2009; 8:235–47.
12. A. Eladati A, Denidni TA. Frequency selective surface for beam-switching applications. IEEE Transactionon Antennas and Propagations. 2013 Jan; 61(1):195–200.
13. Padooru YR, Yakovlev AB, Chen PY, Alu A. Analytical modelling of conformal mantel cloaks for cylindrical objects using sub-wavelength printed and slotted array. Journal of Applied Physics. 2012; 112(3):034907.
14. Chen H, Hou X, Deng L. Design of frequency selective surfaces for a planar slotted waveguide antenna. IEEE Antennas Wireless Propagations Letter. 2009; 8: 1231–3.
15. Zhang J, Wang J, Chen M, Zhang Z. RCS reduction of patch array antenna by electromagnetic band-gap structure. IEEE Antennas Wireless Propagation Letter. 2012; 11:1048–51.
16. Zhu HL, Cheung SW, Chung KL, Yuk TI. Linear-to circular polarization conversion using metasurface. IEEE Transactions on Antennas and Propagations. 2013 Sep; 61(9):4615–23.
17. Zhu HL, Cheung SW, Liu XH, Yuk TI. Design of polarization reconfigurable antenna using Metasurface. IEEE Transactions on Antennas and Propagations. 2014 Jun; 62(6):2891–8.
18. Holloway CL, Kuester EF, Smith DR. An overview of the theory and applications of Metasurfaces: The two-dimensional equivalents of metamaterials. IEEE on Antennas and Propagations Magazine. 2012 Apr; 54(2):10–35.
19. Numan AB, Sharawi MS. Extraction of material parameters for metamaterials using a full wave simulator. IEEE on Antennas and Propagations Magazine, 2013 Oct; 55(5):2891–8.
20. Sung YJ, Jang TU, Kim KS. A reconfigurable microstrip antenna for switchable polarization. IEEE Microwave Wireless Components Letter. 2004 Nov; 14(11):534–6.
21. Zhongbao W, Shanjun F, Shiquiang F, Shouli J. An inmarasat BGAn terminal patch antenna array with unequal input impedance elements and conductor-backed ACPW series-feed network. IEEE Transactions on Antennas Propagations. 2012 Mar; 60(3):1642–7.