A Novel Circularly Polarized Conformal Patch Antenna using Asymmetrically Slotted Ground

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Abstract - *A single layer low profile circularly polarized conformal patch antenna utilizing asymmetrical circular slots at the ground plane is proposed. At first the planar antenna with slotted ground plane is designed. Using the same slot's dimension in the ground plane, the simple square patch is embedded in cylindrically curved structure. At a particular radius of curvature, the antenna showing good result. A simulated 3 dB axial-ratio (AR) bandwidth of around 14 MHz with 54 MHz impedance bandwidth were achieved for planar antenna. The cylindrical curved patch antenna has good impedance band width of 76 MHz and 3 dB axial ratio band width 11 MHz. The 3 dB AR beam width for planar and curved patch antenna 138 degree & 148 degree and 84.2 degree & 58.6 degree in E plane and H plane respectively. The simulated bore sight gain for planar and cylindrical curved antenna are more than 2.89 dBic and 3.12 dBic respectively over the operating band.*

Key Words: **Circularly polarized square Patch Antenna, Coaxial Feed, Impedance mismatch Bandwidth, conformal Antenna, Axial Ratio (AR).**

1. INTRODUCTION

Conformal microstrip antennas have been extensively studied and employed in a variety of communication systems [1-2]. Despite the inherent disadvantages of low bandwidth, medium or low gain, the conformability of these antennas to host surfaces makes them a obvious choice for varied communication applications [1-2]. This 1.9 GHz band is used to support the extension to serve the cordless telephone. In 2005, in India, this band was allocated for cordless telephone.

Circular polarization becomes a need for patch radiator where there may be chances of problem of orientation mismatch between transmitter and receiver [3].

Circular polarization is obtained by the resultant of two linear polarized wave of 90 degree apart. The 90 degree phase shift can be achieved either by singly fed with perturbation in the structure and feeding in diagonal or doubly fed to the patch [3-9]. Another method for obtaining circular polarization by perturbing the structure either in patch or ground plane which produces two orthogonal modes[3-9].

In [6], A singly fed CP antenna is presented with slotted ground plane. Four asymmetric square slots are embedded on the ground and four rectangular slits are etched at the edge centre of the patch for the production of circular polarization [6]. The simulated maximum AR bandwidth (0.938 %,), and impedance bandwidth (4.886 %) were obtained using FR-4 material in [6].

In this article, the interesting thing to produce circular polarization is that, the way to make asymmetric slot placed asymmetrically in the ground plane. The main aim of this paper is to obtain circular polarization in conformal cylindrical patch [10-14] exactly in the same way as that of planar patch. Both the patch antenna on planar structure as well as on cylindrical structure are designed and simulated in CST microwave studio [15]

2 PLANAR ANTENNA DESIGN

A top and bottom view of proposed patch antenna is shown indicated in fig 1. The dimensions of simple patch antenna 34.84 mm x 34.84 mm with ground plane of 46.91 mm x 46.91 mm are designed. The feed is placed along Y axis at the point (-6 mm, 0). Two asymmetrical slots are etched on the ground plane placed asymmetrically for the production of circular polarisation.

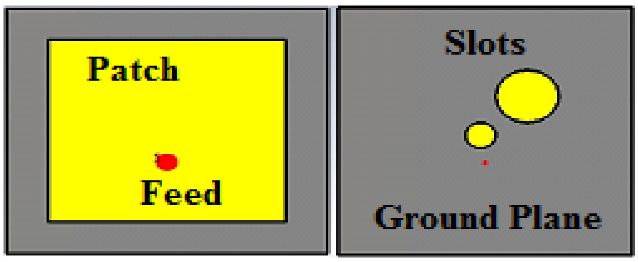
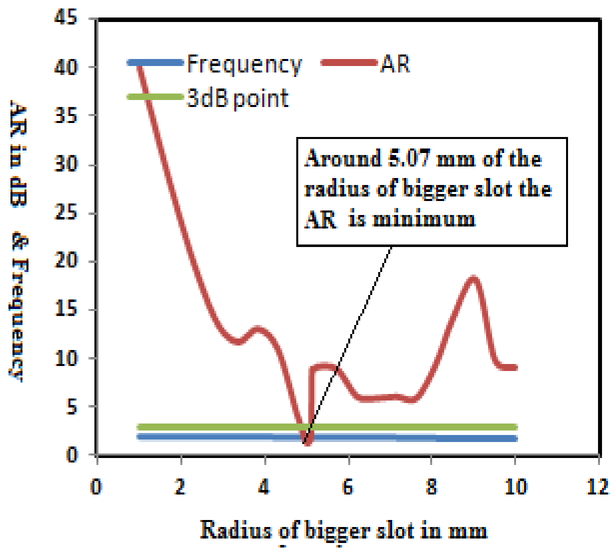


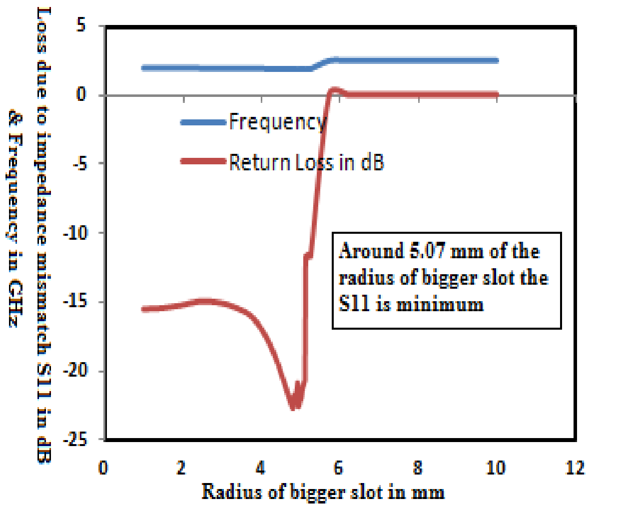
Fig 1. Simple planar patch [12-14]

2.1 Variation of bigger and smaller slots in the ground plane:

Initially the slots were etched at 6.66 mm and -1.04 mm away from the centre along the diagonal [7-8]. At first, the radius of bigger slot is varied and the result is observed in term of S_{11}, AR, and frequency keeping remaining dimension of the patch, and bigger slots etc fixed. The best AR, S_{11} are obtained at a optimized dimension of bigger radius 5.07 mm shown in fig 2 (a-b). The circular polarization is being achieved as the surface current density on the patch is responsible to create phase difference of 90 degree of electrical length due to difference of physical length of diameters of two slots embedded on the ground plane. The frequency remains constant with the variation of radius of bigger slot as shown in figure 2 (a-b).



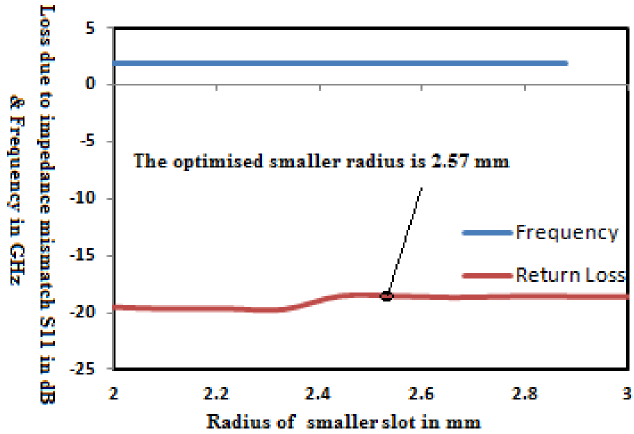
(a)



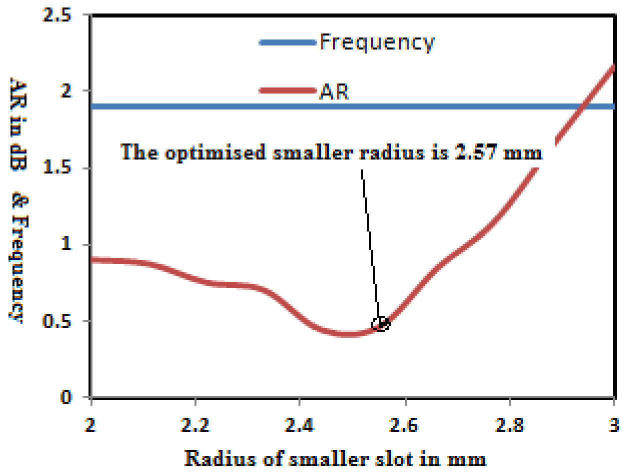
(b)

Fig.2: Variation of AR, S_{11} and frequency with radius of bigger slot

Similarly the best AR and S_{11} under the circular polarization is observed at a optimised smaller radius of 2.57 mm, keeping bigger slot radius as 5.07 mm constant. The variation of axial ratio, S_{11} with smaller radius is shown in fig 3 (a-b). From the fig 2 (a-b) and 3 (a-b), it is cleared that the radius of curvature has no control on frequency. It is merely unaffected with the change of radius of both the slots.



(a)

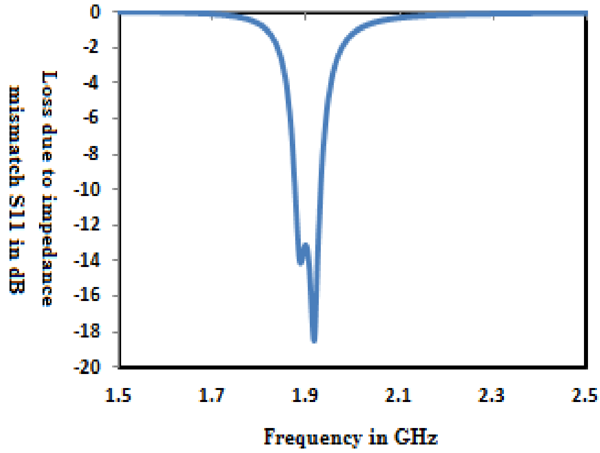


(b)

Fig.3: Variation of AR, S_{11} and frequency with radius of smaller slot

2.2 Result and Discussion

Now with the optimized result of smaller and bigger slots the antenna is simulated for its mismatch impedance band width and axial ratio profile. The following result of planar patch shows that due to introduction of asymmetrical slot in the ground plane, the TM_{10} mode will have more current path than TM_{01}. Hence due to difference in path length, circular polarization results [3-9]. The slot is adjusted to produce CP wave in the patch antenna. The simulated result of optimized patch antenna is shown in fig 4 (a-b) at a frequency of 1.9 GHz. The simulated axial ratio bandwidth are 14 MHz and Impedance mismatch bandwidth achieved is 54 MHz, the directive gain obtained around 2.89 dBic whereas the scanning angular coverage are seen to be 138 degree & 148 degree at E plane and H plane respectively as indicated in fig 5 (a-b).



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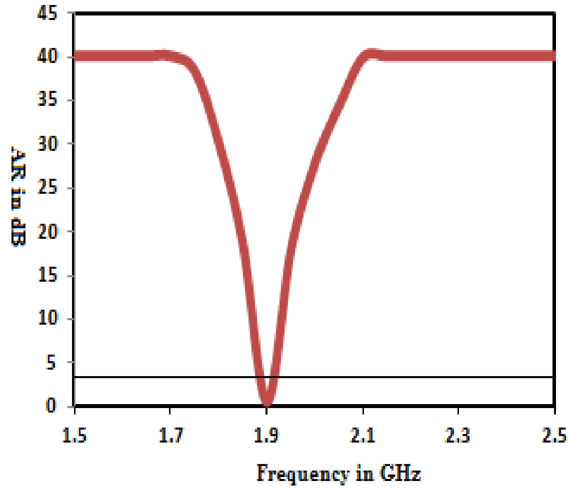
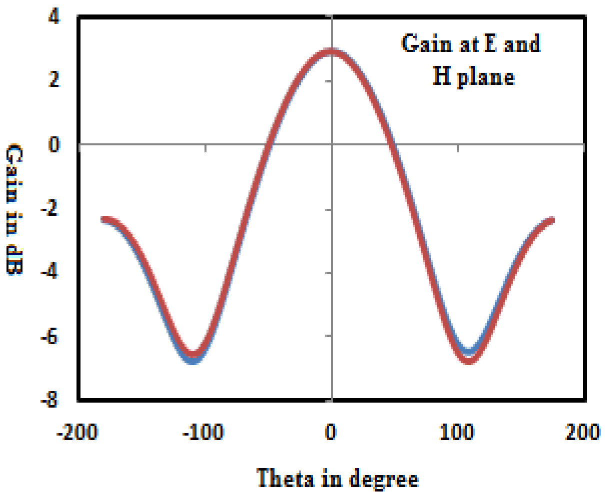
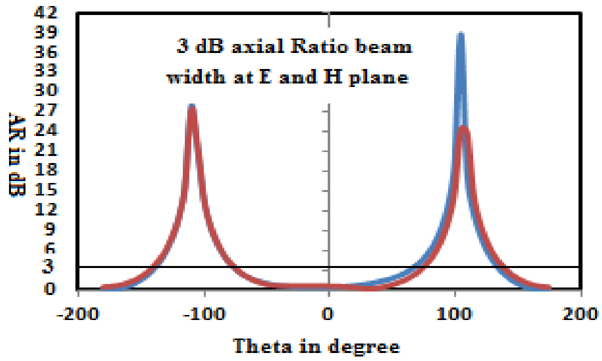


(b)

Fig 4: (a) S_{11} (b) Axial Ratio of optimized planar patch



(a)



(b)

Fig 5 (a) gain (b) Beam width at 1.9 GHz at (a) E plane and (b) H plane

3 Cylindrical Square-Patch Antenna design

A overall view of the above designed patch on cylindrical structure is shown in fig. 6. The simple patch & slotted ground plane (with same radius and same location) are embedded around a substrate cylinder of whose radius of curvature is optimized to be 87.81 mm. The dimension of patch, feed point location, slot dimension etc remains same as that of planar patch.

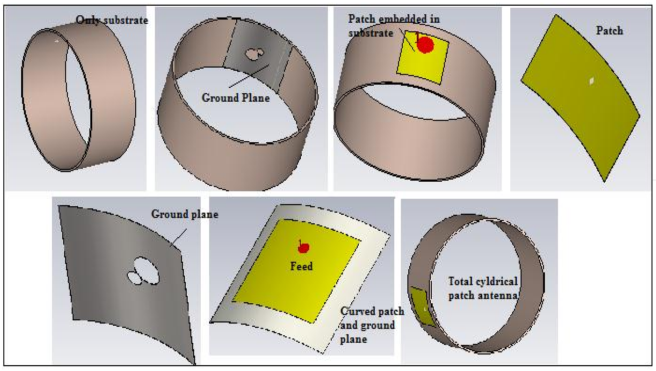


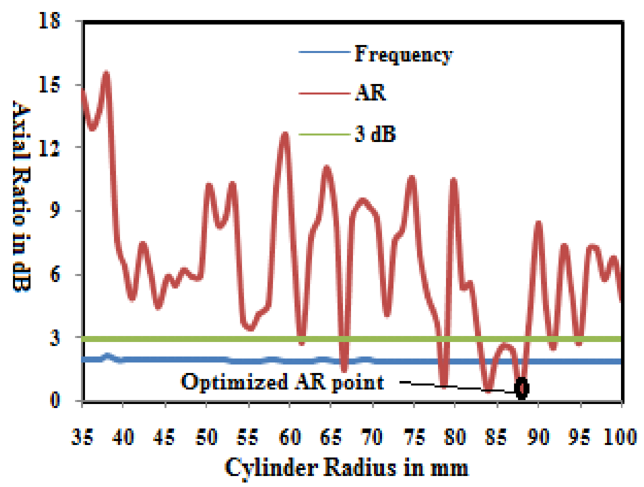
Fig. 6: The patch on cylindrical structure [10-14]

The fig.6 shows the detailed parts of cylindrical patch antenna including substrate, ground plane, patch etc. The first part in above figure is like a band of a wrist watch above which the patch is placed and below which two circularly slotted ground plane is fixed. The patch, ground plane substrate is also shown separately in the fig 6.

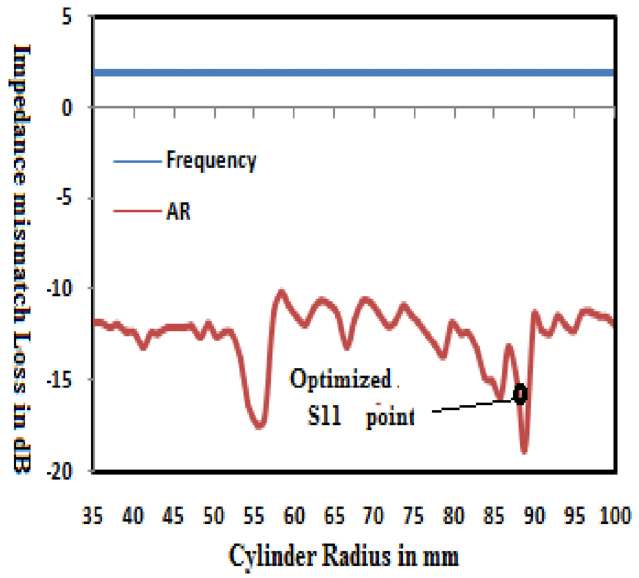
3.1 Variation of radius of curvature of cylindrical conformal antenna:

But main problem to achieve the circular polarization in curved structure is that the fields coming from the patch are neither linearly polarized nor have phase difference of 90 degree. That is why the zigzag curve of axial ratio and S_{11} are observed with the variation of cylinder radius as indicated in fig 7. Both the figures of 7 (a-b), the axial ratio plays a crucial role to optimize the radius of curvature of cylindrical square patch antenna. If observed carefully, at the radius of 87.81

mm only, the tradeoff can be done and a optimized axial ratio and impedance mismatch loss can be achieved. If the radius of curvature is chosen around 68.5 mm, the axial ratio below 3 dB is seen but the impedance mismatch loss is showing comparative less than that of one when compared with the radius of curvature 87.81 mm.



(a)

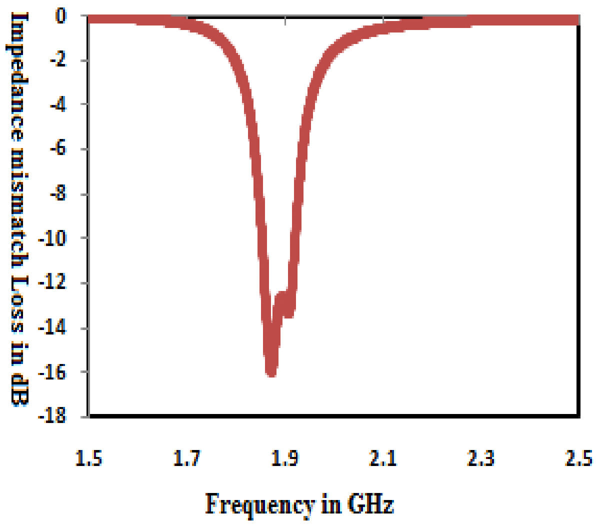


(b)

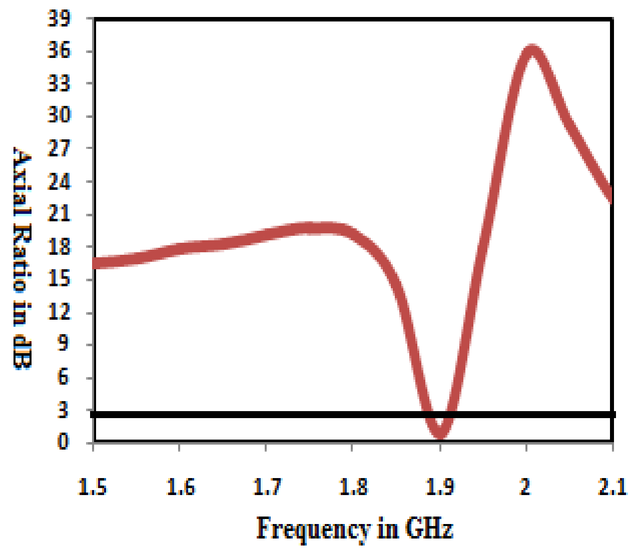
Fig. 7. (a) Axial ratio (b) return loss plot with radius of curvature of cylindrical-rectangular patch antenna

3.2 Result and Discussion

In fig 8 (a-b), at the frequency of 1.90 GHz, when the antenna is optimized at a radius of curvature of 87.81 mm, this curved antenna are having good impedance band width of 76 MHz and 3 dB axial ratio band width 11 MHz. The patch gives intermediate scanning coverage around 84.2 degree & 58.6 degree in E plane and H plane respectively shown in fig 9. Due to existence of large number of basis function, the antenna with slotted ground plane will have less effect on circular polarization. The orthogonal modes in this cylindrical antenna are less prone to form circular polarized wave. For this reason the 3 dB axial beam width is very much less compared with planar structure.



(a)



(b)

Fig. 8. (a) S_{11} plot and (b) axial ratio plot of optimized cylindrical-rectangular patch antenna

The beamwidth of an antenna is an important parameter which is taken into consideration whenever the performance of an antenna is measured. Thus the fig. 9 gives the axial ratio beamwidth which is a plot between axial ratio and angle theta at phi=0^{o} and 90^{0}. This indicates the scanning angle of coverage.

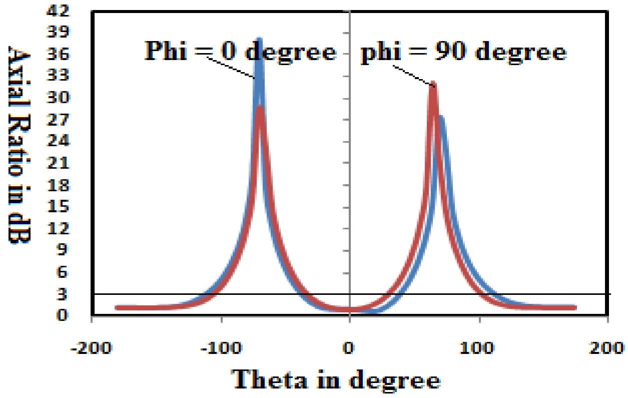


Fig. 9: dB Axial ratio beam width (at phi=0°and 90°)

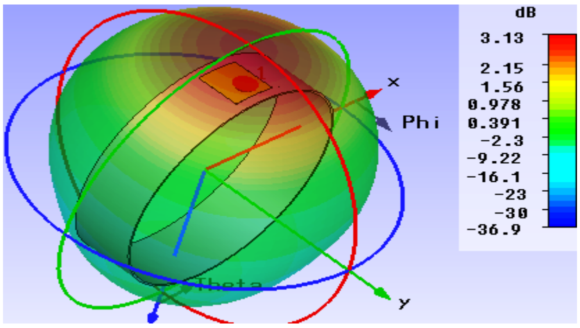


Fig 10: cylindrical patch antenna gain

From the fig 10 it can be stated that the directive-gain of the antenna is around 3.13 dBi and can be seen in the Cartesian polar plot of fig. 11. The gain of this antenna is increased by a small amount compared with the planar patch. Fig 10 and 11 are same as the Z axis in fig 10 directs outwards from the patch. Patch radiated along 180 degree as given in fig 10 and 11with a gain of 3.13 dBic.

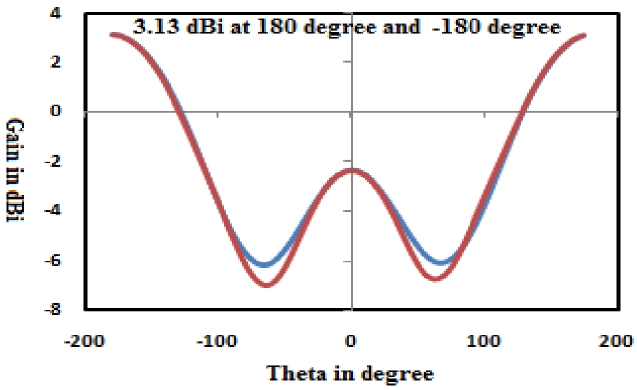


Fig. 11.Cartesian plot for gain of cylindrical antenna.

The surface current density of the cylidrical patch antenna is indicated in fig 12. The distribution is around the slotted hole in the ground. The current density distribution at 0^0, 45^0 ,90^0 and 135^0 is shown in fig 12 [9]. This current density indicates RHCP radiation from the antenna.

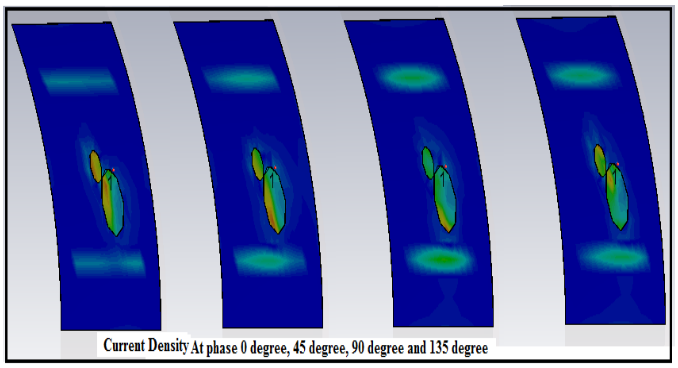


Fig 12: Current density at different time instant [9]

The above current density clearly shows the RHCP radiation as shown in fig 13

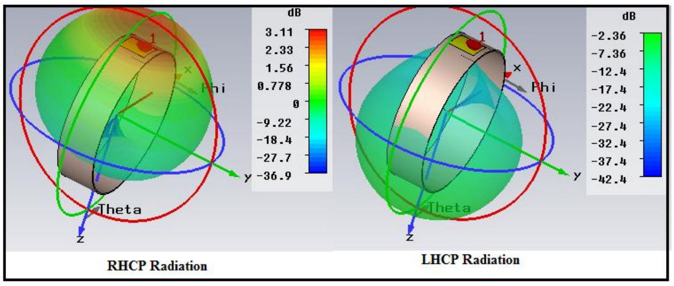


Fig 13: RHCP and LHCP radiation at 1.90 GHz

4. COMPARISON TABLE

Table 1indicatesThe comparison table of the simulated data between the planar patch and cylindrical patch

Table 1

Parameters	Proposed design (Planar)	Proposed design (Cylinder)
Operating Frequency	1.9 GHz	1.9 GHz
Gain	2.89 dBic	3.13 dBic
Minimum AR frequency	1.9 GHz	1.9 Ghz
Impedance mismatch Bandwidth	54 MHz	76 MHz
Axial Ratio Bandwidth	14 MHz	11 MHz
3 dB Axial Ratio Beam Width (at phi=0 and Phi= 90)	138 degree & 148 degree	and 84.2 degree & 58.6 degree

5. CONCLUSION

Singly fed circularly polarized and diagonally and asymmetrically slotted ground plane planar and cylindrical antenna have been studied. Especially the patch on cylindrical structure gives good response in term of impedance mismatch bandwidth, axial ratio and gain. The antenna shows good agreement of RHCP in terms of surface current density.

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REFERENCES

[1] Constantine A. Balanis, "Antenna theory: Analysis and Design.3rd Ed". New York, USA: John Wiley& Sons, Inc, pp.816-842, 2005.

[2] Kin-Lu wong, "Design of Nonplanar Microstrip Antennas and Transmission lines", John Wiley & Sons, Inc.1999

[3] "Circular Polarization vs. Linear Polarization", by intelsat.com & "Why Circular Polarization Antenna ?," By FRC Group South Benjamin Avenue, Mason City, Iowa 50401'.

[4] Kin Lu wong, "compact broadband antenna" John Wiley & Sons, Inc.

[5] Yuzhong Shi, Juhua Liu, "Wideband and Low-Profile Omnidirectional Circularly Polarized Antenna With Slits and Shorting-Vias", IEEE Antennas and Wireless Propagation Letters Volume: 15 Year: 2016

[6] Oktavinus Tanawie Randy, Nasimuddin and Arokiaswami Alphones, "Circularly polarized slotted-ground microstrip antennas for radiofrequency identification readers", Microwave and optical technology letters, Vol. 54, No. 10, October 2012 DOI 10.1002/mop

[7] Nasimuddin, Zhi Ning Chen, and Xianming Qing, "Slotted Microstrip Antennas for Circular Polarization with Compact Size" IEEE Antennas and Propagation Magazine, VOL. 55, NO. 2, April 2013.

[8] Nasimuddin, Z. N. Chen, and X. Qing, "Asymmetric-circular shaped slotted microstripantennas for circular polarization and RFID applications," IEEE Transactions on Antennas and Propagation, vol. 58, no. 12,pp. 3821–3828, Dec 2010.

[9] Nasimuddin, Y. S. Anjani, and A. Alphones, "A Wide-Beam circularly polarized Asymmetric-Microstrip Antenna " IEEE Transactions on Antennas and Propagation 2015.

[10] Kin-Lu Wong and Shyh-Yeong Ke,"Cylindrical-Rectangular Microstrip Patch Antenna for Circular Polarization", IEEE transactions on antennas and propagation, vol. 41, no. 2, february 1993

[11] C. M. Krowne, "Cylindrical rectangular microstrip antenna." IEEE Trans. Antennas Propagat., vol. AP-31. pp. 194-199, 1983.

[12] K M Luk and K F Lee, "Analysis of the cylindrical – Rectangular patch antenna", IEEE Trans. Antennas Propagat., vol. 37, no.2 Feb 1989.

[13] J. *S.* Dahele, R. J. Mitchell, K. M. Luk, and K. F. Lee, "Effect of curvature on characteristics of rectangular patch antenna," *Electron.Lett.,* vol. 23, pp. 748-749, July 1987.

[14] T M Habashy, S M ali, and J A Kong, "Input impedance and radiation pattern of cylindrical rectangular and wrapround microstrip antennas", *Propagat.,* vol. 38, pp. 722-731, may 1990. no.2 Feb 1989.

[15] CST microwave studio suite