Design Simulation of X-band Composite Microstrip Antenna with Circular Polarization

Swapnil Narke[1], Prafulla Jagtap[2], Subra Ananthakrishnan[1], Chinmoy Bhattacharya[3]

[1]*Savitribai Phule Pune University, Pune, India*
[2]*Vishwakarma Institute of Technology, Pune, India*
[3]*Armament Research and Development Establishment* (*ARDE*)*, Pune, India*
Swapnil.narke06@gmail.com

***Abstract*- A composite microstrip patch antenna seated on a hollow conical ground surface is proposed in this paper. The design simulation shows that such composite structure is suitable for circular polarization over a wide beam width. The half-power beamwidth can be broadened over 100^0 by utilizing the hollow conical ground structure. Circular polarization for the microstrip patch is necessary to mitigate the polarization losses during the receiving mode of RF power for rotating body applications. We present the design simulation results to show the improvement of the antenna properties at X-band by the current design as compared to patch only solutions.**

Keywords*:*Rotating bodies, finite hollow cone, circular polarization, axial ratio* (*AR*)*, half power beam-width* (*HPBW*)*, co-polarization.

I. INTRODUCTION

Microstrip patch antennas are adaptable to different shapes of bodies and have distinct properties such as low RF profile, conformity to platform requirements, light weight, ease of manufacturing, etc. [1],[2] Recently, the specific challenges posed by the design specifications such as polarization losses due to rotating bodies, requirements of wide beamwidth in specific direction, low radar cross section (RCS), and high resonating frequency due to smaller nature of dimensions of the aperture have boosted further development of microstrip patch antenna design practices [3],[4]. Antenna characteristics such as half-power beam width (HPBW) in far field, scattering parameters, gain, radiation efficiency, polarization, etc. are always affected in rotating bodies such as in missile, ammunition, artillery shells, etc. We have to optimize the design parameters for the microstrip patch antenna according to the environmental properties in such cases. Antenna radiation beam width can be increased by composite antenna structure having finite conical ground base [5]. Along with beam width consideration, mitigation of polarization losses for rotating bodies is also a challenge in defense applications. Radiation mismatch losses increase drastically because of improper choice of polarization such as for linear polarization in rotating body applications. Recent literature on artillery projectile applications show the utilization of circularly polarized ceramic patch antenna to mitigate polarization losses [6].

We propose a composite structure of a microstrip patch seated on a finite hollow cone for meeting two requirements: (*i*) to achieve circular polarization mechanism by chamfering the two diagonal corners of the rectangular patch antenna shown in Fig. 1(*a*), (*ii*) to achieve wide beamwidth (over 100^0) by assembling the patch antenna with conical ground structure as shown in Fig.1(*b*). We present the simulation results for the axial ratio (AR), HPBW, co-polarization and cross-polarization of radiation to demonstrate the results of improvement by the current design over the patch only solutions at X-band. This design is under fabrication.

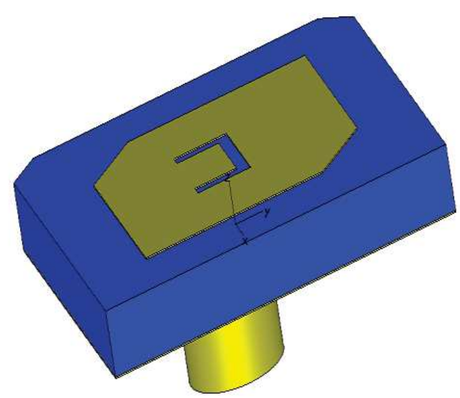

Fig. 1(*a*) Microstrip patch antenna with circular polarization on Arlon AD 250 material.

II. DESIGN SPECIFICATION FOR THE COMPOSITE ANTENNA STRUCTURE

The proposed composite antenna is specified for circular polarization and wide beamwidth. In the composite antenna structure, we use the shape of the

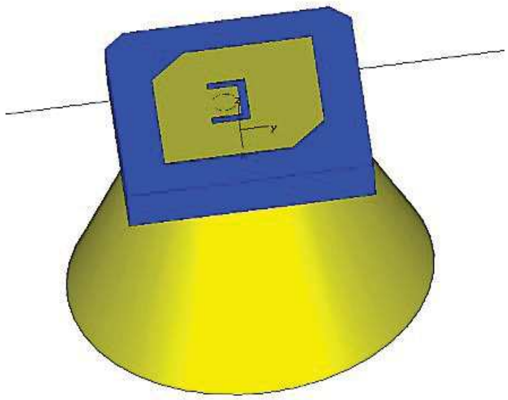

Fig. 1 (*b*) Composite structure of a circularly polarized microstrip patch antenna on a hollow conical base.

hollow frustum whose thickness is greater than the skin depth of copper. The truncated rectangular microstrip patch of 9x9 mm dimension is printed on an electrically grounded square substrate of 12.3x12.3 mm dimension. The substrate material is Arlon AD 250 of thickness 1.52 mm, relative permittivity 2.5, and with tangent loss figure 0.002.The hollow cone is made of copper with height 0.25λ (approx.), and is of uniform thickness of 2 mm from bottom to top. All the physical dimensions of the patch and the cone are shown in Fig. 2(*a*)-(*b*). Microstrip patch of thickness 0.035 mm has been chamfered at the opposite corners by 1.75 mm to generate resonating frequency of two orthogonal modes of transmission along the diagonals of the rectangular patch [11] for the right-hand circular polarization (RHCP). Co-axial feed is used for the antenna that is 0.675 mm off-centered on the axial line as shown in Fig. 2(*a*). One U-shaped slot is introduced on the patch to enhance the voltage standing wave ratio (VSWR) [12].The optimized U-slot dimensions are 3 mm in width and 2 mm in length with 0.4 mm wide as shown in Fig. 2(*a*). The electrical ground of the planar patch antenna is extended as the bottom surface of the substrate is bonded to the finite upper end of the hollow frustum by copper adhesive as shown in Fig. 1(*b*).

III. ANALYSIS OF THE SIMULATION FOR THE COMPOSITE MICROSTRIP PATCH ANTENNA

The electric field lines at the edge of the patch undergo fringing [7]. Electric radiation due to the induced current for an infinite ground plane is exactly the same as the mirror image of the aperture current [8]. However, in our case we cannot apply image theory for the finite ground planes. The analysis of current distribution over finite conical surface and the effect of finite ground on the radiation characteristics have been reported earlier [9], [10]. In the microstrip patch antenna with finite ground surface the vector sum of the current density in the aperture source and the ground plane contribute individually to the total radiating field [8]. For the conical ground surface, the fringes concentrate towards the lower elevation angle and provide wider beam width. The height of the cone is approximately 0.25λ that is helpful for wider HPBW as reported earlier in [5]. In our simulation, we measure the AR, co-polarization, cross-polarization, and polar representation for the antenna radiation pattern. The results are produced for the patch only case in the RHCP mode and for the composite structure separately, and are shown in Fig. 3-6 (*a*), (*b*) respectively in the two–column format. The results in the plots are shown for $\phi=0^0$ in the azimuth plane.

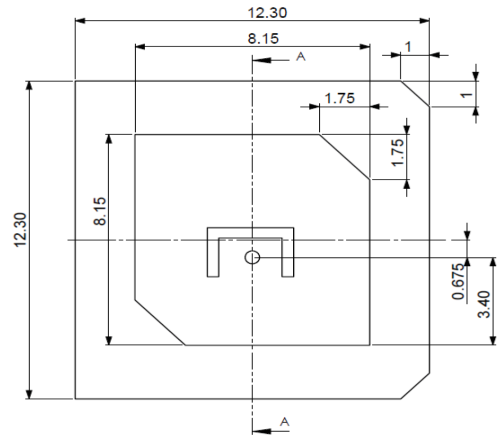

Fig. 2(*a*) Physical dimensions of rectangular microstrip patch antenna (all dimensions are in mm).

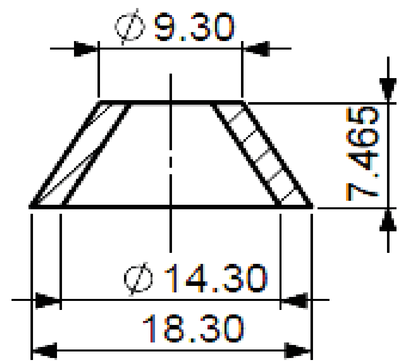

Fig. 2(*b*) Physical dimensions of the hollow conical ground base (all dimensions are in mm).

Circularly Polarized Rectangular Microstrip Patch Antenna.	**Circularly Polarized Composite Microstrip Antenna.**

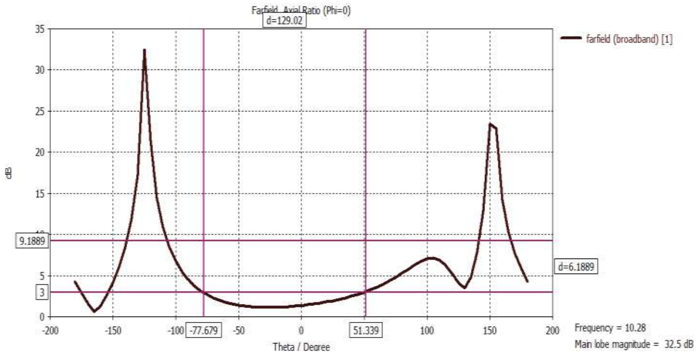

Fig. 3 (a) Axial Ratio (AR) at $\phi=0^0$ plane.

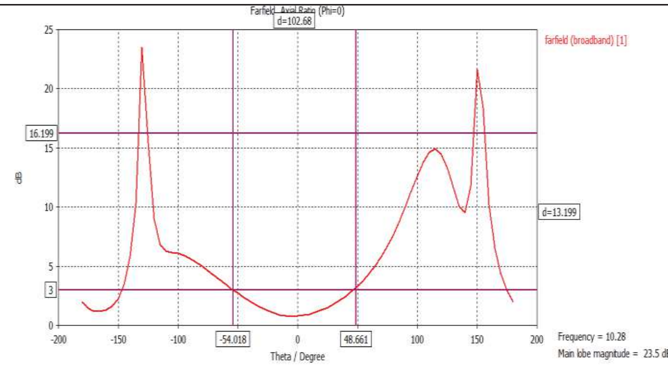

Fig. 3(b) Axial Ratio (AR) at $\phi=0^0$ plane.

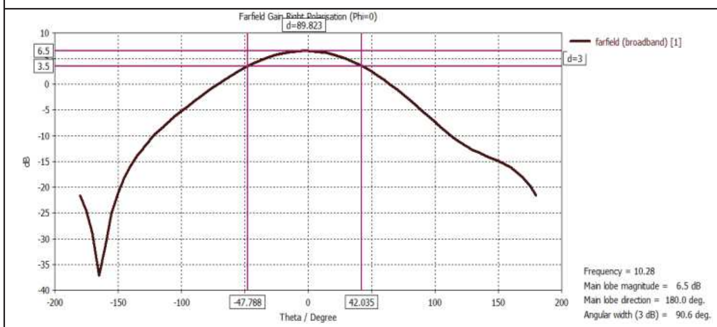

Fig. 4 (a) Co-Polarization over half-power beamwidth (HPBW).

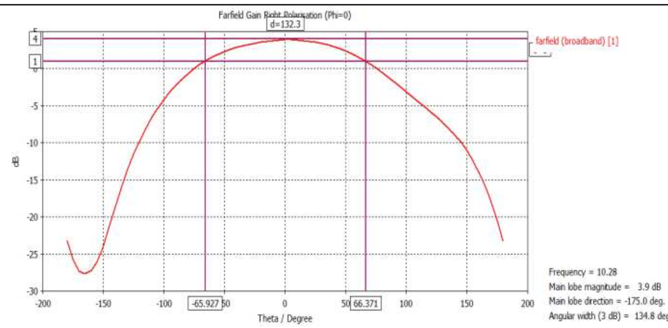

Fig. 4 (b) Co-Polarization over half-power beamwidth (HPBW).

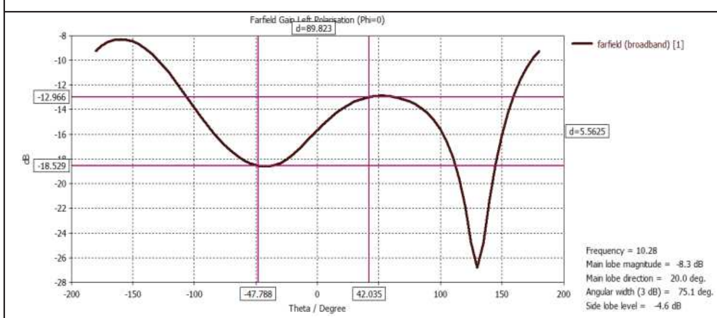

Fig. 5(a) Cross- polarization over half-power beamwidth (HPBW).

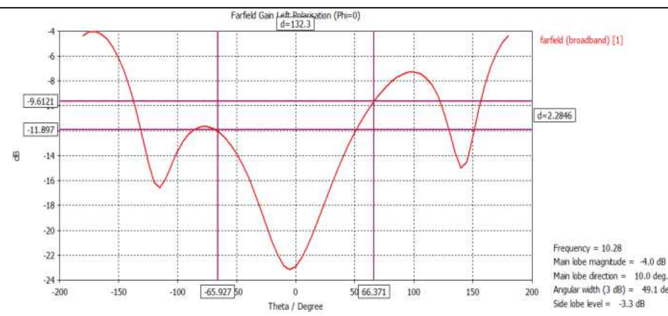

Fig. 5 (b) Cross-polarization over half-power beamwidth (HPBW).

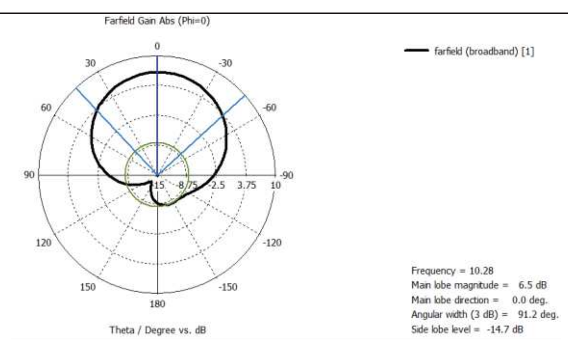

Fig. 6 (a) Polar plot of antenna radiation pattern.

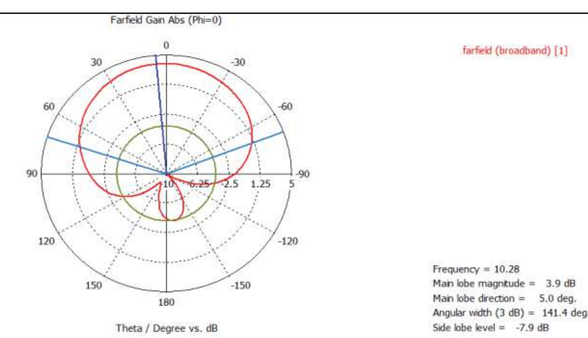

Fig. 6 (b) Polar plot of antenna radiation pattern.

The reported results are produced in CST microwave studio 2012 version and are shown in Table I below.

TABLE I. COMPARATIVE SUMMARY OF ANTENNA CHARACTERISTICS AT 10.28 GHZ

		Single patch antenna	Composite Antenna on hollow conical ground base
Frequency (GHz)		10.28	10.28
Axial Ratio (common in both azimuth plane in degree)		102.09	98.6
HPBW	$\phi=0^0$	91.2	141.4
	$\phi=90^0$	91.2	150.3
Co-polarization	$\phi=0^0$	90.6	134.8
	$\phi=90^0$	92	125
Cross-polarization (dB)	$\phi=0^0$	22.1	20.8
	$\phi=90^0$	22.1	20.8

The AR plot for the composite structure shows lesser window for circular polarization (98.66^0) than the RHCP-patch (128.09^0). This is reasonable as the hollow cone provides a finite ground other than the base of the planar substrate that affects the current density distribution for the orthogonal electric vectors in circular polarization. On the other hand, as more radiation fringe lines now diffract towards the base of the cone the co-polarization is received over wider beamwidth for the composite structure and the cross-polarization is -22 dB below at the zenith. Therefore, the circular polarization in the window of observation is better oriented in the composite antenna structure.

III. CONCLUSION

A composite antenna structure consisting of microstrip patch on Arlon AD250 substrate sitting over a hollow copper cone is presented in the paper. The structure serves twin purposes of achieving wide beamwidth and circular polarization. Simulation results show considerable improvement in the performance of the composite structure over patch only solution. Co-polarization to cross-polarization difference on the zenith position is approximately 20dB for the composite microstrip patch antenna for $\phi=0^0$ and $\phi=90^0$ planes. The reduction in antenna gain in the composite structure is commensurate with wider beamwidth achieved by the design. The wider beamwidth is consistent with axial ratio and co-polarization results for the composite structure. The proposed antenna offers desired characteristics in rotating body application because of circular polarization and wider beamwidth characteristics.

ACKNOWLEDGEMENT

The authors acknowledge the kind permission of Director, ARDE to report the results in the paper.

REFERENCES

[1] L. Josephson and P. Persson, *Conformal Array Antenna theory and design*, IEEE Press, John Wiley & Sons, Hoboken, New Jersey, 2006.

[2] Ramesh Garg, Prakash Bhartia, InderBahl and ApisakIttipiboon, *Microstrip Antenna Design Handbook*, ArtechHouse,INC, 2001.

[3] Hu Yang, ZushengJin, Giorgio Montisci,"*Design Equations for Cylindrically Conformal Arrays of Longitudinal Slots*", IEEE Trans. Antenna and Propagation, vol. 64,no.1, pp. 80-88, Jan2016.

[4] Yuan Yuan and Zhi Xu, "*S-band Circularly Polarization Patch Antenna Design for the LargeCurvature Conformal Structure*", Progress in Electromagnetics Research Symposium Proceedings, China, pp. 1451-1454, Aug. 25-28, 2014.

[5] Yuan-zhu, Shao-qiu Xiao and Bing-zhongWang," *A RHCP Microstrip Antenna with UltrawideBeamwidth for UHF Band Application*", Hindawi Publishing Corporation, International Journal of Antennas and Propagation, 2014, Article ID 472397.

[6] Yoon-KyoungChae, Chan-Ho Lee, Jae-Ho Cha, Wan-Joo Kim, and Bierng-ChearlAhn "*Design of a Ceramic Patch Antenna for Artillery Projectile Positioning Applications*", Journal of KIIT. vol. 15, No. 5, pp. 81-85, May 31, 2017, ISSN 2093-7571.

[7] C.A.Balanis, *Antenna theory*, J. Wiley & Sons, Inc. 2005.

[8] Arun K. Bhattacharyya,"*Effect of Finite Ground Plane on the Radiation Characteristics of a Circular Patch Antenna*", IEEE Trans. Antennas and Propagation, vol. 38, no.2, pp. 152-159, Feb. 1990.

[9] S. Adachi, R.G. Kouyoumjin, R.G.VanSickel "*The finite conical antenna*", IRE Trans. Antennas and Propagation,pp. S406-S4114,December1959.

[10] H. Unz,"*Determination of a current Distribution over a Cone Surface Which Will Produce a Prescribed Radiation*",IRE Trans. Antennas and Propagation,pp. 182-186 , April 1958.

[11] P.C. Sharma and Kuldip C Gupta, "*Analysis and optimized design of single feed circularly polarized microstrip antennas*", IEEE Trans. Antennas Propagation, vol. AP-31, no.6,pp. 949-955, November 1983.

[12] Brain J. Herting,"*Analysis and Design of Electrically Small, Circularly Polarized Cylindrical Microstrip Antennas*", submitted for the degree of Doctor of Philosophy in Electrical and computer Engineering, University of Illinois at Urbana-Champaign,2014.