URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Design of conformal aperture coupled microstrip patch antenna on cylindrical bodies with circular polarization

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Abstract

In this paper, circularly polarized aperture coupled rectangular microstrip patch antenna for X-band application is proposed. Whenever planar antenna is conformed to cylindrical surface, antenna characteristics such as circular polarization gets disturbed. Proposed antenna design is printed on polyimide (ε_r= 3.5) substrate separated by cross slotted ground plane. The conformal antenna design is simulated in CST microwave studio and is under fabrication.

Keywords: *Circular polarization, Aperture coupled, Axial Ratio (AR), Half Power Beam Width (HPBW).*

1. Introduction

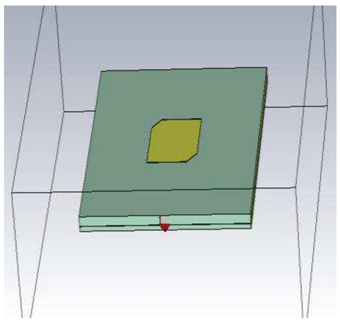
Microstrip Patch Antenna (MPA) is used in conformal shapes due to its low profile characteristics, and for its resemblance with the exterior shapes, useful in aerodynamic scenario [1]. Because of the physical limitations such as smaller dimensions, limited space for antenna placement, physical rotations of platform for such applications, antenna designing task becomes difficult. The conformal cylindrical MPA design and analysis reported earlier are for circularly polarized antenna radiation pattern [2]-[3], array of longitudinal slots on cylindrical body for high gain applications [4], etc. When planar MPA is conformed to the curved surface, electromagnetic properties and their corresponding radiation characteristics get affected. Therefore, we have to optimize antenna characteristics according to desired constraints in physical specifications of the platform. In the rotating body applications such as in missile, artillery shells, etc. radiation losses increase drastically because of mismatch between transmitting and receiving antenna radiation pattern. Improper choices of antenna radiation characteristics increase the power losses while receiving the reflected power from ground clutter. In such cases, circular polarization mitigates the power losses. In case of circularly polarized waves, incident vector gets rotated in opposite phase after reflection from the ground clutter [5]. In such cases, receiving antenna should be polarized in opposite direction.

There are many configurations of feed for MPA such as microstrip feeding, co-axial feeding, aperture coupling and proximity coupling [6]. The microstrip feed and probe feed asymmetry generate higher order modes which are responsible for cross-polarization radiation [6]. Therefore, to maintain the desired polarization, non-conducting aperture coupling has been introduced to minimize such modes [6]. In this paper, we propose circularly polarized aperture coupled conformal MPA on cylindrical surface for X-band applications. We present the optimized antenna characteristics of planar as well as conformal aperture coupled MPA on cylindrical surface simulated in CST microwave studio. The configuration is currently under fabrication.

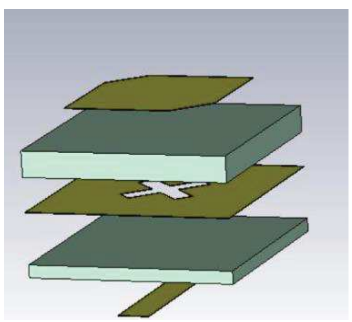
2. Linear and conformal MPA design and configuration

The geometry of aperture coupled circularly polarized rectangular MPA is shown in Fig.1 (a). In the aperture coupled MPA, two substrates are separated by cross-slotted copper ground. The lower side of lower substrate consists of microstrip line and the circularly polarized rectangular patch truncated in opposite corners is placed on the upper side of upper substrate.

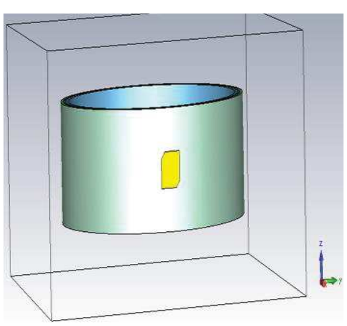
The proposed aperture coupled microstrip patch antenna of 7x7 mm dimensions is printed on the substrate. The substrate material is polyimide of dielectric constant (ε_r) 3.5. The microstrip patch of thickness 0.035 mm is chamfered in opposite corners by 1.35 mm. Width and length dimensions of cross-slots in ground plane are 0.5 mm and 5 mm respectively. Aperture coupled MPA is energized with 1.4 mm width and 14 mm length strip line printed on the opposite side of ground plane on lower substrate. The stack of aperture coupled MPA is shown in Fig.1 (b). Optimized 6.5x6.5 mm aperture coupled circularly polarized rectangular MPA is printed on hollow cylinder of height 24 mm and 31.221 mm outer diameter respectively shown in Fig. 1(c).



(a)



(b)



(c)

Fig.1 (a) Aperture coupled rectangular microstrip patch antenna (MPA), (b) stack of aperture coupled microstrip patch antenna (MPA) (c) geometry of conformal MPA facing in $\theta=90^0$ plane.

3. Analysis and simulation

In the aperture coupled MPA, patch and the microstrip line are not connected directly. However, the patch is excited with the help of scattered electric field generated because of slot in perfectly electric conducting (PEC) ground [7]. The block diagram of aperture coupled microstrip patch antenna is shown in Fig.2 consisting of three ports. Port 1 is the patch, port 2 is the aperture and port 3 represents feed line. The feed line is not terminated at one end that acts as an open stub. The electric field mainly directed across the slot in the width direction (due to smaller dimension as compared to slot length) that induces the linearly polarized surface current into the patch [7]. As shown in Fig.3, the slot in the ground plane acts as N:1 impedance transformer and $L_{ap}C_{ap}$ tank circuit is in series with microstrip feed line. Finally, to account for the radiation field, the patch edges are modeled with parallel $R_{rad}C_{fring}$ circuit with R_{rad} as radiation resistance [7]. The slot in the ground is located at 1.2 mm from the open terminal of feed line. Length of feed line is 13.2mm in case of conformal antenna configuration.

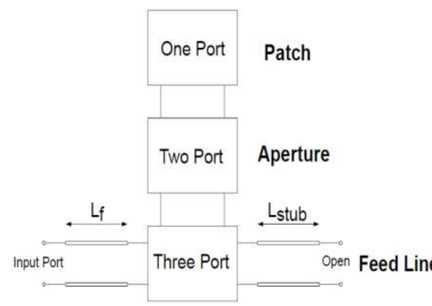


Fig.2 Aperture coupled MPA block diagram [6].

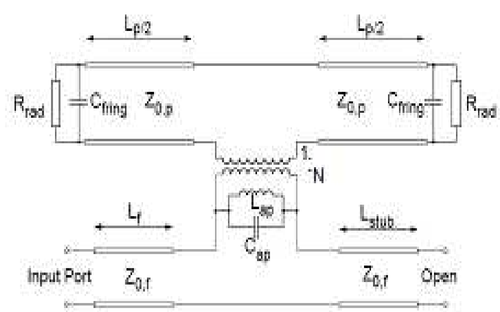


Fig. 3 Aperture coupled MPA equivalent circuit [6].

Because of cross slots in PEC ground plane, scattered electric field induce the surface current in truncated rectangular MPA individually. These two current vectors contribute to circularly polarized antenna radiation pattern. The resonant frequency of the mode is higher than the mode along unchopped diagonal [8]. Therefore, we can express the electric field in the patch cavity in TM_{01} and TM_{10} mode separately. The TM_{11} circularly polarized field vector is the resultant vector of TM_{10} and TM_{01} modes. After conforming planar MPA along the cylindrical patch antenna, current distribution in the antenna aperture along ϕ-direction in cylindrical co-ordinates gets perturbed and increases the cross-polarization level [9]. Therefore, the circular polarization characteristics get destroyed shown in Fig 4. To achieve desired axial ratio and avoid the above, patch antenna dimensions and the feeding position have been optimized.

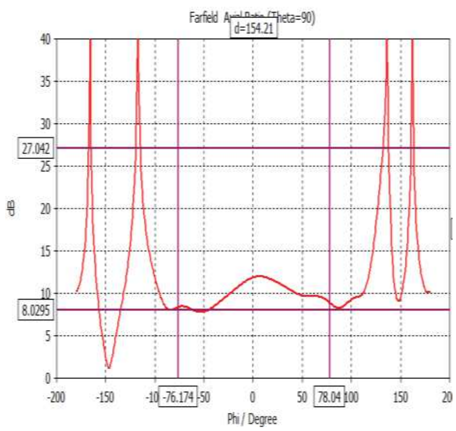


Fig.4 Distorted axial Ratio (AR) of planar aperture coupled MPA on cylindrical surface.

4. Simulation Analysis

The truncated rectangular microstrip patch antenna is conformed to cylindrical surface facing $\theta=90^0$ plane as shown in Fig. 5 along with the antenna radiation pattern directed in x- direction. The simulated axial ratio (AR) for planar MPA below 3 dB is from -84^0 to $+78^0$ as shown in Fig. 6(a). Antenna characteristics are affected because of cylindrical curve. Therefore, surface current in the patch does not sustain the circular polarization. As shown in Fig. 4 and in Fig. 6 (a), axial ratio is increased above 8 dB after conforming truncated rectangular patch onto the cylindrical surface. Therefore, by optimizing the antenna dimensions, we achieved axial ratio below 3 dB, approximately over 151^0 in $\theta=90^0$ plane as shown in Fig. 6 (b) at frequency 9.29 GHz. In the case of conformal antenna, cross-polarization level changes compared to planar patch from -25 dB to -12 dB summarized in Table.1.

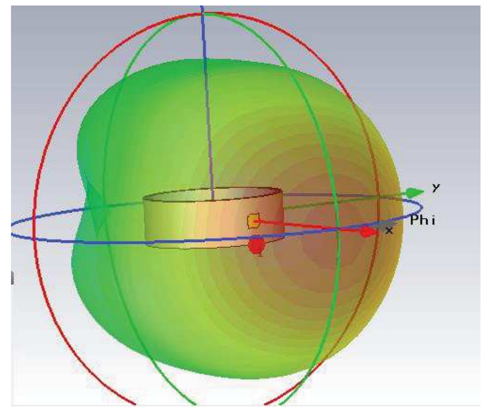
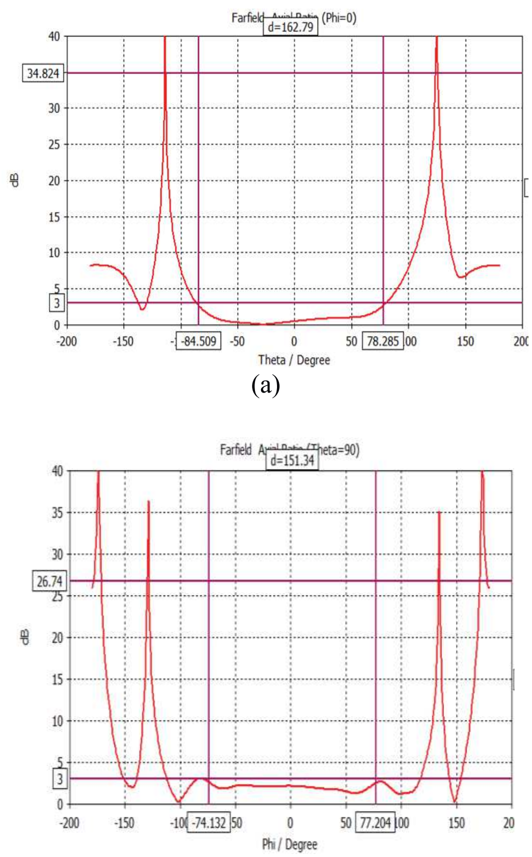


Fig. 5 3-D view of geometry of aperture coupled MPA on cylindrical surface in $\theta=90^0$ plane.



(a)

(b)

Fig.6 (a) Axial Ratio (AR) of planar aperture coupled MPA in $\phi=0^0$ plane, (b) Axial Ratio (AR) of conformal aperture coupled MPA in $\theta=90^0$ plane.

Table 1. Simulated Antenna characteristics

	Planar patch printed on planar surface	Planar patch printed on cylindrical surface
Axial Ratio below 3dB	162^0	151^0
HPBW	77.6^0	85.3^0
Co-polarization (dB)	6.34	6.26
Cross Polarization (dB)	-25	-12

5. Conclusion

Circularly polarized aperture coupled rectangular microstip patch antenna works at X-band conforming to cylindrical surface. The optimized results show the axial ratio from -74^0 to 77^0 below 3 dB for planar aperture coupled MPA. Optimized antenna radiation pattern of planar MPA gets broadened by $\sim 10^0$ after conforming to cylindrical surface. After bending the patch antenna in cylindrical surface, cross polarization level gets increased in zenith. The proposed antenna offers desired circularly polarized radiation characteristics over wider beamwidth for rotating body applications.

Acknowledgement

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

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