High Gain Cylindrical Cavity-Backed Crossed Dipole Antenna

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***Abstract*— A circularly polarized (CP) crossed dipole antenna backed with Perfect Electric Conductor (PEC) and cylindrical cavity reflectors are presented in this paper. The performance of these reflectors is compared here. A comparative study of CP antenna features on PEC and Cavity-backed reflectors to that of reference antenna is carried out in this work. The crossed dipole backed by a cylindrical cavity is able to achieve unidirectional radiation pattern, high gain, high front-to-back ratio along with an efficiency > 90%. The 0.26 λ_0 × 0.23 λ_0 (where λ_0 is free space wavelength at 1.58 GHz) sized antenna backed by a cavity structure yields a total gain of 10.59 dBic at 1.58 GHz and a front-to-back ratio > 25 dB. This antenna can be applicable in Global Positioning Systems (GPS) and satellite communication systems.**

Keywords*— *circular polarization, crossed dipole, cylindrical cavity, probe-feeding, satellite communication

I. INTRODUCTION

In recent trend, the researchers in antenna and propagation domain are mainly focusing on circularly polarized (CP) antennas rather than linearly polarized (LP) antennas due to its potential features. These features include an independent orientation between transmitter and receiver antennas in order to avoid polarization mismatch thereby overcoming the Faraday rotation effects. Also, it neglected the multipath propagation effects so as to avoid the interference between the signals. Traditionally, CP radiation occurs when two orthogonal electric fields with same amplitude and 90^0 phase difference is generated by the antenna. Its advantageous features have motivated the antenna engineers to expedite their research on CP antennas. So, it has been a great interest in various wireless communication systems such as broadcasting services [1], global navigation satellite systems (GNSS) [2], RF identification (RFID) [3], satellite communications [4], mobile communications [5], wireless local area networks (WLANs), wireless personal area networks (WPANs), and Worldwide interoperability for microwave access (WiMAX).

There are some antennas which are circularly polarized such as microstrip patch antennas, helical antennas, and spiral antennas [6]-[8] that can provide efficient antenna characteristics. Since dipole antennas are simple to design, easy to fabricate, and is of low cost so these type of CP antennas are mostly preferred. The crossed dipole and its modified versions have been developed for various narrow band and broadband applications with a frequency range of few Megahertz to Gigahertz. Crossed dipole antennas can radiate omnidirectional patterns along with dual polarized (DP) and circularly polarized radiation [9]. With the help of few additional elements on the radiator it becomes versatile to achieve single-band, multiband, and broadband characteristics depending upon the application.

Feeding is one of the major factors to properly excite the crossed dipole antenna so as to get the desired performance. The feeding mechanisms for CP crossed dipole antennas can be grouped into two types – single feed and multiple feed methods. Multiple feeds require the use of external polarizers such as ring and quadrature hybrid coupler, Wilkinson power divider, T-junction power splitter and many more. It is also found that several CP antennas use coaxial feeds at two feed points having 90^0 phase difference along with the polarizers [10]. This in turn makes the design complex so as to yield good CP performance. But the major challenge lies in the design of a less complex CP antenna with the desired characteristics**.** Therefore, single feeding technique such as coaxial probe feed is adopted which simplifies the antenna design and minimizes the spurious radiation [11]. A 50Ω or 75Ω coaxial probe can be used for feeding the antenna and obtaining the desired characteristics. This feed structure is easy to construct and it is also available plentily with low cost.

With the simple feed, various cavity-backed structures such as rectangular cavity, square cavity, and inverted cavity structure like a pyramidal cavity structure [12]-[14] are used for crossed dipole antennas. Most of the satellite systems need an efficient high gain CP antenna with a large front-to-back ratio, which can be achieved by the use of cylindrical cavity with circular top and bottom apertures along with the conducting walls of the cavity.

The proposed antenna defines a CP crossed dipole using a cylindrical cavity reflector and it is being center-fed with a 50Ω coaxial probe so that it can provide easy impedance matching with less return loss. Here, the rectangular crossed dipole antenna is designed on two types of reflectors i.e., PEC and cylindrical cavity reflectors and their results are compared with respect to the free-space antenna. The cavity-backed antenna is able to achieve a gain of 10.59 dBic with a front-to-back ratio > 25 dB. It also generated an S_{11} bandwidth (< -10 dB) of 11.3% (1.50-1.68 GHz), and an axial ratio bandwidth (< 3 dB) of 8.86% (1.51-1.65 GHz) respectively, so that it can be desirable for GPS applications.

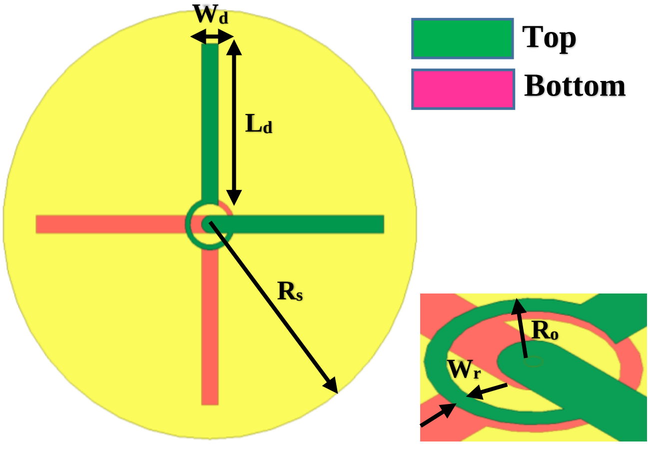
This paper contains four sections: introduction in section-I, antenna design with several subsections in section-II followed by section-III which discusses about the antenna design results, and lastly section-IV concludes the paper.

II. ANTENNA DESIGN AND ITS CHARACTERISTICS

A. Antenna Design

In this study, initially a pair of printed crossed dipole antenna whose length is approximately half of the wavelength is designed on upper and lower part of the substrate. It is designed in free space without using any reflector. It consists of rectangular shaped dipoles having dimension ($L_d \times W_d$) mm^2 being placed on a circular substrate containing Rogers RT/duroid 5880 material with a relative permittivity (ϵ_r) of 2.2, dielectric loss tangent (tan δ) of 0.0009, and a thickness of 0.508 mm. This antenna is fed at the centre with a 50Ω coaxial probe where the inner conductor is connected to the upper part of the radiator and the bottom part is attached by the outer conductor. The antenna design is simulated using Ansys HFSS software.

This antenna consists of double printed vacant quarter rings whose total circumference is quarter-wavelength approximately. It undergoes sequential rotation technique by exciting the radiator. Therefore, the printed orthogonal dipoles along with the quarter rings are responsible for generating CP radiation.The geometry of antenna along with zoomed view of central part having ring structure is shown in Fig. 1.



(a) (b)

Figure 1. (a) Geometry of antenna (b) Zoomed view of ring structure of crossed dipole antenna

The corresponding antenna dimensions with its values are shown in Table 1. The antenna without reflector is taken as the reference antenna for comparison purpose.

The reference antenna produces an impedance matching bandwidth (S_{11} < -10 dB) of 12% (1.50 – 1.69 GHz) and an axial ratio bandwidth (AR < 3 dB) of 8% (1.54 – 1.67 GHz) centered at 1.605 GHz. The minimum value of AR at this point is 0.68 dB which indicates CP radiation. Fig. 2 plots the S_{11} and axial ratio bandwidths of the reference antenna. The designed radiator radiates a bidirectional/omnidirectional pattern as there is no reflector in the antenna. It exhibits the pattern with Right-Hand Circular Polarization (RHCP) radiation on one side along +z and Left-Hand Circular Polarization (LHCP) on the other side in -z direction. Due to the bi-directional characteristic of the antenna in free space, it produces a low gain of around 2.12 dBic at 1.605 GHz. The corresponding radiation pattern with 3D polar plot is shown in Fig. 3. Due to this, more back lobes are formed leading to a low front-to-back ratio of 1.38 dB.

TABLE 1: Dimensions of antenna designed in free space

Antenna Parameters	Symbols	Value (mm)
Dipole arm length	L_d	44
Dipole arm width	W_d	3
Substrate radius	R_s	55
Outer ring radius	R_o	5
Ring width	W_r	1.2

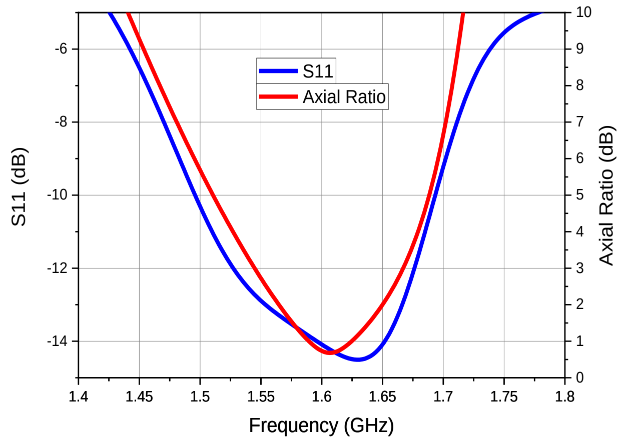
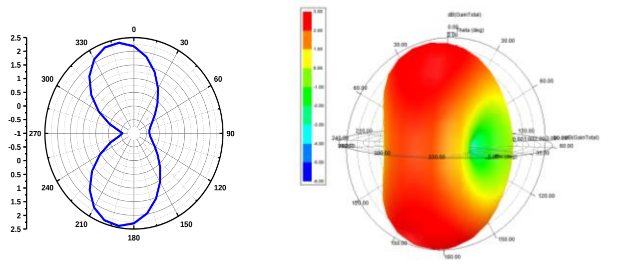


Figure 2. S_{11} and Axial ratio plots of crossed dipole without reflector (reference antenna)



(a) (b)

Figure 3. (a) Radiation pattern at 1.6 GHz (b) 3D Polar plot

B. Study of Unidirectional Antenna using PEC Reflector And Cylindrical Cavity Resonator

The bidirectional radiation patterns were converted to unidirectional patterns with the help of different reflectors. These reflectors can be perfect electric conductors (PEC) or it can be cavity shaped structures to confine the radiation within a pre-defined structure thereby minimizing any side lobes or back lobe radiation. This also, helped to improve the designed antenna characteristics such as gain of the antenna.

PEC reflectors can be utilized to redirect half of the waves radiating to the opposite direction thereby improving the gain of the antenna. The other side objects are partially shield so that the radiation becomes confined to only one direction leading to a unidirectional pattern shown by the antenna. So, the CP crossed dipole antenna is placed on a PEC reflector at nearly λ/4 (λ corresponds to the wavelength in free-space at CP center frequency) distance so that there is no cancellation of image current and radiated current and there is an efficient radiation. Here, the λ/4 distance (H) is taken as 47 mm from the crossed radiator generating unidirectional pattern.

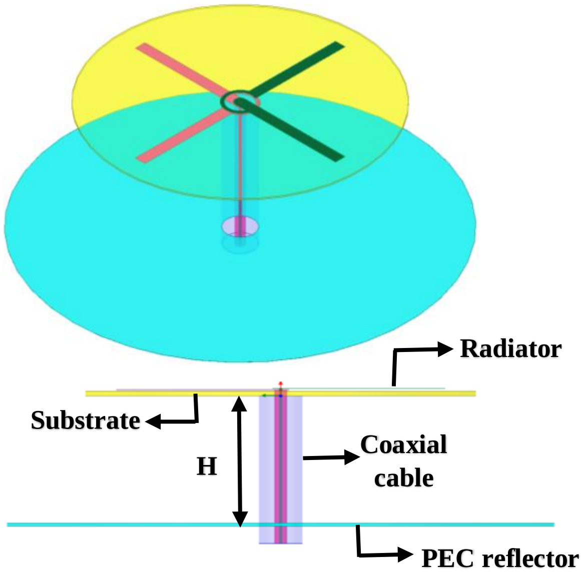


Figure 4. A PEC reflector backed antenna with its side view

By placing the antenna on same substrate using an 80 mm PEC reflector as shown in Fig. 4, it yields an impedance bandwidth (S_{11} < -10 dB) of 15.5% with an axial ratio bandwidth (AR < 3 dB) of 13% with two AR peaks at 1.50 GHz and 1.62 GHz having values 0.28 dB and 1.7 dB to generate CP wave. As compared to the reference antenna, it shows that S_{11} bandwidth has improved by 3.5%, and axial ratio bandwidth by 5% thereby exhibiting broadband characteristics. It yielded a total gain of 8.15 dBic at 1.54 GHz. It has an improved front-to-back ratio of 18.21 dB due to the reduction of number of side lobes with presence of reflector. The S_{11}, and axial ratio plots obtained are given in Fig. 5.

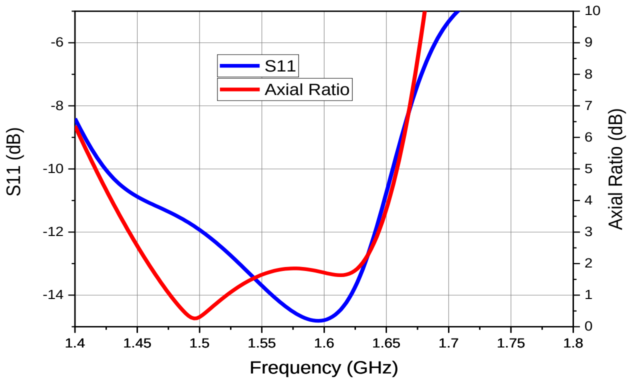


Figure 5. S_{11} and Axial ratio plots of PEC reflector-based antenna

For enhanced characteristics of the antenna from gain and front-to-back ratio point of view, the PEC reflectors are replaced by the cavity-backed reflectors. The cavity cross-section is cylindrical in shape with circular top and bottom apertures of radius 80 mm each respectively. The corresponding antenna design is shown in Fig. 6. The cavity walls surrounding this reflector confine the amount of radiation inside it leading to stable and high gain of 10.59 dBic with a higher front-to-back ratio than the PEC reflector case.

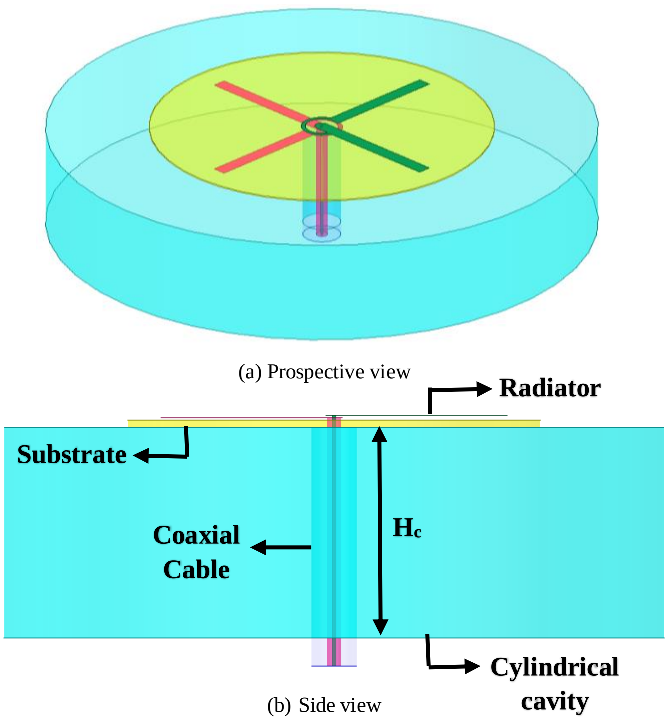
The cavity height (H_c) is kept same as in case of PEC reflector. It is also nearly λ/4 (quarter-wavelength) length from the radiator. The influence of the cavity walls on the circularly polarized radiation of the radiator is investigated. The walls of cavity helped to minimize the back lobe radiation. Table 2 depicts the comparison of CP crossed dipole antennas with different reflectors.

TABLE 2: Comparison of crossed dipole antenna using different reflectors

Reflector Type	**Centre frequency (f_c) (GHz)**	**IBW (S_{11} < -10 dB) in GHz** / **ARBW (AR < 3 dB) in GHz**	**Front to back ratio (dB)**	**Gain (dBic)**
Free space (without reflector)	1.605	1.50-1.71	1.45	2.20
		1.54-1.67		
PEC backed	1.54	1.42-1.66	18.21	8.15
		1.44-1.64		
Cavity backed	1.58	1.50-1.68	824.35	10.59
		1.51-1.65		

***IBW – Impedance Bandwidth, ARBW – Axial Ratio Bandwidth**

From Table 2, it is found that the reference antenna provides a wide IBW of 12% and an ARBW of 8% at the cost of gain and front-to-back ratio. But, to enhance these properties, the reference antenna is designed using a cylindrical shaped cavity resonator which increases the total gain of the antenna by a factor of 8.39 dBic so as to make it suitable for satellite applications. It also has an enhanced front-to-back ratio as compared to PEC reflector and free space of the antenna.



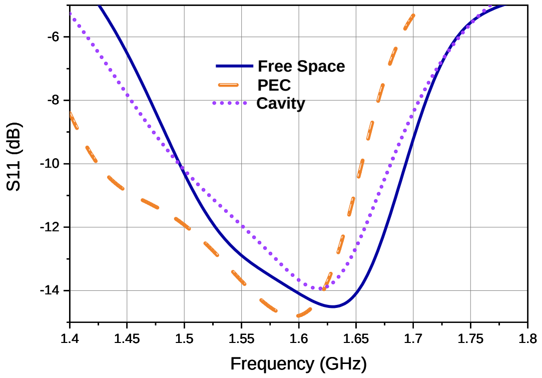
(a) Prospective view

(b) Side view

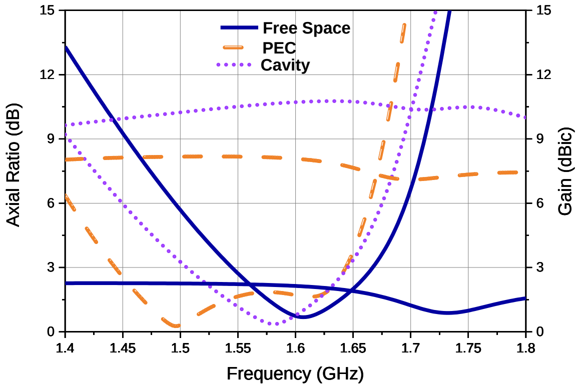
Figure 6. Cylindrical-cavity backed reflector with its (a) Prospective and (b) side view

The S_{11}, axial ratio, and gain values vs frequency for different reflectors are plotted in Fig. 7. It shows that the PEC backed radiator has improved gain of 8.15 dBic with respect to the reference radiator with an increase in the bandwidth within the operating band at 1.54 GHz. The wide axial ratio bandwidth with axial ratio < 3 dB generates CP wave. Also, due to the presence of reflector the number of side lobes gets reduced and this in turn, increases the front-to-back ratio.

Again, with the implementation of cylindrical cavity resonator, the total gain is enhanced more by a factor of 8.39 dBic at the centre frequency. This shows that the antenna with cylindrical cavity-shaped reflector can be used in those applications desiring high gain and more front-to-back ratio.



(a) S_{11} Plot



(b) Axial ratio and Gain plots

Figure 7. (a) S_{11} (b) Axial ratio and Gain plots for different reflectors

III. RESULTS AND DISCUSSION

Here, the S_{11}, and axial ratio (AR) plots of proposed cylindrical cavity backed antenna are analysed so as to determine the operating band. The required plots of the above parameters are shown in Fig. 8. The S_{11} bandwidth is found to be 110 MHz (1.50 – 1.68 GHz) which is around 11.3% and the axial ratio bandwidth is 8.86% (1.51 – 1.65 GHz). The corresponding axial ratio (AR) value is 0.36 dB at 1.58 GHz which shows that the corresponding antenna is a CP antenna. Additionally, it exhibited a total antenna gain of 10.59 dBic with a large front-to-back ratio. The distribution of electric field on the cavity walls is shown in Fig. 9. It shows the concentration of fields in both the inner and outer cavity walls of the resonator leading to a stable and high gain in the operating bandwidth. The counter clockwise rotation of fields indicate that the antenna is Right-Hand Circularly Polarized (RHCP). Also, it is found from the pattern shown in Fig. 10, that the antenna radiates RHCP in broadside direction with more RHCP gain at different phase angles.

Fig. 11 shows the 3D polar plot of the designed antenna which shows a unidirectional radiation pattern with minimized back lobes.

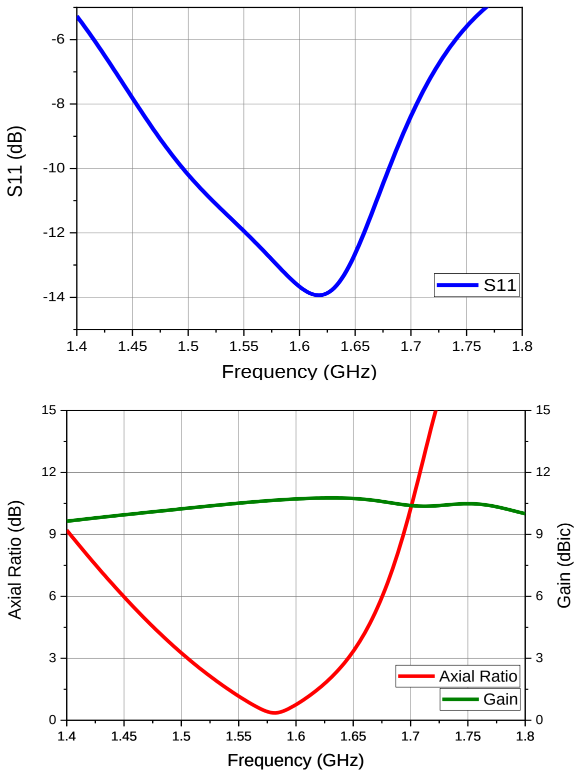


Figure 8. S_{11}, Axial ratio, and Gain plots of cavity-backed antenna

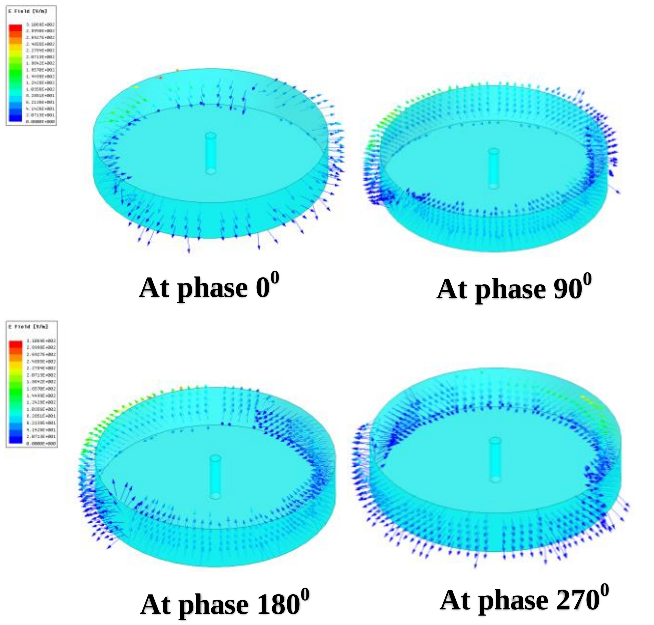
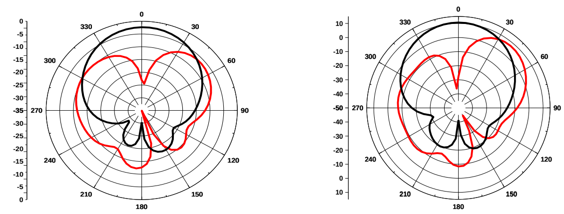


Figure 9. Distribution of electric field on the cavity walls at different phase angles at 1.58 GHz.



(a) (b)

Figure 10. Radiation patterns at (a) $\phi = 0^0$ and (b) $\phi = 90^0$

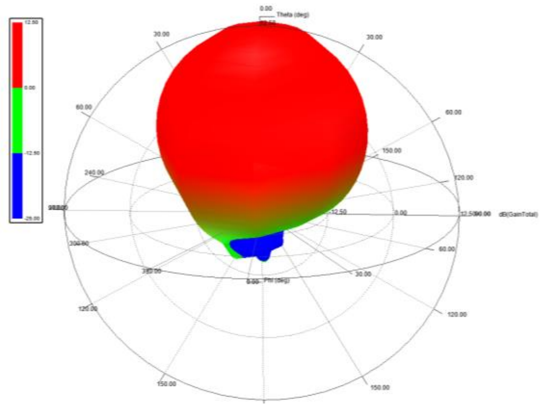


Figure 11. 3D polar plot

TABLE 3: Comparison of properties of crossed dipole antennas with different cavity structures

Ref. No.	**Cavity shapes**	**Centre frequency (f_c) in GHz**	**IBW (S_{11} < -10 dB) in GHz** / **ARBW (AR < 3 dB) in GHz**	**Gain (dBic)**
[12]	Rectangular cavity	1.575	(1.45 – 1.65)	7
			(1.55 – 1.60)	
[13]	Pyramidal cavity	1.175	(1.13 – 1.29)	7.55
			(1.16 - 1.19)	
[14]	Square cavity	2.51	(2.05 -3.67)	8.70
			(2.25-2.78)	
This paper	Cylindrical cavity	1.58	(1.50-1.68)	10.59
			(1.51-1.65)	

***IBW – Impedance Bandwidth, ARBW – Axial Ratio Bandwidth**

Table 3 shows the performance of proposed antenna with cylindrical cavity in comparison to other reference cavity structures. The rectangular cavity structure obtained a narrow CP bandwidth of 3.1% within the operating band having a gain of 7 dBic. But the CP bandwidth got enhanced with the use of square cavity reflectors, to around 21%. Although, the cylindrical cavity structure has less bandwidth than the square shaped cavity, still it yields a high gain of around 10.5 dBic at its centre frequency. The presence of cavity walls with large concentration of fields reduced the number of side lobes and minimized the level of back lobe thereby improving the front-to-back ratio, and its efficiency is found to be more than 90%. The high gain and large front-to-back ratio features indicate that the designed radiator can be suitable for GPS and satellite applications.

IV. CONCLUSION

A compact size RHCP crossed dipole antenna backed by a cylindrical cavity is presented in this paper. The cavity wall effects were studied for enhanced characteristics. In contrast, with the PEC reflector it obtained an impedance bandwidth of 11.3% (1.50 – 1.68 GHz), and 8.86% (1.51 – 1.65 GHz) as an axial ratio bandwidth. Due to large field concentration on the cavity walls, it is able to yield a total gain of 10.59 dBic with a front-to-back ratio higher than 25 dB. It has a radiation efficiency of more than 90%. These features make it useful for GPS as well as satellite communications with appropriate optimization.

V. ACKNOWLEDGMENT

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