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Wide-band Circularly Polarized Cavity Backed Crossed Dipole Antenna

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Abstract

In this paper, a wide-band circularly polarized (CP) crossed dipole antenna is proposed. The CP crossed dipole antenna is backed by a cavity reflector to achieve wide-band CP radiation with enhanced gain and uni-directional pattern accompanied by high front to back lobe ratio. A comprehensive study on the effect of the vertical walls of the cavity reflector on the CP radiation performance has been performed. It is analyzed that the cavity reflector provides an additional CP mode which is merged with the reference CP mode of crossed dipole to get a bandwidth enhancement in the CP operation. The concentration of electric field vectors on the inner walls of cavity provides an enhanced and stable gain of a CP crossed dipole across the entire CP operating bandwidth as compared to a PEC reflector backed crossed dipole antenna. The concept of wide-band, uni-directional and high gain CP crossed dipole antenna is validated by measurement carried out on the fabricated antenna prototype. Measured results confirm that the cavity backed crossed dipole exhibits a CP operating bandwidth of 22.89% (2.52−3.17 GHz), an average gain of 8 dBic and uni-directional radiation pattern with a front to back lobe ratio > 25 dB.

1 Introduction

The crossed dipole antenna is one of the suitable candidate for generation of circularly polarized (CP) radiation [1]. The CP crossed dipole antenna consists of two half-wavelength dipoles placed orthogonally and fed with currents of equal amplitude which are in phase quadrature. The CP crossed dipole antenna exhibits a bi-directional radiation pattern with low gain. However, many wireless applications require antennas with uni-directional radiation with high front to back lobe ratio. So, the crossed dipoles are equipped with a reflector to get the desired uni-directional CP radiation. Classically, the crossed dipoles are used with PEC reflectors to get uni-directional radiation. Several studies have been performed to get an enhancement in CP operating bandwidth of a CP crossed dipole antenna [2]−[3]. The use of PEC reflector in conjunction with a wide-band CP crossed dipole antenna does not lead to an enhanced and stable gain over the entire CP operating band. For the PEC reflector backed wide-band CP crossed dipole, gain drops significantly when the reflector height $\approx \lambda$. Recently, the use of cavity as a reflector with the crossed dipole to get an enhanced CP radiation performance has gained popularity [4]−[8]. The enhancement of 3-dB axial ratio beamwidth of CP crossed dipole antenna has been achieved by means of cavity backing [4]−[5]. The increase in CP operating bandwidth in CP crossed dipole with the use of cavity reflector has been studied in [6]−[8].

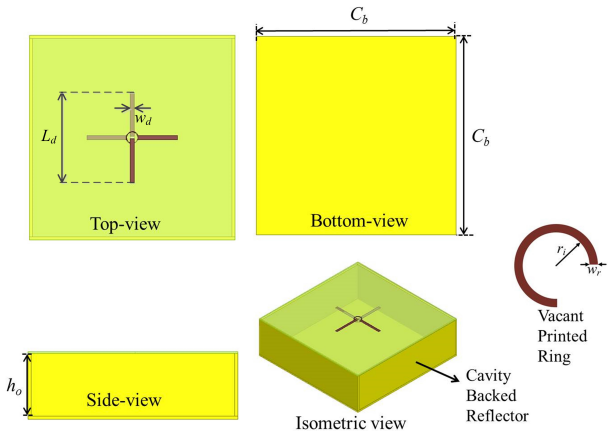

Figure 1. Schematic of the proposed cavity reflector backed CP crossed dipole antenna. L_d = 44 mm, w_d = 2 mm, r_i = 3 mm, w_r = 0.3 mm, C_b = 100 mm and h_0 = 30 mm.

In this work, a wide-band CP cavity backed crossed dipole antenna design is presented. The cavity backing excites a CP mode in addition to the reference CP mode of crossed dipole antenna. The judicious choice of the cavity cross-section dimension can enable the merging of the CP cavity mode with the original CP mode of crossed dipole, leading to an enhancement in CP operating bandwidth. The vertical walls of the cavity reflector concentrate the electric field vectors within them and are capable of providing a stable and enhanced gain in the CP operating band. The proposed concept of wide-band, high-gain and uni-directional CP cavity backed crossed dipole antenna has been validated by means of measurements conducted on fabricated prototype of antenna.

2 Circularly Polarized Crossed Dipole Antenna Backed by a Cavity Reflector

CP crossed dipole antenna consisting of a set of orthogonally oriented dipoles connected through a one quarter va-

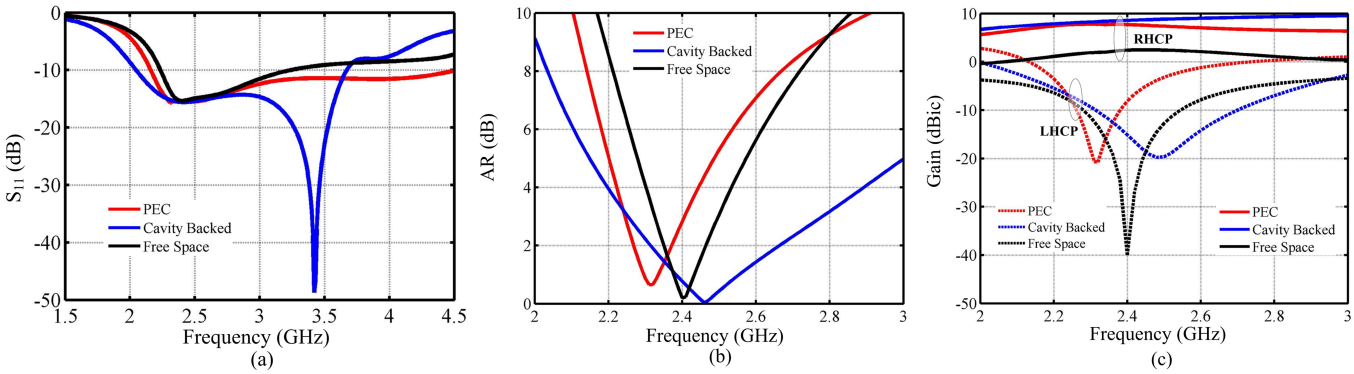

Figure 2. Comparison of (a) S_{11}, (b) AR and (c) gain of the reference crossed dipole in free space, backed by PEC reflector and backed by cavity reflector.

Table 1. Comparison of Operating CP Bandwidth and Gain of the CP Crossed Dipole Antennas

Crossed Dipole	IBW (GHz) ($S_{11} < -10$ dB)	ARBW (GHz) (AR < 3 dB)	f_{cp} (GHz)	Operating CP BW (%) ($S_{11} < -10$ dB and AR < 3 dB)	Gain (dBic)
Free Space	2.24−3.24	2.32−2.50	2.41	7.50	2.20
PEC backed	2.17−4.40	2.24−2.41	2.32	7.33	7.78
Cavity backed	2.05−3.67	2.25−2.78	2.51	21.11	8.70

cant ring acts as the reference design [8]. The reference crossed dipole in free space exhibits a CP operating bandwidth ($S_{11} < -10$ dB and Axial Ratio < 3 dB) of 7.5% centered at 2.41 GHz. A bi-directional pattern with right handed circularly polarized (RHCP) radiation along +z and left handed circularly polarized (LHCP) radiation towards −z is obtained for the reference CP crossed dipole antenna. As the radiation is bi-directional the crossed dipole bears a low gain of 2.4 dBic at 2.41 GHz.

The reference crossed dipole antenna is backed by a cavity with square cross-section to achieve a wide-band CP operation along with high gain and uni-direction radiation pattern. The schematic view of the crossed dipole antenna with the cavity reflector is depicted in Figure 1. In order to study the effect of the four walls of the cavity on the CP radiation performance of CP crossed dipole antenna, a comparative study is carried out on S_{11}, axial ratio and gain of a crossed dipole in free space, crossed dipole backed by a square plate (PEC reflector) and crossed dipole backed by a cavity. The height of PEC and cavity reflectors are taken as 30 mm which is $\approx \lambda/4$ (λ corresponds to 2.41 GHz, CP center frequency of the reference crossed dipole in free space). The cross-section of the cavity and the PEC square plate is taken as 100 mm $\times$ 100 mm. The comparison of S_{11}, AR and gain of the crossed dipole in free space with that of the finite PEC and cavity backed configurations are presented in Figure 2. The operating CP bandwidths and gain obtained for the CP crossed dipole in free space, with PEC and cavity backed reflectors are presented in Table 1. It is seen that with the use of a PEC reflector the gain of the CP crossed dipole antenna is increased, but the axial ratio bandwidth is further narrowed down as compared to that obtained in free space. Thus, the use of a conventional PEC reflector with the CP crossed dipole cannot simultaneously provide high gain and wide CP operating bandwidth. The cavity backing of the crossed dipole has lead to wide CP operating bandwidth with considerable enhancement in antenna gain. Unlike the PEC reflector, the cavity reflector provides a stable and high gain in the entire CP operating band of the crossed dipole antenna.

In order to get an insight into the operating CP bandwidth and gain enhancement of the CP crossed dipole antenna with the use of a cavity backed reflector, the effect of the cavity cross section on the performance of the CP crossed dipole antenna is investigated. Figure 3 shows the variation of axial ratio of the cavity backed crossed dipole antenna for different cross-sections of the cavity reflector. The height of the cavity walls is kept fixed at 30 mm. From Figure 3, it is seen that cavity walls contribute to a higher order CP mode in addition to the reference CP mode of the crossed dipole. The higher order CP is not merged with the reference CP mode for C_b = 60 mm. But, for C_b = 80 mm, both the modes get merged to produce a wide CP operating bandwidth. The two CP modes get separated with further increase in the values of cavity cross-section leading to decrease in the CP bandwidth. However, the gain in the operating CP band get enhanced with the increase in the cavity cross section.

The electric field distributions on the inner and outer sur-

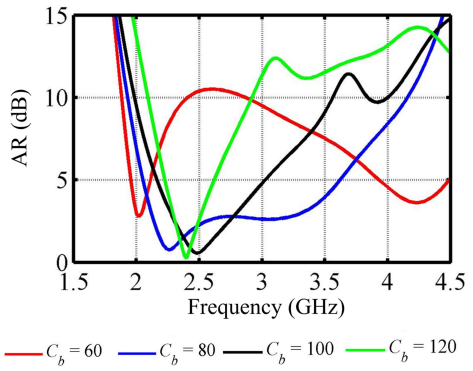

Figure 3. Variation of axial ratio for the different cross sections of the cavity reflector (h_o is kept equal to 30 mm in all cases) for the proposed cavity reflector backed CP crossed dipole antenna.

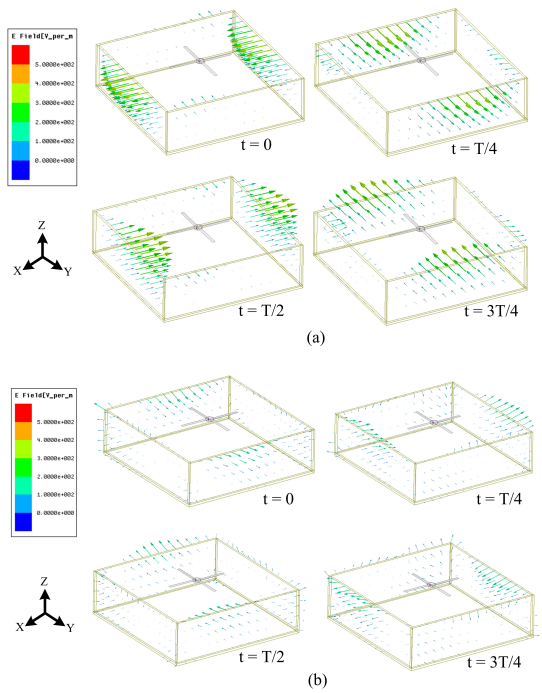

Figure 4. Electric-field distributions on the (a) inner walls and (b) outer walls of the cavity backed reflector at CP centre frequency (2.51 GHz) for the proposed cavity reflector backed CP crossed dipole antenna.

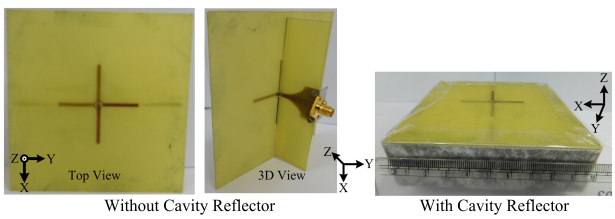

Figure 5. Photograph of the fabricated cavity reflector backed CP crossed dipole antenna.

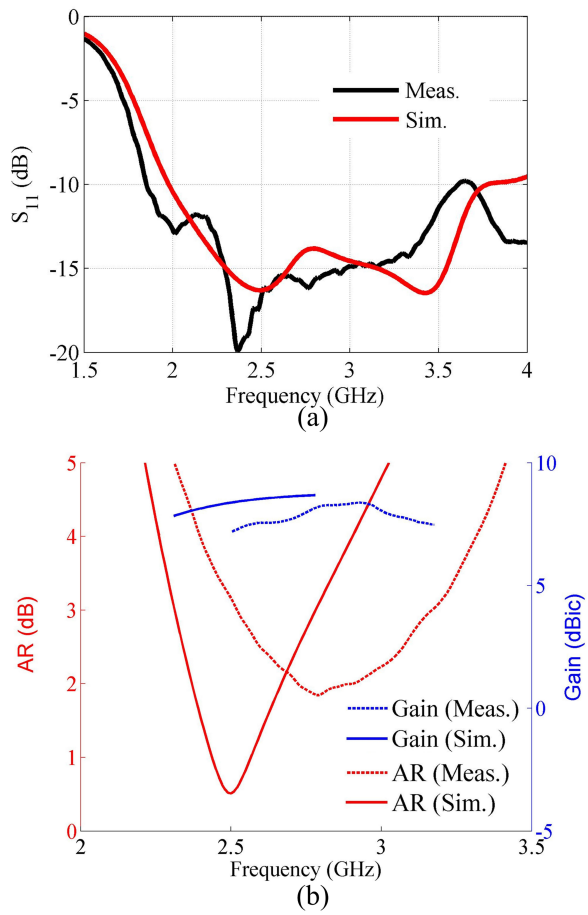

Figure 6. Comparison of simulated and measured (a) S_{11}, (b) axial ratio and gain for the proposed cavity reflector backed CP crossed dipole antenna.

face of the cavity walls at CP centre frequency for different time instants are depicted in Figure 4. The concentration of the electric field vectors on the surface of inner walls is very large as compared to that observed on the outer surface. The concentration of the electric field vectors on cavity surface, leads to the enhanced and stable gain in the operating CP bandwidth of the cavity backed crossed dipole antenna. The counterclockwise rotation of electric field vectors on the inner and outer walls of cavity leads to a RHCP radiation in the broadside direction.

3 Measured Results

In order to validate the concept of high gain, large front to back lobe ratio and wide CP operating bandwidth of the cavity backed crossed dipole antenna, a prototype of the crossed dipole antenna with cavity reflector of dimension 100 mm × 100 mm × 30 mm has been fabricated. A broadband microstrip to broadside coupled strip line transition is used to provide a practical feeding to the crossed dipole antenna [8]. The photograph of the fabricated prototype of the cavity reflector backed CP crossed dipole is depicted in Figure 5.

Table 2. Comparison of Simulated and Measured Operating CP Bandwidth and Gain of the Cavity Backed CP Crossed Dipole Antenna

Cavity Backed Crossed Dipole	f_{cp} (GHz)	Operating CP BW (%) (S_{11} < -10 dB and AR < 3 dB)	Gain (dBic)
Sim.	2.54	18.50	8.44
Meas.	2.84	22.89	8.27

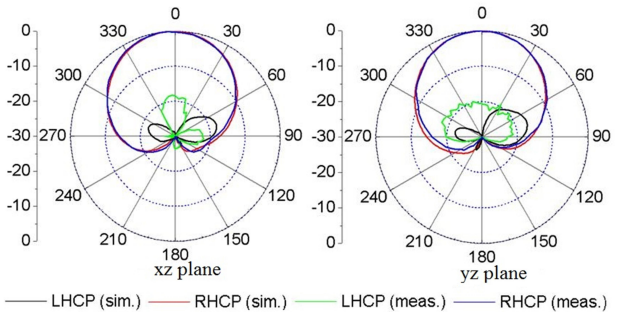

Figure 7. Normalized simulated and measured RHCP and LHCP radiation patterns in the xz-plane and yz-plane for the proposed cavity reflector backed CP crossed dipole antenna.

The comparison between the simulated and measured S_{11}, AR and gain of the CP cavity backed crossed dipole antenna is depicted in Figure 6. The simulated and measured operating CP bandwidths and gain of the cavity reflector backed crossed dipole antenna is provided in Table 2. Measured results shows a shift of 0.3 GHz of the operating CP band as compared to that achieved in simulation. This can be attributed to the fabrication tolerances involved in both the cavity as well as feed network designs which is used with the crossed dipole. The normalized simulated and measured RHCP and LHCP radiation patterns in the xz and yz planes of the proposed antenna at the CP centre frequency are depicted in Figure 7. The isolation between the RHCP (Co-polarized) and LHCP (Cross-polarized) component of radiated fields in the broadside direction ($\theta = 0°$) for both the xz and yz planes is better than 30 dB. The measured front to back lobe ratio in the xz and yz planes at the CP centre frequency is greater than 25 dB.

4 Conclusion

In this work, a wide-band cavity backed CP crossed dipole antenna has been presented. The effects of the vertical walls of cavity on the radiation performance of the CP crossed dipole antenna have been investigated in detail. In contrast to the conventional PEC reflector, a cavity backed reflector of suitable dimension can simultaneously enhance the gain and operating CP bandwidth of the reference CP crossed dipole antenna in free space. The measured results show that the proposed cavity backed crossed dipole antenna bears a CP operating bandwidth of 22.89% (2.52−3.17 GHz). The cavity backing leads to a uni-directional radiation pattern with a stable gain and high front to back lobe ratio (> 25dB) in the CP operating bandwidth. The proposed methodology can enhance the operating CP bandwidth without altering the geometrical parameters of the main radiator. The concept of the use of a cavity reflector for the performance enhancement of a CP crossed dipole can be extended for the sequentially rotated arrays of crossed dipoles to realize further enhancement in CP operating bandwidth along with stable gain.

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