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RESEARCH PAPER

Improved polarization purity for circular microstrip antenna with defected patch surface

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A simple and compact microstrip antenna of circular geometry with circular cut defected patch surface has been proposed for significant suppression of cross-polarized (XP) radiation compared with maximum co-polarized gain without affecting the co-polarized radiation pattern at its dominant mode. This will enhance the polarization purity in the radiation performance of the proposed antenna. About 27–28 dB isolation between co-polarized and XP radiations is achieved with the proposed structure. The present structure is simple and easy to develop commercially. The investigation of the new structure is carried out with a view to eliminate orthogonal resonance, which is generally attributed for high XP radiation from the microstrip patch antenna with conventional circular geometry. Comprehensive study on the resonance and radiation characteristics of the new geometry is presented. The present investigation provides an insightful visualization-based understanding of XP suppression with the present structure.

Keywords: Circular microstrip antenna, Cross polarized radiation, Dominant mode, Orthogonal mode

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I. INTRODUCTION

A microstrip antenna is the most useful low-profile antenna due to its light weight, small size, and low cost. The conventional circular microstrip patch antenna (CMPA) is very easy to fabricate and assemble [1], and hence it has become an attractive radiator for modern wireless and microwave communication systems. The conventional CMPA, resonating at its fundamental TM_{11} mode, produces linearly polarized field along its broadside. The plane of polarization is determined by the vertical *xz*-plane as indicated in Fig. 1. This *x–z* plane is referred as *E* plane. However, some extent of orthogonally polarized field (orthogonal to *xz*-plane or *E p*-lane) is always evident [2, 3] which is referred to as cross-polarized (XP) radiation. The XP radiation fields are more significant in the *H*-plane (*yz*-plane) than in the *E*-plane as obtained in open literature [4]. In particular, the angular region, where the cross-polarization levels go 20 dB lower than the co-polarization levels, are only few degrees near the broadside direction in the *H*-plane. This evidently is a hindrance to the applications, such as adaptive antenna arrays for cellular, mobile land, or other wireless communications, where wide coverage is usually required as indicated in [5]. Consequently, scientist and researchers have been addressing this issue of lowering XP radiation, particularly in *H*-plane since past two decades. Experimental studies indicate the considerable XP level in the *H*-plane, which typically appears about 15 dB below the peak gain.

Few handful investigations, by modifying the feed structure of patch antenna, were reported in [6–9] for reduction of XP radiation. Dual-feed structures with 180° phase difference have been employed in [6, 7]; whereas meander line feeding mechanism is utilized in [8]. About 20 dB of XP suppression has been reported in [8]. Use of probe-fed half-wavelength strip is reported in [9] to improve co-cross polarization ratio and 20 dB of XP suppression compared with co-polarized peak gain is evident from the literature. The modification done to the ground plane shape to suppress the XP radiation about 10–15 dB, is apparent in [10, 11].

Recently, there has been an increasing interest in using defected ground structures (DGS) in microwave and millimeter wave applications. Guha *et al.* [12] were the first to propose the concept of DGS for minimizing XP radiation for a microstrip patch antenna. Subsequent investigations [13–16] confirm that the *H*-plane XP radiation can be minimized by dot, arc and ring shaped DGS. A recently reported article [17] has shown about 10–12 dB suppression of *H*-plane XP radiation compared with conventional circular microstrip antenna using arc-shaped DGS. However, all these investigations lead to complexity in manufacturing process and moreover, authors feel that more investigations are required to find a more simple technique for suppression of the XP radiation.

With this in view, a new and simplified patch structure has been investigated in the present paper and about 27–28 dB of

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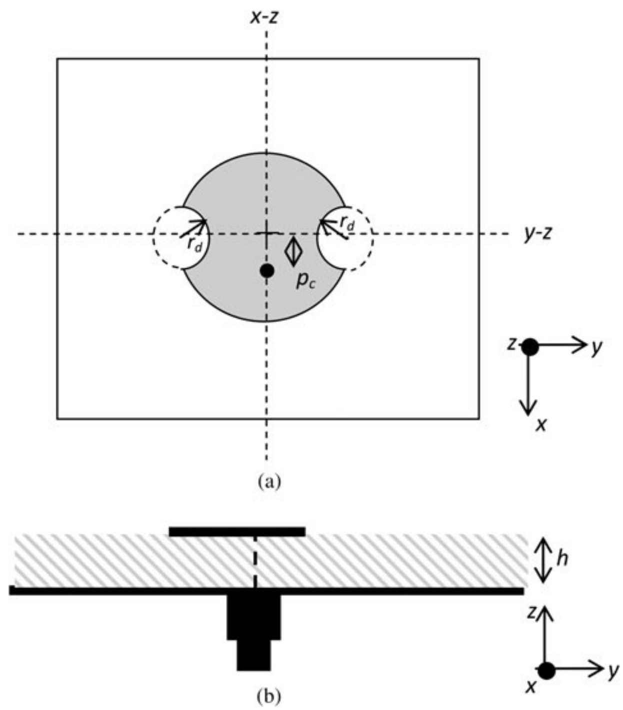

Fig. 1. Schematic representation of the proposed circular microstrip antenna with the circular cut defected surface. (a) Top view and (b) Side view.

XP suppression compared with co-polarized peak gain is revealed. The newly proposed patch structure is basically a circular patch with circular cut defects placed symmetrically at its *H*-plane as shown in Fig. 1. The source of XP fields was theoretically analyzed in [3] and the first higher-order mode was attributed to this phenomenon. Indeed the conjecture of automatic generation of TM_{21} mode (the first higher-order mode for circular patch) leads to conceive such structure, which will affect the field distribution of TM_{21} mode, whereas that for TM_{11} dominant mode is kept unaltered. In order to alleviate the lacunae of earlier studies, the present paper gives a clear insight in to the source of XP radiation. The minimization of XP radiation relative to co-polarized peak gain with the proposed structure is pictorially documented. Few representative measured results are also incorporated to validate the proposed idea.

The present structure may be utilized to the wireless systems where better XP performance is the major issue, e.g. wireless base station network, good quality EMI sensors, linearly polarized array, etc.

II. BACKGROUND, PARAMETRIC STUDIES, AND PROPOSED STRUCTURE

A) Background

The conventional CMPA, resonating at its fundamental TM_{11} mode, produces broadside radiation where the electric fields are linearly polarized along the *E*-plane (*x*–*z*). The radiations are inherently from the fringing fields situated at radiating edges as we know from open literature [4]. However, few fringing fields of the dominant mode are existing in regions A and B as indicated in Fig. 2. It, in fact, takes part in radiation and

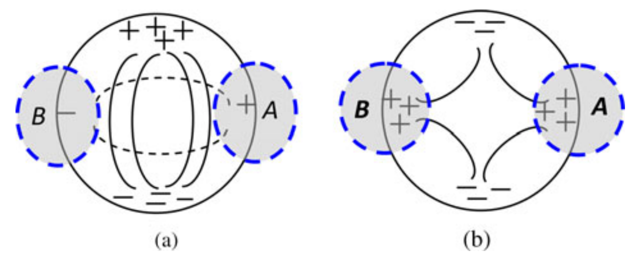

Fig. 2. Electric field and current distribution over patch surface (a) for the dominant TM_{11} mode and (b) for the next higher-order TM_{21} mode.

may produce appreciable amount of power at a certain angle, which may be attributed for XP radiation. The dotted line in Fig. 2(a) shows the electric surface current along the direction, orthogonal to the E-plane; whereas the solid line indicates the same for the pure TM_{11} mode. The first component of electric surface current is accountable for XP radiation. This sort of orthogonal component of dominant mode for XP radiation is apparent from [17]. It is basically due to orthogonal resonance of week TM_{11} mode as reported. Along with this, the automatic excitation of orthogonal higher-order mode TM_{21} is the key factor in producing high XP radiation from the CMPA. The field and current distributions are shown in Fig. 2 for the TM_{11} and TM_{21} modes.

It is clear from Fig. 2(b) that the resonance for the TM_{21} mode is orthogonal to the *E*-plane and hence produces high XP fields. This is also evident from [3]. A close inspection of Fig. 2 discloses that the radiations mainly from regions A and B are responsible for XP radiation. Hence a pair of circular cut defect has been organized symmetrically at the *H*-plane as shown in Fig. 1, which can eliminate the prospect of survival of *E*-fields on those A and B regions. As a consequence the proposed circular cut-defected circular patch antenna (CCDCPA) can minimize the orthogonal resonance as well as produce better XP performance.

B) Parametric studies

The parametric studies, using commercially available software package (high-frequency structure simulator; HFSS v. 14), is utilized to investigate the radiation characteristics of the proposed structure. This is crucial to optimize the dimension of the defect on patch surface.

Figure 3 shows the simulated radiation characteristics of the proposed CCDCPA with the defects of different radial dimensions r_d. The radiation characteristics of simple CMPA with $r_d = 0$ is also incorporated in the same plot for comparison. It appears that if the radius of the defect r_d is increased up to 3 mm, the XP radiation compared to peak co-polarized gain in the *H*-plane decreases in the present structure. Gradually as r_d is increased above 3 mm, the XP radiation performance degrades more compared with maximum co-polarized gain. About 10–11 dB improvement in XP radiation compared with that from CMPA, is revealed with proposed CCDCPA ($r_d = 3$ mm). Consequently about 27–28 dB of XP suppression compared with maximum co-polarized gain is achieved. It is also apparent from Fig. 3(a) that XP performance degrades in the *E*-plane due to incorporation of defect on the patch surface. But in the present investigation it is still below 40 dB compared with maximum co-polarized gain. This may be tolerable for any

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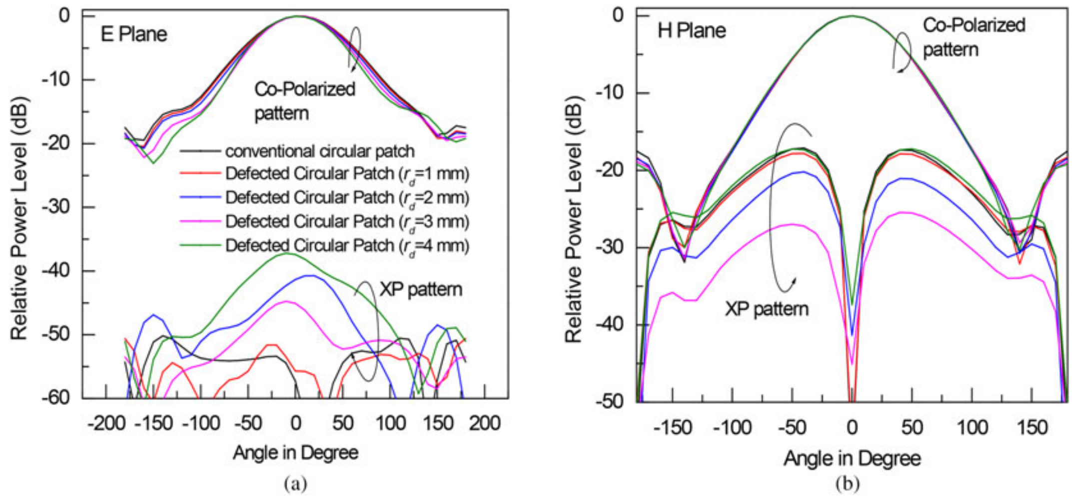

Fig. 3. Comparison of the radiation pattern of the proposed CCDCPA with variable r_d and the conventional CMPA. (a) The *E*-plane and (b) the *H*-plane.

wireless communication link. The profile of co-polarization to cross polarization radiation ratio (Co–XP ratio) as a function of radius of the defect is presented in Fig. 4. It reveals that the best XP radiation isolation compared with its peak co-polarized gain is achieved with $r_d = 3$ mm and is therefore chosen for investigation.

C) Proposed structure

A pair of circular cut defect in CMPA gives birth to the proposed structure as shown in Fig. 1 of CCDCPA. RT duroid ($\varepsilon_r = 2.33$) of 1.58 mm thickness has been utilized as the substrate over the ground plane of 90 × 90 mm. The patch of radius $a = 10$ mm is designed to operate about 5 GHz. Two circular sections each of radius $r_d = 3$ mm have been removed symmetrically to form a CCDCPA-based on parametric studies. The investigation has been performed using [18] to obtain better matching and good Co–XP ratio. The feed position has been shifted to 2.8 mm from the center of the patch for optimization. A prototype has also been fabricated as shown in Fig. 5 with the above-mentioned parameters and is utilized to validate the observed phenomenon.

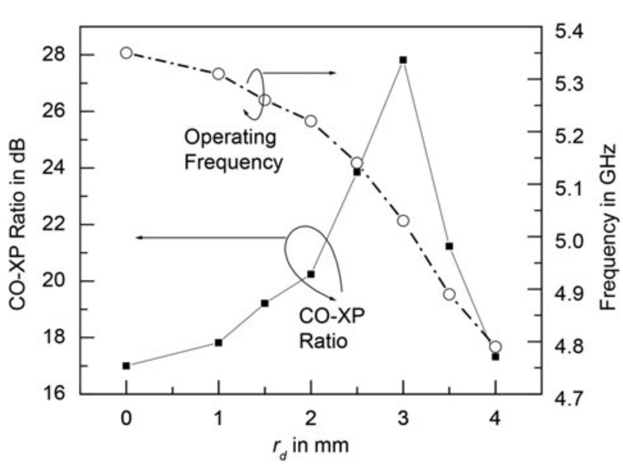

Fig. 4. Variation of the CO–XP ratio and the operating frequency of the proposed structure with variable radius of the defect on the patch surface.

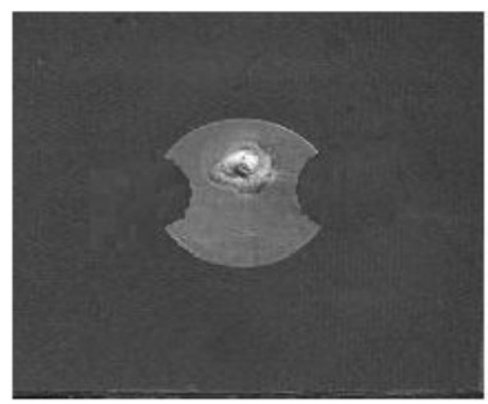

Fig. 5. Fabricated prototype of the proposed CCDCPA with $r_d = 3$ mm.

III. DISCUSSIONS AND MEASUREMENTS

Simulated and experimental investigations of the input and radiation characteristics with the conventional CMPA and the proposed CCDCPA are documented in the following section. The fabricated CCDCPA shown in Fig. 5 is utilized for measurement purpose. But before discussing the results, let us initially concentrate on the reason behind the observations documented in section II B. The parametric study of the proposed structure reveals that for lower dimension of the defect, CO-XP ratio is not good but as soon as it increases, CO-XP ratio improves and the best result is obtained at $r_d = 3$ mm. In fact, when r_d is small, then it cannot perturb or eliminate all electric fields situated in regions A and B of Fig. 2. The fact is clear from the review done on the field components beneath the patch as indicated in the following section. The field components obtained from open literatures as

$$\left.\begin{aligned} E_\rho &= E_\varphi = H_z = 0 \\ E_z &= B_{mnp}A_2 J_m(k_\rho \rho)\cos m\varphi \cos k_z z \\ H_\rho &= -\frac{1}{\mu\rho} B_{mnp}A_2 J_m(k_\rho\rho)\, m \sin m\varphi \cos k_z z \\ H_\varphi &= -\frac{1}{\mu} B_{mnp}A_2 J_m{}'(k_\rho\rho)\cos m\varphi \cos k_z z \end{aligned}\right\} \quad (1)$$

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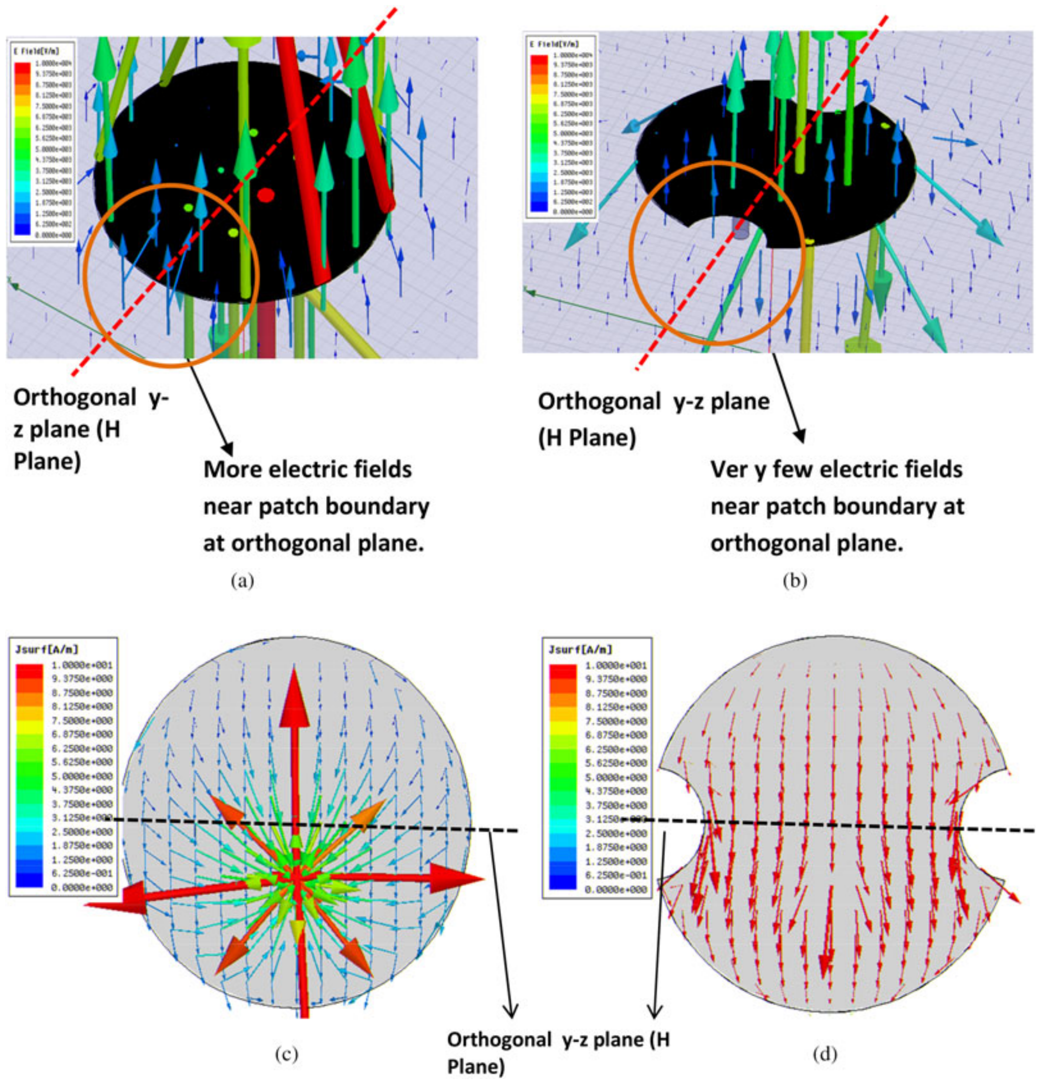

Fig. 6. Comparison of the electric field components and the electric surface currents of the conventional CMPA and the proposed CCDCPA. (a) *E*-fields near the patch boundary on the orthogonal plane of CMPA. (b) *E*-fields near the patch boundary on the orthogonal plane of the proposed CCDCPA with $r_d = 3$ mm (c), J_s on the patch surface of CMPA (d). J_s on the patch surface of the proposed CCDCPA with $r_d = 3$ mm.

For electric surface current J_s over the patch surface, we may write

$$(J_s)_E = \hat{z} \times H_\rho, \qquad (2)$$

along the E-plane or x–z plane

$$(J_s)_H = \hat{z} \times H_\varphi, \qquad (3)$$

along the H-plane or the y–z plane.

The inspection of equation (1) shows that appreciable amount of electric field resides near the edge in the orthogonal plane (y–z or H-plane). As a result, for small radius of the defect r_d; it will not interact much with the H_φ-component. Thereby electric surface current along the direction, orthogonal to E-plane is not eliminated fully as is clear from equations (2) and (3). Consequently, an extended circular cut defect with larger r_d over a relatively wider area at the patch boundary has been considered and about 27.5 dB of XP suppression compared with peak co-polarized gain in the H-plane is observed for $r_d = 3$ mm. It is also observed that when r_d becomes too

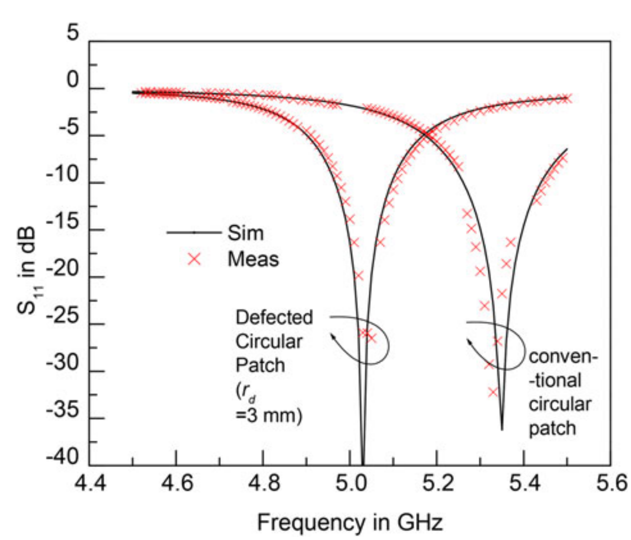

Fig. 7. Simulated and measured reflection coefficient profiles of the CMPA and the proposed CCDCPA with $r_d = 3$ mm.

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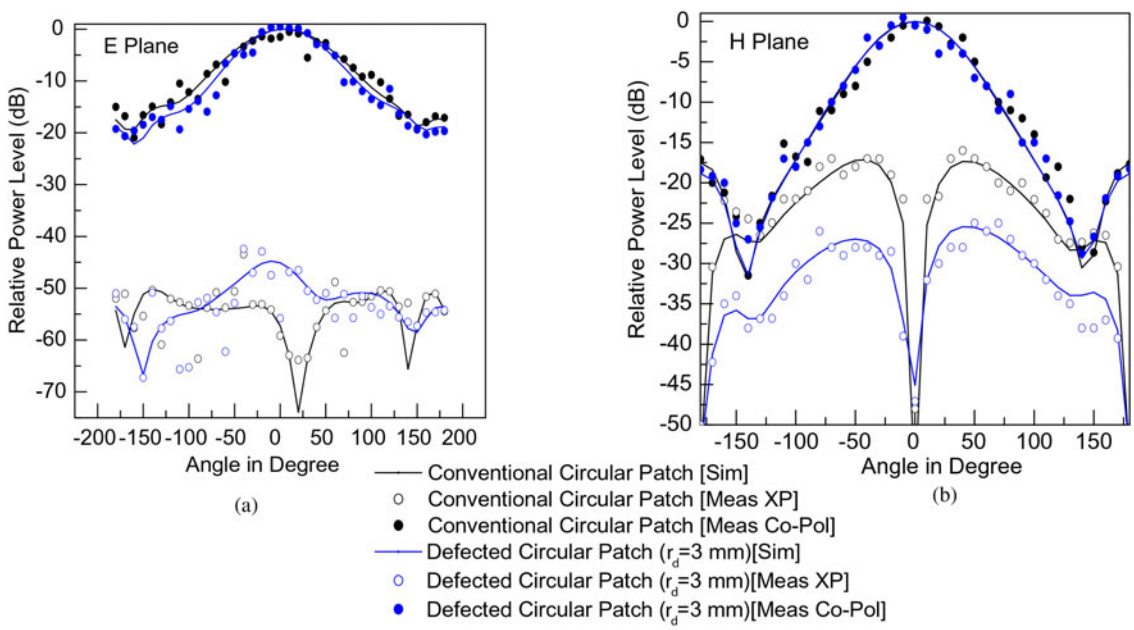

Fig. 8. Comparison of the radiation pattern of the proposed CCDCPA with r_d = 3 mm and the conventional CMPA. (a) The *E*-plane and (b) the *H*-plane.

large, i.e. greater than 3 mm; the radiation from probe is more exposed and contributes in the radiation pattern of CCDCPA resulting higher XP radiation. The XP radiation suppression of about 17 dB compared with peak co-polarized gain in the *H*-plane is observed for $r_d = 4$ mm, which is similar to simple CMPA.

The variation of the operating frequency as a function of r_d of CCDCPA is also shown in Fig. 4. Each resonant frequency value is extracted from the minima of return loss profile, which is well below −30 dB in each case. It is apparent from the figure that as the dimension of the defect r_d on the patch surface increases, operating frequency decreases. The incorporation of the defect has led to the slight shift in resonance frequency toward the lower side of the spectrum. It may be due to the slight lengthening of electric surface current path.

Electric field over the patch boundary at the orthogonal plane is presented in Figs. 6(a) and 6(b) for CMPA and proposed CCDCPA, respectively. It is clear from the figure that, near the patch boundary at the orthogonal plane (*y–z* or *H*-plane), crowding of the electric field is more in CMPA than the proposed structure. Electric surface current (J_s) over the patch surface has been shown in Figs. 6(c) and 6(d) for CMPA and proposed CCDCPA, respectively. It reveals that J_s is less prone to flow along the orthogonal direction in the proposed structure compared with simple CMPA. Hence Fig. 6 further corroborates the fact of low XP radiation from the proposed structure compared with CMPA.

Figure 7 shows the measured reflection coefficient profile as a function of frequency for both the prototypes. Simulation results are also incorporated in the same plot for comparison. Excellent agreement between simulation and measurements is evident. The figure once more substantiates the observation presented in Fig. 4.

Figure 8 shows the comparison of radiation pattern for conventional and proposed structure. Simulation and measured results show close mutual agreement among them. Same type of observation discussed earlier is noted. About 27.5 dB of XP suppression compared with maximum co-polarized gain is revealed while that for conventional structure is about 16 dB. Therefore, the proposed structure present much better Co–XP ratio compared with the conventional CMPA.

IV. CONCLUSION

A new circular cut defected circular patch antenna is proposed for significant improvement of Co–XP ratio for microstrip patch of circular geometry. About 10–11 dB of XP suppression compared with XP radiation from the conventional circular patch is achieved. This results about 27–28 dB isolation between Co and XP radiations in the *H*-plane, while that for conventional geometry, it is only 16–17 dB. The proposed geometry is very simple, easy to fabricate and therefore helps in effortlessness manufacturing process. The new antenna is definitely useful for the wireless communication system where polarization diversity is required to establish with such low-profile microstrip radiator.

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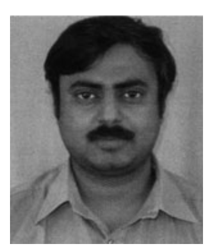

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