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Bandwidth Enhancement Technique of a Dual-Band Circularly Polarized Dielectric Resonator Antenna

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This paper presents the rectangular aperture coupled dielectric resonator antenna with dual-band circularly polarized response. The antenna geometry have stair case shaped rectangular dielectric resonator in the form of main radiating element. The specific geometry provides increment of aspect ratio of the dielectric resonator. This allows merging of various resonant frequencies having higher order modes that result in the bandwidth enhancement. This antenna provides 18.63% and 7.68% of -10 dB S_{11}-parameter bandwidth response in operating passbands, respectively. The specific geometry and the introduction of circular slots in ground plane results in the orthogonal modes excitation at the nearby resonant frequencies. Due to this, the circular polarization response at 7.76 and 8.33 GHz frequencies is achieved. The peak gain of 5.8 and 4.6 dBic is obtained in the respective lower and upper operating passbands. Through parametric analysis, tuning of antenna responseis also achieved. The proposed antenna with the optimized parameters may have potential applications in the microwave C- and X-band setups.

Keywords: Bandwidth enhancement, Circularly polarized, Dielectric resonator, Dual-band response

1 Introduction

The dielectric resonator antenna (DRA) transpires as the prominent category over the conventional conducting patch antennas for the futuristic technologies. It incorporates various advantages like wider bandwidth, lower conduction, and spurious radiation losses, improved far-field radiation parameters and exhibition of several higher order modes inside the DR over the other antennas[1]. The antenna with wide range frequency bandwidth response opens up the window for many applications over the entire operating frequency ranges. Obtaining wideband antenna response is always the focus of the researchers while working in area of antenna designing. In this motif, various DRAs with wideband response has been reported with various techniques at microwave frequency ranges as explained in[2]. Mainly, the wideband response is obtained as the consequence of merging of different modes inside the radiator. Several techniques have been adopted for bandwidth enhancement inside DRA using stacking[3], crating air-gap inside the DR[4] and loading of the metallic patch[5-7].

In addition, the circularly polarized (CP) antenna has been widely gained focus in mitigating the disadvantages of the linearly polarized (LP) antenna. These limitations include orientation mismatch between the transceiver antennas and the degradation of the signal resulting from the multipath propagation[8]. For the microwave frequency region, several research works have been presented on CPDRA which are well explained in[9]. In[10], a dual band CPDRA has been studied and reported with miniaturization technique. In past decades, DRA have gained the attention of researchers for the achievement of circular polarization. As per the reported literatures, several dual and wide-band CPDRA have been introduced. The studies includes DR with modified excitation using cross-slot[11], zonal slot[12] and triangular slot[13]. In addition, modified shapes of the DR like rotated modified DR[14], inverted-sigmoid[9] and chamfered diagonal corners[15, 16]. However, the use of simple rectangular geometry provides the flexibility in the selection of dimensions that reduces the structural complexity of the antenna. This will ease the selection of operating resonant frequency. Also, use of conducting patches on the DR surface also results in the achievement of circular polarization. These techniques have been utilized to excite the orthogonal degenerate modes inside the DR. Apart from these

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techniques, it is still a challenging task to achieve circular polarization in DRA.

In this proposed work, a CPDRA with dual-band response and single aperture coupled feeding mechanism has been analyzed. The antenna geometry consists of stair-case rectangular DR. The specific DR geometry concedes the merging of various higher-order generated modes. This consequently provides the bandwidth enhancement in the impedance pass band response. Thus, a wide dual-band -10 dB impedance response has been obtained. The specific DR geometry with the introduction of circular slots in ground plane results in the orthogonal degenerate modes excitation. This will come up with the achievement of CP response in upper operating pass band. Furthermore, the parametric optimization of antenna has been analyzed and tuning of the results has been obtained. The proposed antenna with optimized parameters can be availed for the applications in the microwave C- and X-bands.

2 Antenna Design Approach

The proposed CPDRA geometry along with the dimensions is depicted in Fig. 1. The antenna substrate is made up of FR_4 epoxy material with relative permittivity, $\epsilon_s = 4.4$. The ground plane is mounted over substrate having dimensions $l_s \times w_s$ and height $0.8\,mm$. The 50 Ωmicrostrip feedline having dimensions $l_f \times w_f$ and stub length, s is used to excite the antenna. The main radiating element is made up of ceramic material, TMM13i with, $\epsilon_r = 12.8$. It is positioned above the ground plane. The DR is excited using the rectangular-shaped slot having dimension$l \times w$ in the ground plane. The DR of height h is made of three rectangular slabs arranged in the form of a staircase as shown in Fig. 1. Two symmetrical circular slots have been etched in the ground plane having radius, r. These are placed below the DR at a distance t from the edge along y-axis to the center of the circular slots. The proposed antenna has been simulated and analyzed with the help of high-frequency structure simulator (HFSS) software.

3 Results Analysis

For the better analysis of this proposed CPDRA, Fig. 2 shows three different DR geometries have been studied. In antenna-1, Fig. 2(a) explains the DR placed on rectangular slot. This configuration of the antenna results in the triple-band $-10\ dB$ impedance response ranges from 7.07-7.81 GHz (9.94%), 8.15-8.54 GHz (4.67%), and 8.87-9.10 GHz (2.55%) in respective S_{11}-parameter response. Further, Fig. 2(b) explains the geometry of DR modified by combining the addition DRs to form the staircase-shaped structure to increase the aspect ratio of the antenna-2 configuration. The increment in the aspect ratio of the geometry provides the merging of higher order modes. Thus, bandwidth enhancement has been achieved. Antenna-2 provides 18.28% (6.56-7.88 GHz) and 7.33% (8.27-8.90 GHz) of operating bandwidth in the respective pass bands. Also, this antenna provides the 1.76 % (8.41-8.56 GHz) 3 dB axial-ratio (AR) response in the upper-band because of the merging of orthogonal degenerate

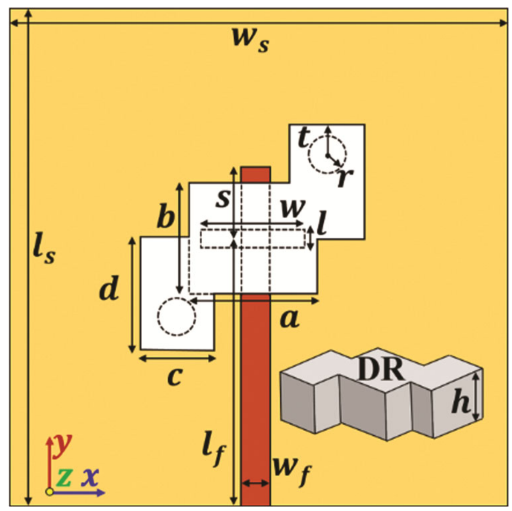

Fig. 1 — Proposed CPDRA geometry ($l\_s = w\_s = 80, a = 14, b = 12, c = 8, d = 12, h = 10.5, l\_f = 40, w\_f = 1.6, s = 7, w = 9, l = 1.2, t = 4$, and $r = 1.8$ (all dimensions are in mm).

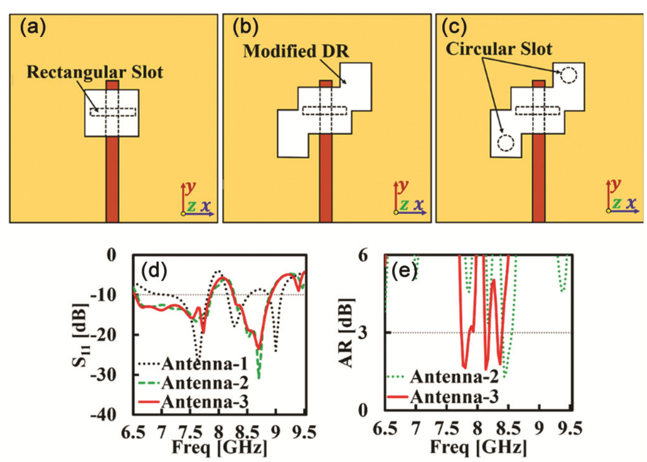

Fig. 2 — The geometrical layout of the (a) antenna-1, (b) antenna-2, (c) antenna-3 (proposed antenna), (d) frequency response of S_{11}-parameter and (e) A R response of different configurations.

modes. Furthermore, the circular slots have been carved out of the ground plane placed beneath the modified rectangular DR symmetrically for the antenna-3 geometry as shown in Fig. 2(c). The circular polarization has been obtained in both the operating bands of the antenna. The introduction of slots in the ground plane affects the modes confinement inside the DR. The change in the field distribution results in the generation of orthogonal degenerate mode inside the lower operating band of the antenna as well. The antenna brings forth the dual-band CP response having 1.66% (7.74-7.87 GHz) and 1.43% (8.30-8.42 GHz) bandwidth in both the bands, respectively. The impedance passband response ranges from 6.52-7.86 GHz (18.63%) and 8.26-8.92 GHz (7.68%) in the respective lower and upper passbands. Table 1 depicts the detailed operating performance of the proposed DRA.

The radiation mechanism can be analyzed using the near-field distribution. Fig. 3.depicts the arrangement of the field vectors inside DR. This Electric field vectors distribution confirms the presence of the horizontally aligned magnetic dipoles at the CP frequencies of the respective bands. Fig. 3(a-b) resembles with the presence of TE^{y}_{311} and TE^{x}_{131}orthogonal degenerate modes in xz-plane and yz-plane, respectively. This results in the generation of CP response at 7.76 GHz frequency. Later, Figs. 3(c-d) shows the E-field distribution that clearly depicts the existence of $TE^{y}_{22\delta+1}$ and $TE^{x}_{22\delta+1}$ orthogonal degenerate modes in xz and yz-plane, respectively. Thus, CP response is achieved at 8.33 GHz resonant frequency. Figs. 4(a-b) explains the far-field radiation mechanism and pattern of the antenna at 7.76 and 8.33 GHz frequencies in yz-plane, respectively. The proposed antenna provides the LHCP dominant pattern at 7.76 GHz frequency.

Table 1 — Operating performance of different antenna configurations. ($\boldsymbol{BW_{im}}$ −Impedance bandwidth, $\boldsymbol{LB}$ −lower band, and $\boldsymbol{UB}$ −upper band)

Configurations	Operating Frequency Range (GHz)			BW_{im}(%)			BW Enhancement (%)	
	LB	UB		LB	UB		LB	UB
Antenna-1	7.07-7.81	8.15-8.54	8.87-9.10	9.94	4.67	2.55	-	-
Antenna-2	6.56-7.88	8.27-8.90		18.28	7.33		8.34	2.66
Antenna-3	6.52-7.86	8.26-8.92		18.63	7.68		8.69	3.01

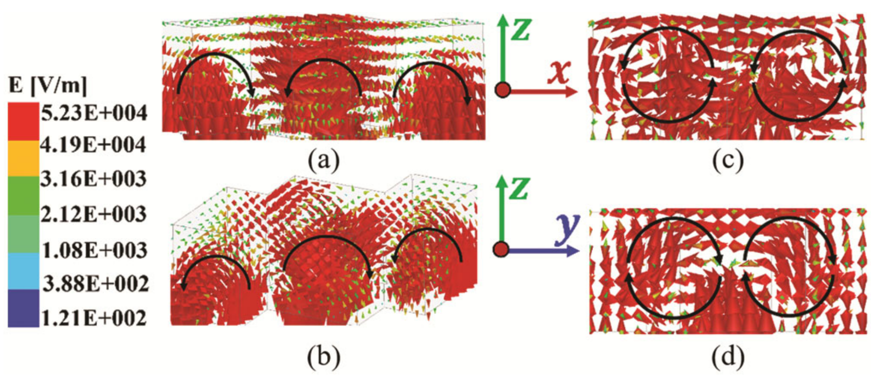

Fig. 3 — The Electric field vectors distribution at 7.76 GHz and 8.33 GHz in (a)-(c) xz-plane, and (b)-(d) yz-plane, respectively.

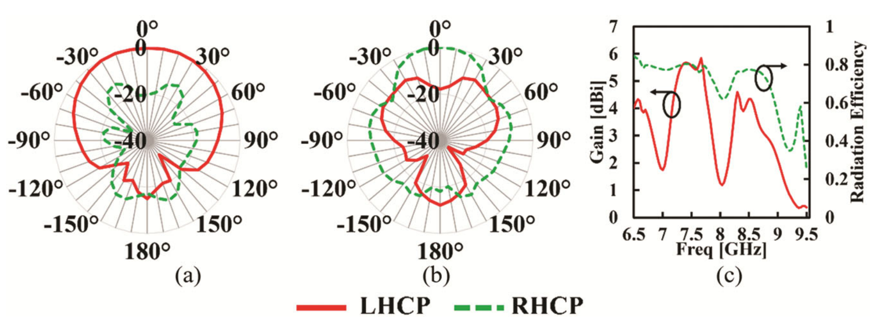

Fig. 4 — TheRadiation pattern at (a) 7.76, (b) 8.33 GHz in yz-plane, and (c) Gain and radiation efficiency of the DRA

However, the antenna provides RHCP dominant radiation at 8.83 GHz resonant frequency as depicted in Fig. 4(b). This confirms the dual polarized behavior having more than 20 dB separation between the polarization components in the boresight direction at $\theta = 0°$. The gain response and radiation efficiency of the proposed antenna is shown in Fig. 4(c). It provides the peak gain of value 5.8 and 4.6 dBic and the radiating efficiency of the antenna with more than 75% in the respective operating passbands.

4 Conclusion

A staircase shaped DRA having dual-band circularly polarized response was developed. The specific geometry of DR results in the increment of aspect-ratio allowing the merging of higher-order modes offering bandwidth enhancement. The proposed antenna allows 8.69% and 3.01% of -10 dB impedance bandwidth enhancement in the respective lower and upper operating passbands. The specific geometry and carving of the circular slots beneath the DR provides the excitation of orthogonal modes inside the DR. It provides 1.66% and 1.43% of the AR bandwidth overlapping both the operating passbands, respectively. The proposed antenna with optimized parameters can be utilized for the C and X microwave frequency bands applications.

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