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A Compact Multiband Hybrid Rectangular DRA for Wireless Applications

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ABSTRACT: A new tri-band rectangular DRA is simulated and tested for wireless communication applications like ISM, Wi-Max, and WLAN. The dielectric resonator antenna structure is excited by a 50 Ω transmission line. The rectangular DRA with concentric square rings is designed to acquire the operation of triple-bands. The investigated antenna parametric study has been accomplished on HFSS tool. The implemented design exhibits triple-band characteristics at 2.16–2.57 GHz, 3.35–4.45 GHz, and 5.35–5.95 GHz, with a fractional bandwidth of 17.3%, 28.1%, and 10.6%, respectively. The implemented concentric square rings are imposed on FR4-substrate material to emphasize the antenna parameters and to minimize the size. The designed antenna has a compact size, good radiation properties, and optimal operational bandwidth. To validate the antenna, it is fabricated, and the results match well with the simulated ones. The antenna is well suitable for wireless communication applications. The fabricated rectangular DRA is measured by using MS2037C Anritsu-Combinational Analyzer.

1. INTRODUCTION

Dielectric resonator antennas (DRAs) have been the subject of intense research from the past few years [1]. DRAs are distinguished from other types of antennas by a number of key characteristics, including excitation, comparatively wide bandwidths, and small size [2, 3]. For instance, a lot of DRAs use highly unique geometrical forms, like flipped ring DRAs, E-shaped DRAs, and H-shaped dielectric resonator antennas [4–6], or use various dielectric constants, like layered ring dielectric resonator antennas or perforated dielectric resonator antennas [7–9]. Even more unusual DRA structures, such as hook-shaped dielectric resonator antennas [10], T-shape dielectric resonator antennas [11], pixelated dielectric resonator antennas [12], multiple circular coil dielectric resonator antennas [13], or DRA structures with slots [14] and hollow sections [15], may be used by other structures. Even though these structures may have extraordinary qualities like wide bandwidths, large gains, or multi-band functioning, it may be difficult to produce them using standard techniques and substrates. Compound dielectrics have garnered a lot of attention lately because of the potential for novel applications. For instance, in [16], a printable dielectric ink that contained ferroelectric nanoparticles was produced. This ink might be used to create a fully printed phase shifter. By using this novel method, it may be possible to bypass the costly substrates that are frequently employed in such applications. Conductive materials that can be utilized for the design of flexible antennas, such as microstrip antennas [17], antennas with flexible substrates having variable ε_r [18], epoxy resin composites utilized for antenna miniaturization [19], or polymer flexible composite substrate material with equal values of permittivity and permeability for reducing the antenna size [20, 25–27] are additional examples of compound materials. Aside from the apparent benefit of reducing manufacturing costs [28, 29], another benefit of such compound materials is that they may frequently be adjusted to meet the requirements, particularly beneficial for research and development projects.

2. RECTANGULAR DRA DESIGN METHODOLOGY

Geometry of the DRA is represented in Figure 1. The customized feed line DRA with limited ground plane is investigated for Industrial, scientific, medical applications, Wireless MAX, and Wireless LAN applications. The enacted design is energized with a microstrip feed line. The implemented concentric square rings are imposed on the FR4 material to emphasize the antenna parameters and to minimize the size. Outer square ring resonates at frequency of ISM band; DRA generates the Wi-max, and WLAN band is generated due to inner square ring. The fabricated DRA design is illustrated in figure 2. The rectangular dielectric resonator antenna occupies $40 \times 20 \times 1.6\,\text{mm}^3$. The rectangular dielectric resonator antenna is modelled on an FR4 substrate with $4.4\varepsilon_r$. To obtain the ISM (2.40 GHz), Wireless Max (3.50 GHz), and wireless LAN (5.50 GHz) frequency bands, the DRA is closely loaded with substrate-based concentric square rings. From Figure 1, it is noticed that the outer square ring is responsible for the first

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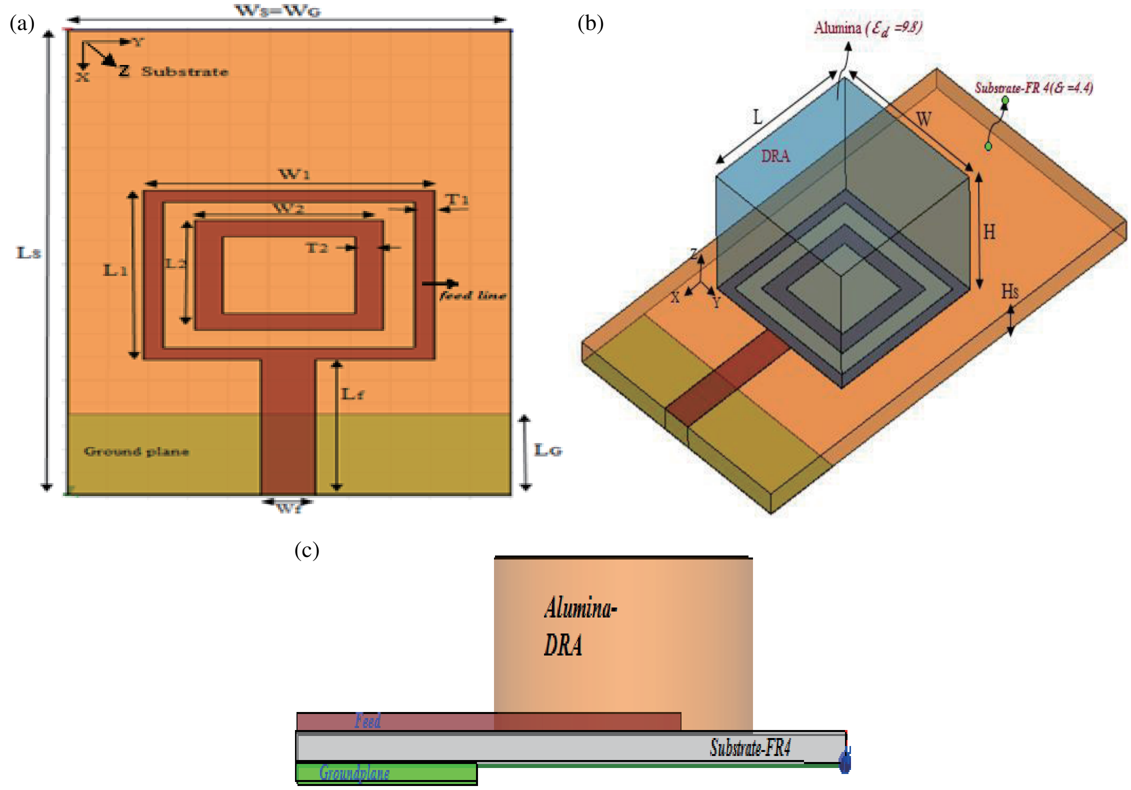

FIGURE 1. Configuration of the rectangular DRA: (a) Top angle; (b) Tilted angle; (C) Side angle.

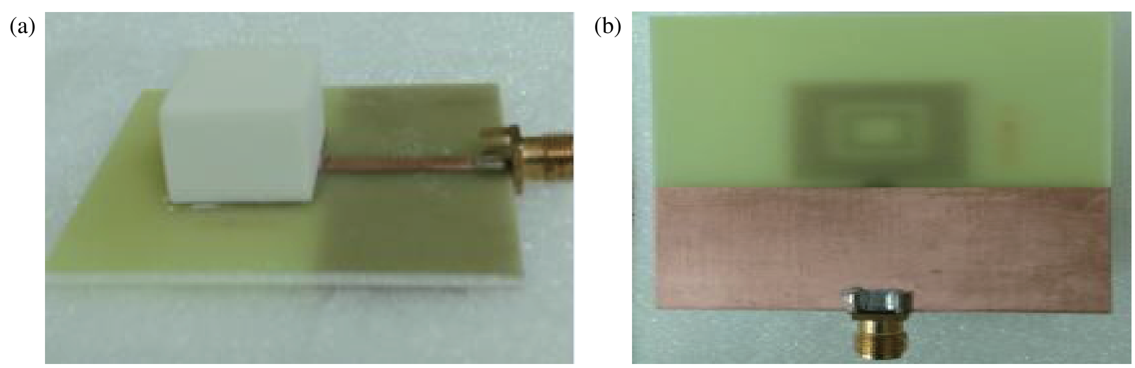

FIGURE 2. Fabricated rectangular DRA: (a) Side angle; (b) Back angle.

band, dielectric resonator antenna responsible for the second band, and the third band is generated due to the inner square ring. The measurements of the antenna with DRA are demonstrated in Table 1.

The theoretical center frequency of a dielectric resonator antenna is calculated as follows [22].

$$k_x = \frac{\pi}{a} \tag{1}$$

$$k_y = \frac{\pi}{b} \tag{2}$$

$$k_z \tan\left(\frac{k_z d}{2}\right) = \sqrt{(\varepsilon_d - 1)k_0^2 - k_z^2} \tag{3}$$

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_d k_0^2 \tag{4}$$

$$f_r = \frac{c}{2\pi\sqrt{\varepsilon_d}}\sqrt{k_x^2 + k_y^2 + k_z^2} \tag{5}$$

where c is the speed of light; ε_d is the relative permittivity of the DRA; f_r is the operating frequency; k_x, k_y, and k_z represent the wave numbers; a, b, d are the length, width, height of rectangular dielectric resonator antenna. By using Equation (5) the resonant frequency of rectangular DRA is calculated and found to be 3.6 GHz. According to [9], the theoretical formula for calculating the resonant frequencies of outer square ring and inner square rings is as follows,

$$f_r = \frac{c}{4(L_R - W_R)\sqrt{\varepsilon_r}} \tag{6}$$

TABLE 1. Dimensions of the rectangular DRA.

Basic configuration	Parameters	Value (mm)	Materials used
Ground plane	L_G	7	Copper
	W_G	22	
Substrate	LS	40	FR-4
	W_S	22	(ε_r, sub = 4.4)
	H_S	1.6	
Feed: Outer square ring	L_1	14.5	Copper
	W_1	14.5	
	T_1	2	
Inner square ring	L_2	9.4	Copper
	W_2	9.4	
	T_2	2.8	
Rectangular DRA	L	14	Alumina
	W	14	($\varepsilon_d = 9.8$)
	H	9	

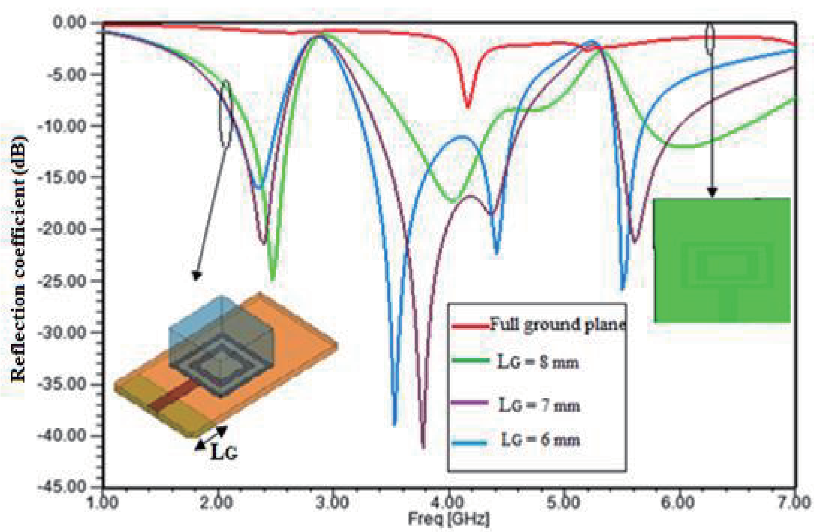

FIGURE 3. Variation of S_{11} with different ground plane length.

where c and ε_r are light velocity and relative permittivity of the substrate, respectively. L_R is the length, and W_R is the thickness of the square ring. By using Equation (6) the resonant frequencies of outer square ring and inner square rings are calculated and found to be 2.7 GHz and 5.4 GHz, respectively.

3. PARAMETRIC ANALYSIS

The investigated antenna parametric study has been accomplished on HFSS tool. The focus of this section is to investigate and explain the development of three bands. Figure 3 illustrates the change in reflection coefficient characteristics as a consequence of ground plane length. Impedance matching is obtained by using the partial ground plane approach. From Figure 3, it is clearly noticed that when the ground plane length decreases, the impedance matching is improved. For the best impedance matching, a ground plane length of 7 mm is employed. It is clear from Figure 3 that when the finite ground plane length of 7 mm is employed, the structure resonates at all three desired bands, i.e., first frequency band (2.45 GHz) is due to outer square ring while the second band (3.8 GHz) generated due to rectangular DRA, and third band (5.6 GHz) is due to inner square ring.

Figure 4 depicts the S_{11} characteristics for several radiating models. It can be seen that when the DR is not employed in the structure of antenna, and the resonance occurs only at lower frequency band (2.45 GHz) and upper frequency band (5.6 GHz). However, when the DR is employed in the antenna structure, resonances occur at all three frequency bands. However, it is evident from Figure 4 that the creation of 2.45 GHz is because of outer square ring, and the DRA responsible for the 3.8 GHz and 5.6 GHz is generated due to the inner square ring. The frequencies of resonances at various bands are confirmed in Sec-

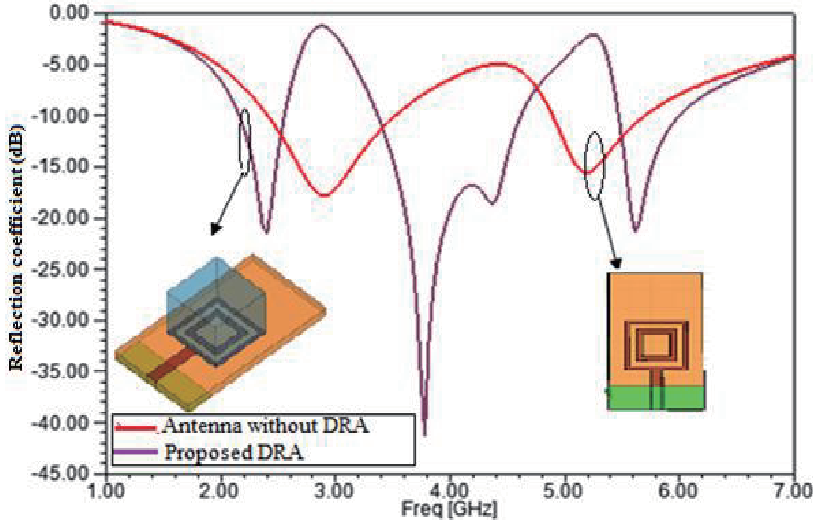

FIGURE 4. Variation of S_{11} for different radiating structure.

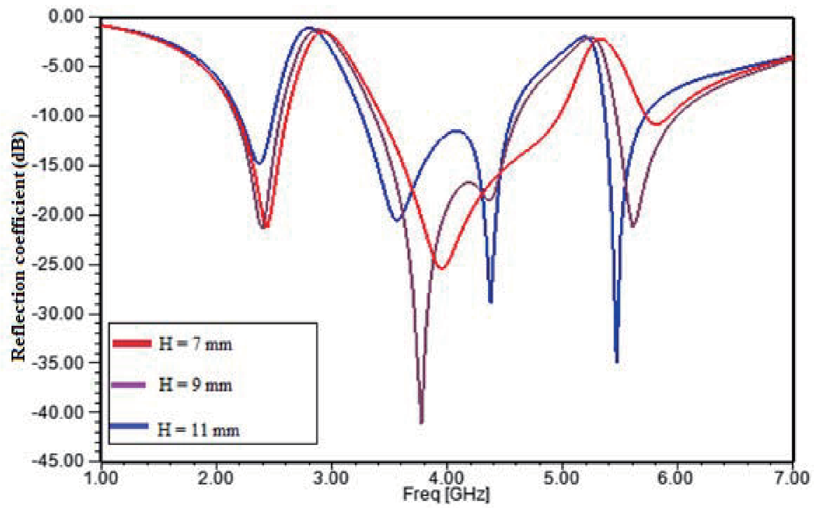

FIGURE 5. Reflection coefficient for different DRA heights.

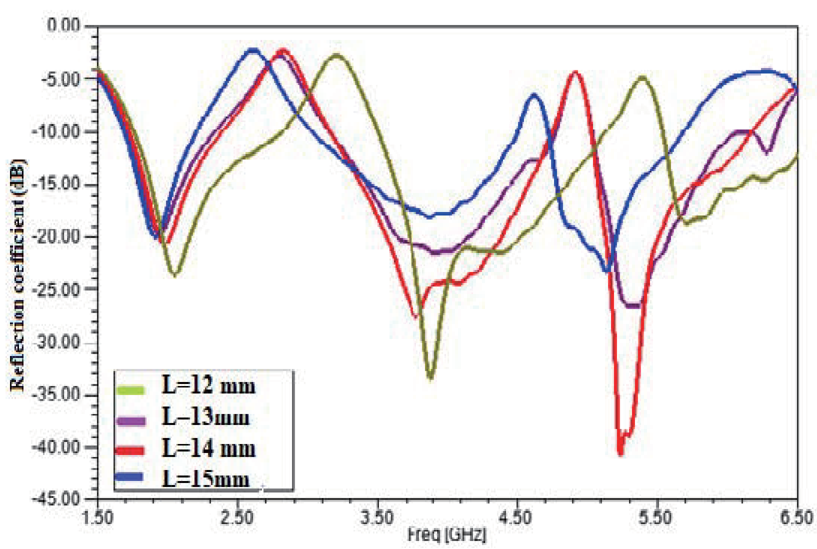

FIGURE 6. Simulated reflection coefficient corresponding to the variation in length of RDRA.

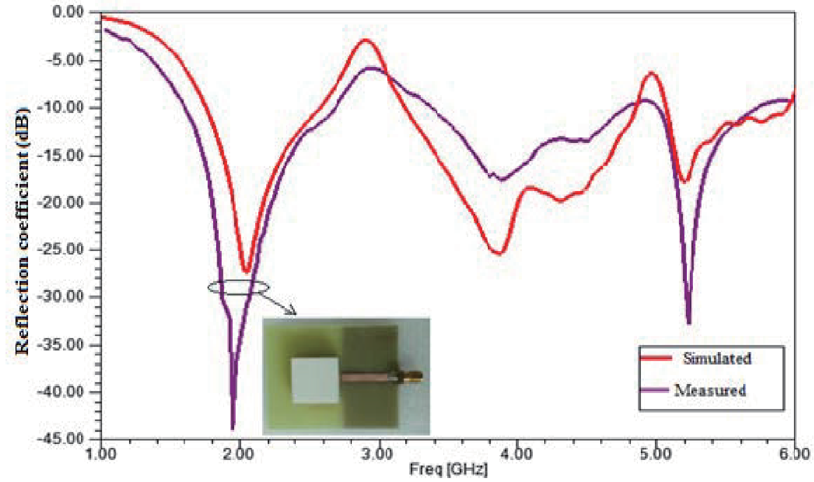

FIGURE 7. Simulated and fabricated S_{11} of the rectangular DRA.

TABLE 2. Rectangular dielectric resonator antenna comparison with existing DRA's literature.

	Lower band		Middle band		Upper band	
DRA shape	Resonant frequency (GHz)	Impedance bandwidth (%)	Resonant frequency (GHz)	Impedance bandwidth (%)	Resonant frequency (GHz)	Impedance bandwidth (%)
Modified RDRA[21]	2.4	24.9	-	-	5.2	12.9
RDRA[22]	1.8	21.9	2.6	24.6	3.4	23.3
RDRA[23]	2.93	3.36	3.26	3.84	5.5	4.19
RDRA[24]	2.4	4.6	3.5	19.1	5.8	5.7
Proposed Antenna	2.4	31	3.5	27.8	5.5	15.1

tion 2 theoretically. Figure 5 exhibits the reflection coefficient for various DRA heights. The resonant frequency diminishes as height increases, which can be observed from Figure 5. This result illustrates that the DRA's height has a considerable impact on the mid and upper frequencies.

Figure 6 shows the simulated reflection coefficient corresponding to the variation in length of rectangular DRA. From Figure 6, it can be observed that by varying the length of rectangular dielectric resonator from 12 to 14 mm by an increment of 1 mm, the mid frequency band and upper frequency band gradually decrease, meeting the design goal. Further increase of length to 15 mm adversely reduces the impedance matching bandwidth at all the desired frequency bands.

4. RESULTS AND DISCUSSIONS

To validate the design, the proposed dielectric resonator antenna is modelled and tested as exhibited in Figure 2. The MS2037C Anritsu combinational analyzer is used to obtain the parameters of the implemented model. Figure 7 exhibits the simulated and fabricated S_{11} of the optimized antenna. As represented in Figure 7, the modelled antenna design covers three resonant frequency bands, i.e., 2.16–2.57 GHz, 3.35–4.45 GHz, and 5.35–5.95 GHz, with a fractional bandwidth of 17.3%, 28.1%, and 10.6%, respectively. The fabricated results matched well with the designed dielectric resonator antenna results.

The measurement of radiation pattern in the far filed of manufactured antenna was performed in an anechoic chamber. Figure 8 illustrates the simulated and fabricated model radiation patterns in E-plane and H-plane at 2.40 GHz, 3.50 GHz, and 5.50 GHz. In both the principal planes (E&H), there is good co-pol and cross-pol difference in broadside direction, i.e., more than 20 dB at all three frequency bands, and it has omnidirectional patterns at all three frequency bands. The measured radiation pattern is in close accordance with simulated radiation pattern.

Figure 9 depicts the simulated and measured gains of the proposed DRA. From Figure 9, it is observed that the peak gains at 2.40 GHz, 3.80 GHz, and 5.40 GHz are about 2.3 dBi, 3.5 dBi, and 4.2 dBi, respectively. It is observed from Figure 9 that the values of peak gain at mid band and upper band are higher than lower band because these frequency bands are originated from rectangular DRA, combination of rectangular DRA and inner square ring, respectively. The measured and simulated gains are in close agreement at all three desired frequency bands.

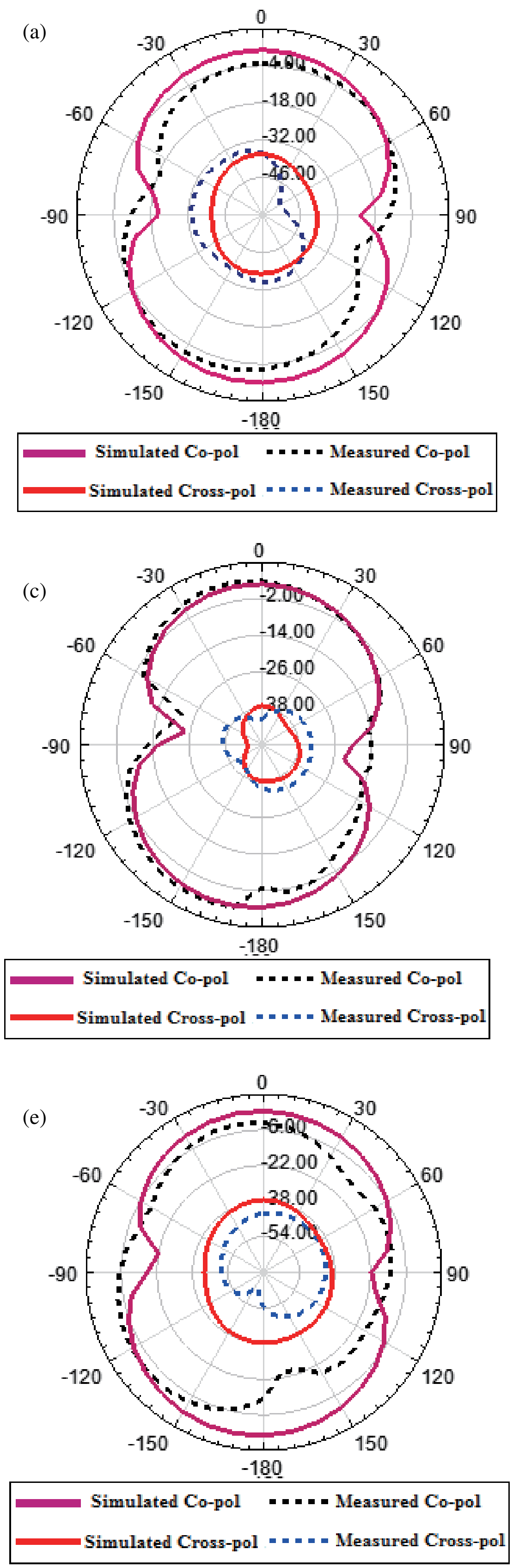

FIGURE 8. Simulation and measured radiation pattern for rectangular shaped DRA (a) H-plane at 2.4 GHz, (b) E-plane at 2.4 GHz, (c) H-plane at 3.5 GHz, (d) E-plane at 3.5 GHz, (e) H-plane at 5.5 GHz, (f) E-plane at 5.5 GHz.

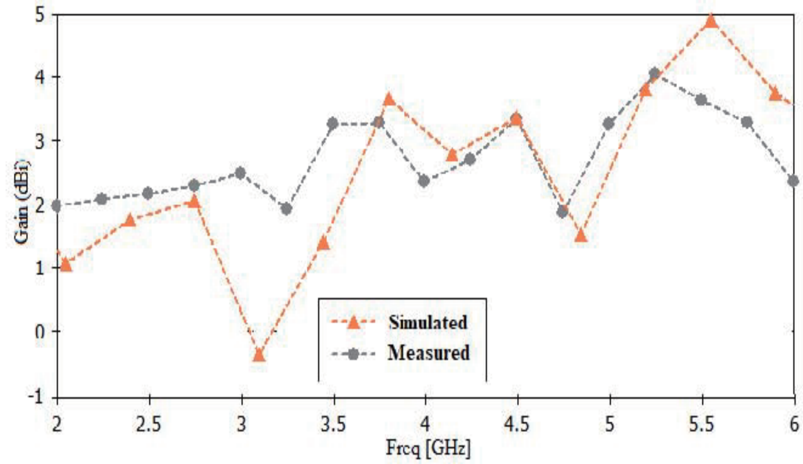

FIGURE 9. Simulated and measured peak gain of proposed antenna.

Comparison of the rectangular DRA with the available existing DRA designs based on impedance bandwidth [21–24] is shown in Table 2, and the proposed DRA has a large impedance bandwidth compared to the current antennas.

5. CONCLUSION

In this paper, a tri-band rectangular DRA using hybrid technique for wireless application is implemented. The implemented model's main characteristic is the development of tri-band frequencies, such as ISM (2.16–2.57 GHz), Wireless Max (3.35–4.45 GHz), and wireless LAN (5.35–5.95 GHz). The proposed antenna is implemented and offers a fractional bandwidth of 17.3%, 28.1%, and 10.6% at frequencies of 2.40 GHz, 3.50 GHz, and 5.50 GHz, respectively. The developed configuration illustrates better radiation properties at three functional bands, and it also has average gain of 3.1 dBi over the desired bands. The intended design is simple and also compact. The proposed antenna can be appropriate for wireless applications with these features.

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