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Surface Mountable Multiband Dielectric Resonator Antenna for Wireless Communication Systems

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Abstract—This paper presents a star-shaped compact dielectric resonator antenna for wideband and multiband wireless applications. The holes in the dielectric slab have been created to achieve wider bandwidth. The star-shaped alumina dielectric is placed on a low cost FR-4 substrate and fed using a microstrip line. The electrical dimensions of the proposed dielectric resonator antenna are $0.86\lambda_0 \times 0.86\lambda_0 \times 0.13\lambda_0$. The proposed design resonates at multiple frequency bands of 5.04–6.13 GHz, 6.87–7.97 GHz, and 8.58–9.63 GHz having the fractional bandwidths of 20.76%, 15.3%, and 11.4%, with peak gains of 3.71 dBi, 6.20 dBi, and 8.10 dBi, respectively. The design was fabricated to validate the simulation results. Good agreement can be seen between the measured and simulated results.

1. INTRODUCTION

Advancement in communication technology, enhanced mobility, and digitization has increased the demand for performance on networks and mobile devices. The massive demand for wireless portable devices is estimated to grow exponentially. Portable mobile devices are expected to have multiple applications. Different applications have diverse standards, and they work on different frequency bands. This has led antenna designers to looking towards multiband antennas. Undoubtedly this is the era of wireless communication where multi-band antennas are of extreme importance and are extensively required.

Dielectric resonator antenna (DRA) has gained attention due to its high radiation efficiency, compactness, and low dielectric and surface losses [1, 2]. Dielectric resonator antenna makes use of dielectric material as radiators. Coaxial feed, microstrip feed, and aperture feed are some of the commonly used feeding techniques to feed the dielectric. The dielectric material having a dielectric constant of 5–30 has superior radiation characteristics because it permits radio waves to get out through the boundaries. Employing higher-order modes in conjunction with fundamental modes to achieve multiple resonances in dielectric resonators is communicated in [3]. Various shapes of dielectric material have been proposed to achieve multiband characteristics in [4–8]. Stacking of dielectric resonator materials to attain multiple bands has been discussed in [9–11]. Hybrid dielectric resonator antennas which employ the method of adding a resonating structure with a dielectric resonator to achieve multiband characteristics are examined in [12–17]. CPW and slot coupled fed dielectric resonator antennas to realize multiband characteristic are presented in [18–20]. Chaudhary et al. proposed a dielectric resonator antenna having permittivity variation in the azimuth direction to achieve multiband characteristics [21]. Guha et al. proposed the method of exciting different modes to achieve multiband characteristics in dielectric resonator antenna [22]. Vinodha and Raghavan used multiple dielectric resonator material and modified feed to attain the multiband operation [23]. Sharma and Brar analysed a pentagon-shaped dielectric resonator antenna to accomplish multiband characteristics [24]. The effect

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of creating holes in the rectangular dielectric resonator on bandwidth performance of the DRA is studied in [25].

In this communication, an eight-point star-shaped DRA having cylindrical holes is analysed. Due to the enormous demand for wireless applications, antenna researchers are working on antennas that can achieve multiple bands of resonance. The novelty of the proposed design is that it resonates at the three resonant frequency bands of 5.04–6.13 GHz, 6.87–7.97 GHz, and 8.58–9.63 GHz with the fractional bandwidths of 20.76%, 15.3%, and 11.4% and peak gains of 3.71 dBi, 6.20 dBi, and 8.10 dBi, respectively. The presented design has a wide bandwidth and good gain suitable for application in IEEE 802.11a Wi-Fi and ISM band (5.40 GHz), WLAN, Medical & Industrial Heating (5.72–5.87 GHz), Fixed Wireless Access (6.87–7.97 GHz), and X band (8.58–9.63 GHz). High Frequency Simulation Software has been utilized for numerical computation.

This article presents the analysis of an engineered star-shaped dielectric resonator antenna. The article is organized as follows. Section 2 depicts the proposed model and its design. Section 3 deals with the result analysis and its discussion, and the last Section 4 discusses the conclusion.

2. PROPOSED MODEL AND DESIGN

The evolution stages in reaching the proposed star-shaped design with cylindrical holes are shown in Fig. 1. It can be inferred that the star-shaped boundaries provide wider bandwidth and additional third band at higher frequency. Furthermore, adding cylindrical holes to the dielectric slab reduces the quality factor which in turn improves the bandwidth performance of the proposed design. The top-view, feed-view, and isometric view of the proposed simulated design, and top view and ground plane view of the manufactured sample are shown in Fig. 2. The star-shaped dielectric resonator antenna with cylindrical holes is made up of alumina ceramic (dielectric constant = 9.8, loss tangent = 0.002). It is placed on a low cost 50 mm × 50 mm FR-4 sheet (dielectric constant = 4.4, loss tangent = 0.02) having a thickness of 1.6 mm. The DRA is fed using a simple microstrip feedline technique. The 8-point star-shaped DRA is formed using two square DRAs. One of the squares is rotated by 45 degrees and united to form the engineered shape.

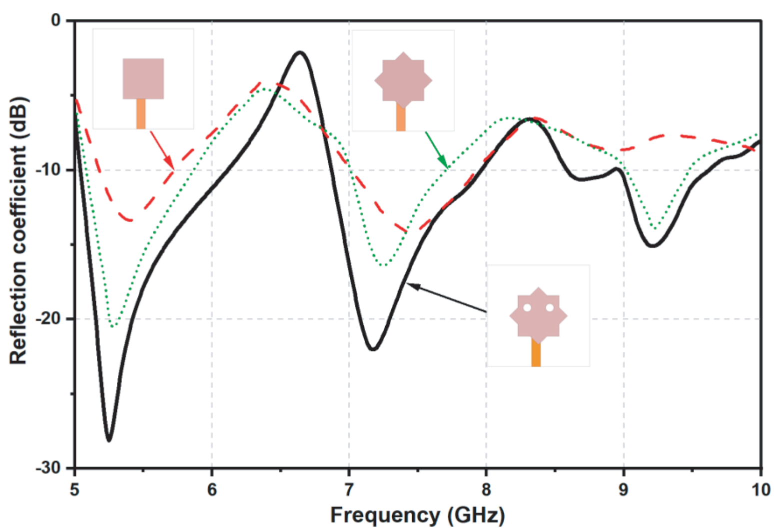


Figure 1. Evolution of proposed design.

3. PARAMETRIC STUDY

The star-shaped dielectric resonator antenna structure fed using a simple microstrip feed line is proposed in this work. The parametric analysis of the proposed design was undertaken to investigate its attributes. The height of the dielectric resonator, the diameter of the cylindrical slots, and size of DRA (parameter

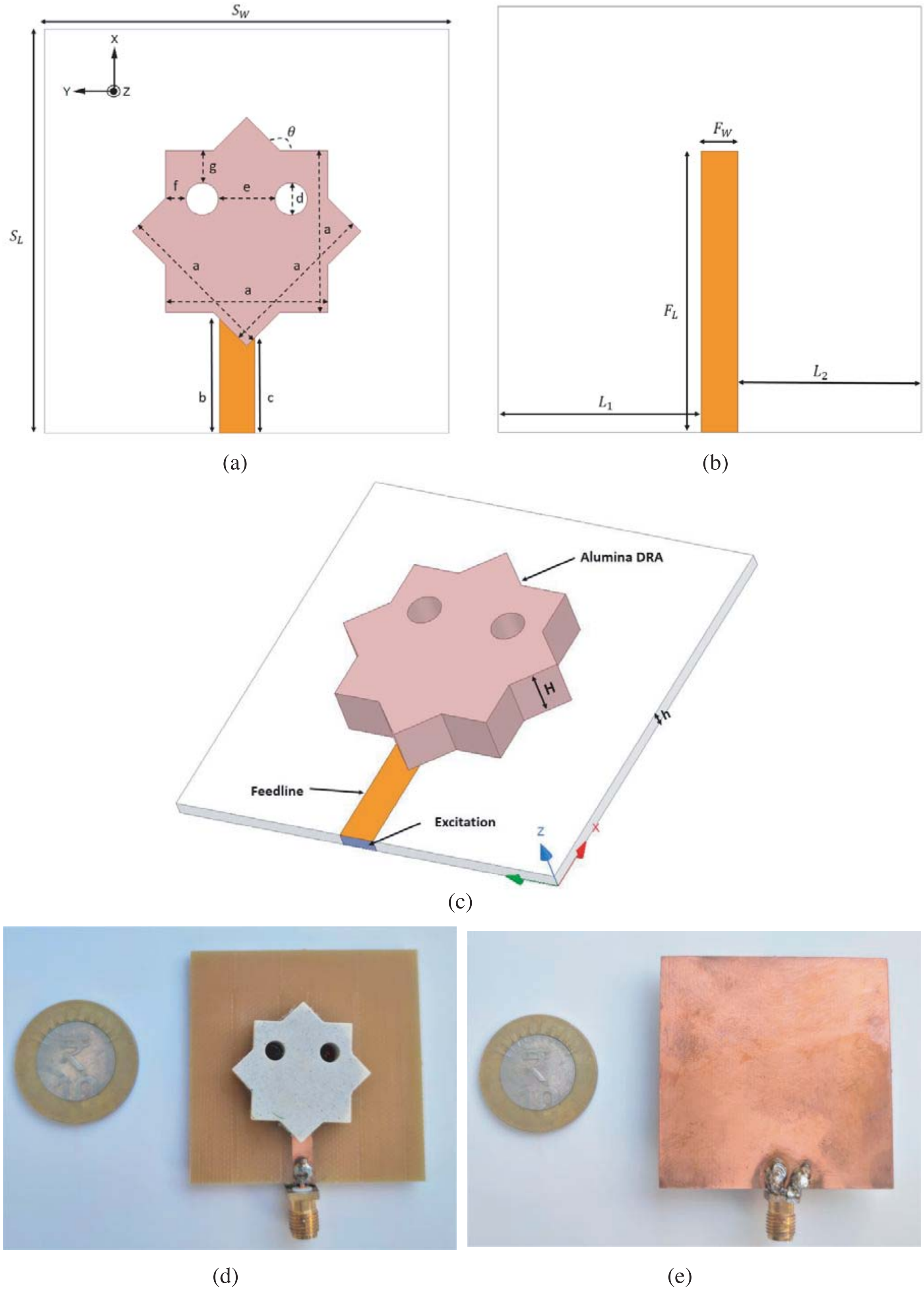
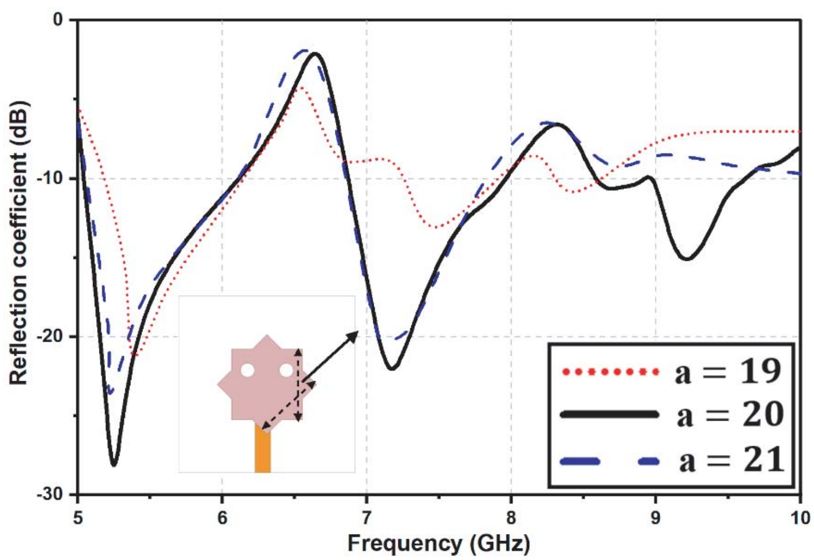
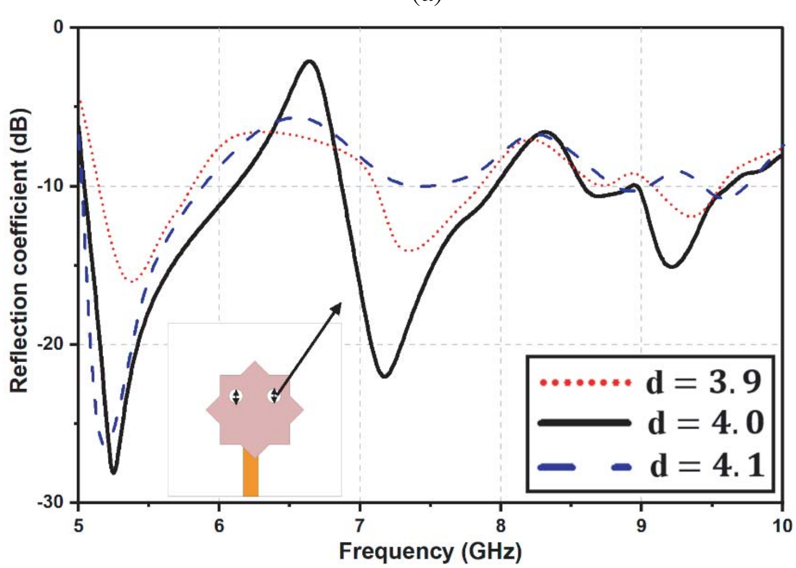


Figure 2. The proposed antenna geometry. (a) Top view. (b) Feed view. (c) Isometric view. (d) Top view of manufactured sample. (e) Ground plane view of manufactured sample.

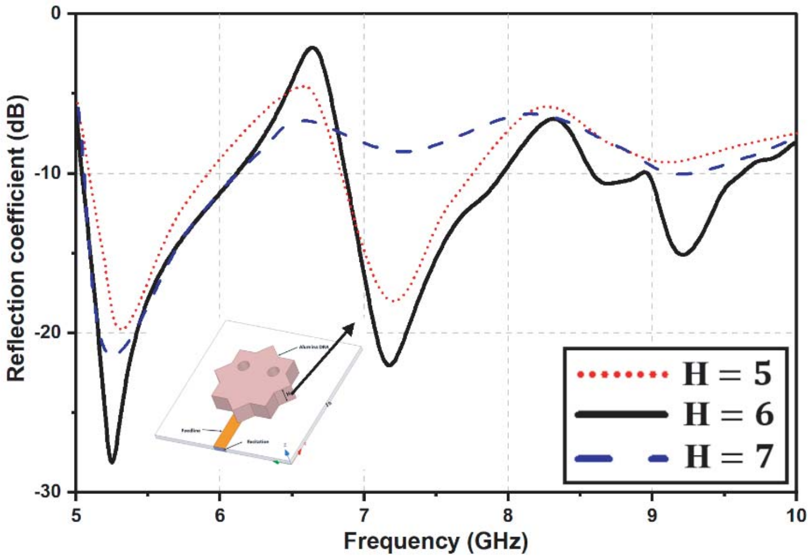
a) were varied to understand their effects on the performance of the antenna. Fig. 3(a) demonstrates the effect of variation in size of the DRA (parameter a) from 19 mm to 21 mm. It can be observed that as the size of the DRA is increased the frequency band shifts towards the lower band. The optimal size of 20 mm was chosen as it provided the third resonance in the desired bands. Fig. 3(b) depicts the effect of varying the hole diameter of both the holes from 3.9 mm to 4.1 mm. It can be observed that as the diameter of the hole increases the dielectric constant decreases that leads to the improvement in the fractional bandwidth. Fig. 3(c) portrays the effect of varying the height of alumina slab from 5 mm to 7 mm. It can be observed that as the size of the dielectric resonator increases there is a shift in resonance towards the lower band, and the bandwidth performance is improved. The optimum height of the DRA was chosen to be 6 mm as it covered the desired bands. The allowed domain of variation in size of DRA (a), diameter of cylindrical holes (d), and diameter of cylindrical holes (d) is from 15 mm to 25 mm, 1 mm to 7.5 mm, and 4 mm to 11 mm, respectively.



(a)



(b)



(c)

Figure 3. The reflection coefficient performance of the proposed antenna due to the variation in (a) parameter a, (b) diameter d of both the holes, and (c) height of the DRA.

4. RESULT ANALYSIS AND DISCUSSION

The star DRA with cylindrical holes was manufactured to validate the proposed design. The dimensions used for the fabrication and simulation are depicted in Table 1. Fig. 4(a) depicts the simulated and measured reflection coefficient characteristics of the proposed dielectric resonator antenna. High Frequency Simulation Software has been utilized for numerical computation. The manufactured prototype was experimentally measured and tested using the N9915A vector network analyser. The variation between the numerically determined and experimentally tested results are due to the mismatch in the practically available and simulation model material parameters. Furthermore, fabrication and calibration errors are also potential reasons for variations in the results. It can be inferred from Fig. 4(a) that the proposed design covers the frequency bands of 5.04–6.13 GHz, 6.87–7.97 GHz, and 8.58–9.63 GHz with the impedance bandwidths of 20.76%, 15.3%, and 11.4%, respectively. Fig. 4(b) presents the simulated and measured values of peak gain and simulated radiation efficiency. It can be observed that the proposed DRA based antenna has a peak gain of 8.10 dBi and maximum radiation efficiency of 82%. The radiation efficiency of DRA significantly depends on the type of the dielectric

Table 1. Dimensions of the proposed DRA.

Parameter	Dimension (in mm)	Parameter	Dimension (in mm)
a	20	b	14
c	11.9	d	4
e	7	f	2.5
g	4	S_W	50
S_L	50	H	6
h	1.6	F_L	4.35
F_W	4.35	L_1	21.65
L_2	24		

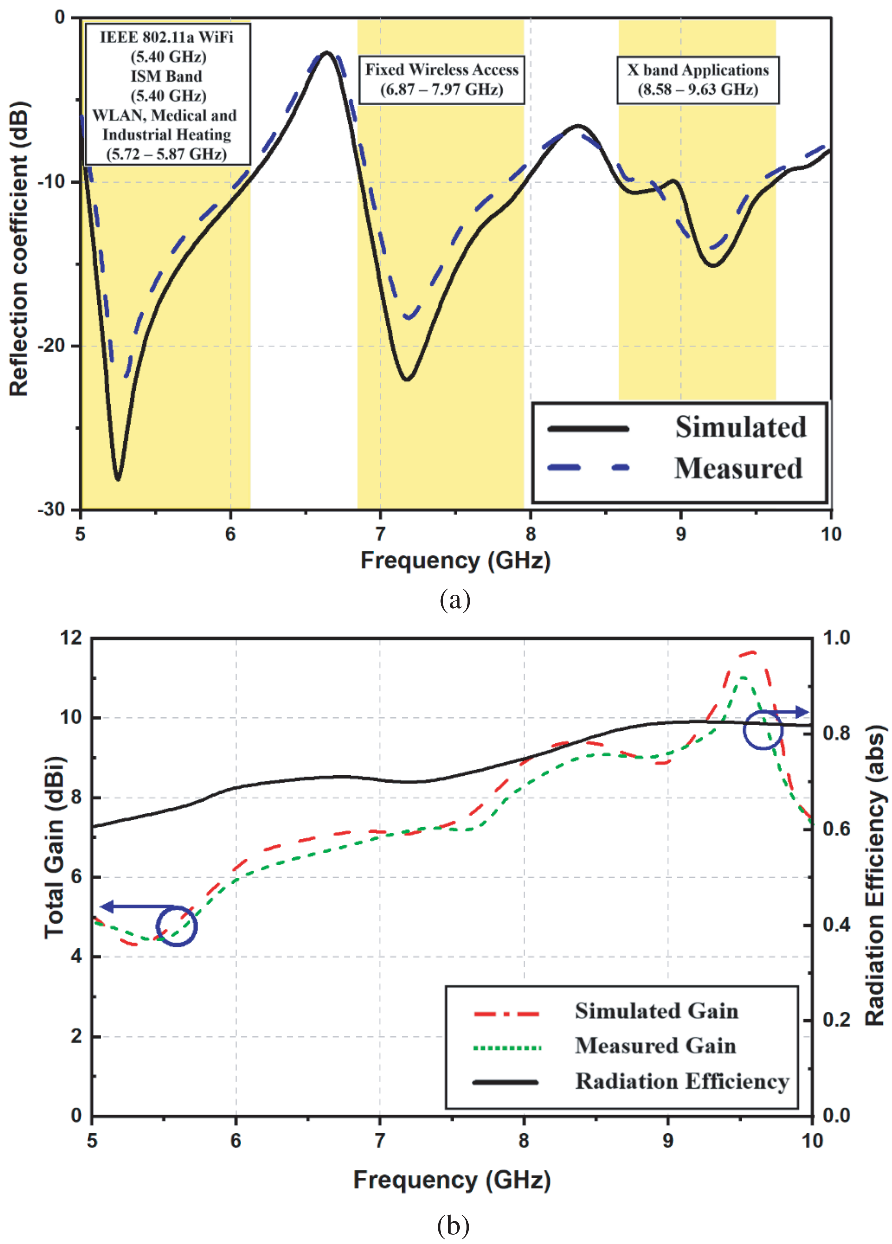


Figure 4. Simulated (continuous) and measured (dashed) reflection coefficient, total gain and efficiency of the proposed dra antenna. (a) Reflection coefficient. (b) Total gain ($\theta = 32$ and $\phi = 28$) and radiation efficiency.

and substrate material. Low loss dielectric materials such as Roger TMM10 and the low loss substrate like Rogers RO-3035 or RO-3006 can improve the efficiency of the presented design. However, the cost of the antenna will substantially increase. Hence, trade-off between the efficiency and the cost needs to be considered. Depending on the application of the proposed antenna, suitable material can be chosen so as to meet the desired criteria. Fig. 5 shows the electric field distribution at centre frequencies of 5.25 GHz, 7.18 GHz, and 9.21 GHz. The simulated results of radiation patterns have been derived using simulation software, and the measured results have been obtained by measuring the gain of the prototype placed in an anechoic chamber as shown in Fig. 6.

The E-plane and H-plane radiation patterns at 5.25 GHz, 7.18 GHz, and 9.21 GHz are presented in Fig. 7. It can be observed that the cross-polarization level in both the E plane and H plane of the

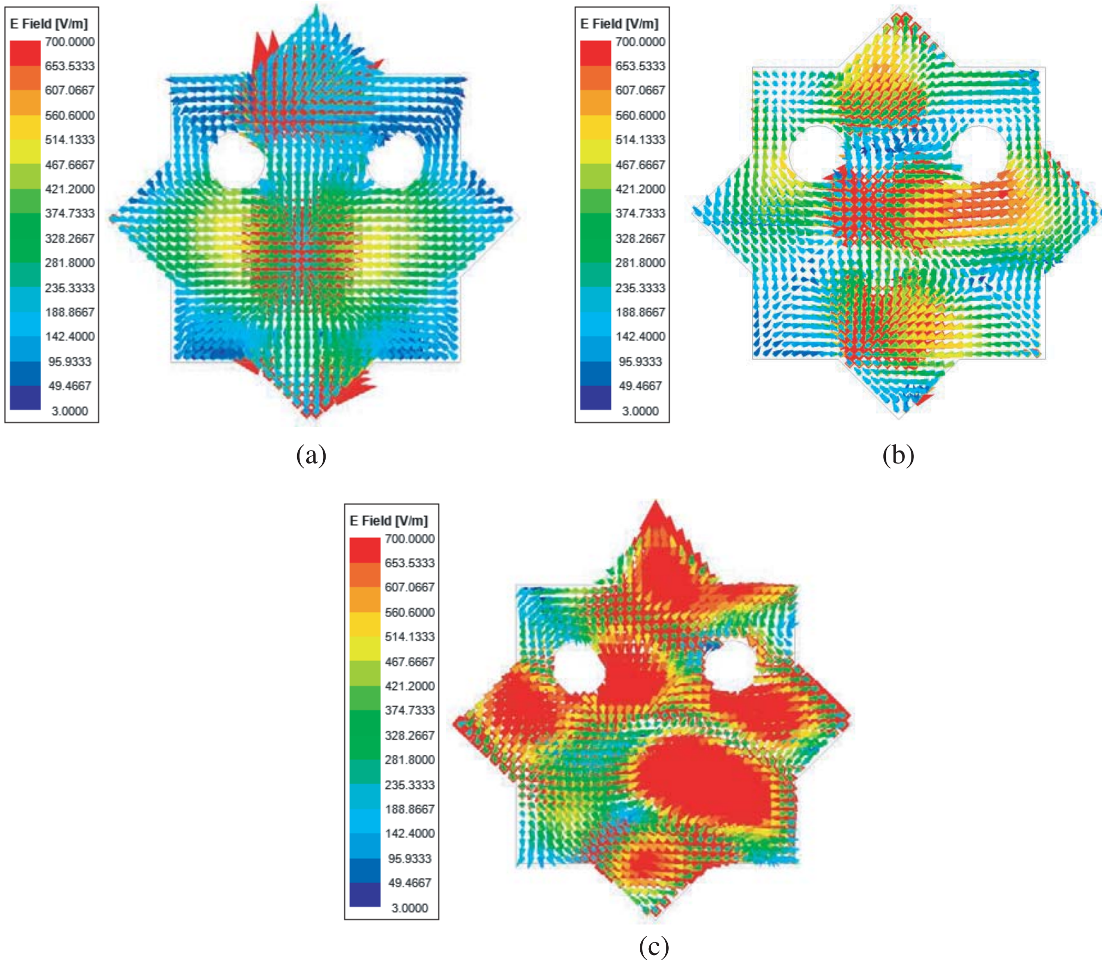
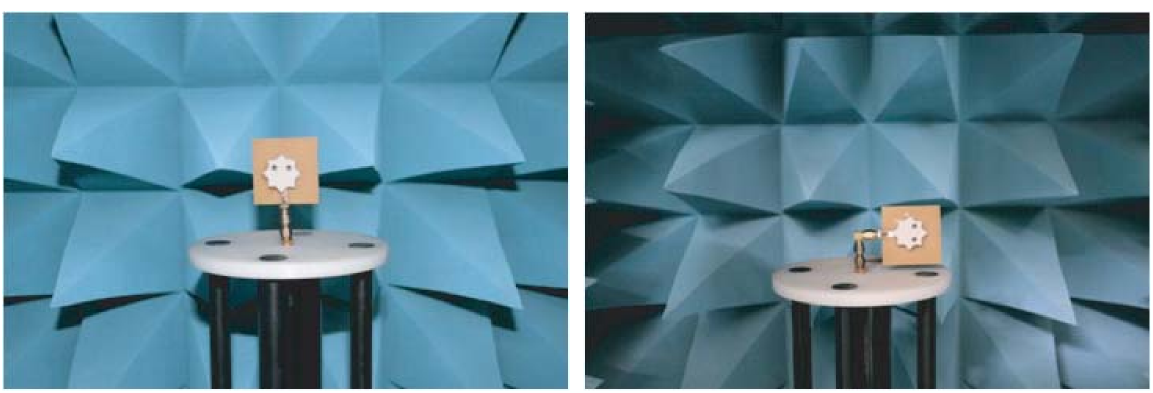


Figure 5. Electric field distribution at centre frequencies. (a) 5.25 GHz. (b) 7.18 GHz. (c) 9.21 GHz.



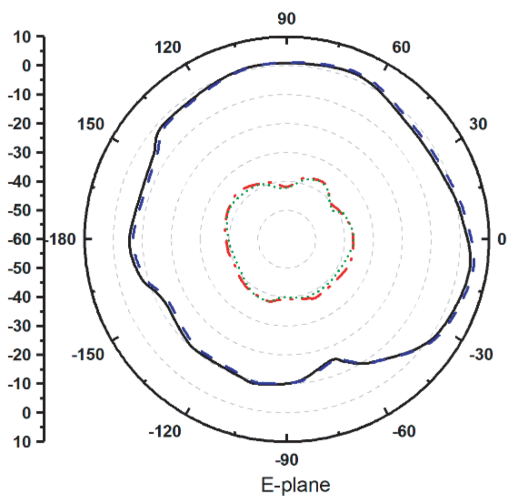
(a) (b)

Figure 6. Radiation pattern measurement setup. (a) E-plane. (b) H-plane.

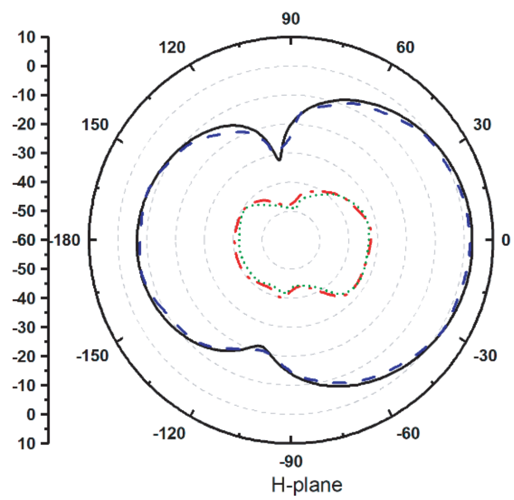
proposed design is below 20 dB, and the antenna radiates in broadside direction. Good similarity can be observed between the measured and simulation results. The robustness of the presented antenna depends on the effectiveness of the adhesive; however, the dielectric constant of the adhesive will have its effect on the reflection coefficient performance. Furthermore, there are design configurations in the literature that house DRA in the substrate to improve the robustness of the antenna [30]. Furthermore, there are design configurations in the literature which house DRA in the substrate to improve the robustness of the antenna [30], though the fabrication complexity increases in these designs. The cost of the presented antenna is low due to the cost-effective FR-4 substrate and the alumina type DRA. However, the fabrication of a slotted DRA is a relatively complex process compared to its counterparts

Table 2. Performance comparison of the proposed DRA based antenna with other DRA antennas from literature.

Ref.	Size (mm^3)	Frequency Bands (GHz)	Fractional Bandwidth (%)	Peak Gain (dBi)
[26]	$60 \times 60 \times 7.0$	2.50–2.76	9.88	5.6
[27]	$50 \times 50 \times 7.50$	5.00–6.67	28.30	5.2
[28]	$50 \times 50 \times 5.80$	6.79–7.27	6.82	5.8
[29]	$50 \times 50 \times 5.80$	7.41–8.21, 9.11–12.65	10.2, 32.53	2.5, 5.5
This work	$50 \times 50 \times 7.60$	**5.25, 7.18, 9.21**	**20.76, 15.3, 11.40**	**8.10**



(a)



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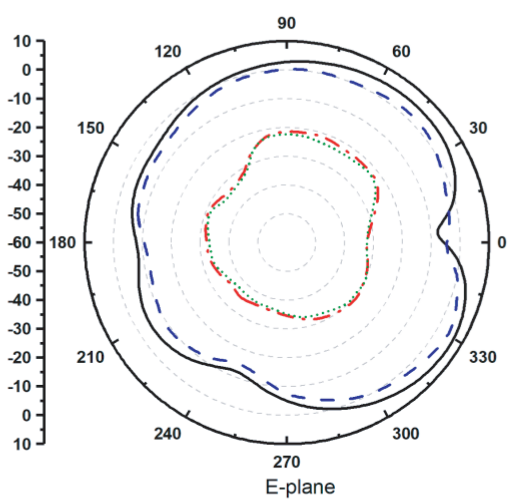

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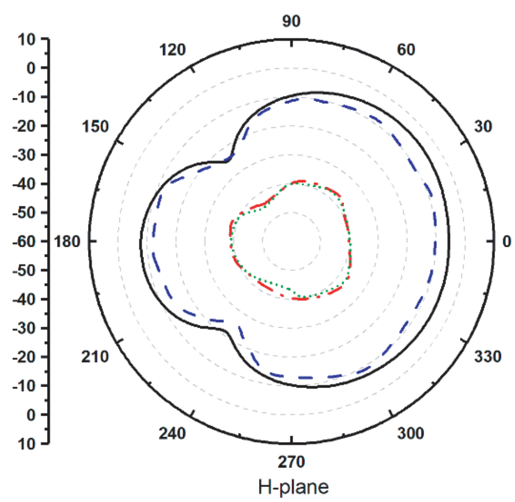

(d)

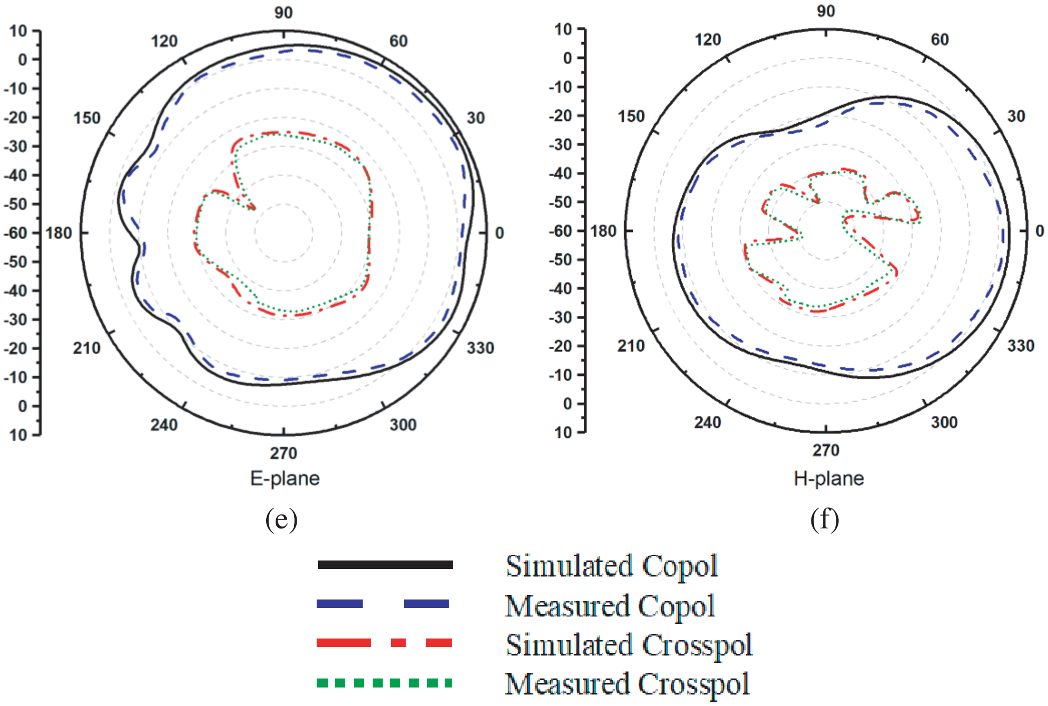

Figure 7. Radiation pattern of proposed DRA in E-plane and H-plane. (a) E-plane (y-z plane) at 5.25 GHz. (b) H-plane (x-y plane) at 5.25 GHz. (c) E-plane (y-z plane) at 7.18 GHz. (d) H-plane (x-y plane) at 7.18 GHz. (e) E-plane (y-z plane) at 9.21 GHz. (f) H-plane (x-y plane) at 9.21 GHz.

like rectangle and cylindrical DRA. Table 2 presents the comparison of the proposed design with other dielectric resonator-based multiband antennas in the literature. The size of the presented design is comparable to the antennas compared. However, the peak gain of the presented antenna is more than other antennas tabulated in Table 2. The other advantages that the proposed design offers are that it resonates at three resonant frequencies, and wide bandwidth has been achieved at each resonant frequency. It can be inferred that multiple bands of operation, good bandwidth, and high gain with stable radiation patterns are some of the advantages of the proposed design. The proposed compact antenna is suitable for WLAN, fixed wireless access, and X-band applications.

5. CONCLUSION

An engineered star-shaped compact dielectric resonator antenna fed using a microstrip feeding technique is proposed. The proposed antenna having radiation efficiency of 82% covers multiple frequency bands with fractional bandwidths of 20.76% (5.04–6.13 GHz), 15.3% (6.87–7.97 GHz), and 11.4% (8.58–9.63 GHz), and peak gains of 3.71 dBi, 6.20 dBi, and 8.10 dBi, respectively. The high gain, wide bandwidth, good radiation efficiency, and multiband characteristics make the proposed design suitable in WLAN, fixed wireless access, and X-band applications.

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