Design of Rectangular Dielectric Resonator Antenna for Mobile Wireless Application

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Abstract – In this article, a pentaband rectangular DRA is explored and presented. The proposed antenna has a crescent-shaped radiating element with defected ground structure and it is feed by 50-Ω microstrip line. The RDRA invariably has two similar dielectric resonators made up of RT5870 is positioned on top of the crescent-shaped patch. With the use of a dielectric resonator, the proposed structure has good improvement in impedance bandwidth and gain. The proposed rectangular DRA has penta operating frequency bands with resonant frequency at 1.49 GHz, 2.00 GHz, 2.50 GHz, 5.49 GHz, and 7.75 GHz. The projected structure exhibits the broadside radiation pattern with the maximum gain and directivity of 4 dBi and 4.5 dBi, respectively. The gig of the projected RDRA is validated with the help of simulated results by CST software. The observed results of the proposed antenna indicate that it can be a potential candidate for GPS, PCS, UMTS, ISM, WLAN, Wi-MAX applications.

Index Terms – GPS, ISM, mobile, rectangular DRA, RT5780, wireless application, WLAN.

I. INTRODUCTION

In the last two decades, the demand for multiband antennas has increased because of the rapid increase in wireless communication and miniaturization of wireless devices [1-3]. To properly equip with the modern wireless device requirement, there is a high demand for the new antenna technology. Multiband antenna is the new antenna technology that plays a vital role in satisfying the need for modern wireless communication systems. The multiband is achieved with the needed help of a wide variety of practical techniques such as defected ground structure, meandering the patches, introduction of slots, metamaterial [4-8], and DRA [9-12]. Because of the high radiation efficiency and compactness without any losses, the Dielectric Resonator antenna (DRAs) has naturally attracted more antenna researchers.

For Modern wireless communication systems, the DRA is the Competent antenna technique because of its advantage, such as large bandwidth, decreased production cost, and fabrication difficulty. The relative dielectric permittivity used in DRA, its shape, size, and operating modes [11-13] decides the DRA's resonant frequency. It is excited by various feeding structures with the help of coupling. When low permittivity is used, the DRA will be larger, while that is not the case in high permittivity dielectric. Various shapes are reported in the literature for the DRA, like rectangular, Cylindrical, and hemispherical. Compact DRA [14-16]is designed with the help of printing the conducting material on the dielectric, but the resonant frequency and the bandwidth are highly reduced. The impedance bandwidth can be enhanced by placing the DRA on a patch [17,18]. The major challenge for design the antenna for modern wireless communication is its multiband operation along with compact size, the resonator shapes decide the reasoning band, and radiation pattern will be changed [19]. Various unique geometries [20] are proposed for the DRA, such as triangular, conical, and biconical, to enhance the antenna's bandwidth. Stacking [21-24] two DRAs results in an improvement in impedance bandwidth. In [25], cross-shaped DRA with coaxial feed and a metal strip is proposed for wideband circular polarized performance. In [26], a dual circular polarized band is achieved by incorporating the metal strip at the sides of the DRA, and the bandwidth enhancement with the help of parasitic patches on DRA is proposed in [27]. Still, the major drawback is the low-profile nature of DRA is not maintained, and there is an increase in fabrication difficulty. In [28], two layers of sapphire is used as a dielectric resonator to achieve dual-band. The gain improvement is achieved with the metamaterial superstrate, which is reported in [29]. In [30], MIMO DRA is proposed for UWB application. In [31], dual-band DRA is proposed with a ring-shaped DRA made up of alumina, and in [32], H shape DRA is proposed with microstrip feed for triple-band wireless application. In [33], a filtering feed network is proposed for single wideband operation, and in [34], with the help of metallic strips along with DR, the Penta band DRA is reported. In [35], a triple-band antenna with CPW slotted feed and foam is reported.

In this paper, a multiband Rectangular DRA (RDRA) is proposed for mobile wireless applications [36]. With the help of CST electromagnetic software, the

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optimization of the RDRA is done. The structural complexity of the proposed antenna is very less. The entire structure is fed with a simple microstrip patch antenna. The dielectric resonator [37-39] improves the impedance bandwidth and gain of the proposed structure. The size of the dielectric resonator used is very small and chemical glue is used for bonding. The combination of the simple crescent shape patch along with DRA, makes the proposed DRA as a Hybrid RDRA for wireless radio communication. The anticipated structure has a dimension of 37.5 x 57 x 0.8 mm^3. The proposed rectangular DRA has operating bands 1.38 GHz to 1.70 GHz, 1.90 GHz to 2.09 GHz, 2.36 GHz to 2.87 GHz, 5.18 GHz to 5.93 GHz and 7.61 GHz to 7.88 GHz. Section 2 gives the theory regarding the Design of RDRA, Section 3 & 4 presents the geometry, and DRA experimental results and Section 5 is the conclusion.

II. THEORETICAL FACET OF RDRA

Figure 1 represents the 3-D of Rectangular DRA. The RDRA has a rectangular dielectric resonator of ε_r relative dielectric constant, presents width, b represents the length, and h represents the substantial height of the RDRA. Because of the three geometrical parameters independent of each other, the rectangular DRA offered more design suppleness than a cylindrical-shaped DRA. The Rectangular DRA [40-43] is analyzed with the needed help of a dielectric waveguide model. The TE_{111}, which is the resonant frequency of RDRA, is calculated from the equations shown below [3]:

$$f_o = \frac{c}{2\Pi\sqrt{\varepsilon_r}}\sqrt{k_x^2 + k_y^2 + k_z^2}, \quad (1)$$

$$k_{z=} \frac{\Pi}{a}, \quad (2)$$

$$k_{z=} \frac{\Pi}{2b}, \quad (3)$$

$$d = \frac{2}{k_y}\tanh\left(\frac{k_{yo}}{k_y}\right), \quad (4)$$

$$k_{yo} = \sqrt{k_x^2 + k_y^2}. \quad (5)$$

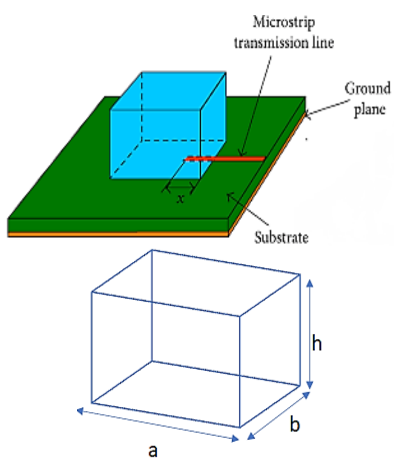


Fig. 1. 3D view of microstrip feed rectangular DRA.

III. RDRA FOR MOBILE WIRELESS APPLICATION

In this paper, a multiband DRA is proposed. In this intricate design, two similar dielectric resonators are placed on a top extreme of the Crescent-shaped patch, which is correctly fed microstrip line of 50-ohm. The various stages of Rectangular DRA are presented in Fig. 2. The proposed structure possesses a defective ground structure with the ground dimension of l_g x w_g x t mm^3. A slot of size l_s x w_s x t mm^3 is etched from the top upper left corner of the ground to make it as defective ground structure. The defective ground structure is created in order to match the impedance at the resonating bands. The Projected DRA structure has four stages of evolution, such as Antenna I, Antenna II, Antenna III, and Antenna IV. In Fig. 3, the back view of Antenna I, II, III, and IV are depicted, and a perspective view in the CST design environment is presented in Fig. 4. The final antenna design, along with its parameters, is shown in Fig. 5, and the parameter values are listed in Table 1. The antenna I is a single crescent patch antenna with microstrip feed and defected ground structure, and it resonates at dual-band from 1.34 GHz to 2.43 GHz and 5.17 GHz to 6.22 GHz. Antenna II is designed by including another crescent ring, which is electromagnetic couple to the first ring and this structure is having Penta band response from 1.40 GHz to 1.70 GHz, 2.03 GHz to 2.40 GHz, 4.24 GHz to 4.40 GHz, 5.26 GHz to 6.09 GHz and 7.01 GHz to 7.46 GHz. In Antenna III, both the crescent rings are directly connected to the feed line, and the structure operates at the Penta band from 1.42 GHz to 1.77 GHz, 2.02 GHz to 2.13 GHz, 2.42 GHz to 2.90 GHz, 5.23 GHz to 6.00 GHz and 8.14 GHz to 8.43 GHz. Antenna IV, the proposed RDRA, in which two similar dielectrics are placed on the crescent-shaped patch.

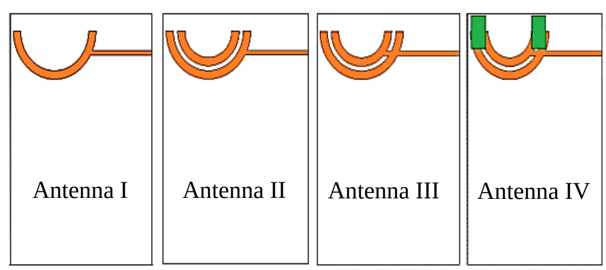


Fig. 2. Front view of Antenna I, II, III and IV.

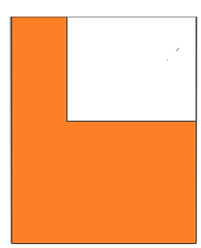


Fig. 3. Back view of Antenna I, II, III, and IV.

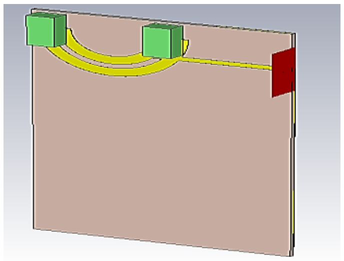


Fig. 4. Perspective view of the proposed DRA.

The dielectric resonator is made up of the material with relative permittivity of 2.33, and the size of the DR is a x b x h mm^3. The proposed Rectangular DRA operates in the Penta band from 1.38 GHz to 1.70 GHz, 1.90 GHz to 2.09 GHz, 2.36 GHz to 2.87 GHz, 5.18 GHz to 5.93 GHz, and 7.61 GHz to 7.88 GHz. The antenna geometry, along with its parameters, is presented in Fig. 5. Taking the 1.7 GHz as the base frequency, the maximum dimension of the 0.68 λ_0. The entire structure is fabricated 4.4 dielectric constant FR4 substrates. Section of two circles with different radius constitutes the radiator. A part of the ground near the feeding point is etched, which helps in tuning the multiple resonances. The outer radius is designed for the 1.7 GHz, and it can be evident from the surface current plot presented in Fig. 11 (a) with the optimized defected ground structure the 5.2GHz is achieved. Then the second ring is responsible for the 2.2 GHz band, which is proved with the help of surface current density in Fig. 11, in which it is seen that the maximum surface current is associated with the inner ring. Then the feed line is extended to the inner ring so that the coupling is increased, which results in the impedance matching and additional frequency resonance due to change in the current flow direction. Further, the performance of the antenna is enhanced with the help of DRA.

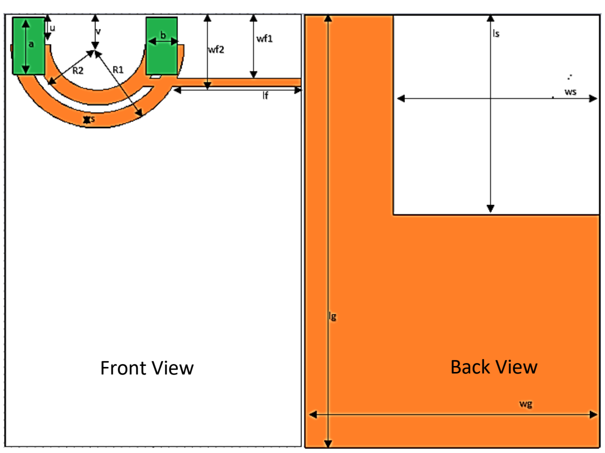


Fig. 5. Parameters of proposed RDRA for mobile wireless application.

Table 1: Antenna design parameter value in mm

Wg	lg	Ws	ls	wf_1	wf_2	l_f	R_1
37.5	57	26.25	24.75	8.5	9.5	17.9	11
R_2	a	b	u	v	s	t	h
8	7.5	4	4	5	2	0.035	1

Figure 6 depicts the S_{11} characteristics plot of Antenna I, II, III, and IV. The Antenna I is operated in two bands with a single crescent ring. The Antenna II is designed by adding another crescent ring. The inner ring and outer ring are not directly connected. This structure has an addition to resonance because of the second crescent ring. Then in Antenna III, both the rings are connected to each other through the feed line. The current is directly transferred to both the rings, and as a result, reliable impedance matching is achieved. Then the two symmetrical DRA is placed at the optimized position so that the antenna performance is slightly improved, and the DRA has a direct effect on the higher resonant frequency. The comparison of the operating frequency band with DRA and without DRA is presented in Table 2. On observing that, it is pragmatic that with the inclusion of the dielectric resonator, there is a slight increase in the bandwidth with a small reduction in the impedance matching, which is due to coupling loss.

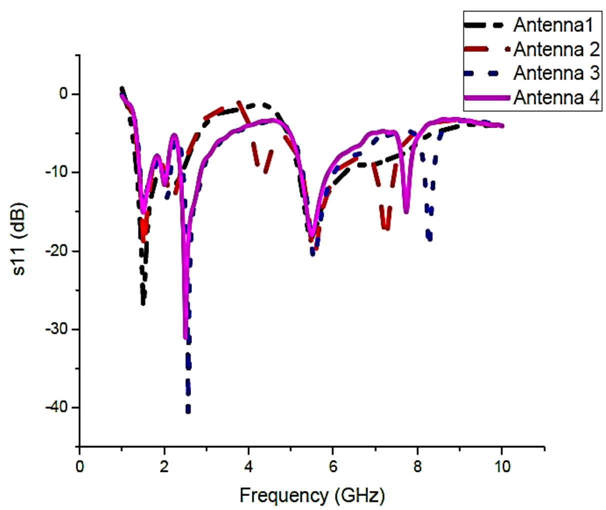


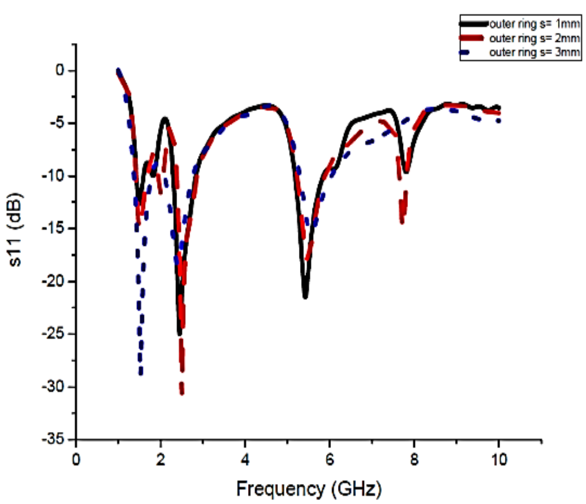
Fig. 6. S_{11} characteristics - various stages of proposed antenna.

All this analysis is depicted in Figure 7. Similarly, the parameters of the dielectric resonator are analyzed for deciding the optimum dimensions. The a, b, and h are varied, and its return loss characteristics are studied. In Fig. 8, the return loss plot for various dimensions of the dielectric resonator is presented. From which it is carefully observed that h=1mm, has an excellent performance in terms of impedance bandwidth in higher-order resonating bands, and therefore, is chosen as the dielectric resonator height. The impedance matching gets reduced as the increase in the height of the dielectric. The reason is due to the larger ratio of volume to the surface at higher-order modes, so h = 1 mm is chosen for the final design.

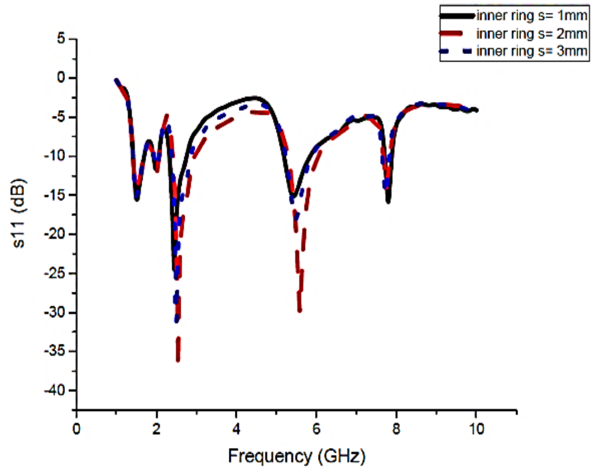
Table 2: Antenna III vs Antenna IV

Band	Antenna III					Proposed RDRA (Antenna IV)				
	Fl (GHz)	Fu (GHz)	Return Loss (dB)	Bandwidth (MHz)	Gain (dBi)	Fl (GHz)	Fu (GHz)	Return Loss (dB)	Bandwidth (MHz)	Gain (dBi)
Band 1	1.42	1.77	-14.34	354	3.01	1.38	1.72	-15.32	340	4.27
Band 2	2.02	2.13	-13.4	119	1.35	1.9	2.09	-11.93	190	2.62
Band 3	2.42	2.9	-40.99	449	1.41	2.36	2.87	-31.32	510	2.66
Band 4	5.23	6	-21.19	744	2.51	5.18	5.93	-18.24	750	3.77
Band 5	8.14	8.43	-19.79	282	-0.34	7.61	7.88	-15.31	270	0.912

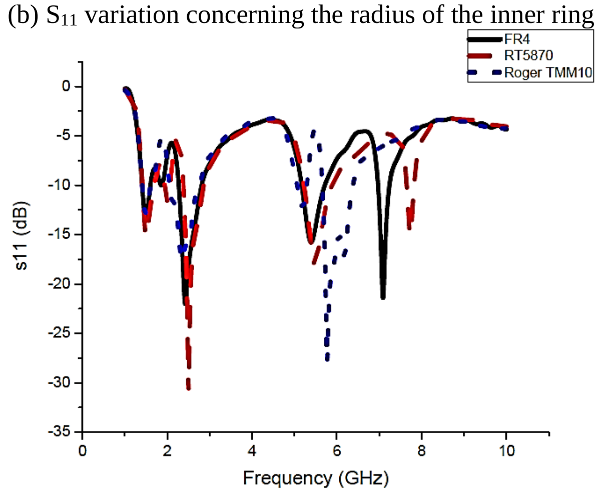
The dimension 'a' has a direct impact on the higher resonant frequency, and 'b' has a very profound effect on a lower frequency. The values a=4mm and b=7.5mm is chosen for the final design since it has very good impedance matching in all the resonating bands. At 7.75 GHz band alone, the impedance matching provided by a=6mm is high, for all the other bands a=4mm is providing slightly higher impedance matching. So, a=4 mm is chosen for final design.



(a) S_{11} variation concerning the radius of the outer ring

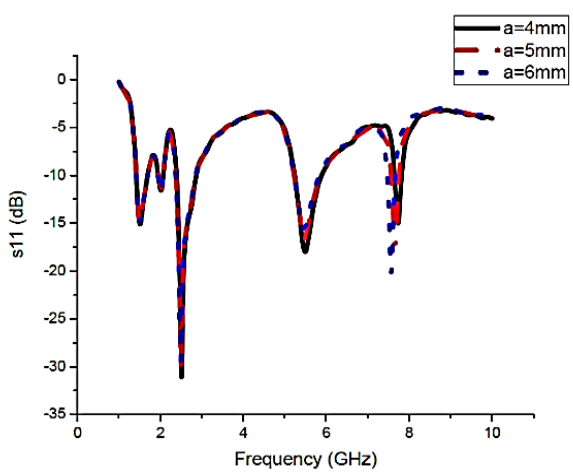


(b) S_{11} variation concerning the radius of the inner ring

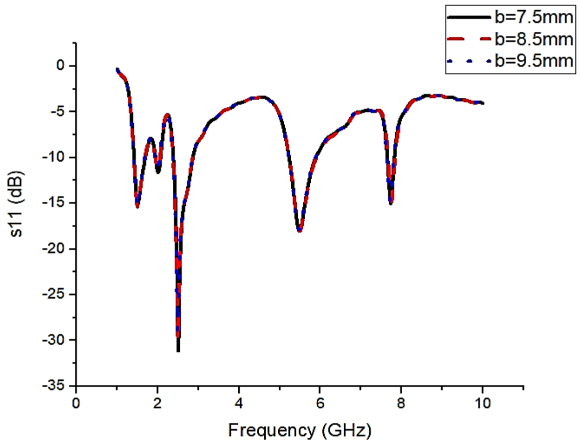


(c) S_{11} variation concerning the substrate material

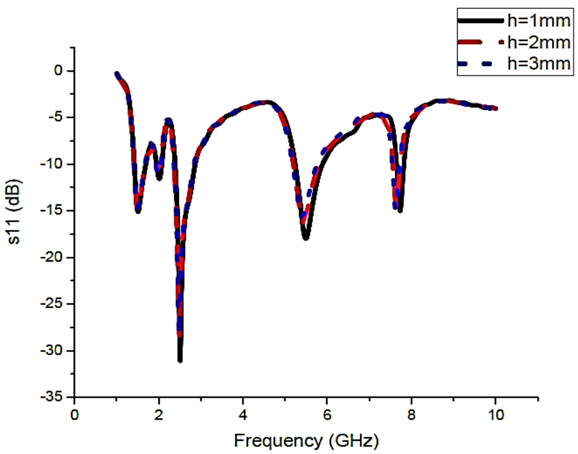
Fig. 7. Parametric analysis of patch dimensions and substrate types.



(a) S_{11} variation concerning DR dimension a



(b) S_{11} variation concerning DR dimension b



(c) S_{11} variation concerning DR dimension h

Fig. 8. S_{11} variation concerning the DR dimensions.

IV. RESULT AND DISCUSSION

In Fig. 9, the S_{11} of the RDRA is presented; from the figure, we can observe that the proposed rectangular dielectric resonator antenna is having Penta operating frequency bands with resonant frequency at 1.49 GHz, 2.00 GHz, 2.50 GHz, 5.49 GHz, and 7.75 GHz. In Figure 10, the simulated and measured VSWR of the proposed antenna is presented, which is observed from that the VSWR is lower than 2 in all the operating bands. This desired result shows that the proposed structure is having very decent impedance matching in the resonating bands.

In Fig. 11, the surface current distribution of the RDRA for mobile wireless applications at various resonating frequencies is presented. From the figure, we can see that the surface current is concentrated maximum on the crescent-shaped patch which couples with the dielectric resonator, is placed at the top of the patch. In Fig. 12, the simulated and measured radiation pattern at various frequencies is presented, from which we can observe that the proposed structure has an omnidirectional radiation pattern except at the higher mode resonant frequencies.

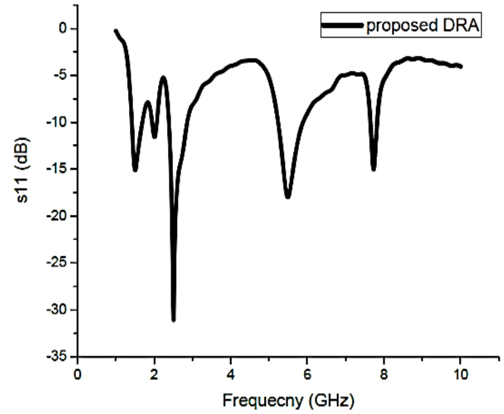


Fig. 9. S_{11} plot of proposed RDRA.

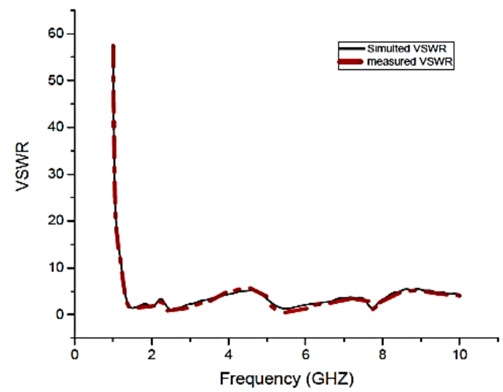
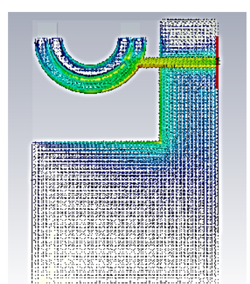
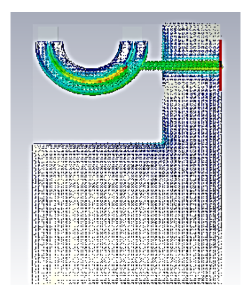


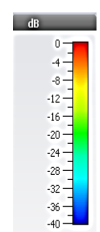
Fig. 10. VSWR of proposed RDRA.

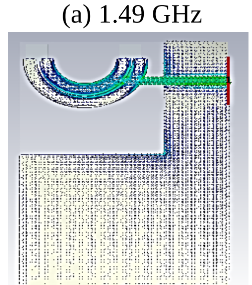


(a) 1.49 GHz

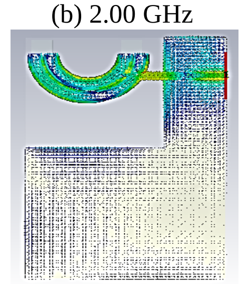


(b) 2.00 GHz

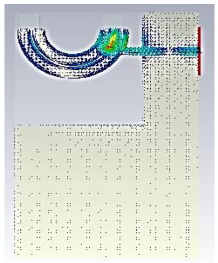




(c) 2.5 GHz

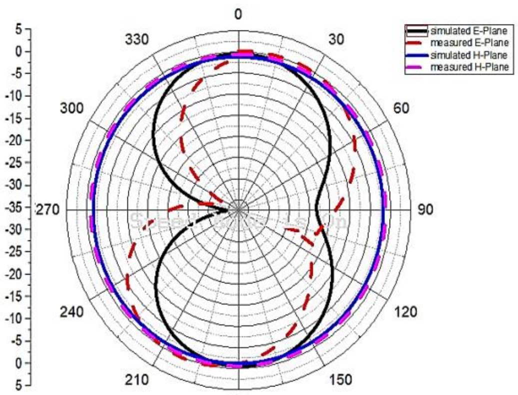


(d) 5.49 GHz

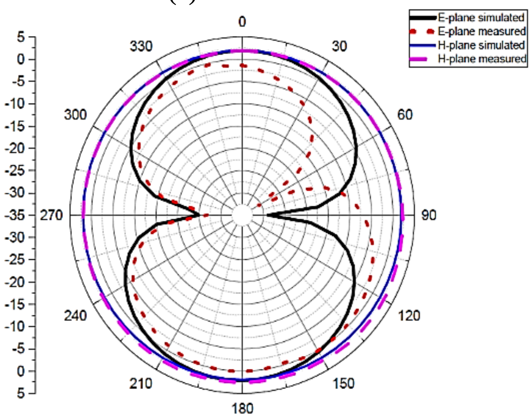


(e) 7.75 GHz

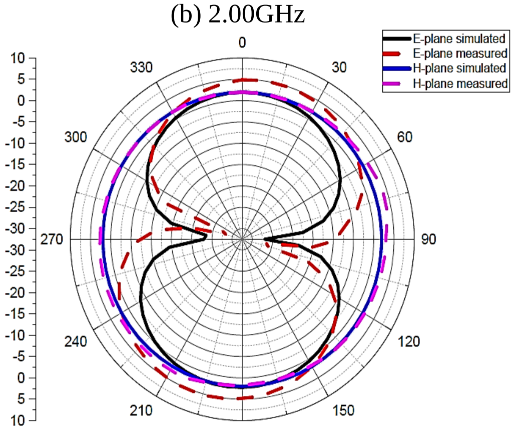
Fig. 11. Surface current of proposed antenna.



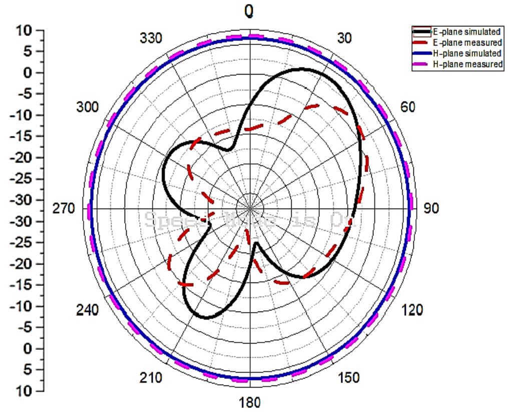
(a) 1.49 GHz



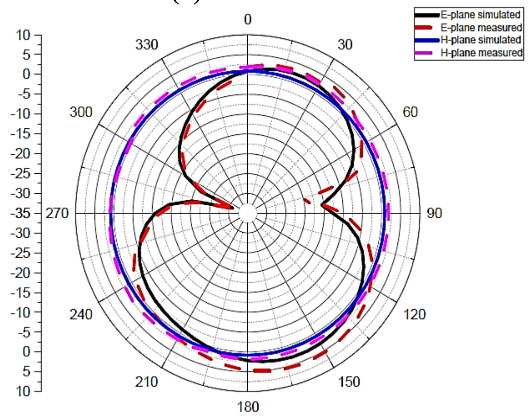
(b) 2.00GHz



(c) 2.5 GHz



(d) 5.49 GHz



(e) 7.75 GHz

Fig. 12. E plane and H plane pattern (measured and simulated comparison).

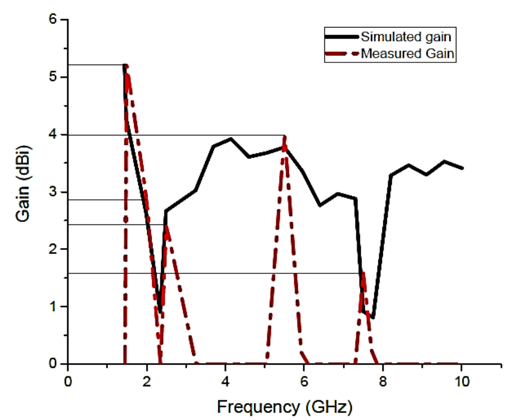


Fig. 13. Gain of the proposed RDRA.

In Fig. 13, the gain of the proposed RDRA is presented, and the measure gain is above 1.5 dBi. The measured gain is 5.216, 2.867, 2.428, 3.986, and 1.586 dBi at 1.49, 2, 2.5, 5.49, and 7.5GHz resonant frequency, respectively. In Fig. 14, the directivity of the RDRA is plotted. The proposed structure is capable of having a maximum directivity of 4.5dBi.

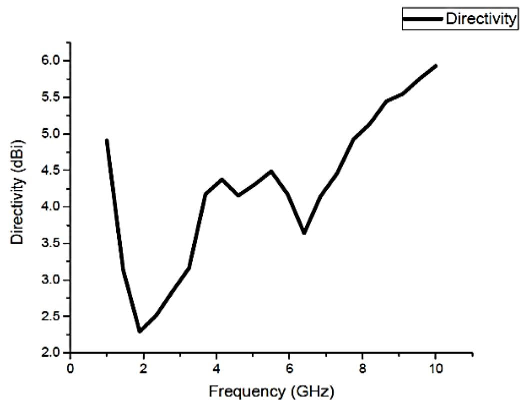


Fig. 14. Directivity plot of the proposed RDRA.

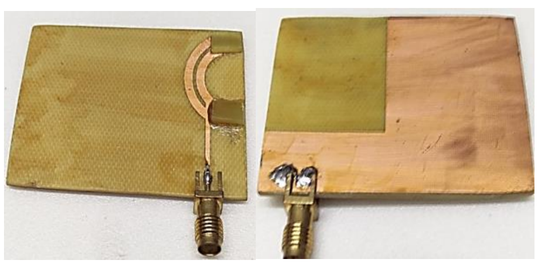


Fig. 15. Front and back view of the fabricated antenna.

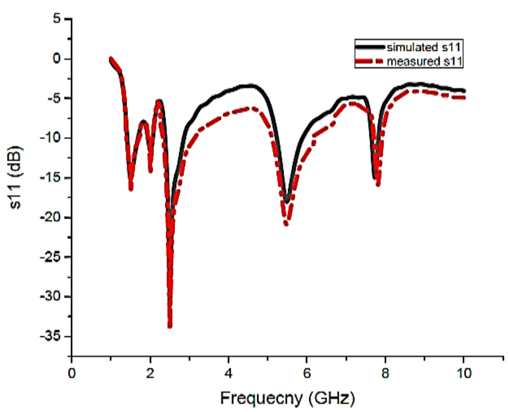


Fig. 16. Measured result vs. simulated result of proposed DRA.

In Table 3, the proposed work is compared with DRA available in the literature, and from the table, we can observe that the proposed DRA outperforms all the reported DRA. In Fig. 15, the fabricated antenna is depicted and measured using network analyzer N5230A. The simulated results are accurately related to the measured result and presented in Fig. 16. In Table 4, the measured and simulated S_{11} and bandwidth results are tabulated.

Table 3: Comparison with literature

Ref. No	No. of Bands	Feeding Method	Resonating Band (GHz)	DRA Material	DRA Size (mm)
31	Dual band	Microstrip	2.28-2.93, 4.26-4.65	Alumna	13.5 x 13
32	Triple band	Aperture couple	1.89-2.64, 4.13-5.47, 5.54-5.59	Alumna	40.5 x 31 x 19.68
33	Single band	Filter feed network	2.9-3.4	RT TMM 10	18.5 x 18.5 x 15.3
34	Penta band	Microstrip	2.38-2.42, 3.41-3.62, 3.93-4.26, 4.75-4.94, 5.01-5.39	Roger RT6010	18 x 18 x 9
35	Triple band	Slotted CPW	3.3-3.7, 4.8-5.0, 5.8-5.9	Foam	10 x 11 x 7
Proposed work	Penta band	Microstrip	1.38-1.70 GHz, 1.90-2.09, 2.36-2.87, 5.18-5.93, 7.61-7.88	RT5870	4x 7.5x1

Table 4: Simulated vs. measured results

Simulated Results					Measured Results				
Fl (GHz)	Fu (GHz)	Return Loss (dB)	Band Width (MHz)	Resonant Frequency (GHz)	Fl (GHz)	Fu (GHz)	Return Loss (dB)	Band Width (MHz)	Resonant Frequency (GHz)
1.38	**1.72**	**-15.32**	**340**	**1.50**	**1.39**	**1.74**	**-16.7**	**350**	**1.51**
1.9	**2.09**	**-11.93**	**190**	**2.00**	**1.954**	**2.053**	**-14.38**	**99**	**2.00**
2.36	**2.87**	**-31.32**	**510**	**2.50**	**2.332**	**3.142**	**-32.36**	**810**	**2.52**
5.18	**5.93**	**-18.24**	**750**	**5.42**	**5.112**	**6.17**	**-20.015**	**1058**	**5.43**
7.61	**7.88**	**-15.31**	**270**	**7.731**	**7.723**	**7.91**	**-15.77**	**187**	**7.82**

V. CONCLUSION

A rectangular DRA is proposed for the radio application. The proposed antenna is designed in four stages. Antenna I is a simple microstrip fed with a single crescent patch antenna with a defected ground structure. Antenna II is designed by including another crescent ring which is electromagnetic couple to the first ring, Antenna III both the crescent rings are directly coupled to the feed line, and Antenna IV is the proposed RDRA, in which two similar dielectric resonators made up of RT5870 is placed on a crescent-shaped patch in order to achieve multiband with good impedance bandwidth. The performance of the proposed RDRA supported by the simulated results. The proposed rectangular DRA has Penta operating frequency bands with resonant frequency at 1.49 GHz, 2.00 GHz, 2.50 GHz, 5.49 GHz, and 7.75 GHz, which covers the GPS, PCS, UMTS, ISM, WLAN, and Wi-MAX applications

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