A Novel Rectangular Dielectric Resonator Antenna with dual wide bands for 'X' and 'Ku' band applications

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Abstract

A novel 'Nine' shaped Rectangular Dielectric Resonator Antenna (RDRA) with transformed microstrip feeding technique is proposed and investigated for dual band operation. The proposed DRA has thin profile and operates at several frequency bands such as "C" band, "X" band and "Ku" band frequencies. Establishing the new 'Nine' shaped DRA along with transformed microstrip feeding; efficacy of proposed antenna has been significantly improved and producing dual impedance bandwidth of 45.59%, and 28.1%. The microstrip feeding with three stubs having suitable dimensions stimulates enormous coupling between DRA and the feeding element. This set up causes the generation of TE_{111} and TE_{112} modes accountable for dual wide bands. The proposed DRA is fabricated using Rogers RT Duroid 6010 material with high dielectric constant of 10.2 and its characteristics were measured. Good agreement is acquired between measured and simulated results. It is quite beneficial for air traffic control, defense tracking, RADAR, vehicle speed detection, weather monitoring and satellite applications.

Keywords

Rectangular Dielectric Resonator Antenna (RDRA), dielectric constant, 'Ku' band, RT Duroid material, RADAR, 'X' band

1. Introduction

The development of low loss ceramic materials opened the way for the use of Dielectric Resonator Antennas. Dielectric resonators are high Q and low loss elements used for circuit applications such as filters, oscillators and offering a more compact alternative to the waveguide cavity resonators and provide more amenable technology for printed circuit integration [1]. At present, DRAs are more powerful radiators and highly efficient against planar antennas due to its striking features such as good design flexibility, versatility, high radiation efficiency and lower losses. Among the types of DRA, rectangular shape offers a second degree of freedom making it the most versatile of the basic shapes [2]. Therefore, Rectangular shaped DRA was chosen in the present design over cylindrical and hemispherical shapes. Currently, dual band antennas are fulfilling the needs of modern wireless communication. It is always preferable to have dual band antenna instead of a single wide band antenna which suffers owing to losses and poor impedance matching between the operating frequencies. This inspires several researchers and antenna designers to design dual band antennas. So far, many techniques have been recommended for the dual band design of DRA. Dielectric Resonators could operate in dual bands by making changes either in the structure of DRA [3-4] or excitation methodologies [5-9]. Then operating DRA in higher order modes is one of the best techniques to realize dual or multiband. Higher order modes, on one hand elude the requirement of additional resonator, but on the other hand, it increases system complexity. Another technique highlights that dual bands were obtained when metallic patch was loaded together with DRA. They can also be achieved by introducing slot resonator as a feed to excite DRA [10-11] and employing parasitic effects on DRA [12-14]. But these methods could not extend the bandwidth greater than 5.3%. In [15], dual bands are produced by inducing two endfire modes TM_{101} and TM_{103} in hemispherical DRA. But hemispherical DRA has a limited design of freedom compared to cylindrical and rectangular DRA. [16] Emphasizes that modes of cylindrical DRA such as TM_{011} and TM_{012} originates the generation of dual bands. Eventhough the design of cylindrical DRA has additional freedom compared to hemispherical DRA; it could achieve the bandwidth of only 7.99%. These limitations were overthrown in a proposed antenna which is an enhanced version of [17] and further the measured results are incorporated to verify the simulated results. The proposed novel 'Nine' shaped DRA with transformed microstrip feeding provides optimum technique for achieving dual wide bands.

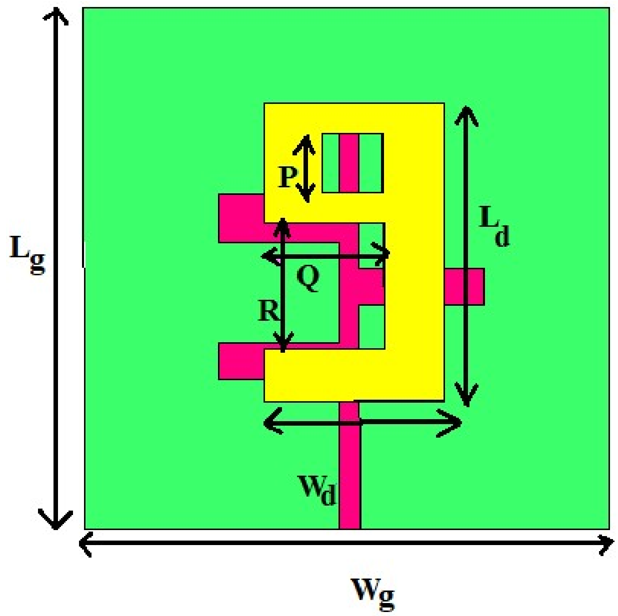
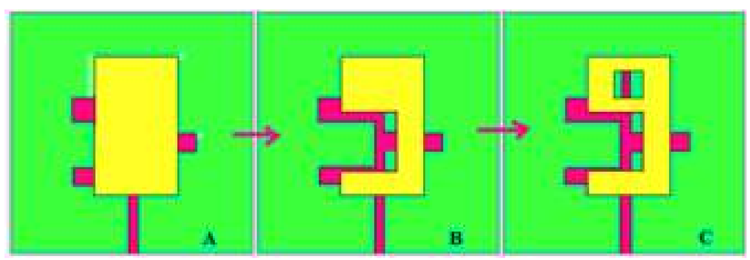
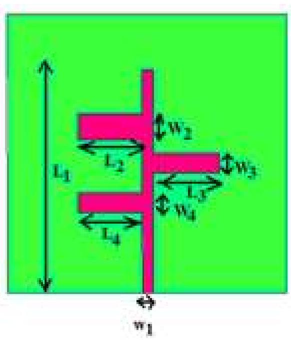
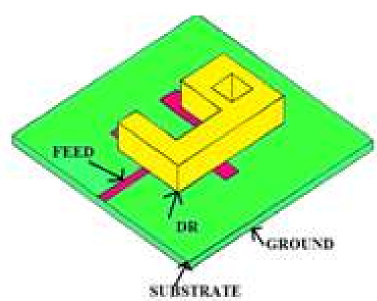


Fig. 1 Detailed geometry (Top View) of 'Nine' shaped DRA



(a)





(b) (c)

Fig. 2 (a) Design evolution of 'Nine' shaped DRA (b) Geometry of the feed (c) Three dimensional View

Suggested design yields lower bandwidth from 6.85-10.53 (45.59%) and upper bandwidth from 11.13-15.46 (28.1%) covering "C", "X" and "Ku" bands desirable in weather monitoring, military, RADAR and satellite broadcast applications. The following sections reveal about antenna design, parametric analysis and comparison of measured results with simulated results.

2. Antenna configuration and design

The complete structure and top view of the 'Nine' shaped DRA is depicted in Fig. 1. In this design, DRA exploits a ground plane of length L_g and width W_g. Having the same dimensions, substrate material made up of FR4, thickness of 1.6 mm and dielectric constant of 4.4 is mounted on a ground plane. Above the substrate, feedline shown in Fig 2(b) is fixed to energize DRA. The rectangular DR of 'Nine' shape was made up of Rogers RT Duroid 6010 material whose dielectric constant is 10.2 and loss tangent is 0.0023 placed above the substrate. Fig. 2 shows the design evolution of the proposed DRA, detailed geometry of the feedline and three dimensional view of 'Nine' shaped DRA. In configuration 'A', an ordinary rectangular DR is located above the feedline as depicted in Fig. 2(a). In configuration 'B', a rectangular volume of $Q \times R \times H$ is notched along the side wall. Further, in configuration 'C', another small square volume of $P \times P \times H$ is drilled. As a consequence of two notches, the resultant DRA appears like the numeral '9'. This is how the 'Nine shaped DRA' is derived from the basic rectangular DR. Both rectangular and square portions were removed from DRA in order to minimize the effective permittivity of whole volume. This in turn decreases the Q factor and increases the overall bandwidth of DRA. Micro-stripline feeding is favored in this current design because of its fabrication simplicity and easy optimization of the feed. It is fortunate that microstrip feeding doesn't require drilling as needed by coaxial feed or aperture coupled feed and most importantly, it reduces spurious radiation. As illustrated in Fig 2(b), microstrip line feeder is placed at the centre of substrate, whose length is L1 and width is W1 respectively. Three stubs with length L2, L3, L4 and width W2, W3, W4 were fixed at an appropriate location where it increases coupling between DRA and the feeder. The following section exemplifies the parametric study of the above three configurations A, B, C and essentiality of stubs coupled with central microstripline. Resonant frequency of RDRA was found by employing the popular DWM (Dielectric Waveguide Model) given in [18]. In rectangular DRA, the dominant TE_{111} mode is excited and whose resonance frequency f_0 is estimated from

$$f_0 = \frac{c}{2\pi\sqrt{\epsilon_r}}\sqrt{k_x^2 + k_y^2 + k_z^2} \quad (1)$$

Where

$$k_x = \frac{\pi}{a} \quad ; \quad k_y = \frac{\pi}{b} \quad (2)$$

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

In the above equations, $\in_r$ denotes dielectric constant of RDRA, k_0 is the free space wave number, c is the velocity of light and k_x, k_y and k_z are wave numbers along x, y and z directions respectively. Dimensions of 'Nine' shaped DRA were obtained by determining initial dimensions from the above equations. Then final optimized dimensions were found from thorough parametric study using HFSS 14 simulation software. Table 1 exhibits the final dimensions of proposed DRA.

Table 1. Dimensions of the proposed DRA

Parameters	Lg	Wg	L1	W1	Ld	Wd	H	L2
Dimension (mm)	35	35	28	1.35	26	12	5	8
Parameters	W2	L3	W3	L4	W4	P	Q	R
Dimension (mm)	3.25	8.3	2.5	8	2.45	4	5	8

3. Parametric study and discussion

To finalize the precise geometry for DRA and to obtain exact length and width for stubs, the role of parametric study is crucial and the same was accomplished by means of ANSOFT HFSS 14 simulation software which is based on finite element method. The shape of proposed DRA is analyzed primarily by executing parametric study on configurations A, B and C discussed in the previous section. This study is absolutely useful to validate the final shape of DRA. Fig. 3 illustrates return loss variations for the configurations A, B and C. From the figure it is evident that configuration 'A' without notches excited by triple stub feeding results in triple resonance with narrow bandwidth. Especially, the second band is very narrow and has poor bandwidth. Configuration 'B' having single notch yields quad resonance with poor bandwidth. Configuration 'C' which is the recommended design, achieves dual wide bands from 6.85-10.53 and 11.13-15.46 covering C band, X band and Ku bands with good impedance matching. Quad bands in configuration 'B' reduced as dual bands with extremely large bandwidth after drilling the square volume P ×P× H. Removal of specific portions in DRA reduces the overall volume and Q factor of DRA leads to improvement in impedance bandwidth. Hence the shape of proposed DRA is adapted in the current design.

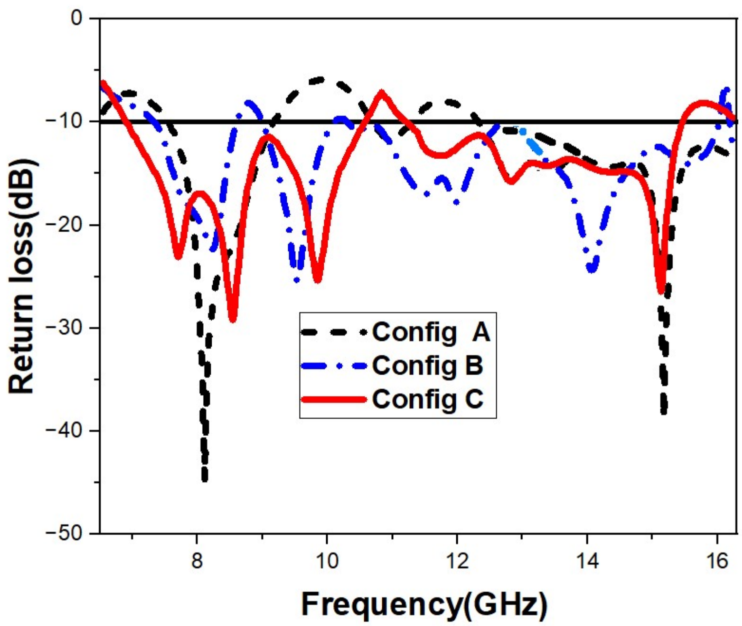


Fig. 3 Graph of return loss for A, B and C configurations

After validating the structure of proposed DRA, another parametric study is carried out to fix the suitable dimension for square volume 'P'. Drilling of appropriate dimension of square volume 'P' is very essential to enhance the bandwidth and its simulated returnloss characteristics for various values are shown in Fig.4. Except for the value of 4 mm, all other values such as 3mm, 4.5 and 5 mm were resulted in multiple bands with narrow bandwidth and poor impedance matching. Hence the optimized value of 'P' is fixed as 4 mm.

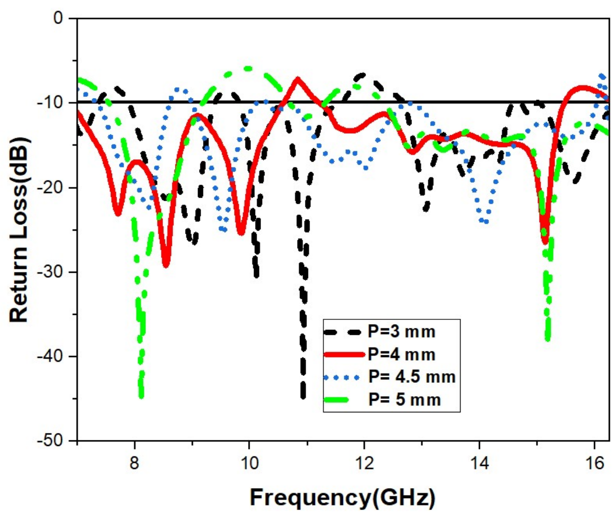


Fig. 4 Return loss characteristics for various 'P' values

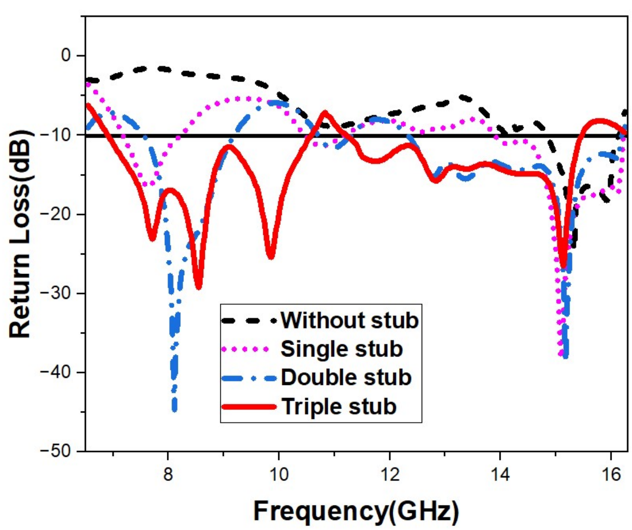


Fig. 5 Return loss characteristics for stubs

Then next study is carried out to emphasize the inclusion of triple stubs at proper locations along with central microstrip feedline. Fig. 5 depicts the graph of return loss variations for single, double, triple stubs and without stub. If no stub is connected with central feed, DRA resonate at single frequency with less bandwidth. If single stub is connected, it provides two narrow bands with poor impedance matching. When two stubs are connected, bandwidth is somehow improved but it is less compared to triple stubs which offers good impedance matching and dual wide bands as represented in Fig. 5. This parametric study explicates the significance of three stubs connected along with central microstripline. Here stubs are used as tuners to get wide bandwidth. From the parametric study it is clear that, for attaining large bandwidth, three stubs must be attached at appropriate locations in a feedline as shown in Fig. 2(b). Fig. 6 illustrates simulated return loss characteristics for length (L_2) of second stub. Resonance is not obtained in the desired frequency range as long as L_2 is less than 7 mm. When it is raised to 8 mm, it yields two wide bands. Bandwidth keeps on reducing if L_2 is increased above 8 mm as shown in the graph. Other values of stubs were optimized in the same way using parametric study.

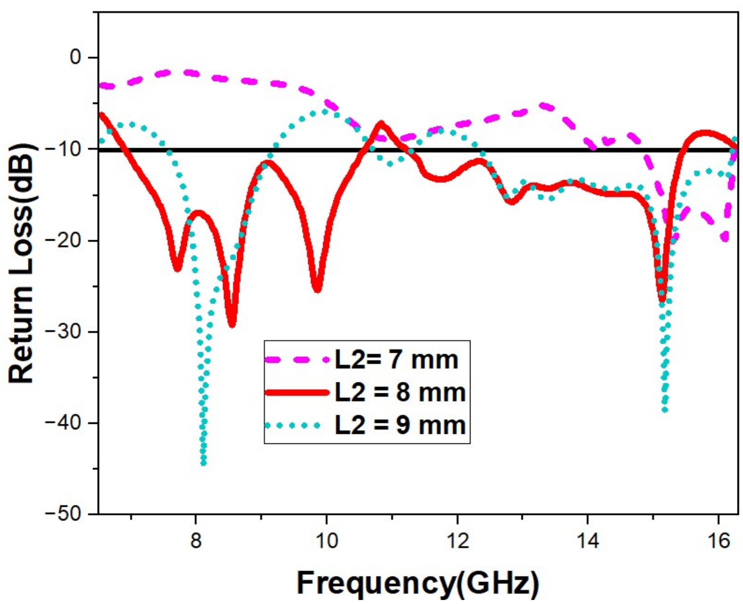


Fig. 6 S_{11} Characteristics for various values of L_2

4. Experimental results and discussion

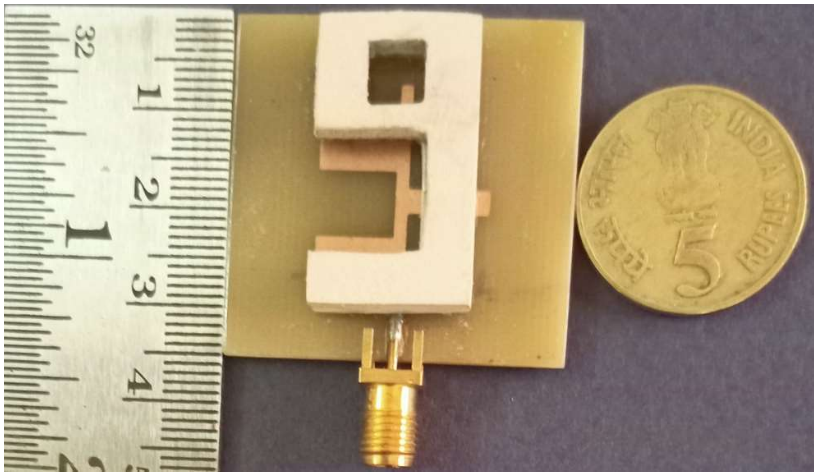


Fig. 7.Photograph of fabricated nine shaped DRA

Prototype of proposed ‘Nine’ shaped DRA is shown in Fig.7. It was fabricated using optimized dimensions as given in Table1. Return loss characteristics of fabricated DRA were measured using PNA E8362B network analyzer. As exhibited in Fig.8, good agreement is reflected between simulated and measured return loss results. But, very small discrepancy occurs owing to fabrication errors such as machining of DRA to its correct dimension, positioning of DRA on the ground and manual errors during measurements. Fabricated DRA resonates at two centre frequencies such as 8.51 GHz and 15.14 GHz and produces dual bands from 6.8510.53 and 11.13-15.46 GHz with a bandwidth of about 45.59% and 28.1% respectively. These bands are extremely favorable in “C” band, “X” band and “Ku” band applications. The first resonance is caused by TE_{111} mode and second resonance is caused by TE_{112} mode. Prototype of current design was manufactured by using Rogers RT Duroid material. Two layers of ‘Nine’ shaped segments having the thickness of 2.5 mm were machined from the RT Duroid material bar. Those two layers were stacked one above the other and bonded by commercially available Araldite glue with very low dielectric constant. Dielectric constant of glue must be very less to avoid the maximum deviation between simulated and measured results. Far field radiation characteristics of proposed DRA were tested in an anechoic chamber. E-Plane and H-Plane radiation patterns of simulated and measured results at the centre frequencies 8.51 GHz and 15.4 GHz are shown in Fig 9 and 10. It shows that DRA is linearly polarized and radiates in broadside direction. It produces stable radiation pattern for the entire operating frequency range. Good agreement is reflected between measured and simulated co-polarized amplitudes of E and H plane radiation patterns.

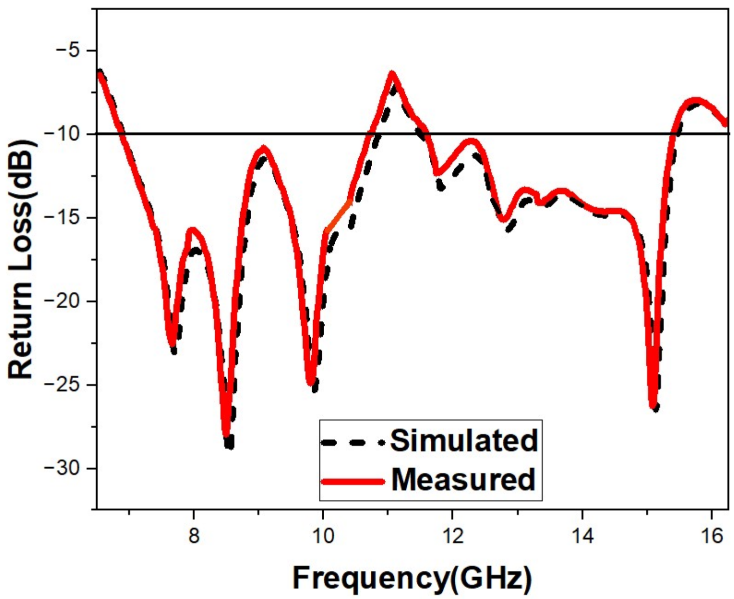


Fig. 8 Return Loss for Nine-shaped DRA

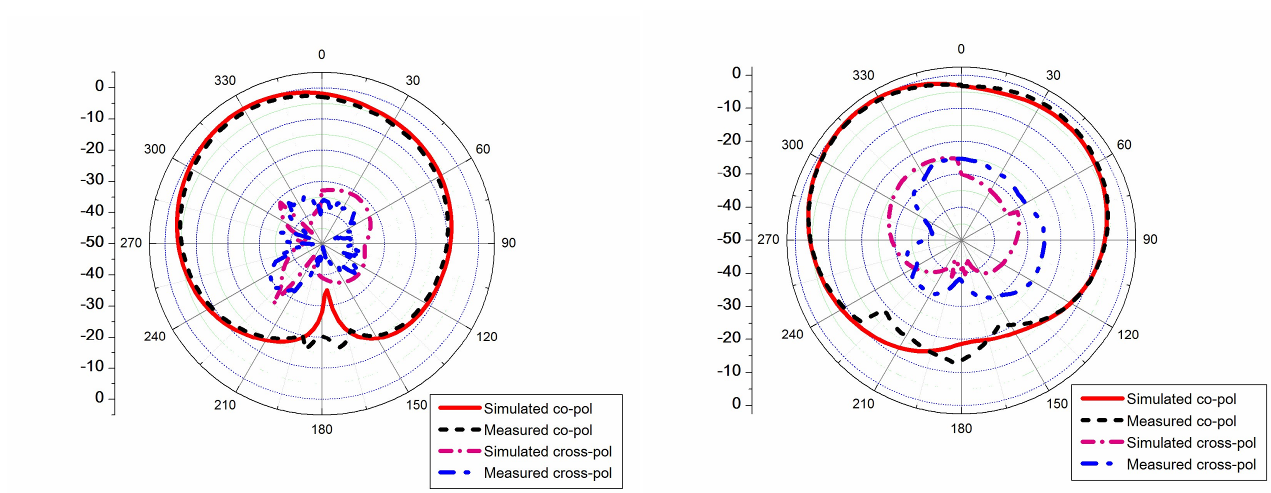
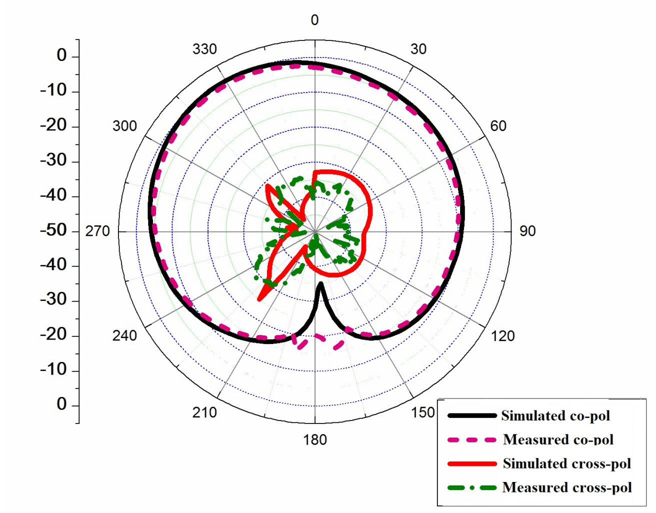


Fig. 9 E Plane radiation Pattern of the proposed DRA at 8.51 GHz



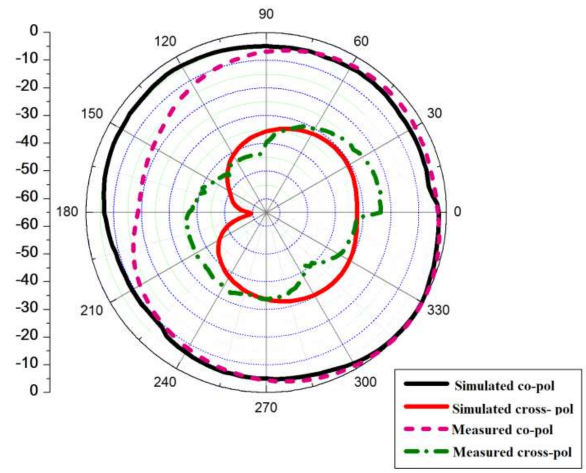


Fig. 10 H plane radiation pattern of the proposed DRA 15.4 GHz

It should be noted that co-polarization amplitude levels are so high as opposed to cross-polarization amplitude levels in both radiation patterns. Gain characteristics of proposed DRA are experimented and measured. Customarily, Horn antenna is utilized as a reference antenna to measure the gain of RDRA. Fig.11 displays the graph between frequency and Peak gain of 'Nine' shaped Dielectric Resonator Antenna.

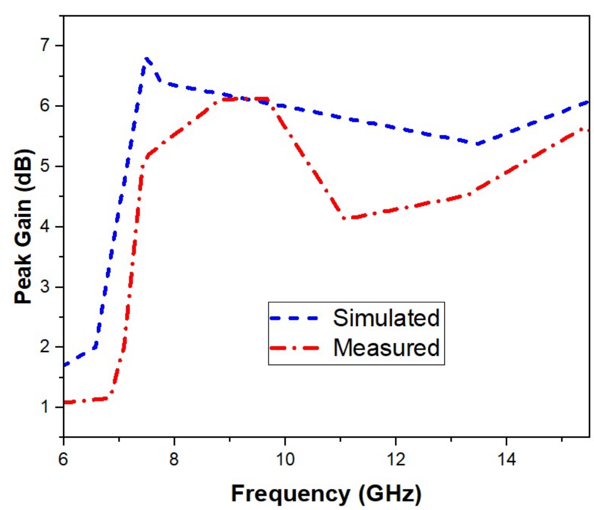


Fig. 11 Gain of Nine-shaped DRA

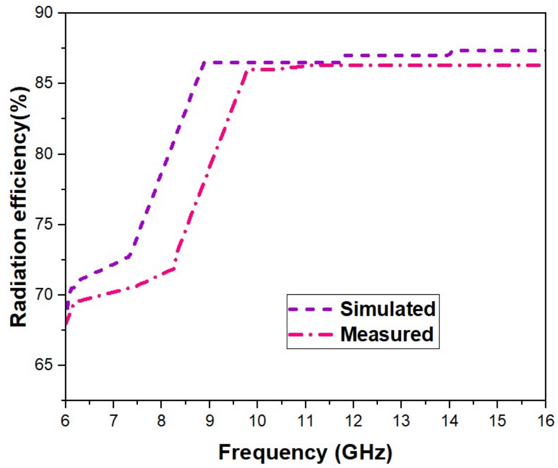


Fig. 12 Radiation Efficiency of Nine-shaped DRA

Table 2. Comparison of Nine-shaped DRA and other published DRAs

Reference	DRA Shape	Feed Type	Height (mm)	Gain (dBi)	Bandwidth (%)
[16]	CDRA	Probe	8.72	1.3 & 3.3	5.71 & 7.99
[19]	RDRA	Microstrip Line	18.5	4.02 & 7.52	15.5 & 8.3
[20]	CDRA	Microstrip Line	10	4.3 & 5.8	26.25 & 11.17
[21]	CDRA	Microstrip and Waveguide	19.4	6.81	30.77& 32.73
[22]	RDRA	Microstrip Line	19.2	6.05 & 7.72	25 & 13
Proposed RDRA	RDRA	Microstrip Line	5	5.9 & 5.5	45.59 &28.1

Here the measured peak gain is 6.13 dBi. Gain at the first resonant frequency is 5.94 dBi and at the second resonance frequency is 5.54 dBi respectively. Simulated versus measured radiation efficiency of present design is given in Fig.12. It clearly shows that more than 88% of simulated radiation efficiency and greater than 85% of measured radiation efficiency were obtained which is a good sign of proposed DRA. A comparison is made to realize the significance of present design with other published DRAs given in reference list. As mentioned in Table 2, proposed antenna furnishes extremely large bandwidth and high gain with very minimal thickness compared to other DRAs.

5. Conclusion

A 'Nine' Shaped, micro-strip fed, Rectangular Dielectric Resonator Antenna was investigated extensively for dual wideband operation. Dual wide bands are achieved as a result of 'Nine-shaped' geometry and triple stub micro-strip feeding. The proposed design technique and geometry are absolutely straight forward and is very much compatible with MMIC integration technique. The simulated and measured results have good coincidence with each other. It is a very compact, low profile antenna yields high gain, stable radiation pattern over the working band of frequencies and is pertinent for defense tracking, weather monitoring, satellite broadcast and RADAR applications.

Conflict of interest

The author has no relevant financial or non-financial interests to disclose.

The author declares that no funds, grants, or other support were received during the preparation of this manuscript.

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