ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20230911000930
Original scientific paper

Multiband Circularly Polarized Apex Etched Hybrid Rectangular Dielectric Resonator for Wireless Applications

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Abstract: The hybrid Dielectric Resonator Antenna (DRA) with circular polarization is another key research area since it can provide better antenna characteristics required by modern-day communication standards than the DRA with linear polarization. In this article, a Hybrid rectangular DRA is proposed. The Proposed DRA is excited with a novel feeding structure which is the combination of apex etched rectangular monopole and microstrip feed. The feeding structure is printed on a material with a dielectric constant of 4.4. The DR of 9.8 dielectric constants is placed on top of the patch. The proposed structure resonates at four different bands 1.42-1.52 GHz, 3.76-4.36 GHz, 4.92-5.35 GHz, and 7.02-8.74 GHz. The Critical parameters are analyzed and optimal dimensions are identified using the CST software. The proposed antenna exhibits circular polarization, which is validated with the axial ratio and electrical field distribution. The simulated results of the surface current are presented to validate the performance The measurement result is compared with the simulated results and found to be in agreement. The gain is well maintained above 1.5 dBi in all the resonating bands. A stable radiation pattern across all the resonating bands is achieved.

Keywords: apex etched rectangular monopole; CST software; dielectric resonator antenna; linear polarization; microstrip feed

1 INTRODUCTION

Among the antenna researchers, the Dielectric Reosonator Antenna [DRA] [1] has gained much attention in the past three decades due to its features such as stable-tuneable radiation pattern, wide impedance bandwidth, low weight, high gain, good radiation efficiency, and low losses. The DRA with rectangular and cylindrical shapes are widely used due to the ease of fabrication. Due to its radial compatibility, the cylindrical DRA outperforms the rectangular DR. The cylindrical Dielectric Resonator [DR] has been widely used by researchers in the past decades. Most of the devices require a multiband operation, since the amount of space available in the apparatus is very small for the antenna integration. The instruments available now satisfy multiple wireless standards simultaneously; therefore, they need various antennas operating at different frequencies. This will require more space for the antenna integration. To overcome this, the researchers focused on designing an antenna with multiband characteristics; due to its low-profile nature, the microstrip patch antenna [2] serves this efficiently. But the major disadvantage of microstrip is the low bandwidth and radiation efficiency. Metamaterials, [3, 4, 6, 7] subwave length structures with unconventional electromagnetic traits like negative permitivity, permeability, and refractive index, have captivated researchers in recent decades. These properties, stemming from structure rather than constituents, enable novel electromagnetic device design.

The hybrid DRA, which combines the microstrip patch and dielectric resonator, can provide better antenna characteristics required by modern-day communication standards than the DRA with linear polarization [3]. A variety of techniques have been developed to achieve circular polarization; one such technique is the excitation technique which uses single or dual feed. A mechanical method of injecting fluid inside the DRA is reported in [4] to achieve circular polarization. Some other techniques which are capable of attaining circular polarization are by incorporating modification in the Dielectric resonator structures, reconfigurability achieved with combination diode and DRA in Multiple dielectric layers in [5].

2 LITERATURE SURVEY

In [6-10], single-band DRA with circular polarization is achieved by including the patch at the corner of the DRA structure. In the circular polarized [CP] DRA is presented for tri-band operation, the hybrid DRA with loop modification is used to achieve the CP. The single fed DRA is proposed, which operates at dual-band with resonating frequencies at 1.5 and 2.4 GHz, in [11-13], diagonally grooved DRA is proposed for CP, and in [14-16], with the help of parasite patches on the DRA excited with triangular aperture is submitted for CP. In [17-19], frequency Selective Surface and Electromagnetic bandgap structures integrated with DRA to excite different modes are offered. In all the above-proposed works, the DRA has a significantly more significant size, complex feeding mechanism, poor axial bandwidth, complexity in design and fabrication.

In this article, a multiband hybrid DRA is presented. The proposed antenna has a simple design and can achieve circular polarization in the operating bands. The proposed antenna operates at four different bands from 1.42-1.52 GHz, 3.76-4.36 GHz, 4.92-5.35 GHz, and 7.02-8.74 GHz. The fourth band is created due to the combined effect of the apex etched rectangular monopole and RDRA. The fourth band's enhancement is due to merging the higher-order modes created by the RDRA and rectangular monopole. The apex etching in the rectangular monopole is responsible for the band formed at 4.23 and 5.28 GHz. The circular etching is accountable for the overall impedance matching, and the inverted L-shaped strip is responsible for the band at 1.47 GHz. The proposed antenna is compared with the hybrid antenna in the literature and found to be performing well. The geometry of the proposed hybrid RDRA is presented in section 2, followed by the parametric analysis in section 3. The proposed hybrid RDRA is discussed in section 4, and the article is concluded in section 5.

3 PROPOSED SYSTEM

The proposed apex excited hybrid rectangular DRA has five stages of evolution. The Hybrid nature is sure to be the combination of microstrip patches that act as DRA feed. The dielectric material in this proposed structure has a dielectric constant of 9.8 width an δ 0.002. This DRA is excited with an apex etched rectangular patch monopole excited by the microstrip feed. The Apex etched rectangular monopole is constructed on an FR4 dielectric material. In Fig. 1, the five-evolution stage of the proposed antenna is presented. The microstrip feeding structure and the apex etched rectangular monopole used to excite the dielectric resonator are shown in Fig. 2a. In Fig. 2b, the perspective view of the proposed antenna is presented in the CST simulation environment. The entire simulation is carried out using CST EM studio simulation software.

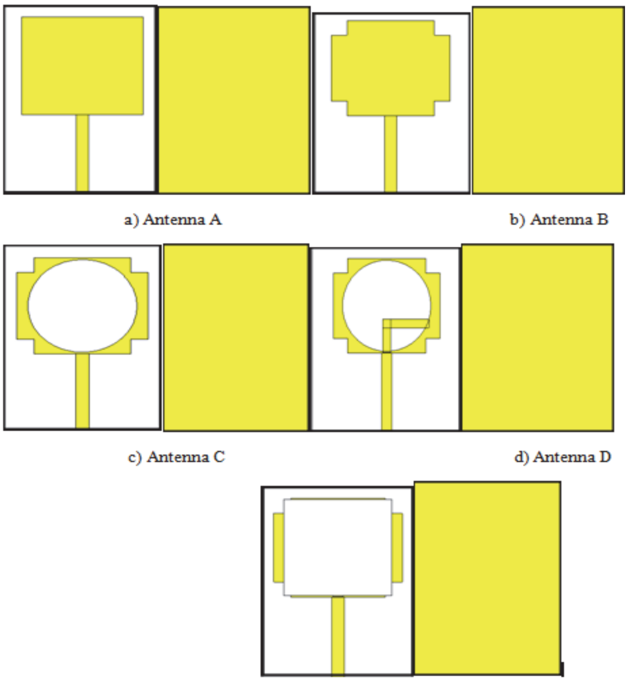
a) Antenna A b) Antenna B
c) Antenna C d) Antenna D
e) Antenna E

Figure 1 Evolution of proposed apex etched hybrid RDRA

The proposed apex etched rectangular DRA has a seed element of antenna A. Antenna A is a simple rectangular patch antenna. The antenna can operate at three different bands from 7.15-7.42 GHz, 7.66-8.01 GHz, and 9.21-9.89 GHz. Then, a square is etched at the four apexes of the rectangular patch, and as a result, due to an increase in the electrical length, the resonant frequency shifts its operation from 4.55-4.76 GHz and 5.35-5.57 GHz. In antenna C, a circle of radius U is etched on the rectangular patch, which disrupts the current flow available on the rectangular patch. It also improves the impedance bandwidth in all the resonating bands. To distribute the energy from the feed line and to achieve the feeding flexibility, an inverted L shaped strip is introduced in the circular etched rectangular patch, which in turn creates the new frequency of operation from fro1.58 GHz to 1.67 GHz., which is considered to be antenna D. Finally the antenna E is constructed by placing the rectangular DRA precisely on the top of the circular slot etched on the apex etched rectangular monopole. In Fig. 3, the proposed antenna parameters and their optimum dimensions are in Tab. 1. In Fig. 4, the antenna's return loss evolved during the proposed apex etched circular polarized hybrid DRA design.

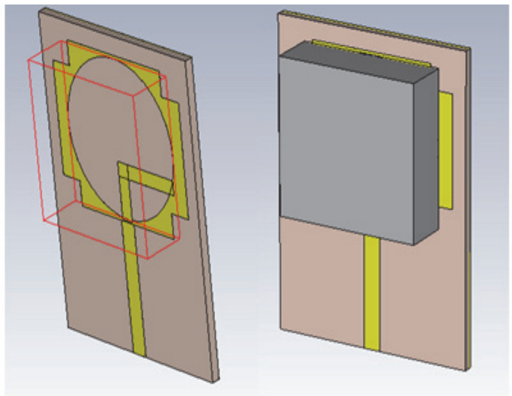
a)Monopole used to excite the RDRA b) Perspective View

Figure 2 Proposed apex etched hybrid RDRA in CST environment

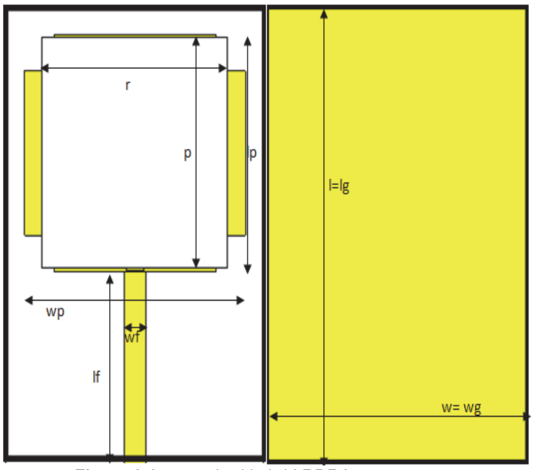

Figure 3 Apex etched hybrid RDRA parameters

Table 1 Apex Etched Hybrid RDRA parameter values (in mm)

w	l	wf	lf	wp	lp	r	p	h_1	wf_2
35	50	3	21	20	36	12	11	8	13.1
wf_1	lf_1	y	t	h	s_1	s_2	s_3	lg	wg
2.3	8.8	12.5	0.0035	1.6	4	4	0.0035	50	35

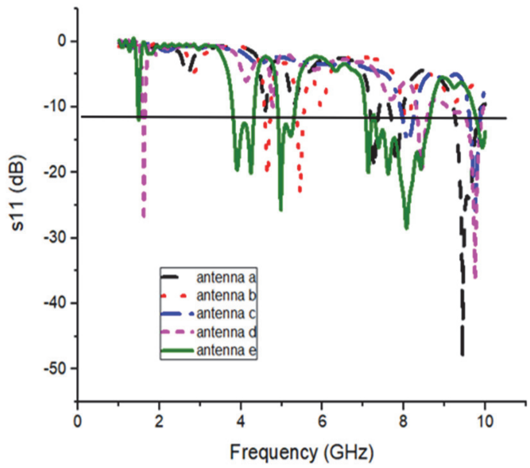

Figure 4 Comparison of return loss plot of the antenna

3.1 Parametric Analysis

In Fig. 5, the antenna A return loss is compared with Antenna E. The figure shows that the introduction of the DRA has created new bands of resonance. At the same time, it improves the impedance bandwidth of the proposed structure by combining the higher-order modes of the antenna. The critical parameters of the proposed antenna are parametrically analyzed to choose the optimum dimensions. The ground length *lg*, the inverted *L* strip width wf_1, DRA width *r*, and DRA height h_1 are analyzed using parametric analysis of CST to decide the final optimum values used for the fabrication. First, the ground length is varied as ½, *lg* ¾ *lg*, and *lg*. The comparison plot of the effect of ground length on the S_{11} plot is presented in Fig. 6. From the figure, it is observed that the ground length directly impacts all the resonating bands. For the full ground length, the proposed structure has good impedance bandwidth in all resonating bands, and therefore it is chosen for the final fabrication.

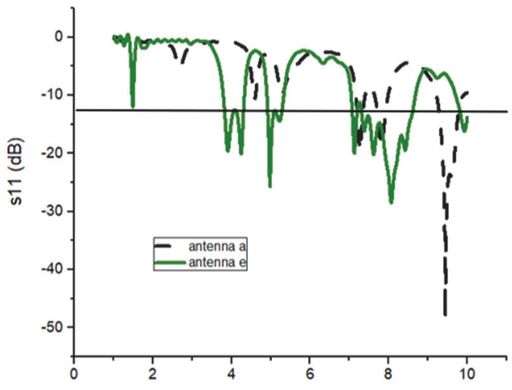

Figure 5 Antenna A vs. antenn E

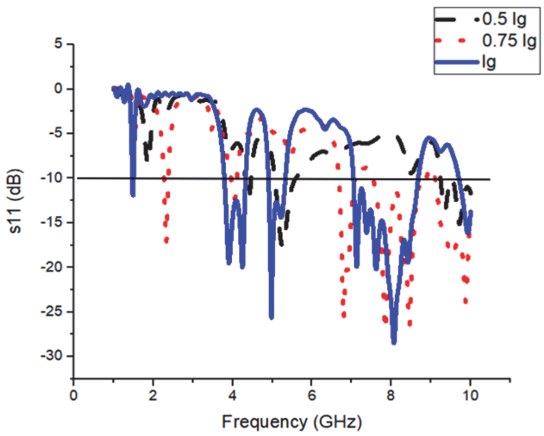

Figure 6 Return loss comparison for various ground length

Next, similarly, the invented *Ls* trip feed width wf_1 is analyzed. The inverted feed width is having an impact on the 1.47 GHz and 5.28 GHz bands. The wf_1 is increased from 2.1 mm to 2.5 mm in steps of 0.2 mm. The effect of wf1 is plotted against the frequency of operation in Fig. 7. From Fig. 7, it is noted that the wf_1 = 2.3 mm has good impedance matching, and hence it is chosen for the final fabrication.

The critical parameters of the DRA have then been analyzed first. The DRA width increased from 10 mm to 14 mm in steps of 2 mm. In Fig. 8, the effect of the width is plotted, from which it is observed that the *r* = 12 mm is achieving good impedance bandwidth in all the resonating bands. Followed by the effect of rectangular DRA height, the height is increased in steps 2 mm from 6 mm to 10 mm; it is found from Fig. 9 that the h_1 of 8 mm is the optimum dimension. If we increase the height of the DRA, the resonating frequency shifts right, and higher frequencies are more affected.

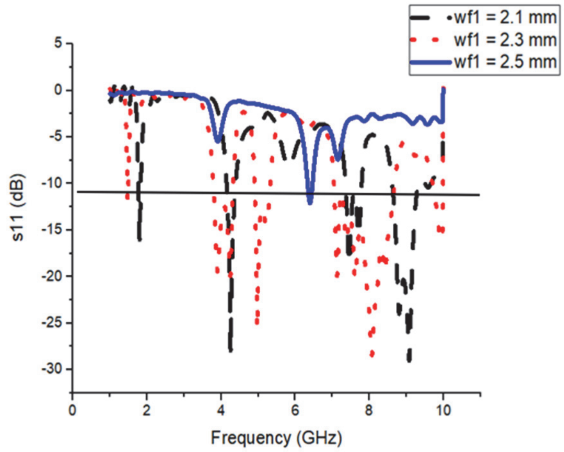

Figure 7 Return loss comparison for Incented *L* strip width

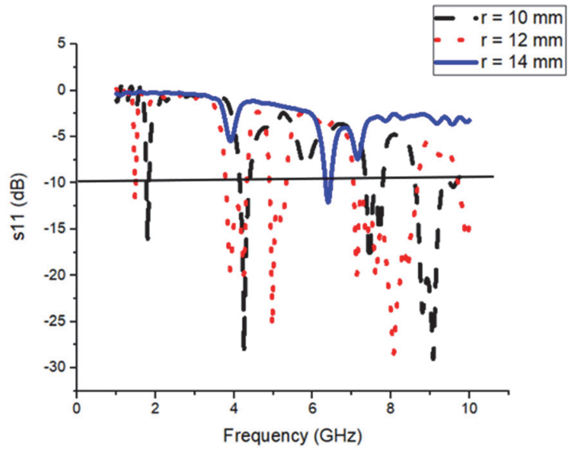

Figure 8 Return loss comparison for various DRA width

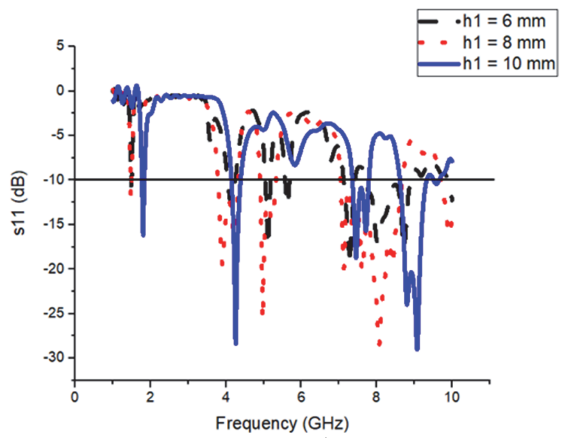

Figure 9 Return loss comparison for various DRA height

4 RESULTS AND DISCUSSION

The proposed apex etched hybrid rectangular DRA is proposed to operate in four bands from 1.42-1.52 GHz, 3.76-4.36 GHz, 4.92-5.35 GHz, and 7.02-8.74 GHz. This multi-band is generated with four different resonating modes. The First band, 7.02 to 8.74 GHz, is caused by the apex etched patch feed with a microstrip line. Then, etching the circular slot and adding the inverted L-shaped strip improves the impedance bandwidth and leads to a new band at 1.47 GHz. It is evident from the surface current distribution at 1.47 GHz presented in figure 10. Adding the DR over the slot of the rectangular monopole leads to the addition bands from 3.76-4.36 GHz and 4.92-5.35 GHz.

The DR also has a reasonable impact on the other bands. There is a significant improvement in the impedance bandwidth in the 7.02-8.74 GHz band due to the merging effect of the higher-order modes of RDRA and monopole. In Fig. 10, the E filed distribution of the DRA at various resonating frequencies, proving the existance of circular polarization. At 1.47 GHz, the E field rotates in an anticlockwise direction; at 3.97 GHz E field turns in clockwise order; at 4.23 and 4.96 GHz, the E field rotates in an anticlockwise direction. In 5.28, 7.09, and 7.63 GHz E field rotates in a clockwise direction, whereas at 8.24 GH E field rotates in an anticlockwise direction. Clockwise rotation exhibits the Right Hand CP while the Anti clockwise rotation indicates the Left Hand CP.

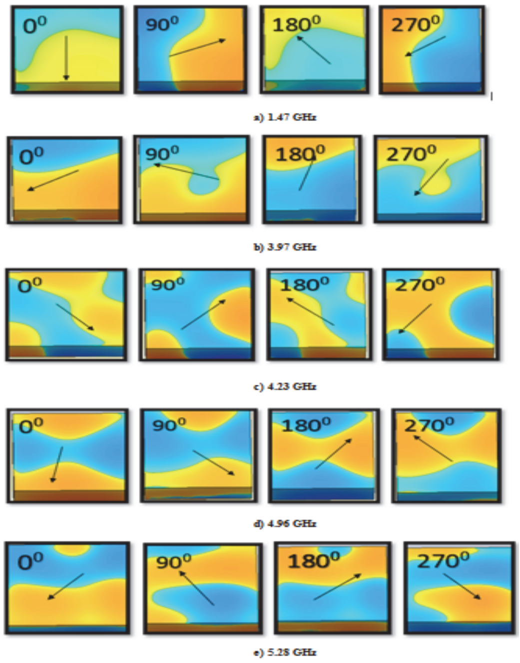

Figure 10 E filed distribution of the DRA at various resonating frequencies

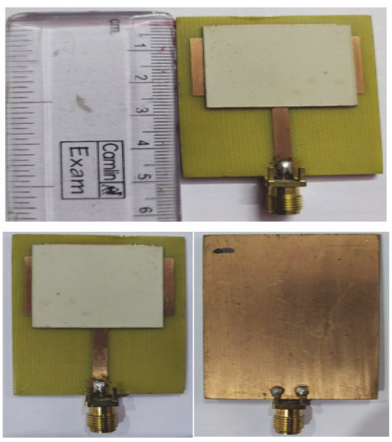
Figure 11 Fabricated antenna

In Fig. 11, the fabricated antenna is presented. The fabrication process is carried out with the help of photolithographic process. The measured return loss is compared with simulated results, which is found to agree. The surface current is more concentrated on the external ring slot which leads to the change in the frequency. The deviation between the simulated and measured results in Fig. 12 may be due to the dielectric constant error of the DR, the air gap between DR and the apex etched monopole and the connector error during measurement. The deviation is also due to fabrication and errors occured during the measument. The Radiation pattern of the proposed antenna is presented at various resonating frequencies. The 3D gain pattern, E plane, and H plane pattern for the proposed apex etched hybrid rectangular DRA resonating frequencies are presented. The H plane exhibits an omnidirectional radiation pattern in all the resonating bands, and the E plane shows the dipole radiation pattern. The radiation pattern is stable in both E and H planes at all the resonating bands.

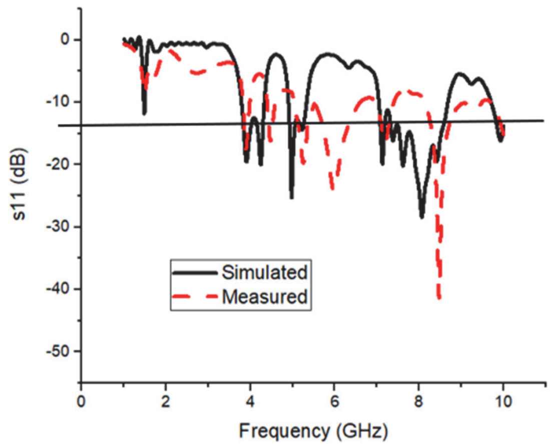

Figure 12 S11 of the proposed antenna (simulated vs. measured)

In Tab. 2, the proposed antenna is compared with other multiband DRA. In Fig. 13, the axial ratio is plotted against the frequency, and it is found that at resonating frequency, the axial ratio is less than 3 dB, which proves the existence of circular polarization. In Fig. 14, the gain of the proposed Hybrid DRA is presented, and the proposed structure is found to have a reasonable gain above 1.5 dB in all the resonating frequencies.

Table 2 Proposed antenna in comparison with other multiband DRA

Ref No.	Size in $W \times L \times H$ mm	Operating Bands in GHz
16	50 × 50 × 11.2	1.24-1.36, 2.56-2.88, 3.4-4.08, 5.08-5.72
17	45 × 90 × 13	0.89-0.93, 1.78-2.02, 2.31-2.38
18	40 × 40 × 14.6	2.5-2.76, 3.38-3.54, 4.9-5.3, 5.5-5.61
19	100 × 100 × 10	1.7-1.99, 2.5-2.69
Proposed	35 × 50 × 8	1.42-1.52, 3.76-4.36, 4.92 -5.35, 7.02 -8.74

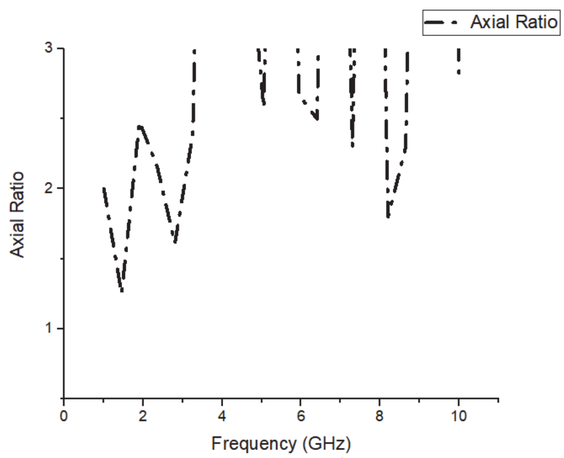

Figure 13 Axial ratio vs. frequency

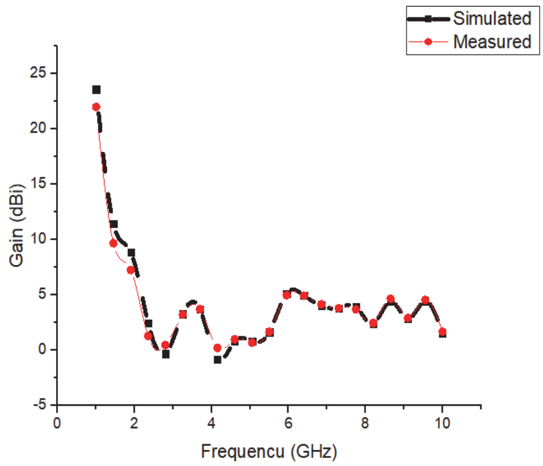

Figure 14 Gain vs. frequency

In Tab. 3, the simulated and measured results are compared. In Fig. 15, the measurement setup of the proposed antenna in the anechoic chamber is depicted.

Table 3 Simulated vs. measured result

Band	Operating Band / GHz		Band width / MHz		Gain / dB	
	Simulated	Measured	Simulated	Measured	Simulated	Measured
1	1.42-1.52	1.48-1.50	103	20	8.45	9.47
2	3.76-4.36	3.8-3.97	560	170	1.85	3.7
3	4.92-5.35	5.49-6.62, 6.95- 7.42	382	1130 470	1.76	1.25
4	7.02-8.74	8.11-9.52, 9.68-10	1652	1410 320	4.35	4.54

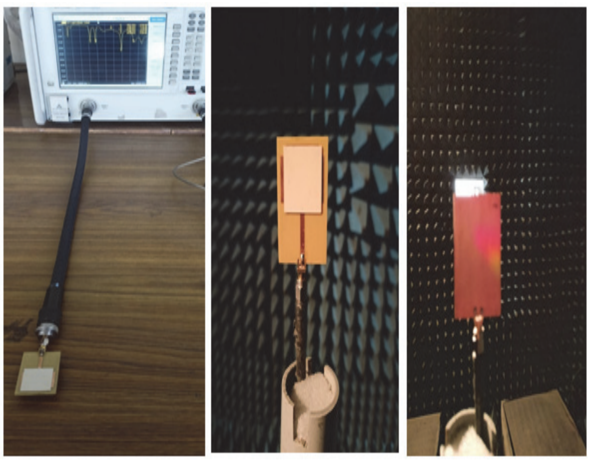

Figure 15 Proposed antenna in anechoic chamber

The proposed Hybrid DRA has a simple structure, multiband capability, stable gain, circular polarization, and stable radiation pattern. The proposed antenna's unique properties make it a suitable antenna for all wireless applications such as GPS, WiMAX, WLAN, 5G, and other C band applications used in personal communication devices.

5 CONCLUSIONS

A multiband Hybrid DRA is proposed for the wireless standards used in personal communication devices. The proposed antenna has a rectangular dielectric resonator placed on the apex etched rectangular monopole. The microstrip line feeds the DRA and the rectangular monopole, which are operated at four different bands with multiple resonant frequencies.. The band of operation is from 1.42-1.52 GHz, 3.76-4.36 GHz, 4.92-5.35 GHz, and 7.02-8.74 GHz. The proposed structure exhibits circular polarization at the resonant frequencies, and it is validated with the axial ratio and electric field distribution presented in the article. The dimensions are optimized with the critical parametric analysis. The simulated surface current is delivered to validate the development of multiband characteristics. The maximum gain of 8 dBi is achieved by the proposed antenna. The designed antenna is fabricated and measured. The measured results are on par with the simulated results. Stable radiation pattern with high gain, multi-band characteristics, compact and simple structure is the significant feature of the proposed Hybrid DRA.

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