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A Compact RDRA with Surface Mounted Short Rectangle in Wireless Applications

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Abstract: A compact rectangular dielectric resonator antenna (RDRA) with a surface-mounted short rectangle (SMSR) having an E- a shaped microstrip feed of wide aperture slot investigated for C-band operation in applications of Radar as well as wireless. The surface-mounted short rectangle improved the gain and efficiency characteristics. The size, material, and cost are essential considerations in designing an antenna due to advancements in C-band applications. The RDRA designed on a small-size substrate is 46x46x1.6 mm^3 made with FR4. It is rugged and can withstand in all pressure conditions. The proposed design utilizes copper has high conductivity and low cost for SMSR enhancement of return loss up to -47 dB, additionally gain to 9.4 dB, and observed bandwidth impedance of 19.6 % in the wide frequency of (5.75– 7.5) GHz. Furthermore, 3dB beam width attained in E – plane 108.43^0 whereas in H – plane is 64.36^0. The proposed SMSR design outcomes the conventional counterparts in all salient parameters, including return loss, impedance bandwidth, Gain, and Radiation efficiency with small size and low cost.

Keywords: RDRA, SMD, SMSR, High gain, Aperture slot coupling, Microstrip feed.

1. Introduction

The dielectric resonator antenna has a distinct advantage as it lacks metal parts that can cause loss. For ease of fabrication, compact size, lower cost, and minimum conductor losses, the rectangular DRA (RDRA) has been accepted as a good substitute for the conventional antenna in wireless communication, either radar systems or terrestrial microwave links. Circularly polarized wideband [1] hybrid DRA with characteristics obtained 3dB axial ratio and impedance bandwidth 43.8 % and 80.5 % and average gain 3.55 dB and radiation efficiency 95 %. The aperture coupled step walled RDRA substrate size is 61x61x2 $mm^3$is suitable for automotive radars, GPS, and telemetry [10]. The proposed compact design RDRA with surface mounted rectangle improved gain and efficiency in C- band applications.

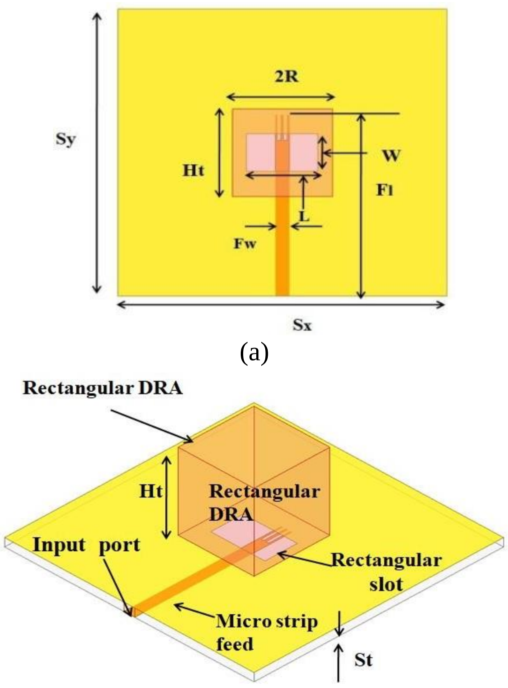
1.1 Literature review

The circularly polarized RDRA [2] operated in dual-band and observed impedance bandwidths are5.16%, 14.55 %, Gains 5.2 dBi, 5.7 dBiand radiation efficiencies are 93.73 %, 96.24 %. The antenna is used for microwave access and WLAN applications. Nasimuddin and Eselle [3] have proposed high gain RDRA integrating with SMSH, surface-mounted- short- horn, and increased gain to 8.5 dBi at 5.95 GHz resonant frequency, 3.2% impedance bandwidth. Though SMSH improved, the gain impedance bandwidth is low. A low profile wideband [4]. DRAOmni-directional patterns were observed in the wide band frequency (4.78 to 12.32) GHz and gain range (2.08 to 3.52) dBi. Furthermore, based on compass navigation satellite applications, two cross-slot frequency bands of the circularly polarized Antenna [5] have been proposed. In the case of RDRAs excited by microstrip line feed with a slotted ground plane [6], the average gain observed is 4.69 dB with radiation efficiency of 74.84 %. For wideband dual potential magneto-electro dipole aperture coupled antenna [7], its impedance bandwidth 11.4 % and gain 7 dBi. Moreover, RDRA

Table 1. Parameters of the designed antenna 1 andantenna 2

Name of the Parameter	Parameter	Value (mm)
RDRA height	Ht	15
RDRA Width/length	2R	14
Substrate thickness	S_t	1.6
Slot width	W	6
Slot Length	L	10
Substrate Length	S_x= $\mathbf{S_y}$	46
Ground plane length	Gx = Gy	46
Microstrip feed Length	F_l	29
Side of SMS Rectangle	RL = RW	16
The thickness of the SMS Rectangle	Ws	2

with uniaxial material would achieve an impedance bandwidth is 20.65 % and a gain of is8.4 dBi [8]. In [9], stacked RDRA with wide band circularly polarized broadside radiation characteristics achieved a radiation efficiency of 89.48 %, ranging from 2.27 to 5.80 dBi. The triple-band RDRA [11] excited with a novel composite feeding structure and an ultra-wideband [12] DRA achieved its relative bandwidth 90.9% and gain 6.2 dB. A new microstrip compact square-type antenna [13] integrated with a quasi-planner surface-mounted horn obtained an impedance Bandwidth of 2.3 % at a resonant frequency of 8.85 GHz. A circularly polarized dual-band [14] DRA is coupled with simple rectangular aperture. Linear-circular-polarization [15] dual-wide-band cylindrical DRA used for WiMAX applications. A new feeding method [16] for exciting higher-order resonant modes in DRA and hybrid resonator DRA [17] consists of a microstrip patch resonator coupled to a dielectric resonator. The rectangular dual band DRA [18], by using a U-slot feed, obtained a gain at 2.38 GHz is 6.05 dBi and at 5.22 GHz is 7.72 dBi. A circularly polarized wideband [19] cubic DRA has a question mark-shaped microstrip feed that gives impedance bandwidth 35.35% at a frequency 3.14 GHz. A new technique [20] was introduced to increase the bore sight gain of RDRA. A compact single-polarized [21] DRA excited by the two different feed lines. An RDRA [22] introduced a new excitation method to excite higher-order radiating modes$TE^{y}_{1,2,2}$ and $TE^{y}_{\delta,4,2}$ modes used for C-band. An RDRA [23] with unique conformal H-shaped micro strip feed that gives a gain of 6.8 dB and impedance bandwidth of 20 % used for satellite/WiMAX applications. A wideband circularly polarized dual-mode [24] gives an impedance bandwidth of 26.84 % and an efficiency of 87.32 %. A Compact Wideband Multimode [25] DRA fed with parallel standing



(a)

(b)

Figure. 1 The Geometry view of antenna 1: (a) Isometric view and (b) Top view with wide aperture slot

strips obtained a gain (5.5 - 9.5) dBi. The new researchers [26-30] improved Gain, but the antenna size is large. In this paper, SMSR-based RDRA is proposed for wireless communications. The standard rectangular-shaped DRA with the integration of a copper-made surface-mounted short rectangle on a low permittivity substrate. The rectangular DRA has a wide aperture slot in the ground excitation for an E-shaped microstrip line and has a resonance frequency of 6.2GHz. The main one is it can be suitable in all pressure conditions and overcomes the conventional counterparts in all salient antenna parameters. The effect of the height of RDRA on the salient parameters has been investigated by parametric analysis resulting in optimization at 15 mm for the desired improvement.

2. Configuration and Design of Antenna-1

A compact RDRA with surface-mounted short rectangle (SMSR) DRA having an E- shaped microstrip feed of wide aperture slot is presented in this section as illustrated in two stages. In the first stage, the aperture slot with E- a shaped designed microstrip feed on the substrate developed and integrated with RDRA, its geometry presented in Fig. 1.

The Near E-field distribution of proposed antenna 1 is depicted in Fig. 2 by an E-shaped microstrip being excited. There is a phase difference

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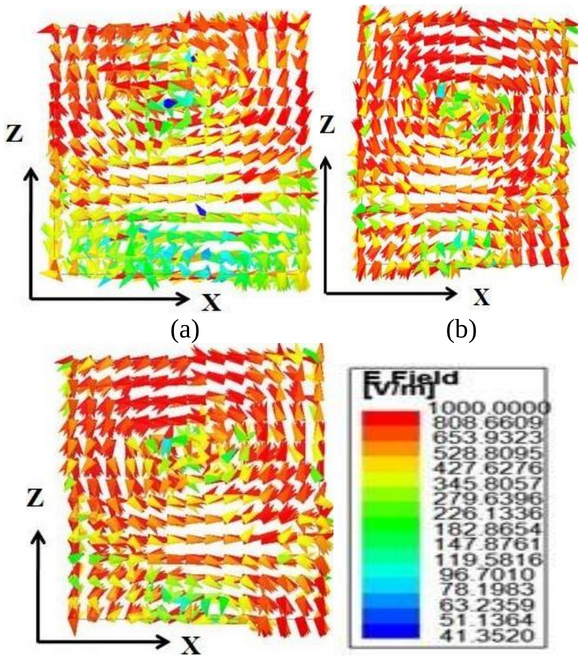
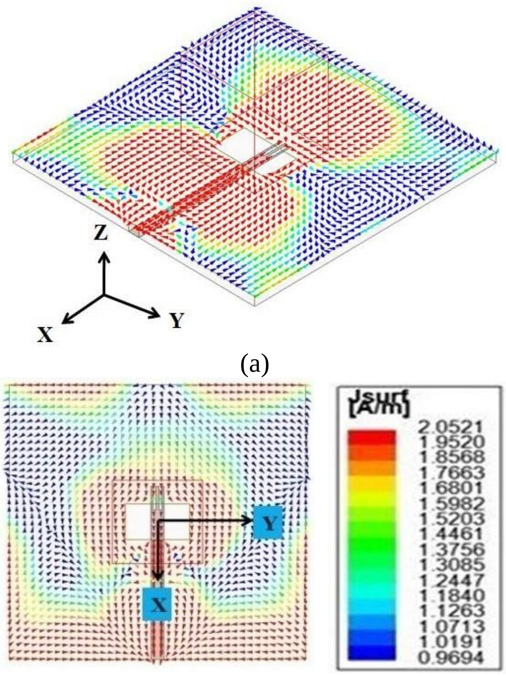


(a) (b)
(c) (d)

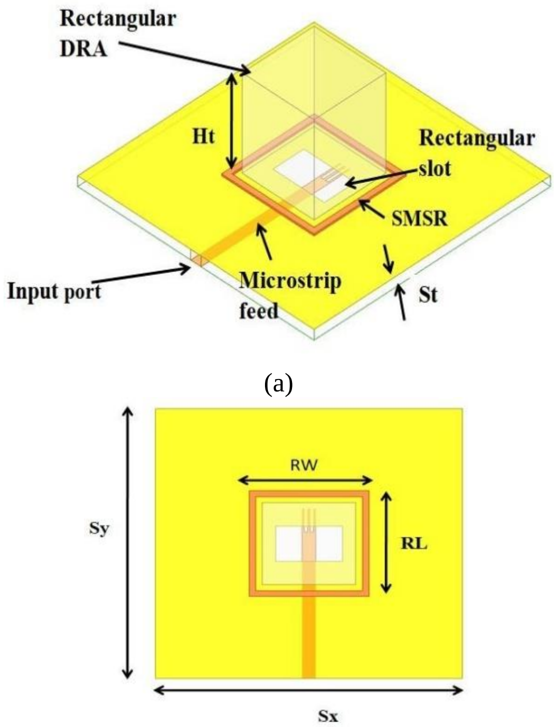
Figure. 2 E antenna 1field distribution left side view: (a) Phi scale for Figs. A, B, & C: = 0^0, (b) Phi = 90^0, (c) Phi = 180^0 and (d) scale for fig a,b,& c)



(a)
(b) (c)

Figure. 3 Antenna's surface current distribution 1: (a) Isometric angle (XYZ) Phi = 0^0, (b) Top View (XY) Phi = 90^0 and (c) Scale at 6.2 GHz

90^0 between them. It is observed that the Modes are circulating in a clockwise direction. Fig. 3 gives the surface current distribution in antenna 1, mainly focusing on E- the shaped microstrip feed line and within the DRA, whereas the current intensity on the ground plane is relatively weak. It is observed that a quasi-loop is formed, which is a magnetic dipole equivalent.



(a)
(b)

Figure.4 The Geometry of antenna 2: (a) Isometric view and (b) Top view with wide aperture slot

3. Configuration and design of antenna

The compact RDRA with surface-mounted short rectangle (SMSR) DRA has an E- shaped microstrip feed of wide aperture slot second stage as follows. The proposed SMSR integrates RDRA geometry, as shown in Fig. 4. The SMSR concept improves the Gain through which the energy fields are coupled into the integrated RDRA. The wide aperture slot is surrounded by an SMSR with a length RL= 16mm, RW= 16mm, and its thickness of 2mm placed above the substrate with a height of 0.3mm.

At a resonance frequency of 6.2 GHz, Fig. 5 depicts the Near E-field distribution of proposed antenna 2 and the E-fields within Rectangular DRA. There is a phase difference of 90^0 between them. It is observed that the modes are circulating in the anti-clockwise direction in and in the clockwise direction. Fig. 6. shows the surface current distribution in the proposed antenna 2, and the current mainly focuses on E- the shaped microstrip feed line and SMSR.

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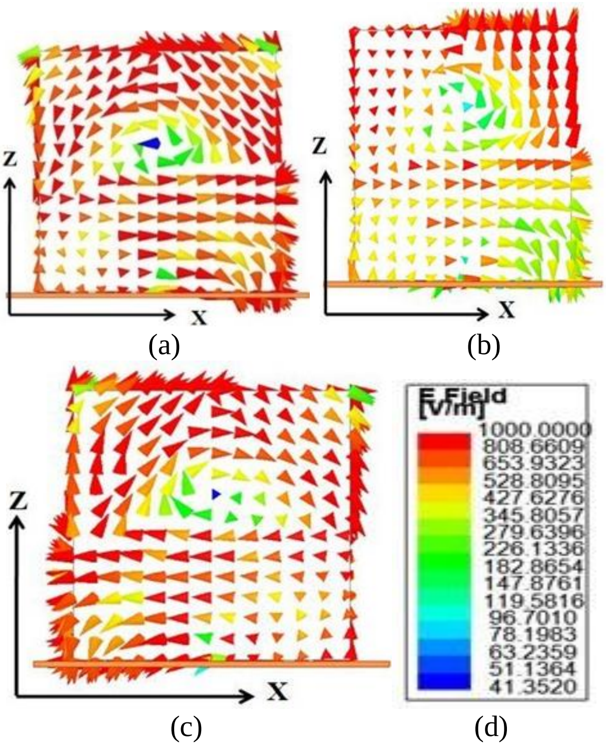

Figure. 5 Antenna 2's near E-field distribution left side view: (a) Phi = 0^0, (b) Phi = 90^0, (c) Phi = 180^0 and (d) scale at 6.2

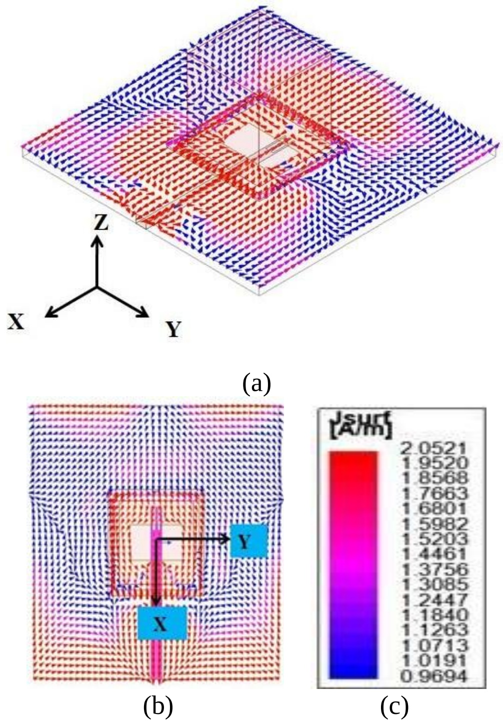

Figure. 6 Antenna 2's surface current is distributed: (a) Isometric angle (XYZ) Phi = 0^0, (b) Top View (XY) Phi = 90^0 and (c) Scale at 6.2 GHz

4. Principle of working

The compact rectangular dielectric resonator antenna (RDRA) with surface-mounted short rectangle (SMSR) DRA substrate made by FR4 glass epoxy, and the ground is of the same length (S*x*), and breadth (Sy) is 46mm, as shown in Fig 4. The wideband characteristics observed in RDRA, with the height-to-length ratio greater than 2. The dimensions are optimized by parametric analysis. The RDRAs Resonant Frequency depends on the dielectric material's size, RDRA shape, and dielectric constant. The RDA's resonant frequency is calculated by the following equation

$$f_{res} = \frac{397}{2\pi R}\left(c_{oR}\right) \quad (1)$$

Where R= ½ width of RDRA [mm]

$$c_{0R=} \frac{1.6 + 0.513k + 1.392k^2 - 0.575k^3 + 0.088k^4}{\epsilon_{d_R}^{0.42}}$$

$$k = \frac{R}{2 * \mathrm{Ht}} \quad (2)$$

5. Optimized RDRA with SMSR by antenna analysis

5.1 Optimization of dimensions

The compact rectangular dielectric resonator antenna (RDRA) consists of a rectangle dielectric resonator placed on the ground – plane along with a wide aperture slot. There are spurious radiations obtained as the aperture slot works as a monopole current element exciting the magnetic field into DRA. The parameters of the antenna are influenced by the height, length, width, and nature of the dielectric material of the DR. Parametric analysis is essential for the optimization of the dimensions. It is fractional to note that the observed value of return loss at RDRA height of 15 mm is high, and the size of the substrate is 46x46x1.6 mm^3 at resonant frequency 6.2 GHz by parametric analysis.

5.2 Coupling of E-fields and surface current distributions

Furthermore, near E – field distributions, surface current distributions. The proposed antenna 2's near E – field distributions, surface current distributions, in Fig (5-6). RDRA with an E-shape microstrip is fed through a rectangular slot in antenna 1. This acts as a horizontal magnetic dipole that will be created by microstrip coupling, which will stimulate the fields in the DRA. In antenna 2, a surface mount short rectangle (SMSR) is mounted on the ground plane. An electromagnetic force is generated around the

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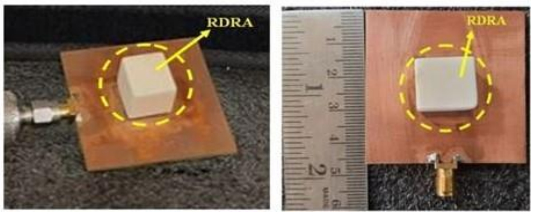
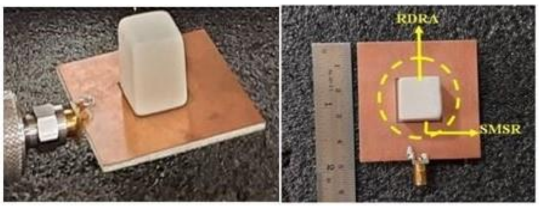


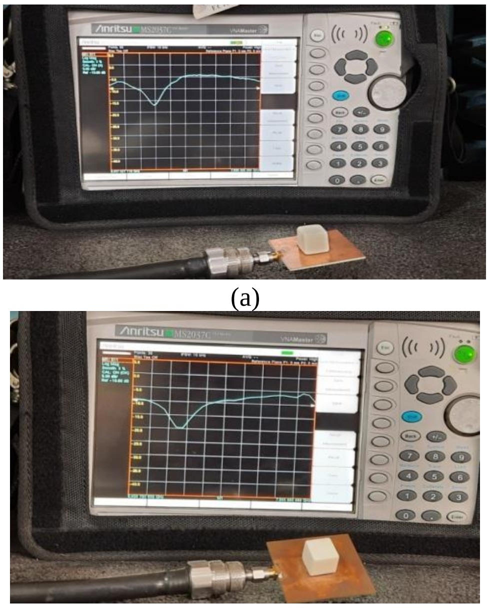
(a) (b)

Figure. 7 The fabricated proposed of Antenna 1: (a) 3D view fabricated antenna 1 and (b) Antenna 1 top view



(a) (b)

Figure. 8 The fabricated proposed of antenna 2: (a) Top view without RDRA and (b) Top view with RDRA



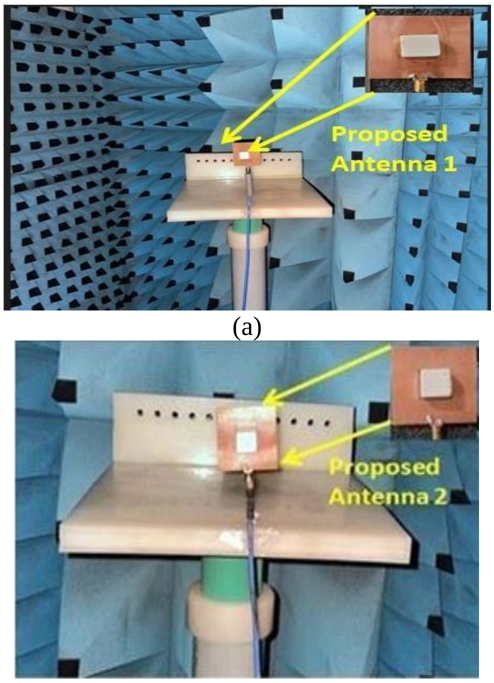
(b)

Figure. 9 (a)The reflection measurement of antenna 1 and (b) The reflection measurement of antenna 2

structure via a surface-mount short rectangle (SMSR) that is mounted on the ground plane. As a result, the current can flow while being influenced by the field generated by the microstrip line. The higher current distribution at a resonance frequency will increase the impedance bandwidth and gain.

5.3 Authorization of simulated results

Fig. 7 shows the fabricated proposed antenna 1 with the SMA connector. The proposed antenna 2 is fabricated in Fig. 8 with an SMA connector. The



(b)

Figure. 10 (a) The anechoic chamber measurement of Antenna1 and (b) the anechoic chamber measurement of antenna 2

Table 2. Proposed antenna without and with simulated and measured impedance band width

Simulated & measured	**f_r Ant 1**	**IMBW Ant 1**	**f_r Ant 2**	**IMBW Ant 2**
Simulated	6.13	5.71%	6.2	18.4 %
Measured	6.14	6.19%	6.2	19.6 %

antenna parameters were measured in an anechoic chamber, and the simulation results of the designed antenna 1 and antenna 2 were obtained by using HFSS.

To authorize simulation results of the antenna 1 reflection coefficient, the antenna 1 reflection coefficient results were measured with the help of Anritsu VNA MS 2037C, as shown in Fig. 9. With the aid of an Anritsu VNA MS2037C, the antenna 2 reflection coefficient measurements were measured in order to validate the simulation results in Fig. 10. It can observe that the impedance bandwidth of antenna 1 is 6.19 % in the frequency band (5.94 GHz – 6.32 GHz), and antenna 2 is 19.6 % in the frequency band (5.75GHz – 7 GHz). The gain, radiation pattern, and Efficiency results were measured with the help of a standard waveguide horn antenna (1GHz- 40GHz) and horn antenna 1 and antenna 2 as a reference shown in Fig. 11 and Fig. 12 using the Anritsu VNA MS2037C antenna test system. From Table 2, the proposed antenna 1

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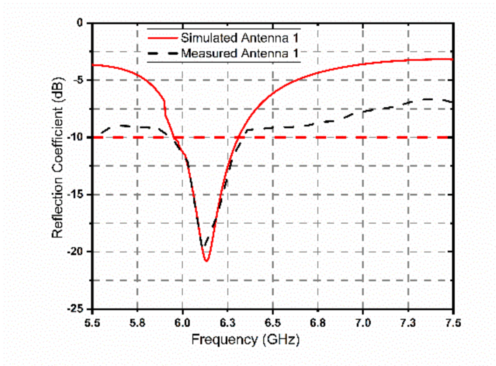

Figure. 11 Reflection coefficient versus frequency antenna 1

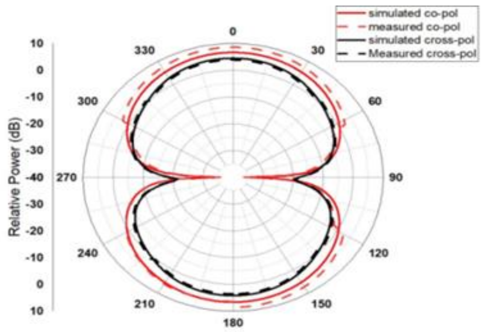

Figure. 12 2D radiation pattern E -the plane of antenna 1

Table 3. Proposed antenna parameters without & with SMSR

Antenna Parameters	Simulated Without SMSR	Measured Without SMSR	Simulated With SMSR	Measured With SMSR
Return Loss (dB)	20.8	19	47.5	46
E-plane co-pol E-plane cross-pol (dB)	109.84^0 97.95^0	105.44^0 93.35^0	110.83^0 108.21^0	108.43^0 102.11^0
H-plane co-pol H-plane cross-pol (dB)	70.68^0 45.34^0	68.58^0 42.24^0	68.46^0 44.18^0	64.36^0 43.8^0
Gain (dB)	5.5 - 8.75	6 - 8.4	7.25 – 9.75	7.5 – 9.4
Radiation efficiency (%)	91	88	92	90

structure covered a single frequency band, i.e., simulated 5.95GHz – 6.3GHz. With a fractional bandwidth of 5.71 % and measured 5.94 GHz - 6.32 GHz with fractional bandwidth of 6.19%.

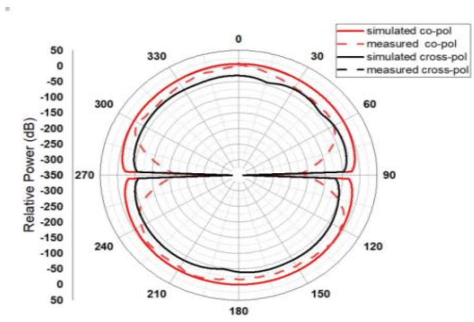

Figure. 13 2D radiation pattern H -the plane of antenna 1

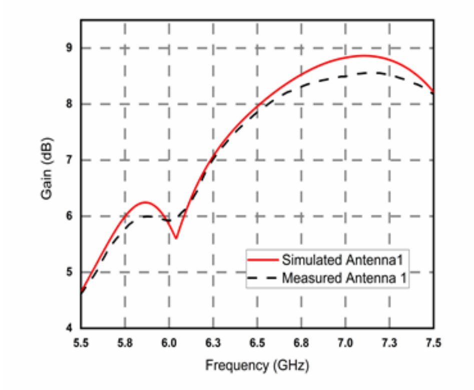

Figure. 14 The gain of antenna 1

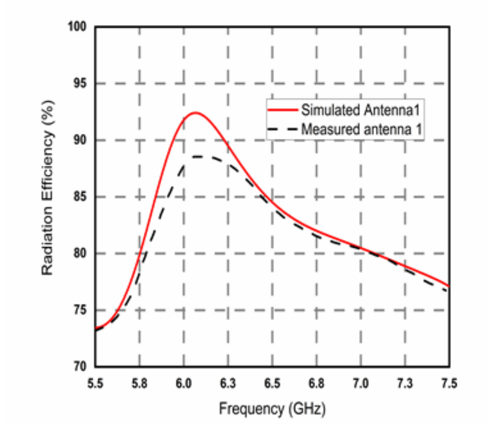

Figure. 15 The radiation efficiency of antenna 1

6. Results and discussions

The proposed compact rectangular dielectric resonator antenna with SMSR resonated at 6.2GHz, covering the applications in the C band. It can be used to track RADAR and wireless communications. Both antennas results simulated and measured are presented in Table 3. The measured and simulated results of Antenna 1's antenna parameters are presented in Figs. 13–15. The measured and simulated results of antenna 2's antenna parameters are presented in Figs. 18–20. In Table 4. The present work is compared with other researcher's works.

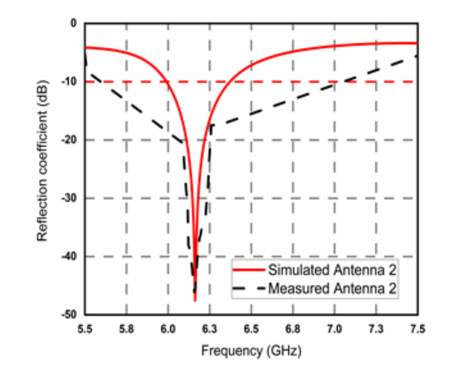

Figure. 16 Reflection coefficient versus frequency

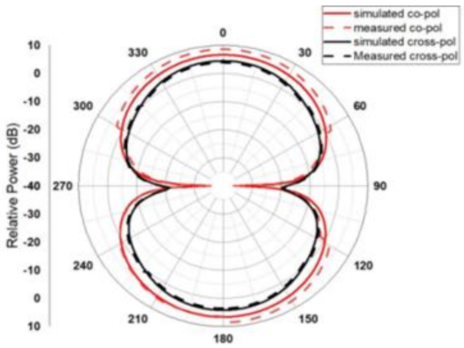

Figure. 17 the E plane of Antenna 2's2D radiation pattern

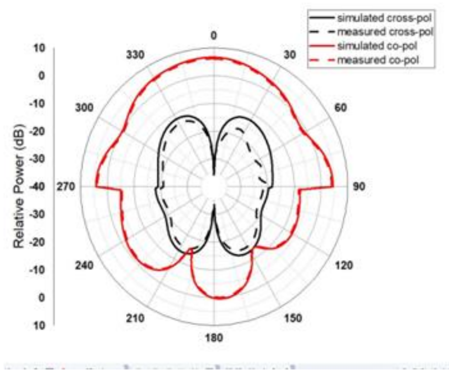

Figure. 18 2D radiation pattern H plane of antenna 2

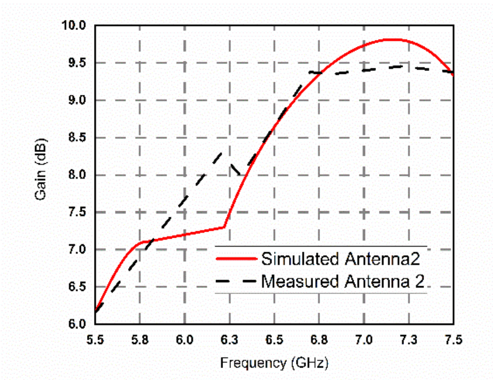

Figure. 19 The gain of antenna 2

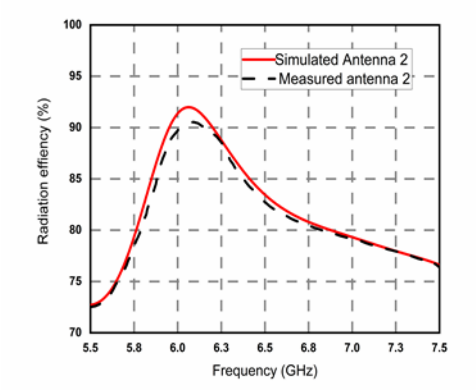

Figure. 20 The radiation efficiency of antenna 2

Table 4. The comparisons of the proposed SMSR work with previous research works

Year /Ref.No	**Type of Antenna**	**Substrate size (mm^3)**	**IMBW (%)**	**3dB HPBW (E-plane & H-plane**	**Gain (dB)**
2020 [10]	Step-walled RDRA	61x61x2 mm^3	22.80%	149^0 125^0	5.6
2021 [26]	RDRA	76x76x1.52 mm^3	7.29%	71^0 115^0	7.1
2021 [27]	RDRA	5.76x5.76x0.254 mm^3	4.07%	-	8.04
2022 [28]	RDRA	50x50x0.813 mm^3	5.5%	234^0 140^0	2.5
2022 [29]	RDRA	13.2x10x0.254 mm^3	11.5%	78^0 74^0	7.85
2022 [30]	RDRA	80x80 mm	10%	-	6.2
Proposed work	RDRA	46x46x1.6 mm^3	19.6%	108.43^0 64.36^0	9.4

6.1 Antenna parameter 3dB beamwidth

Fig. 12 shows the far-field 2D pattern is like a figure of eight, and simulated and measured co –polarization 3 dB beam widths are $109.84^0$and 105.44^0, and simulated and measured cross-polarization 3 dB beam widths are 97.95^0 and 93.55^0, respectively. Fig. 13 shows the 2D far-field pattern is Omni directional in H-plane, simulated and measured co –polarization 3 dB beam widths are 70.68^0 and 68.58^0, and simulated and measured cross-polarization 3 dB beam widths are 45.34^0 and 42.24^0, respectively. Fig. 17 shows a far-field radiation pattern simulated and measured in E-plane co–polarization 3 dB beam widths are 110.83^0 and

108.43^0, and simulated and measured cross-polarization 3 dB beam widths are 108.21^0 and 102.11^0, respectively. Fig. 18. shows a far-field pattern in H-plane co –polarization 3 dB beam width simulated 68.46^0 and the and cross-polarization 3 dB beam width simulated 44.18^0 and measured 43.10^0, respectively. Thus the proposed antenna counterpart, the 3dB beamwidth.

6.2 Antenna parameter gain

Fig. 14 shows antenna 1simulated gain is 5.65dB – 7.5 dB in the frequency band 6.0GHz – 6.35 GHz, and the measured Gain is 5.9dB – 7.85dB. Fig. 15 shows simulated, and measured radiation efficiencies are 92 % and 88 % of the proposed antenna 1, which evidences that the proposed antenna is an efficient radiator. The SMSR technique with a designed E-shape feed is employed in this paper enhanced Gain. Fig. 20 shows simulated and measured radiation efficiencies are 92 % and 90 %, which evidences that the proposed antenna 2 is an efficient radiator. Fig. 19 shows simulated Gain is 7.25-9.75 dB and the measured gain of 7.5-9.4 dB of antenna 2. The gain improved with SMSR technology.

6.3 Antenna parameter impedance bandwidth

Fig. 16 shows that proposed antenna 2 covers a single frequency band, simulated 5.82 GHz – 7.0 GHz. with a fractional bandwidth of 18.4 %, and measured 5.75 GHz to 7.0 GHz with fractional bandwidth of 19.6 %. The bandwidth improved in C-band applications.

7. Conclusions

The compact rectangular dielectric resonator antenna (RDRA) with a surface-mounted short rectangle (SMSR) having an E- shaped microstrip feed of wide aperture slot has been investigated for improvement of desirable. It is rugged and suitable for all pressure conditions due to the low permittivity substrate and small size. It is evident that compact rectangular dielectric resonator antenna (RDRA) with a surface-mounted short rectangle (SMSR) having an E- shaped microstrip feed of wide aperture slot, as studied in this research endeavor, are extensively suitable for tracking Radar in C-band. It has been established that SMSR integrated RDRA antenna 2 with substrate size 46x46x1.6 mm^3, optimized dimensions operating in the frequency band 5.75 GHz – 7 GHz, C –Band enhanced Gain of 9.4 dB. It improved return loss of -47 dB, with an impedance bandwidth of 19.6 %, high efficiency of 90 %, and beam widths at 3 dB in E plane $109.43^0$and H-plane 64.36^0. Furthermore, the antenna is best suitable for wireless communications due to its counterparts the antenna parameters.

Conflicts of Interest

Satya Anuradha M was principle investigator, Professor in the Department of ECE, Andhra University, declares no conflict of interest. Syamala M, research scholar, Andhra University, declares no conflict of interest. All authors declare no conflict of interest.

Author Contributions

The proposed work directed and coordinated by Satya Anuradha M, and provided conceptual and technical guidance for all aspects. Syamala M was the principle investigator. planned methodology, configured and designed, simulated results by using HFSS software. To validate simulated results, the measured results are carried out in anechoic chamber at KL University, Guntur. The original draft prepared by Syamala M, it was edited and supervised by Satya Anuradha M. The total work was funded by their own.

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References

[1] K. Rajkishor, Nasimuddin, and C. R. Kumar, “Wideband circularly polarized hybrid dielectric resonator antenna with bi-directional radiation characteristics for various wireless applications”, *R.F. and Microwave Computer Aided Engineering*, Vol. 29, pp. 1-10, 2019.

[2] G. Anshul and G. R. Kumar, “Dual-Band Circularly Polarized Aperture Coupled Rectangular Dielectric Resonator Antenna for Wireless Applications”, *IEEE Access*, Vol. 6, pp. 11388-11396, 2018.

[3] Nasimuddin and E. Karu, “Gain Enhancement of a Dielectric Resonator Antenna with use of Surface Mount Short Horn”, *Microwave and Optical Technology Letters*, Vol. 49, No. 5, pp. 1162-1166, 2007.

[4] A. Mohammad, O. Homayoon, and S. K. A. Rahim, “Wideband Rectangular Dielectric Resonator Antenna for low-profile applications”, *IET Microwaves, Antennas &*

Propagation, Vol. 12 Issue. 1, pp. 115-119, 2017.

[5] W. X. Chuan, S. L. Lin, and W. Zhong, “Single-Feed Dual-Band Circularly Polarized Dielectric Resonator Antenna for CNSS Applications”, *IEEE Transactions on Antennas and Propagation*, Vol. 2, pp. 1-6,2017.

[6] K. Rajkishor and C. R. Kumar, “Modified Microstrip line-fed Rectangular Dielectric Resonator Antenna with the slotted ground plane for wide circular polarization”, *Microwave and Optical Technology Letters*, Vol. 58, No. 1, pp. 206-210, 2016.

[7] Z. Z. Yuan, and W. K. Li, “Wideband Dual Polarized Dielectric Magneto Electric Dipole Antenna”, *IEEE Transactions on Antennas and Propagation*, Vol. 66, No. 10, pp. 5590-5595, 2018.

[8] F. Saeed, O. Homayoon, and M. Ladislau, “High Gain Rectangular Dielectric Resonator Antenna using Uniaxial Material at Fundamental Mode”, *IEEE Transactions on Antennas and Propagation*, Vol. 1, pp. 1-6, 2016.

[9] K. Rajkishor and C. R. Kumar, “Stacked Rectangular Dielectric Resonator Antenna with different volumes for wideband circular polarization coupled with step-shaped conformal strip”, *R. F. and Microwave Computer Aided Engineering*, pp. 1-8, 2019.

[10] S. H. H. Mashhadi, J. Y. Chang and C. Jingdong, “Wide 3 dB beamwidth step walled Rectangular Dielectric Resonator Antenna”, *Electromagnetic Waves and Application*, pp. 1-3, 2020.

[11] G. Anshul and G. R. Kumar, “Hybrid Rectangular Dielectric Resonator Antenna for Multiband Applications”, *IETE Technical Review*, pp. 1-8, 2019.

[12] W. Fan, Z. Chuanfang, and X. Yu, “Ultra Wideband Dielectric Resonator Antenna Design Based on Multilayer For”, *IEEE Transactions on Antennas and Propagation*, pp. 1-10, 2019.

[13] A. A. Rahman, A. K. Verma and A. S. Omar, “High Gain Wideband Compact Microstrip Antenna with Quasi Planner Surface Mount Horn”, *IEEE MTT-S International Microwave Symposium Digest*, Vol. 1 pp. 571–574**,** 2003.

[14] F. X. Sheng and L. K. Wa, and L. E. Hock, “Singly-Fed Dual-Band Circularly Polarized Dielectric Resonator Antenna”, *IEEE Transactions on Antennas and Propagation Letters*, Vol. 13, pp. 995-998, 2014.

[15] F. X. Sheng and L. K. Wa, “Linear- Circular-Polarization Designs of Dual-/Wide-Band Cylindrical Dielectric Resonator Antennas”, *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 6, pp. 2662-2671, 2012.

[16] M. H. Seko, F. S. Correra, and S. A. Long, “Microstrip Feeding for the Excitation of a higher-order Resonant mode in Cylindrical Dielectric Resonator Antenna”, *In. Proc.of SBMO/IEEE MTT-S, International Microwave, and Optoelectronic Conference (IMOC*), AguaselIndoia. Razil. 2017.

[17] P. E. Karu and S. B. Trevor “Hybrid-Resonator Antenna Experimental Results”, *IEEE Transactions on Antennas and Propagation*, Vol. 53, No. 2, 2005.

[18] F. X. Sheng and C. S. Ming, “Design of the Wide Dual-Band Rectangular Souvenir Dielectric Resonator Antenna”, *IEEE Access*, Vol. 7, pp. 161621-161629, 2019.

[19] K. Rajkishor and C. R. Kumar, “A Wideband Circularly Polarized Cubic Dielectric Resonator Antenna Excited with Modified Microstrip Feed”, *IEEE Antennas and Wireless Propagation Letters*, pp. 1-4, 2015.

[20] F. Saeed, O. Homayoon, and F. Saeed, “Gain Improvement of Rectangular Dielectric Resonator Antenna by Engraving Grooves on its Side Walls”, *IEEE Antennas and Wireless Propagation Letters*, pp. 1-4, 2017.

[21] P. Y. Mei, H. P. Fei, L. K. Wa, and Z. X. Yin, “Compact Single Dual Polarized Filtering Dielectric Resonator Antennas”, *IEEE Transactions on Antennas and Propagation*, pp. 1-4, 2018.

[22] G. Anshul and G. R. Kumar, “New excitation scheme to excite higher order radiating modes in rectangular dielectric resonator antenna for microwave applications”, *Microwave Power and Electromagnetic Energy*, pp. 1-12, 2018.

[23] U. Illahi, J. Iqbal and M. H. Jamaluddin, “Singly-Fed Rectangular Dielectric Resonator Antenna with a Wide Circular Polarization Bandwidth and Beamwidth for WiMAX/Satellite Applications”, *IEEE Access*, Vol. 7, pp. 66206-66214, 2019.

[24] K. Rajkishor, T. S. Reddy, and C. R. Kumar, “A New Dual mode Wideband Circularly Polarized Dielectric Resonator Antenna”, *IEEE Transactions on Antennas and Propagation*, pp. 2-10, 2019.

[25] A. Rashidian, L. Shafai, and M. K. David, “Compact Wideband Multimode Dielectric Resonator Antennas Fed With Parallel Standing

Strips", *IEEE Transactions on Antennas and Propagation*, Vol. 60, No. 11, pp. 5021-5031, 2012.

[26] M. Elahi, A. Altaf, and K. C. Hwang, "Circularly Polarized Dielectric Resonator Antenna with Two Annular Vias", *IEEE Access*, Vol. 9, pp. 41123-41128, 2021.

[27] G. Abinash, M. H. Jamaluddin, and A. A. Althuwayb, "Circular Patch Fed Rectangular Dielectric Resonator Antenna with High Gain and High Efficiency for Millimeter Wave 5G Small Cell Applications", *Sensors*, Vol. 2694, pp. 1-19, 2021.

[28] B. Zhang, J. Ren, and Y. Yingzeng, "Design of Dielectric Resonator Antenna Array with Wide-Angle Scanning Based on Dual Magnetic Currents", *IEEETransactions on Antennas and Propagation*, pp. 1-11, 2022.

[29] M. Chaojun, Z. S. Yong, and Z. Chen, "Millimeter-Wave Fully Integrated Dielectric Resonator Antenna and Its Multi Beam Application", *IEEETransactions on Antennas and Propagation*, Vol. 70, No. 8, pp. 6571-6580, 2022.

[30] U. Illahi, J. Iqbal and M. I. Sulaiman, "A Novel Design and Development of a Strip Fed Circularly Polarized Rectangular Dielectric Resonator Antenna for 5G NR Sub 6 GHz Band Applications", *Sensors*, Vol. 22, No. 553, pp. 1-16, 2022.