(Received 9 July 2023, Accepted 13 December 2023, Scheduled 24 December 2023)

A Novel Stacked Rectangular with Surface Mounted Short Rectangle Dielectric Resonator Antenna in C-Band Applications

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ABSTRACT: A novel stacked rectangular structure with surface-mounted short rectangle dielectric resonator antenna (SRSMSR) with an E-shaped microstrip feed through a wide aperture slot was investigated for C-band operation in wireless communication and tracking radar applications. The developed design uses copper for SMSR to improve return loss up to -46 dB, gain up to 10.7 dB, and an observed impedance bandwidth of 20.6% in the broad frequency range of 5.69 GHz–7.0 GHz. The 3 dB beamwidth achieved in the E-plane is 89.82°, while that in the H-plane is 24.31°.

Keywords: Stacked Rectangular Dielectric Resonator Antenna, Surface Mounted Short Rectangle, Aperture slot coupling, Microstrip feed, C-band

1. INTRODUCTION

Dielectric resonator antennas (DRAs) have a number of benefits, including simple excitation, minimal metallic losses, and high radiation efficiency. In the field of wireless communications, the requirement for higher data rates arises from the need to accommodate wide impedance bandwidth. A stacked rectangular dielectric resonator antenna (SR-DRA) [1] with a gain of 5.23 dB and a 10 dB impedance bandwidth of 13.57% is suitable for WLAN applications in the 5.0–5.72 GHz frequency range. A triangular dielectric resonator antenna (TDRA) [2] with a 10 dB impedance bandwidth of 22.92%, can be utilized in WLAN, mobile terrestrial, and aeronautical communication systems. A half-mode-backed cavity structure and dielectric-resonator antenna [3] achieved 7% impedance bandwidth, 6.2 dB gain, and 46% efficiency using standard CMOS technology. The metamaterial used in dual-segment [4] rectangular dielectric resonator antennas gives them a 32.8% impedance bandwidth and a peak gain of 10.22 dB for the C-band. A cylindrical dielectric resonator antenna (CDRA) [5, 6] has been developed to work in both dual-band and triple-band frequencies, making it suitable for applications such as monolithic manufacturing, WLAN, and WiMAX. A stacked rectangular dielectric resonator antenna [7, 8] with $\epsilon_r = 9.8$ achieved 12.2% and 21.7% impedance bandwidths with gains of 5.5 and 6.0 dBi, while a stacked antenna with $\epsilon_{r1} = 15$ and $\epsilon_{r2} = 2.2$ achieved 40% impedance bandwidth with a gain of 9 dBi. A dielectric resonator antenna is fed by a conformal strip [9] and a microstrip line. This gives radar applications a 23.14% impedance bandwidth and 6.4 dB gain. A wideband quarter cylindrical dielectric resonator antenna (q-CDRA) [10] with a probe feed and two segments had a bandwidth of 85.13%, a peak gain of 4.85 dB, and a radiation efficiency of 98.5%. A two-layer higher-order mode circular polarization (CP) RDRA [11] had 11 dB gain and 1.9% and 1.78% impedance bandwidths. A rectangular dielectric resonator antenna with dual-band properties was created using two sapphires [12] of the same dielectric constant but different sizes, achieving 26 dB return losses and 2.5 dB peak gains. A step-walled rectangular dielectric resonator antenna, [13] excited with microstrip feed through a slot, achieved a gain of 4.5 to 5.5 dB in the broad band. A rectangular dielectric resonator antenna (RDRA) [14, 15] with a parasitic patch provides 6.5 dB gain and 22.01% impedance bandwidth used for WIMAX applications, while a rectangular DRA with a circular patch provides a gain of 8.04 dB and an impedance bandwidth of 4.07%, making it suitable for indoor millimeter-wave 5G small cell applications. A stacked rectangular structure dielectric resonator antenna [16] is used with a U-shaped microstrip feed [16]. A C-band RDRA with a faulty ground structure [17] at 6.2 GHz is optimal for satellite uplink applications and has a fractional bandwidth of 12.14%, return loss of 30 dB, gain of 7.95 dB, and an efficiency of 91.5%. The RDRA is a suitable choice for applications in the 4–8 GHz C-band range, including telemetry, TV White Signal, weather RADAR, and GPS, as indicated by references [18–20].

The proposed stacked rectangular structure with a surface-mounted short rectangle operating at 6.2 GHz has a wide impedance bandwidth and high radiation efficiency. In this study, a single RDRA (Al_2O_3) with a value of 9.8 and an E-shaped microstrip feed achieved an impedance bandwidth of 20.6% and a high efficiency of 91.4%. There are five sections in the paper. The introduction is in Section 1. The design and geometry of the antenna are covered in Section 2.

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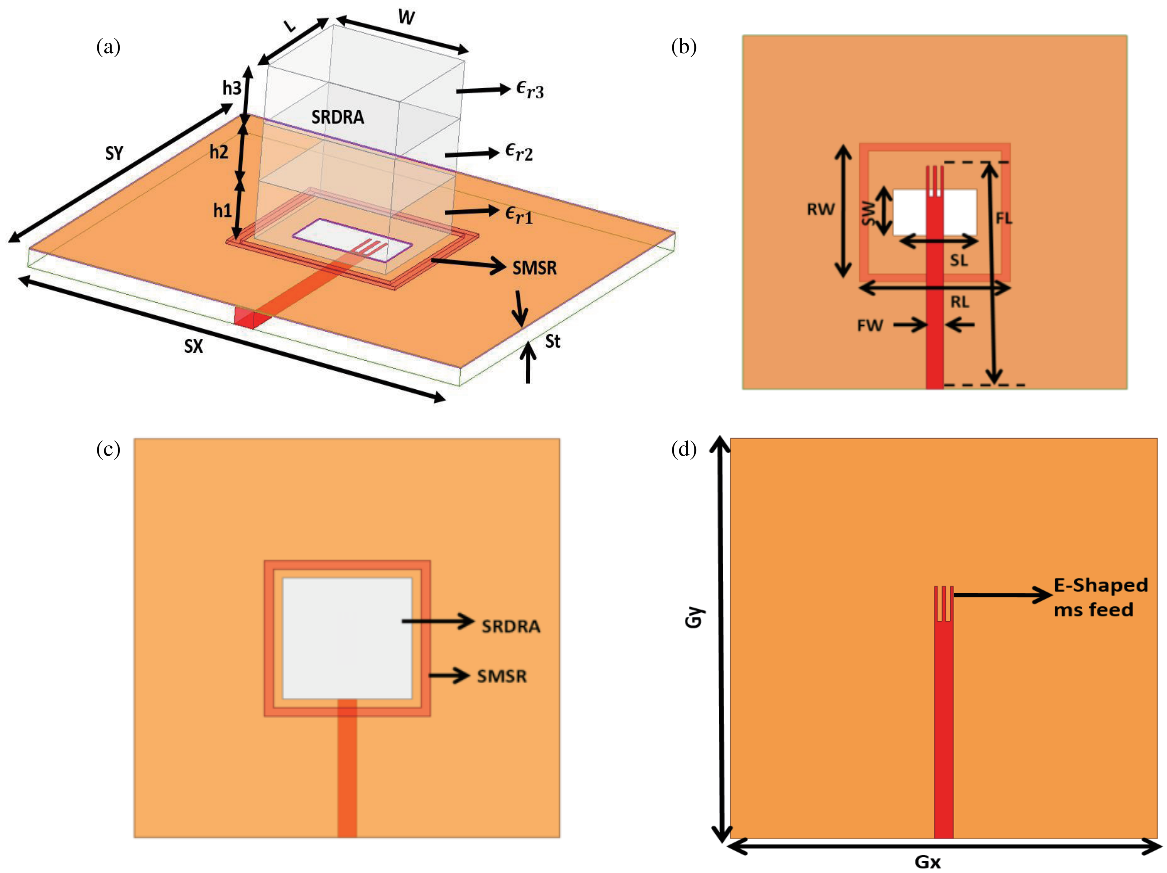

FIGURE 1. The Geometry of the proposed Antenna. (a) Isometric view. (b) Top view without SRDRA with aperture slot. (c) Top view SRDRA with SMSR. (d) Bottom view with E-shaped microstrip feed.

The operational principle and design calculation are shown in Section 3. The simulated and measured results of the proposed antenna are discussed in Section 4, and the conclusion is provided in Section 5.

2. GEOMETRY OF AN ANTENNA

The geometry of an stacked rectangular surface mounted short rectangle (SRSMSR) dielectric resonator antenna is illustrate in Figure 1. It is made of high permittivity ceramic material. There are three ceramic dielectric sheets stacked on top of each other in the pattern shown in Figure 1(a). The dielectric sheets have the same permittivity values, which are written as ϵ_{r1}, ϵ_{r2}, and ϵ_{r3}. They are also known by their thicknesses, which are $h1$, $h2$, and $h3$. The ceramic materials utilized in this configuration demonstrate a notable permittivity, characterized by a relative permittivity ($\epsilon_{SDRA} = 9.8$) and a loss tangent ($\tan\delta = 0.002$). The three ceramic dielectric layers are joined together through the application of an adhesive material. The substrate layer underlying the stacked ceramic layers is composed of a flame-retardant epoxy substrate (*FR4*). The substrate being examined possesses a relative permittivity ($\epsilon_S = 4.4$) and a loss tangent ($\tan\delta = 0.02$). The substrate serves as a support platform with a thickness of *st*, featuring a surface-mounted short rectangle, SMSR, on the substrate's top surface and a wide aperture and direct feed line on its bottom surface. An integrated rectangular DRA powers a quasi-planar surface-mounted short horn (SMSH) [18] made of copper blocks with a ground-mounted rectangular coupling slot. The effectiveness of this structure on antenna gain is demonstrated in [18, 19]. The impedance bandwidth and gain are further improved by a stacked rectangular structure with surface-mounted short rectangle (SRSMSR). The energy fields are coupled into the SRSMSR DRA through a broad aperture slot. The aperture slot has dimensions *SL* and *SW*. The ground and substrate have the same size $Sx \times Sy$. The SRSMSR DRA is stacked by combining three (5 mm thick) ceramic plates and placing an air gap between the stacked DRA and ground plane to obtain the required height.

3. OPERATIONAL PRINCIPLE

Figure 1 illustrates a rectangular dielectric resonator antenna (RDRA) that is aperture-coupled and designed with a low profile using a high permittivity ceramic material. The aperture is perpendicular to both the microstrip line and the DR longer dimension (i.e., the 10 mm side is in the y direction). A broad aperture slot connects the SRSMSR DRA, and a specially con-

TABLE 1. Parameters of the proposed antenna stacked DRA with SMSR.

S. No	Name of the parameter	Specification of Parameter	Specification value (mm)
1.	Height in SDRA $h1 = h2 = h3$	*Ht*	15
2.	Width/length SDRA	*2R*	14
3.	Substrate Thickness	*St*	1.5
4.	width of Slot	*SW*	6
5.	length of Slot	*SL*	10
6.	Length of Substrate	$Sx = Sy$	46
7	Length of Ground	$Gx = Gy$	46
8	feed length	*FL*	29
9	feed width	*FW*	2
10	Length/width of SMSR	$RL = RW$	16
11	Rectangle thickness of the SMSR	*Ws*	2

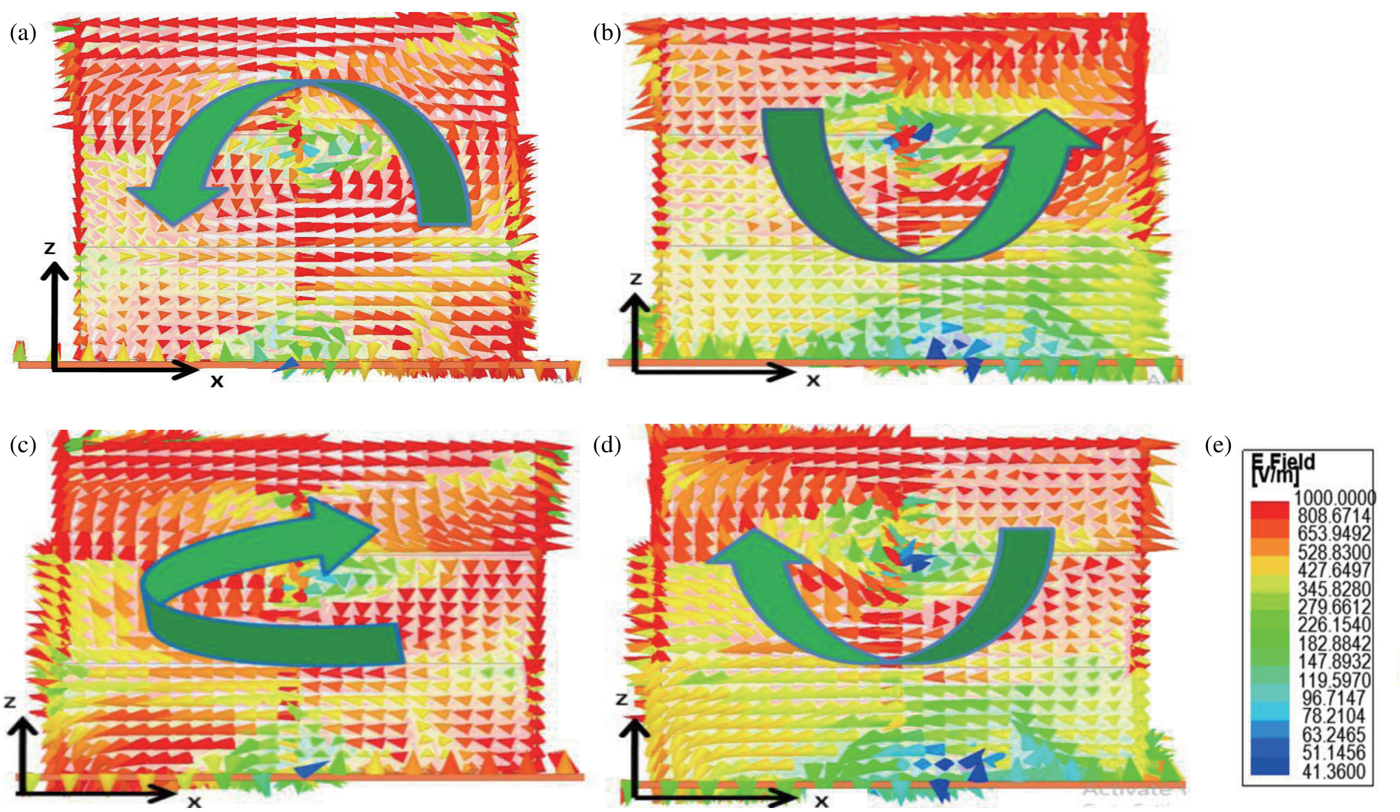

FIGURE 2. Left side view of the Antenna E-field distribution (a) Phi = 0° (b) Phi = 90° (c) Phi = 180° (d) Phi = 270° (e) Scale for a, b, c & d at 6.2 GHz.

structed microstrip line supplies power. The surface-mounted short rectangle (SMSR) improves the gain through which the energy fields couple into the integrated stacked DRA. The ground plane has an etched rectangular aperture of 10 mm × 6 mm, through which a 50-Ω microstrip line feeds it. The aperture will act like a magnetic monopole parallel to the x-axis. After the DRA stacks are adhered to the ground plane with gum (adhesive), an air gap forms between the stacks. The RDRA is constructed utilizing a high ceramic material possessing a relative permittivity value of 9.8. The relative permittivity values are typically within the range of 5 to 12. The greater values of 12 are not good for high gains. The wideband characteristics can be observed in CDRA with a ratio of height to radius greater than 2 [20]. The length to height ratio of this proposed SRSMSR DRA is around unity, whereas the length to height ratio of the original RDRAs is 2 [21]. The antenna parameters are as shown in Table 1.

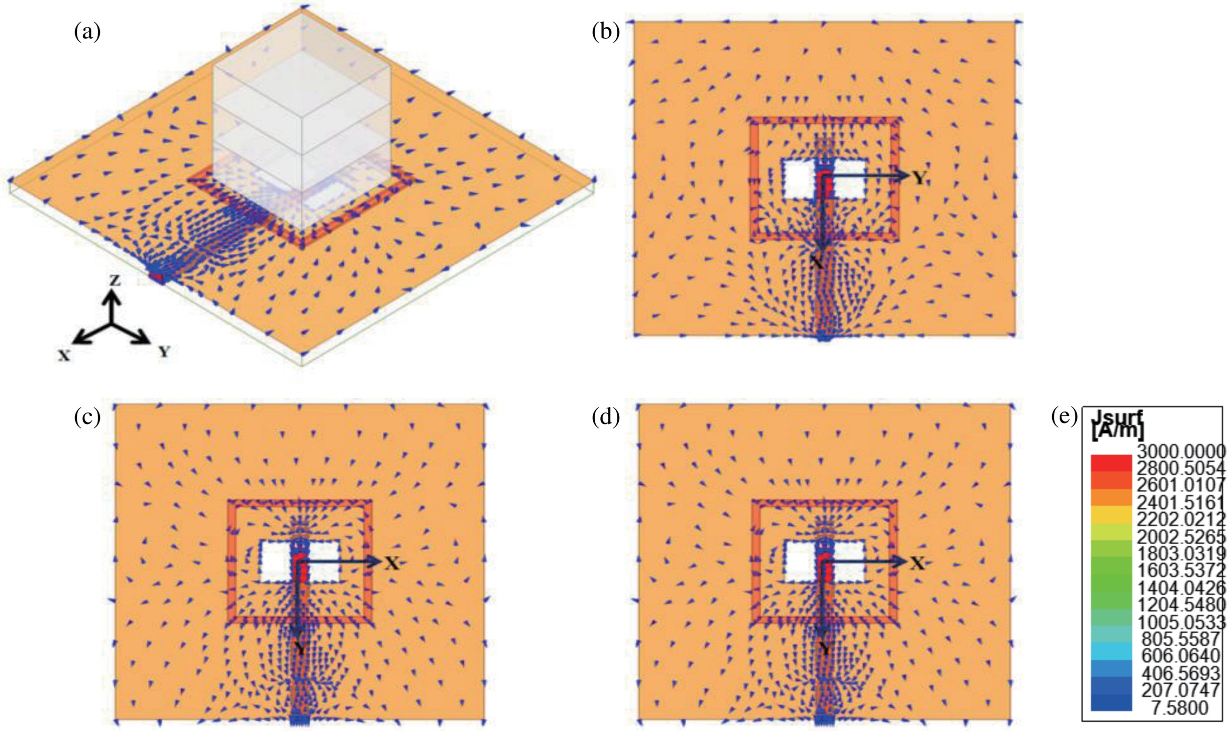

FIGURE 3. Antenna current distribution on surface. (a) 3D view *(XYZ)* Phi = 0°. (b) Top View (*XY*) Phi = 90°. (c) Top view (*XY*) Phi = 180°. (d) Top view (*XY*) Phi = 270°. (e) Scale for a, b, c & d at 6.2 GHz.

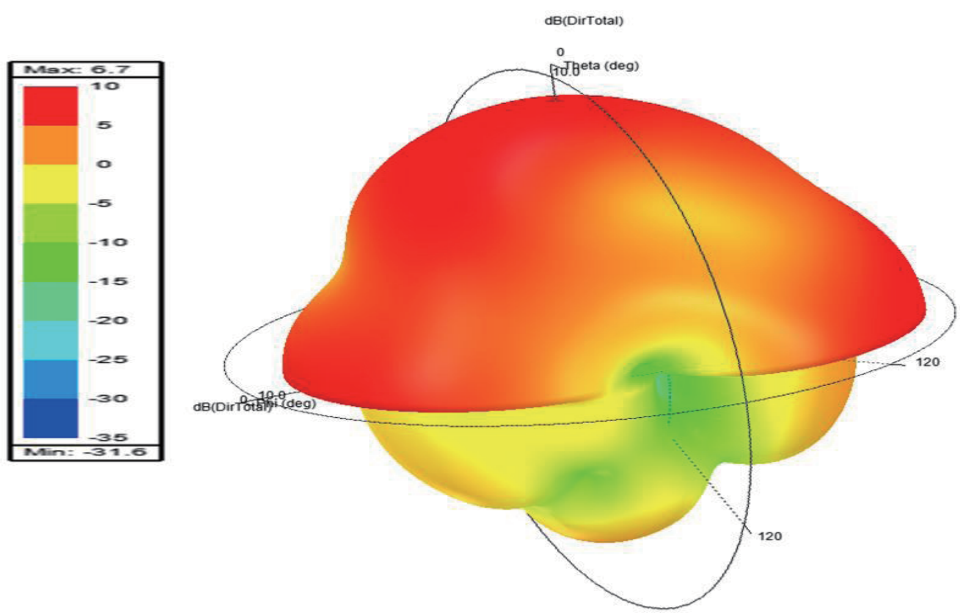

FIGURE 4. 3D proposed antenna's radiation far-field pattern.

The initial dimensions of the SRSMSR resonant frequency, as derived by the following formulas, are shown in [21].

$$F_r = \frac{397}{2\pi R}\left(c_{o^R}\right) \quad (1)$$

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

$$k = \frac{R}{2 * Ht}$$

where $Ht = 3*$ height of ceramic plate $= 3 * 5\,\text{mm} = 15\,\text{mm}$. For the resonant frequency 6.2 GHz, the dimensions of the SRDRA are optimized in this paper. l = length or width of RDRA = 14 m, $R = l/2 = 7\,\text{mm}$. Height of ceramic plates, $h1 = h2 = h3 = 5\,\text{mm}$. Substrate dielectric constant

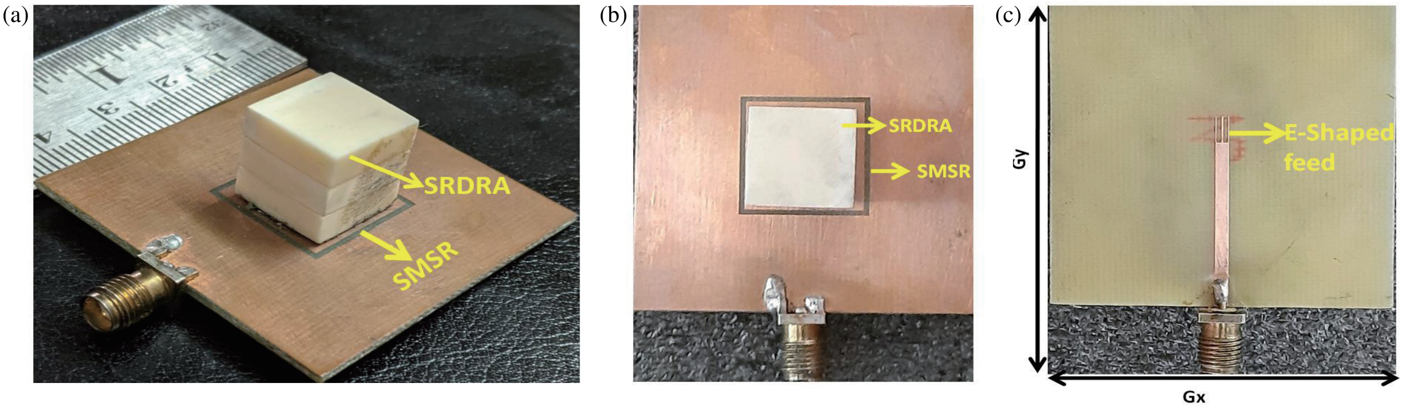

FIGURE 5. (a). 3D view of proposed antenna. (b) Top view with SMSR and SRDRA. (c) Bottom view with E-shaped microstrip feed.

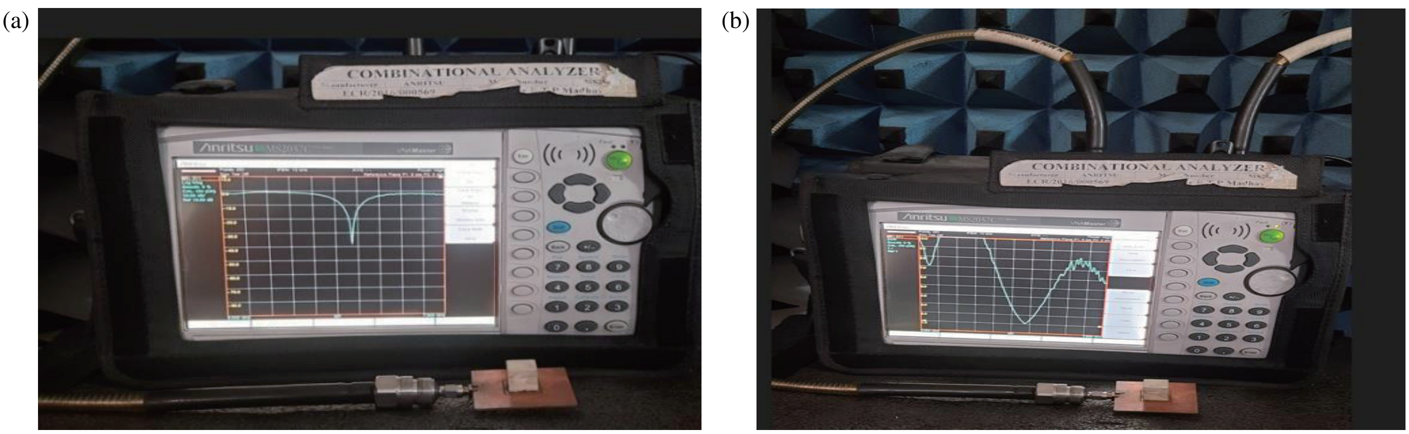

FIGURE 6. SRSMSRDRA. (a) Reflection coefficient measurement setup. (b) Measurement setup VSWR.

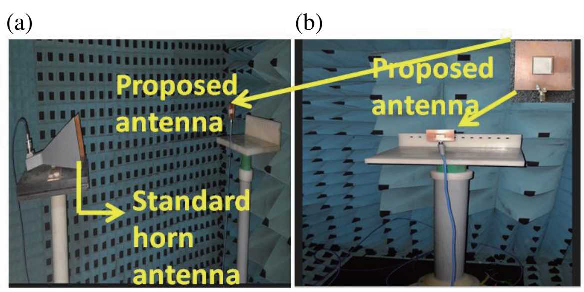

FIGURE 7. Gain and far-field measurements set up with SRSMSR DRA (a) & (b).

$\epsilon_{SDR} = 9.8$, $\epsilon_{SDR}^{0.42} = 2.608$. $k = 0.233$ for $Ht = 15$ mm & $l = 14$ mm. Then the resonant frequency $F_r = 6.2$ GHz.

Using equations developed by the presented dielectric waveguide model (DWM) [21], the design dimensions of the RDRA were established.

$$K_x \tan K_z \frac{d}{2} = \sqrt{(\in_1 -1)\, K_0^2 - K_x^2} \tag{3}$$

where $K_x = \sqrt{\in_{r1}\, K_0^2 - K_y^2 - K_z^2}$, $K_z = \frac{\pi}{h_1}$; $K_y = \frac{\pi}{R}$; $K_0 = \frac{2\pi f_0}{c}$, $C = 3 \times 10^8$ m/s.

The DWM equations were changed by substituting effective height (h) and effective permittivity (ϵ_{eff}) for slab 1's dielectric constant ($\in_{r1}$) and height ($h1$), respectively. This was done to account for the effect of identical dielectric materials on the resonant frequency of the stacked RDRA. The height of the slabs added together is the stacked RDRA's effective height.

$$Ht = h_1 + h_2 + h_3 \tag{4}$$

The effective permittivity is calculated using

$$\in_{eff} = \frac{\in_{r1} + \in_{r2} + \in_{r3}}{3}$$

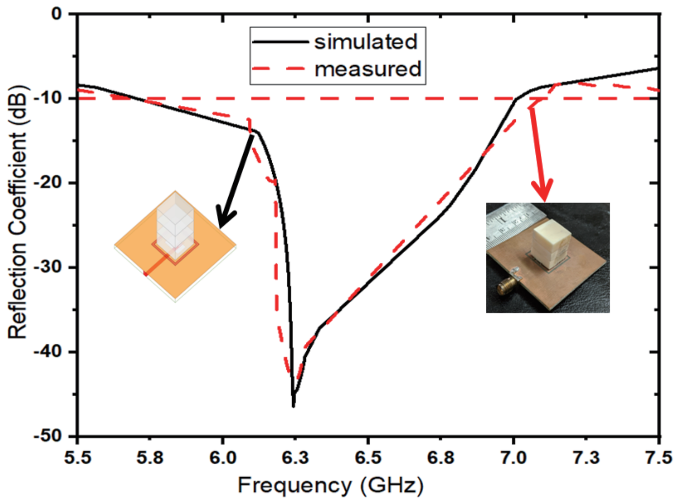

FIGURE 8. Reflection coefficient versus frequency.

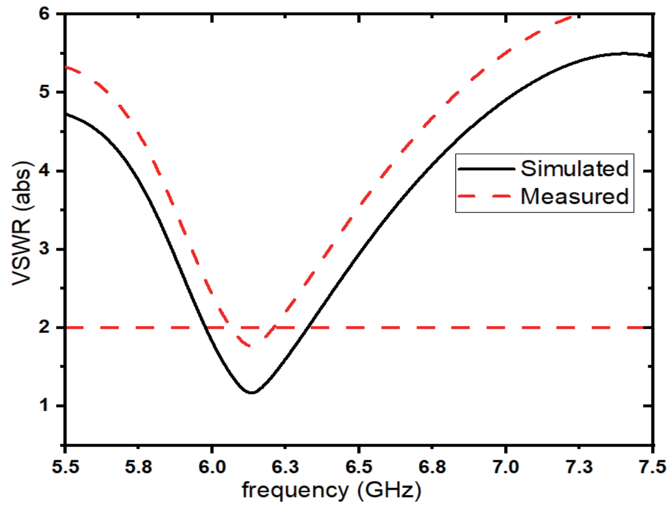

FIGURE 9. VSWR versus frequency.

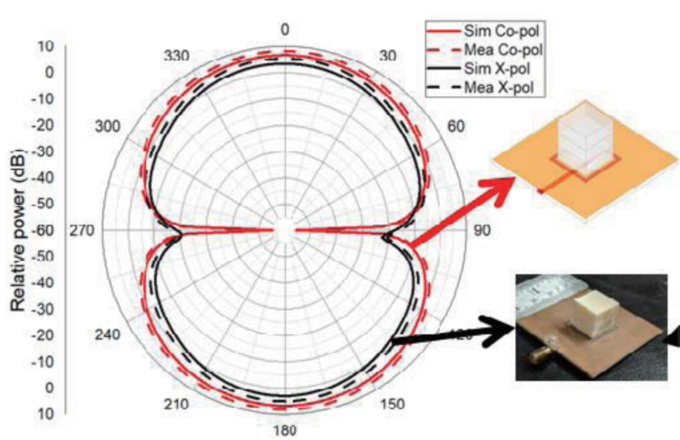

FIGURE 10. 2D radiation pattern (E-plane).

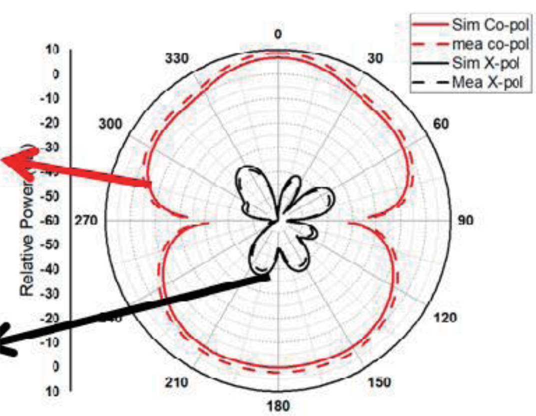

FIGURE 11. 2D radiation pattern (H-plane).

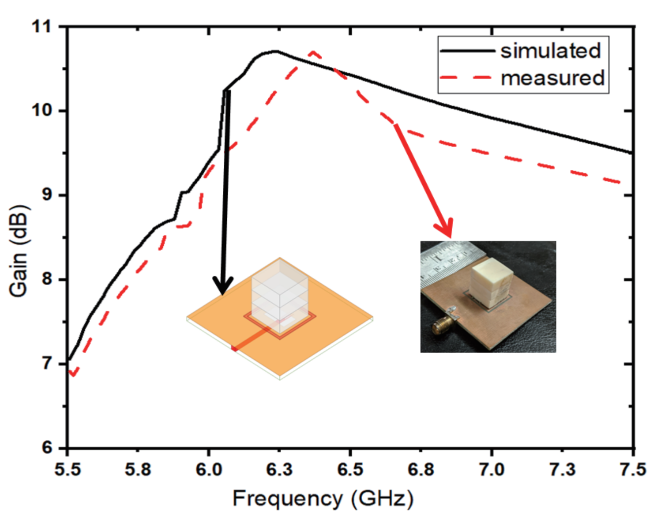

FIGURE 12. Gain versus Frequency.

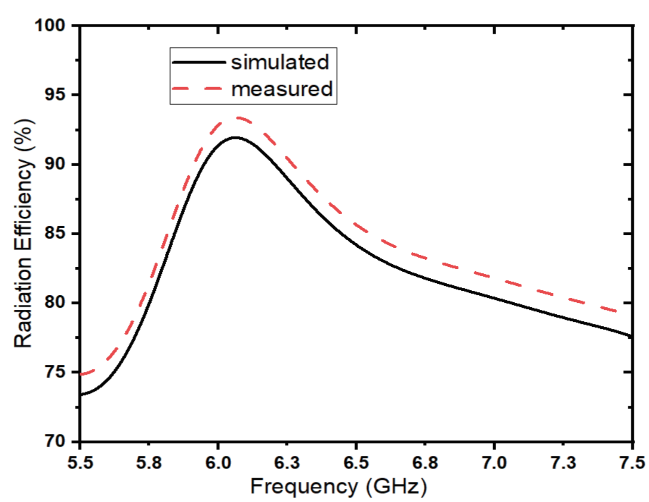

FIGURE 13. Radiation efficiency versus Frequency.

TABLE 2. Comparison of the bandwidth of an impedance-fabricated Antenna measured with simulated.

Measured and Simulated	Resonating frequency (GHz)	Range of frequency (GHz)	% Impedance Bandwidth
Measured	6.125	5.68–7.05	21.5%
HFSS	6.24	5.69–7.0	20.6%

TABLE 3. Simulated and Measured parameters of designed antenna.

S. No	Parameters of Antenna	Simulated	Measured
1	Reflection coefficient (dB)	46.4	42.74
2	VSWR	1.3	1.7
3	3 dB beam width (dB) E-plane co-polarization 3 dB beam width (dB) E-plane cross-polarization	89.82° 76.54°	91.21° 78.64°
4	3 dB beam width (dB) H-plane co-polarization 3 dB beam width (dB) H-plane cross-polarization	39.96° 24.31°	42.98° 26.45°
5	Gain (dB)	10.7	10.5
6	Radiation efficiency (%)	89.8 %	91.4%

Figure 2 shows the proposed antenna's near-E field distribution after the E-shaped microstrip feed is excited. The phase difference between Figures 2(a)–(d) is 90°. It has been noticed that the modes are moving in both clockwise and anticlockwise directions. Figure 3 depicts the surface current distribution of the proposed antenna. The proposed antenna's surface current distribution is shown in Figure 3. The current is primarily focused on the E-shaped microstrip feed line. Figures 3(a), (b), (c) & (d) show the surface current distributions of the isometric view and the top view with DRA. The current is moving in the ground plane and along the edges of the surface mount short rectangle (SMSR). The current mainly focuses on the E-shaped microstrip feed line, and it is observed within the DRA. It is noticed that the electric field and surface current movements are uniform. Figure 4 shows the three-dimensional radiation far-field pattern of the proposed antenna stacked with SMSR simulated by Ansoft HFSS at 6.2 GHz. Electric field and surface current motions are shown to be uniform.

4. ANALYSIS OF ANTENNA

4.1. Measurement of Reflection Coefficient and VSWR

Figure 5 depicts the proposed antenna after fabrication (a) SRSMSR with DRA isometric view, (b) SRDRA with SMSR top view, (c) back view with E-shaped microstrip feed. To validate the optimized simulated results, the measurement setup for reflection is shown in Figure 6(a). The proposed antenna's reflection coefficient characteristic is extracted using the Anritsu vector network analyser, model number VNA MS2037C (5 kHz–15 GHz). To determine the designed antenna's voltage standing wave ratio (VSWR) characteristic, Figure 6(b) is used. A comparison between simulated and experimental results is shown in Table 2. It has been established that the suggested antenna structure is operated with a fractional bandwidth of 21.5% in a single frequency band, particularly 5.68–7.05 GHz. In order to calculate the fractional bandwidths, the center frequency is taken into consideration. The results from simulation and measurement are in good agreement. However, some discrepancies between the results of simulation and measurement may be brought on by the interaction between an adhesive and an SMA (subminiature version A 50 Ω) connector. A typical waveguide horn antenna (1 GHz–40 GHz) is used to assess the proposed antenna's gain and far-field measurements in an anechoic chamber using the key sight signal generator N5173 B, as shown in Figures 7(a) & (b).

Ground plane features include a large aperture slot and the projected SRSMSR DRA. As a monopole current element, the aperture slot energizes the magnetic field into DRA, producing incorrect radiation. DR height, length, breadth, and dielectric material affect antenna characteristics. By using parametric analysis, the dimensions are optimized. At an SRDRA height of 15 mm and a resonant frequency of 6.2 GHz, the observed value of return loss is high. The simulated parameters of the proposed antenna are shown in Table 3.

TABLE 4. The Comparisons of the proposed SRSMSR DRA work with the previous researcher's works.

Ref.no	Type of Antenna	Feed mechanism	10 dB IMBW (%)	Gain (dB)	Efficiency (%)
13	SWRDRA	MS feed	22.80 %	5.6	NA
16	SRDRA	Ms feed	13.95 %	5.9	91 %
17	RDRA With DGS	MS feed	12.24%	7.95	90%
18	RDRA with SMSH	MS feed	3.2%	8.5	NA
19	RDRA with SMSR	Ms feed	19.6 %	9.4	90 %
PW	SRDRA with SMSR	Ms feed	21.5 %	10.7	91.4 %

5. RESULTS AND DISCUSSIONS

In order to validate the simulation results of the antenna, it is necessary to assess the reflection coefficient and the antenna's performance. The measurement of the reflection coefficient was conducted using the Anritsu VNA MS2037C (5 KHz–15 GHz), and the results are depicted in Figure 8. The outcomes of the antenna, both simulated and measured ones, are displayed in Tables 2 and 3. The antenna has an impedance bandwidth of 21.5% within the frequency range of 5.68 GHz to 7.05 GHz, utilizing a 50 Ω microstrip feed line as the feeding mechanism. Figure 9 depicts the value of VSWR as 1.7. The E-plane and H-plane radiation patterns are illustrated in Figures 10 and 11, respectively. The measurement of the antenna gain and efficiency for the proposed SRSMSR DR is conducted utilizing a reference horn antenna spanning the frequency range of 1 GHz to 40 GHz. This measurement setup is illustrated in Figures 12 and 13, where a typical waveguide horn antenna is also employed. The gain of the antenna throughout the frequency band spanning from 5.68 GHz to 7.05 GHz is measured to be 10.5 dB. An antenna is a device used in the field of telecommunications to transmit or receive electromagnetic waves. The effectiveness of an antenna within the frequency range of 5.5 to 7.5 GHz has been measured to be 91.4%. The findings of the simulated and observed return loss exhibit a high level of concurrence, but with some marginal disparities attributable to fabrication tolerances.

6. CONCLUSIONS

A new stacked rectangular structure with a surface-mounted short rectangle (SRSMSR) dielectric resonator antenna with an E-shaped microstrip feed and wide aperture slot has been looked into in order to improve desired characteristics. A comparison of the designed SRSMSR work with other research works is made, as shown in Table 4. The (SRSMSR) Dielectric Resonator Antenna, which had a small size of $46 \times 46 \times 1.6\,\text{mm}^3$, operated in the frequency range of 5.68–7.05 GHz with an improved gain of 10.5 dB, an improved return loss of -42.7 dB, an efficiency of 91.4%, and beamwidths of 3 dB in the E-plane 91.21° and H-plane 42.98°. It is clear that the SRSMSR Dielectric Resonator Antenna designed in this research endeavor, with an E-shaped microstrip feed and a wide aperture slot, is ideally suited for tracking radar and wireless applications in wireless communications.

ACKNOWLEDGEMENT

The authors would like to thank the Antenna and Liquid Crystal Research Center (ALRC), KL University, Guntur, Andhra Pradesh, India, for their assistance in the fabrication and measurement of the antenna prototype model.

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