

**A 28/32/38 GHZ CIRCULARLY POLARIZED DRA
MICRO-STRIP ANTENNA FOR 5G MM-WAVE
APPLICATIONS**

Chandra Sekhararao Kaitapalli[#], Arunachalam Kavitha^{*}

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Abstract

In modern communication system, mobile communication spectrum, below 3 GHz bands, faces more shortage and is not able to serve people with more efficient device connectivity and required data speed. Upon this background, 5G wireless communication – the 5th generation mobile technology standards are able to deliver high data rates, low latency communications, and massive device connectivity. For the efficient deployment of the 5G systems, and in order to support higher bandwidth, there is a dire need to design a compact and efficient antenna at mm wave frequencies (26/28 and 38). The resulting antenna, as the outcome, has been established to possess a compact size of $10 \times 12 \times 0.254 \text{ mm}^3$ that covers three bands from the frequency spectra. The lower band resonant frequency is located at 26.74 GHz, the range between 25.44 GHz and 28.37 GHz, the middle band resonant frequency is located at 32 GHz, the range between of 31.08 GHz and 32.48 GHz, and the higher resonant frequency is located at 38.76 GHz, the range between 36.04 GHz and 40.34 GHz. In this article a modified novel structure of partial ground plane and DRA are used to get the better radiation enhancement and circular polarization. In this, the circularly polarized bands consist of the axial ratios $< 3 \text{ dB}$ which are 27.95 GHz to 28.37 GHz, 31.08 GHz to 31.67 GHz, and 36.04 GHz to 38.73 GHz. The gain achieved is greater than 6.5 dBi and the efficiency is greater than 96% over the three bands. Ultimately, it is proved to be the right option for 5G mm wave applications.

Key words: patch antenna, dual-band, DRA, mm wave frequencies, circular polarization, partial ground plane

[#]Corresponding author.

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Introduction. Today, the development of wireless technology is to reach the fifth generation (5G), possibly by using mm wave, which is considered the capable option [1]. The currently available allocated 5G spectrum in a single system requires operating antennas in 26/28 GHz and 38 GHz centre frequency communication bands [2]. As a communication device [3,4], the antenna plays a dynamic role in the field of communication.

On the other hand, Circularly Polarized (CP) antennas have considerable benefits such as insensitivity towards equipment orientation, suppression of multipath fading, and resistance towards inclement weather. Therefore, researchers have mainly focused on wideband circularly polarized antennas for advanced wireless communication systems [5].

The current challenge of designing a tri-band DRA patch antenna is to achieve significant enhancement in circular polarization, and gain relatively wide bandwidth in each band. There are many ways to achieve this tri-band operation. And, in addition, slotted techniques are more common methods where an asymmetric slot is introduced in the antenna structure to change the current flowing direction and to form multiple distinct resonant frequency bands. Based on this modern approach, a surface opening cross-shaped patch in [6], an edge-opening slotted patch antenna in [7], open-ring slotted antennas in [8], an opening S-shaped slotted patch in [9], and an opening asymmetrical arrow-ended cross-slotted antenna in [10] are proposed. But all the antennas mentioned above have poor circular polarization performance because the slots break the symmetry of the patch. In [11], the antennas realize the dual-band operation by designing two patches which are stacked together. ZUO et al. [12] stacked a layer of parasitic elements over the radiating patches, and the structure introduces two mutually coupled radiating elements. But all these two-patch antennas have much lower RHCP gain. To improve the antenna's gain and reduce the back lobe level, a wide dual-band circularly polarized antenna combining slot and micro strip modes with high impedance surface ground plane is reported in [13], but for all this, complex manufacturing procedures are required, and it is not suitable for mass production. So, two eccentric rings and an arc-shaped conducting strip are introduced to achieve the dual-band CP operation [14]. But due to the asymmetry of the structure, the axis ratio (AR) is too large, and the problems of low gain and narrow bandwidth also cannot be resolved. It has been proved by many studies that the RHCP gain of patch antenna or micro strip antenna can be improved effectively by using the capacitive feed method [15].

With the existing models, one of the disadvantages of using printed antennas is high metallic loss and high surface wave loss. This can be overcome by using Dielectric Resonators (DRs). It has been observed in literature survey that DRs can be more attractive alternatives to low gain antennas such as micro strip patches, monopole, and dipole. It has also been found that DRAs can also be considered to be efficient radiators by exciting appropriate mode [16].

Using different frequencies in multiple systems requires the use of multi-band antennas. The proposed antenna has a compact size of $10 \times 12 \times 0.254 \text{ mm}^3$ with respect to length, width and height; it covers three bands from the frequency spectra. The lower band resonant frequency is located at 26.74 GHz, the range between 25.44 GHz and 28.37 GHz, the middle band resonant frequency is located at 32 GHz, the range between 31.08 GHz and 32.48 GHz, and the higher resonant frequency is located at 38.76 GHz, the range between 36.04 GHz and 40.34 GHz. In this article a modified novel structure of partial ground plane and DRA are used to get the better radiation enhancement and circular polarization. The gain achieved is greater than 6.5 dBi and the efficiency is greater than 96% over the three bands. The antenna designed is based on the Finite Element Method (FEM) in HFSS (High Frequency Structure Simulator). Finally, it is proved to be the right option for 5G mm wave applications.

DRA patch antenna description and design. In this novel method, a circularly polarized rectangular antenna structure made of Rogers RT/duroid 5880 (tm) substrate is proposed. The configuration of the proposed antenna is shown in Fig. 1(a) and (b). The overall size of the antenna is $10 \times 12 \times 0.254 \text{ mm}^3$. The proposed radiating structure is designed on a Rogers RT/duroid 5880 (tm) substrate with a dielectric constant of 2.2.

The selected topological structure consists of the radiating patch structure on top layer as shown in Fig. 1(a), and the bottom layer has a partial ground plane, which occupies the back of the substrate, as shown in Fig. 1(b).

From the literature survey, it is observed that the DRA embedded antennas reflect excellent radiation performance over the traditional antennas. So, in the proposed antenna, the gain enhanced by mounting DRA (Al_2O_3 _ceramic) with permittivity of 9.8 on radiating patch is shown in Fig. 1(a). For the wide band and circular polarization the partial ground plane was incorporated in proposed antenna structure as shown in Fig. 1(b). The design specifications of proposed antenna are shown in Fig. 1(a) and (b).

The radiation performance of the proposed antenna is studied using four steps in design structure. In step-1, the radiation is observed by mounting the dielectric resonator on radiating patch structure and without incorporating partial ground structure on ground plane. In step-2, the radiation is observed by incorporating rectangular defected ground structure slot with an area of $L_{gs1} \times W_{gs1}$ on ground plane, here the area $L_{gs2} \times W_{gs2}$ is filled with radiating material (copper). In step-3, the area $L_{gs2} \times W_{gs2}$ filled with radiating material (copper) is removed, now the ground becomes partial and is observed to have good radiation enhancement. For the purpose of the study, in step-4 the radiation of the proposed antenna structure is observed without DRA.

The architecture and analysis of antennas have been carried out using the time domain and the frequency domain methods applying commercial EM software HFSS.

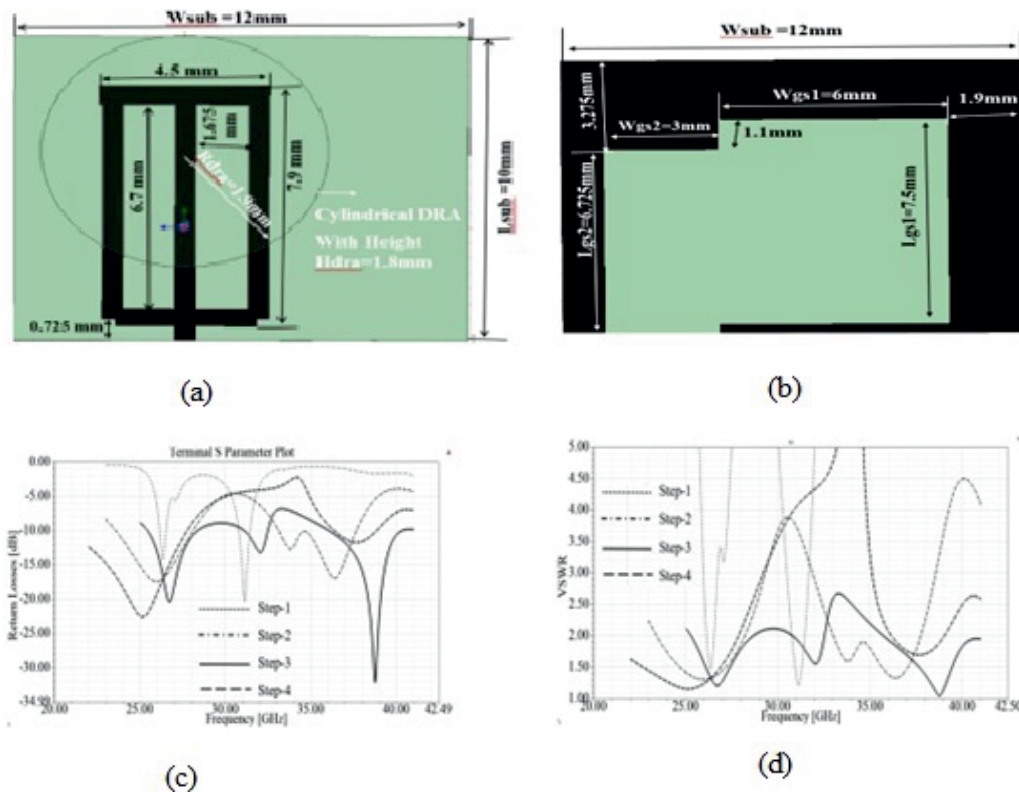


Fig. 1. Prototype and results of the proposed antenna structure. (a) Top view of prototype. (b) Bottom view of prototype. (c) The plot of return losses from the designs made as per step-1, step-2, step-3 and step-4. (d) The plot of VSWR from the designs made as per step-1, step-2, step-3 and step-4

Results and observations. From the literature survey, it is observed that the DRA embedded antennas reflect excellent radiation performance over the traditional antennas. So, in this article, the proposed DRA antenna is studied to its complete effect. The gain enhanced by the mounting DRA (Al_2O_3 ceramic) with permittivity of 9.8 on radiating patch is shown in Fig. 1(a). For the wide band and the circular polarization the partial ground plane is incorporated in the proposed antenna structure as shown in Fig. 1(b). The resulting antenna has been found to possess a compact size of $10 \times 12 \times 0.254 \text{ mm}^3$, and to cover three bands from the frequency spectra. The lower band resonant frequency is located at 26.74 GHz, the range between 25.44 GHz and 28.37 GHz, the middle band resonant frequency is located at 32 GHz, the range between 31.08 GHz and 32.48 GHz, and the higher resonant frequency is located at 38.76 GHz, the range between 36.04 GHz and 40.34 GHz. The incorporated partial ground plane and the mounted DRA on radiating patch are caused to get the better radiation enhancement and circular polarization over the three bands. The circularly polar-

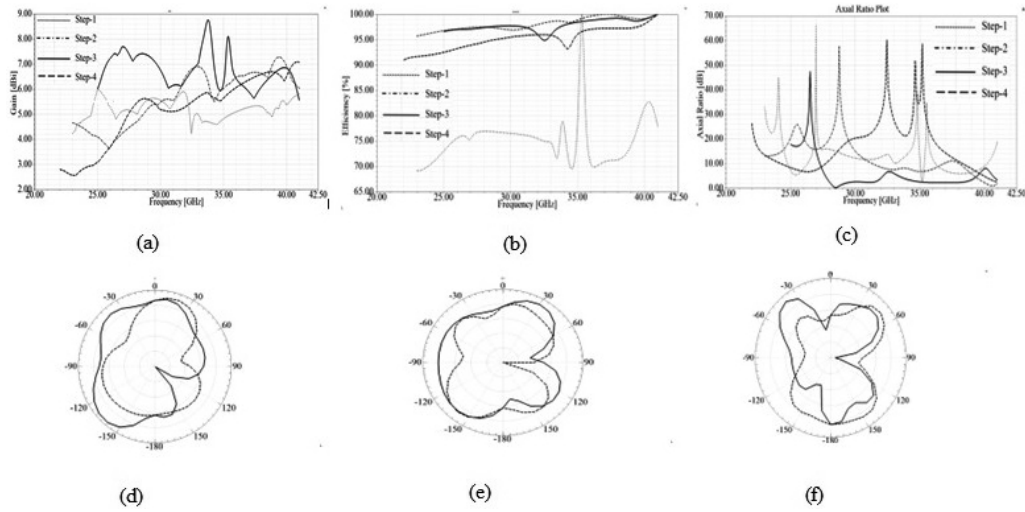


Fig. 2. Farfield results of the proposed antenna structure. (a) The plot of peak gain from the designs made as per step-1, step-2, step-3 and step-4. (b) The plot of efficiency from the designs made as per step-1, step-2, step-3 and step-4. (c) The plot of axial ratio from the designs made as per step-1, step-2, step-3 and step-4. (d) E-plane and H-plane patterns at 26.74 GHz. (e) E-plane and H-plane patterns at 32 GHz. (f) E-plane and H-plane patterns at 38.76 GHz

ized bands consist of the axial ratio < 3 dB which are 27.95 GHz to 28.37 GHz, 31.08 GHz to 31.67 GHz and 36.04 GHz to 38.73 GHz. It is observed that the gains are 7.48 dBi, 6.4 dBi, and 6.53 dBi, respectively, and the efficiency 97.1%, 96.1%, and 99%, respectively, with respect to resonant frequencies. The significant enhanced results of the proposed DRA antenna structure can be viewed in step-3 of Fig. 2 and Table 1. The comparative results of the proposed work with the related works presented in the literature can be viewed in Table 2.

T a b l e 1

The results from the designs as per step-1, step-2, step-3 and step-4

Step No.	Operating frequency band (GHz)	Resonant frequency (GHz)	VSWR	Gain (dBi)	Efficiency (%)	CP band (GHz)
1	26.15–26.52	26.32	1.48	4.98	76.03	—
	30.78–31.44	31.44	1.23	5.76	76.02	—
2	23.58–28.09	26	1.31	3.69	97.14	—
	33.10–37.66	36.4	1.33	6.54	99.85	—
3	25.44–28.37	26.74	1.21	7.48	97.1	27.95–28.37
	31.08–32.48	32	1.56	6.4	96.1	31.08–31.67
	36.04–40.34	38.76	1.05	6.53	99	36.04–38.73
4	21–27.75	25.12	1.16	3.1	92.6	—
	36.36–38.84	37.7	1.7	6.54	97.2	—

T a b l e 2

The comparison of proposed antenna results with related works presented
in the literature

Ref. No.	Size (mm)	Operating frequency band (GHz)	Resonant frequency (GHz)	Gain (dBi)	Efficiency (%)	CP band (GHz)
[²]	20×5.5	27.72–28.17 36.7–38.9	28 38	5.2 5.9	— —	—
[⁵]	30×30	7.1–22	—	7.0	70	7.1–7.9
[¹⁷]	—	—	28 38	7.9 6.9	— —	—
[¹⁸]	—	—	28 38	5.2 5.0	84 91	0.3 0.5
[¹⁹]	5×5	26.8–29.4 37.7–40.2	28 38	7.7 9.4	— —	—
[²⁰]	8×8	— —	28 38	5.1 5.7	88 90	0.25 0.25
This work	12×10	25.44–28.37	26.74	7.48	97.1	27.95–28.37
		31.08–32.48	32	6.4	96.1	31.08–31.67
		36.04–40.34	38.76	6.53	99	36.04–38.73

The reflection coefficient is a measure of how much power is reflected in return at the antenna port due to the transmission line mismatch. The S11 value is in dB and is a negative value, which represents the ratio of the reflected power of port 1 to the incident power. If $S_{11} < -10$ dB, 90% of the excitation power is transmitted.

Figure 2(d)–(f) shows the principle plane radiation patterns (E-plane and H-plane radiation patterns) at resonant frequencies 26.74 GHz, 32 GHz, and 38.76 GHz. The principle plane patterns show the focusing of beam into various directions in E-plane and H-plane.

The radiation performance from the proposed antenna is studied using four steps in design structure. In step-1, the radiation is observed by mounting the dielectric resonator on the radiating patch structure and without incorporating the partial ground structure on ground plane. In this case the antenna operated in dual bands is 26.15 GHz to 26.52 GHz and 30.78 GHz to 31.44 GHz with resonating frequencies 26.32 GHz and 31.44 GHz. The gain observed at 26.32 GHz and 31.44 GHz are 4.98 dBi and 5.76 dBi, respectively. The efficiency observed at 26.32 GHz and 31.44 GHz are 76.03% and 76.02%, respectively. Here again there are no circularly polarized bands in which the axial ratio is < 3 dB.

In step-2, the radiation is observed by incorporating rectangular defected ground structure slot with an area of $L_{gs1} \times W_{gs1}$ on ground plane, here the area of $L_{gs2} \times W_{gs2}$ is filled with radiating material (copper). Here the radiation observed is better compared to step-1 design. In this case the antenna operated in

dual bands 23.58 GHz to 28.09 GHz and 33.10 GHz to 37.66 GHz with resonating frequencies 26 GHz and 36.4 GHz. The gain observed at 26 GHz and 36.4 GHz are 3.69 dBi and 6.54 dBi, respectively. The efficiency observed at 26 GHz and 36.4 GHz are 97.14% and 99.85%, respectively. Here too, there are no circularly polarized bands in which the axial ratio is < 3 dB.

In step-3, the area $L_{gs2} \times W_{gs2}$ filled with radiating material (copper) is removed. Now, the ground becomes partial and observes significant radiation enhancement compared to step-2. This is the best step in this study. The resulting antenna as per step-3 covers three bands from the frequency spectra. The lower band resonant frequency is located at 26.74 GHz, the range between 25.44 GHz and 28.37 GHz, the middle band resonant frequency is located at 32 GHz, the range between 31.08 GHz and 32.48 GHz, and the higher resonant frequency is located at 38.76 GHz, the range between 36.04 GHz and 40.34 GHz. The incorporated partial ground plane and mounted DRA on radiating patch are caused to get the better radiation enhancement and the circular polarization over the three bands. The circularly polarized bands consist of the axial ratio < 3 dB which are 27.95 GHz to 28.37 GHz, 31.08 GHz to 31.67 GHz and 36.04 GHz to 38.73 GHz. It is observed that the gains are 7.48 dBi, 6.4 dBi and 6.53 dBi, respectively, and the efficiency is 97.1%, 96.1% and 99%, respectively, with respect to resonant frequencies.

For the purpose of the study, in step-4 the radiation of the proposed antenna structure is observed without DRA. The antenna designed as per step-4 is reflecting degradation in radiation performance compared to step-3 design. In this case, the antenna operated in dual bands 21 GHz to 27.75 GHz and 36.36 GHz to 38.84 GHz with resonating frequencies 25.12 GHz and 37.7 GHz. The gains observed at 25.12 GHz and 37.7 GHz are 3.1 dBi and 6.54 dBi, respectively. The efficiency observed at 25.12 GHz and 37.7 GHz are 92.6% and 97.2%, respectively. Here again, there are no circularly polarized bands in which the axial ratio is < 3 dB.

The results from the designs as per step-1, step-2, step-3 and step-4 are given in Table 1, the near field results (return losses and VSWR) can be observed in Fig. 1(c), (d) and the far field results (Gain, efficiency, axial ratio and E&H plane patterns) can be observed in Fig. 2 (a)–(f).

From Fig. 1(c), (d), Fig. 2(a)–(f) and Table 1, it is observed that the significant radiation enhancement is acquired at step-3 over step-1, step-2 and step-4. So, it is clear that the antenna design made as per step-3 radiates well with significant radiation properties. The antenna at this stage contains three operating frequency bands. The lower resonant frequency is located at 26.74 GHz, and it has -10 dB ($VSWR \leq 2$) impedance bandwidth of 2.93 GHz from 25.44 GHz to 28.37 GHz. And the gain at this band is 7.48 dBi. The middle resonant frequency is located at 32 GHz, and it has -10 dB ($VSWR \leq 2$) impedance bandwidth of 1.4 GHz from 31.08 GHz to 32.48 GHz. So, the gain at this band is 6.4 dBi. The

higher resonant frequency is located at approximately 38.76 GHz. The -10 dB impedance bandwidth of 4.3 GHz (between about 36.04 GHz to 40.34 GHz), and the gain at frequency band is 6.53 dBi. Figure 1(d) shows the VSWR of the proposed antenna designed as per step-1, step-2, step-3 and step-4, which is less than or equal to 2 on operating frequency bands.

The results show that the proposed design has been critically verified by a good resonant frequency, and it is a tri-frequency antenna with a very large bandwidth.

The current study is conducted to evaluate the performance of the antenna. This study is significant because it had unsatisfactory results before the antenna was manufactured.

Conclusions. The mm-wave (28 GHz/32 GHz/38 GHz) the triple band circularly polarized antenna is proposed in this paper. The antenna is designed by introducing dielectric resonator loading technology. Moreover, in order to solve the problem of narrow radiation bandwidth of the microstrip antenna, a new type of partial ground plane is proposed. This can greatly widen the radiation bandwidth. In addition, it has got wide circularly polarized bands consisting of axial ratio < 3 dB over the operating bands. The gain achieved is greater than 6.5 dBi and the efficiency is greater than 96% over the three operating bands. Undoubtedly, this is more preferable option for 5G mm wave applications.

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*Department of Information and
Communication Engineering
Anna University
Chennai, Tamilnadu, India
e-mail: kcr.429@gmail.com*

**Department of Electronics and
Communication Engineering
M. Kumarasamy College of Engineering
Karur, Tamilnadu, India
e-mail: kavivenkat99@gmail.com*