

Ultra-Wideband Fractal Antenna With Elliptical Defected Ground Structure On Rogers Rt/Duroid 6002 For 19.75–23.46 Ghz And 27.25–36 Ghz 5g Mm-Wave Bands

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ABSTRACT

This paper presents a ultra-wide band fractal microstrip antenna incorporated with a defective ground structure designed specifically for Millimeter-wave 5G communication systems. The antenna uses an elliptical DGS in conjunction with a modified triangular fractal patch to improve radiation performance and impedance bandwidth. The antenna design aligns with the 5G NR spectrum allocations and spans 19.75-23.46 GHz and 27.25-36 GHz bands, fabricated on a RT/Duroid 6002 substrate. Simulated and measured results show strong agreement, with efficiencies surpassing 98% and 72%, reflection coefficient of -35 dB and -28 dB, and peak gain of 9.07 dB and 7.12 dB, respectively. DGS and fractal geometry work together to efficiently increase the impedance bandwidth, gain, and downsizing without sacrificing the performance, making it a great choice for small and powerful Millimeter-wave wireless device.

Keywords: Defective Ground Structure, Ultra-wide Band, 5G communication, Fractal antenna, RT/Duroid 6002

INTRODUCTION

In the light of the recent works done on wireless communication, there are still a lot of crucial factors to take into account for the next 5G wireless communication generation, despite the recent advancements in wireless communication [1]. The main aspects of this 5G wireless communication will be the significantly higher frequency and bandwidth compared to that of 4G system [2-3]. Both of these will be achieved by Millimeter frequency band [4]. Researches are being done to create antennas with compact sizes which can provide both high frequency and wider bandwidth for faster wireless communication [5]. Communication in daily life depends on Access to small, portable, high-performance devices that support fast data rates and operate at low signal power. [6].

Microstrip patch antennas (MPA) are the most effective way to do this [7]. Some important features of MPA i.e. its simpler design, small size, and low profile, which make it simple to combine with other wireless communication system components, it is a preferred structure for high-speed data [8]. The microstrip antenna is one of the most popular printed antenna types and is essential to the architecture of contemporary wireless communication systems. The basic form of a patch antenna consists of a conducting patch printed on a ground plane that emits only at the chosen frequency range. They provide good compatibility with handheld devices' inbuilt antennas.[9]. Using a traditional PCB fabrication method, microstrip antennas are quite easy to create. These antennas have a small impedance bandwidth because they are resonant structures. The low gain and microstrip bandwidth restrictions.[10]. Numerous techniques are employed to reduce the size of microstrip patch antennas while simultaneously increasing their bandwidth and gain. These methods involve cutting slots in

the patch, fractal geometry, and defective ground structure [11]. A variety of configurations, including slots with dumbbell, I, U, and elliptic shapes, are proposed to use DGS to improve antenna performance [12]. Etching the desired form from the ground plane is how DGS is accomplished. The form and location of these ground plane slots determine which extra resonant frequencies they introduce. Additionally, the DGS causes the antenna to resonate at a lower frequency, which makes the antenna smaller. By reducing harmonic frequencies, slots in the ground plane increase the antenna's resonance and aid in the DGS antenna's gain improvement [13-15].

Many techniques are proven to be effective to obtain wideband performance with notches and slots [16]. Numerous fractal forms exist, including Sierpinski, Hilbert, Koch, Minkowski, and fractal arrays [17]. Patch area reduces and resonant length rises when fractal geometries are applied [18]. Slot-loaded antennas outperform the conventional rectangular patch antenna in terms of resonance frequency, VSWR, return loss, and bandwidth [19]. DGS and fractal approaches are used for small antennas in the published literature. However, the importance of fractal DGS slots in the ground plane for enhancing antenna performance has not been investigated. According to the current work, the use of fractal DGS slots on the ground plane lowers higher harmonic frequencies in addition to providing compactness. [20-22]. The substrate to be used for antenna design is RT/Duroid 6002. Because of its low Dielectric constant ~ 2.94 , loss tangent of ~ 0.0012 , and exceptional thermal stability, RT/Duroid 6002 is used as the substrate. It is perfect choice for high-frequency, multilayer, and precision antenna applications benefits greatly from its exceptional dependability due to its low moisture absorption and copper matched thermal expansion [23].

In this proposal work, a microstrip patch antenna is designed for 5G applications. Fractal shapes are used on the antenna and ground to improve bandwidth and gain. The antenna performance is checked using parameters like return loss, gain, VSWR, directivity, and bandwidth for both the simulated antenna and the fabricated antenna.

ANTENNA DESIGN

In this work, firstly a triangular shaped patch antenna has a metal patch on top and a metal sheet at the bottom, with a thin layer of special insulating material (RT/Duroid 6002) between them that is 1.52 mm thick. It is an ordinary antenna that is designed resonate at multiple frequencies or can be simply said to work at multiple bands by using basic equations where only a -10 dB frequency band has been achieved. The design of this antenna can be seen in Figure 1.

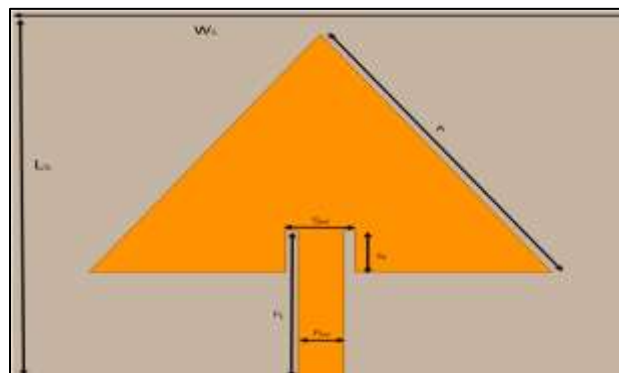


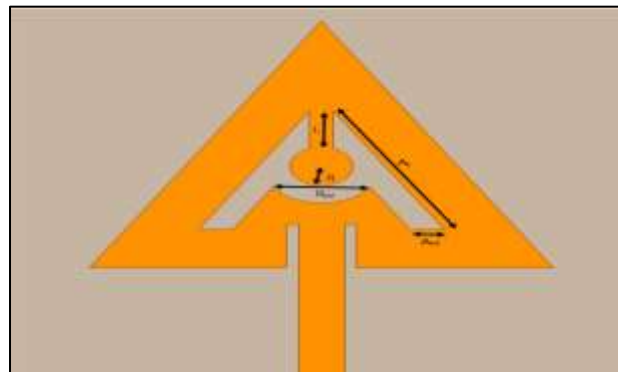
Figure 1. Basic Triangular patch antenna design

The dimensions of the designed antenna are mentioned in the Table 1.

Table 1 Dimensions of Basic Triangular patch antenna

Parameters	Values(mm)
W_s	40
L_s	40
A	25.98
S_w	4.4
S_L	3.5
F_w	2.92
F_L	16

For bandwidth enhancements, fractal slot is etched out of the triangular batch. It is done by first removing a triangular slot and a segment shaped slot from the patch and then adding a circular element to it. Defected ground structure is then applied to this designed antenna. The design is made by using elliptical arcs on the plane ground surface made up of conducting element, and then slotting them out to form defected ground surface as shown in Figure 2b.

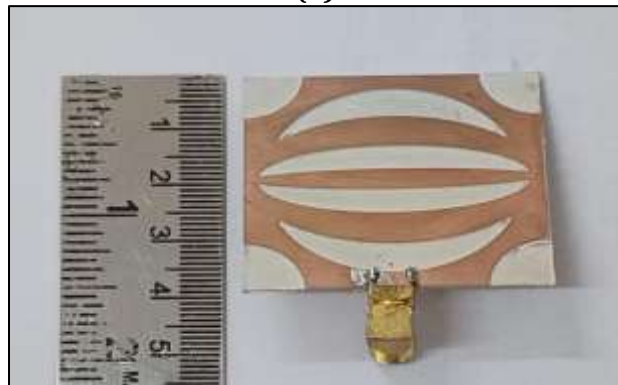
**(a)****(b)****Figure 2. Modified Patch Antenna Design (a) Patch View, (b) Ground View****Table 2 Dimensions of Modified Patch Antenna**

Parameters	Values(mm)
A_l	14
L	3.8
R	2
R_w	6.2
A_w	2.2

This antenna design is then fabricated to test its performance in the real-world with substrate RT/Duroid 6002, with thickness of 1.52 mm. The performance of the built antenna may vary somewhat from models due to variations in manufacturing and material. Deviations such as copper cladding thickness ($\pm 5 \mu\text{m}$), connector misalignment (0.1–0.2 mm), etching tolerance ($\pm 50 \mu\text{m}$), or substrate inhomogeneity (± 0.04 in dielectric constant, ± 0.0012 in loss tangent) can cause resonance shifts (up to ~ 1 GHz), variations in return loss (5–10%), additional losses, and decreased efficiency (~ 4 –6%). To lessen these effects, we promise precise connection alignment, optimal component isolation, and strict adherence to manufacturing procedures.



(a)



(b)

Figure 3. Fabricated antenna (a) front and (b) back view

RESULTS AND DISCUSSIONS

The constructed antenna is thoroughly verified in an anechoic chamber to ensure that the far-field radiation characteristics match models. Combining this reflection-free environment with a Vector Network Analyzer (VNA) and a traditional reference horn antenna, which is used to record the radiation patterns, yields accurate performance data. The validation is completed by carefully comparing the simulated data with the observed characteristics, including VSWR, gain, radiation patterns, and return loss. The radiation characteristics of the proposed triangular shaped patch antenna with slots and defected ground surface and performance are all discussed here.

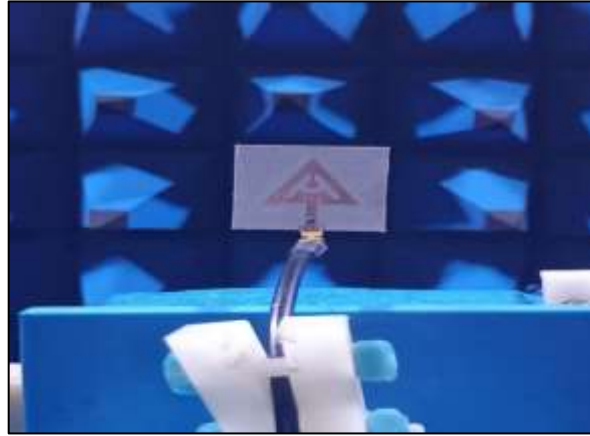
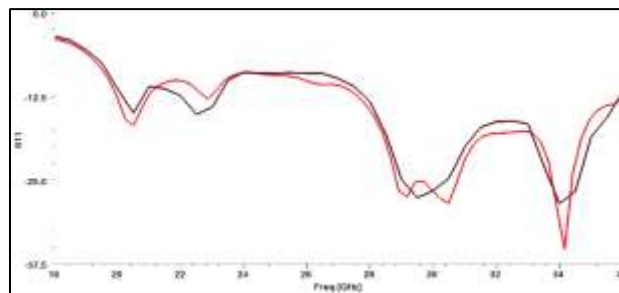


Figure 4. Experimental setup of fabricated antenna anechoic chamber setup

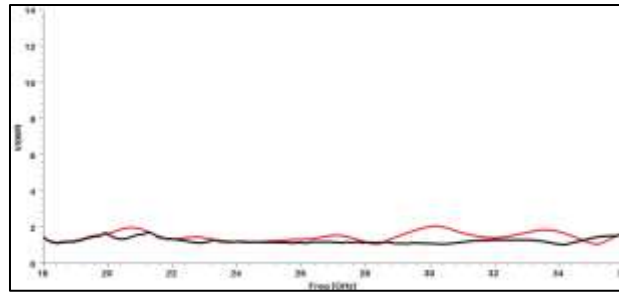
SCATTERING PARAMETERS

The simulated and measured reflection coefficient (S11) results match well, with only a small shift in frequency. This small difference happens because a slot is used on the patch and a defected ground structure (DGS) is added. For the simulated antenna, the impedance bandwidth (based on the -10 dB limit) ranges from 19.71 to 23.41 GHz and 25.75 to 36 GHz, with a minimum S11 value of -35 dB. For the fabricated antenna, the bandwidth ranges from 19.758 to 23.465 GHz and 27.25 to 36 GHz, with a minimum S11 value of -28 dB. Overall, the total bandwidth is 13.95 GHz for the simulated antenna and 12.46 GHz for the fabricated antenna, as shown in Figure 5(a).

As seen in Figure 5(b), the VSWR for both manufactured and simulated antennas stays below 2 during the course of the operating bandwidth, with minimum values of 1.099 and 1.041, respectively.



(a)



(b)

Figure 5. Simulated and Measured (a) Return loss S_{11} and (b) VSWR

GAIN

The comparison of the gain between the simulated and measured antennas shows the overall radio performance and efficacy of the proposed design. As seen in Figure 6, the simulated antenna runs consistently in the working band, peaking at 25.5 GHz with a gain of 9.07 dB. However, due to material losses and tiny manufacturing errors, the measured antenna exhibits a considerably lower gain, peaking at 7.12 dB at 25.5 GHz. The simulated findings, taken together, provide outstanding gain characteristics, confirming the effective design and radiation behaviour optimization of the antenna.

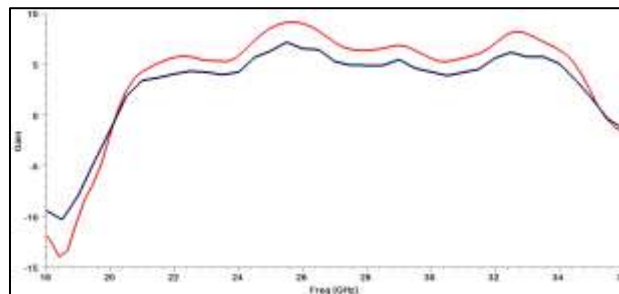


Figure 6. Simulated and Measured Gain

EFFICIENCY VS FREQUENCY

The antenna's overall power consumption and radiation performance may be inferred from efficiency against frequency. The simulated antenna, depicted in Figure 7, achieves a maximum efficiency of 99.6% at 31 GHz and sustains values above 98 % throughout the operational frequency range. The tested antenna records a maximum efficiency of 90.1% at 20 GHz, despite the fact that conductor losses and manufacturing flaws significantly reduce its performance. The simulated antenna's efficiency is much higher.

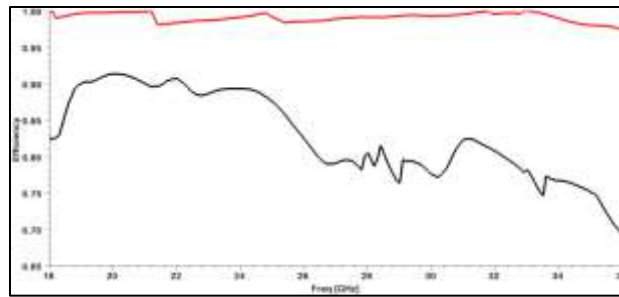


Figure 7. Simulated and Measured Efficiency vs Frequency plot

SURFACE CURRENT DISTRIBUTION

When an antenna is excited by a radio frequency signal, the generated electric currents flow in a pattern known as the surface current distribution. These currents are created when the electromagnetic field interacts with the antenna's conductive material, transforming the electric field into tangential currents that emit radiation, as shown in Figure __. Two distinct frequencies- 20GHz and 28 GHz, are used to display the surface current distribution of the proposed MIMO antenna.

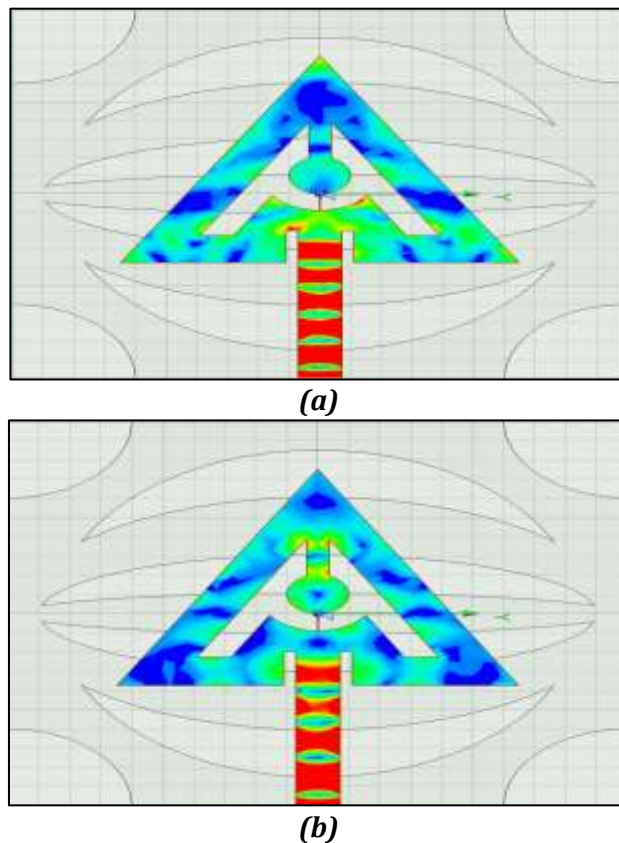


Figure 8. Surface Current Distribution of the proposed antenna at different frequencies, (a) at 20 GHz, (b) at 28 GHz

Table 3: Summary of simulated and measured performance parameters of the presented antenna

Parameters	Simulated	Measured
S11 (dB)	-35	-28
VSWR	1.041	1.099
Bandwidth (GHz)	13.95	12.46
Peak Gain (dB)	9.07	7.12
Efficiency	>98%	>72%

DISCUSSION

The designed antenna can work at several different frequency ranges. Since it is a multi-band antenna, it can support many communication systems at the same time using one antenna. This makes the system more flexible and removes the need to use many separate antennas for different frequencies. Table 5 shows a comparison based on design and performance measures, and it proves that the proposed antenna has better radiation performance, including higher gain, wider bandwidth, and improved diversity performance.

Table 4: Comparative analysis with prior works

Ref. No.	Size(mm ²)	Frequency Range (GHz)	Bandwidth (GHz)	VSWR	Peak Gain(dB)	Efficiency
[24]	74x70	4.01-4.82, 7.6-7.94	1.35	1.103	2.03	~70%
[25]	15x16	6-9.7, 11-11.5, 15-16.2	5.4	1.1	6.58	-
[26]	40x40	27.1-29.1, 29.5-32.6, 37.5-38.5	11.4	-	5.9	
[27]	24x40	3.05-3.7, 5.1-14.2	9.75	1.21	2.1	-
[28]	14x13	3.4-14	10.6	1.109	3.92	>70%
[29]	30x25	2.88-3.26, 3.4-11.68	8.66	-	2.71	>71%
This work	40x40	19.758-23.465, 27.25-36	12.46	1.099	7.12	>72%

CONCLUSION

The design, simulation, and experimental verification of a small multi-Band fractal antenna with enhanced radiation performance have been completed. The measured results closely align with the simulated ones, validating the reliability and trustworthiness of the proposed design methodology. The antenna ensures steady operation over a wide frequency band by attaining reflection coefficient of -28dB, an impedance bandwidth of 12.46GHz and peak gain of 7.12dB. The main reason of the minor deviation between the simulated and measured results are irregularities in substrate and fabrication tolerances. Despite all this, the suggested antenna's high efficiency, ultra-wide bandwidth and size make it well-suited for the 5G communication systems.

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