# A High-Gain Quasi-Fractal Antenna with Wide Range Operation for 5G Applications over V-Band Spectrum

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***Abstract*— In this paper, a vertical cascade of T-shaped fractal-like antenna is presented for operating at V-band. The fractal-like antenna is shown to provide wideband performance. The radiator consists of interconnected series of elliptical structures of different sizes that were constructed on Roger RT/duroid 5880 substrate. The proposed antenna design was verified using HFSS and CST electromagnetic solvers. The overall dimension of the antenna is 16×18×0.79 mm$^3$. The antenna is shown to provide an average gain exceeding 6.5 dBi across 59 GHz to 68 GHz. The simple geometrical configuration of the antenna and its radiation characteristics makes it a potential candidate for 5G applications operating in V-band.**

***Index Terms*—ultra-wideband, millimeter wave, V-band, 5G communication.**

## I. Introduction

Being a fundamental component of wireless systems, an antenna plays a critical role in the design of all communication system [1-2]. Present and future communicating devices are getting compact day by day, resulting in need of a more compact communication system [3]. Along with these requirements the modern communication systems are required to have features of wideband, high gain, low latency rate, and high data rate for effective communication [4]. It has been shown that these features can be realized by designing antennas of certain geometries [5].

To nullify these demands, enormous research work has been done to design antennas at higher bands in the EM spectrum. This is necessary because the lower part of the EM spectrum is becoming very crowded [6]. Millimetre wave band (30–300 GHz) provides numerous unlicenced spectrum, which can be utilized for modern communication systems [7]. V-band has got a lot of attention due for several reasons, i.e., it provides a wide spectrum and low signal absorption as compared to other mm-wave bands [8]. Several efficient V-band antennas have been reported in literature for various applications [9–18].

In [9], a circularly polarized beam array antenna operating in V-band is proposed, which operates over the wideband of 52–67 GHz. The antenna in [10] provides a high gain of 11.8 dB across 54 GHz – 66 GHz however it has overall size of 26×33 mm$^2$, which is considered large for modern compact devices. Various compact sized antennas have been reported in [11–13]. These antennas suffer from either narrow bandwidth, low gain or complex structures which makes them expensive to fabricate.

A compact high gain gap coupled 4×1 antenna array is reported in [14]. The unit element constituting the array has a narrow bandwidth however the array configuration operates across 57.5 GHz to 62.8 GHz. The array design is structural simple to implement however it's relatively large for some practical applications. In [15], a wideband and high gain antenna array is presented which uses a wideband feeding technology. The array antenna consists of two layers to achieve a compact topology. The total size of the integrated array antenna is equal to the size of the radiating aperture. On the other hand, in [16] a wire grid antenna array is presented. This antenna operates over a wideband and has a high gain, but the 16×16 is relatively large. In [17] a two-element monopole antenna uses a partial ground defected ground structure (DGS). The size of this antenna too is relatively large. It is evident from the literature review the design of wideband antennas with high gain at V-band is challenging.

Contrary to the techniques employed in the above works, we have adopted to use a patch structure to design an ultra-wideband antenna that offers high gain performance at V-band. In this paper we have presented a compact antenna that has a simple fractal-like geometrically and operates over an ultra-wideband with high gain performance. The structure of the paper is as follows: Section II presents the geometry of the proposed antenna design, and the key parameter analysis are discussed in Section III. The paper is concluded in Section IV.

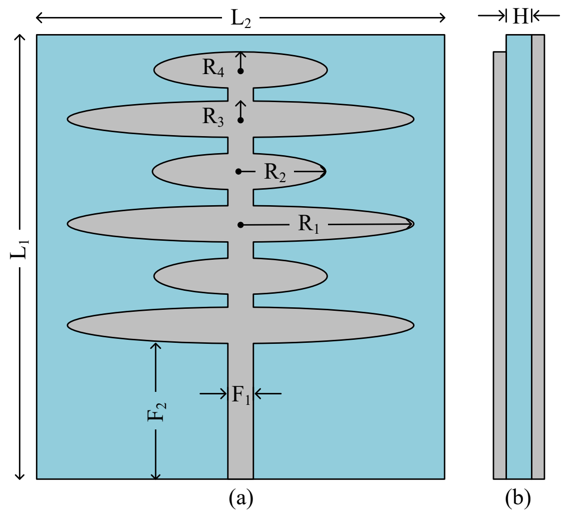


Fig.1. Proposed patch antenna, (a) front view, and (b) side view.

## II. Proposed Antenna

The geometrical of the proposed antenna is shown in Fig. 1. The radiation element resembles a T-shaped fractal-like structure consisting of interconnected series of elliptical structures of different sizes. The antenna was constructed on Roger RT/duroid 5880 substrate having a thickness of 0.79 mm, relative permittivity of 2.2, and loss tangent of 0.0009. Back side of the antenna substrate is a ground layer that acts as a reflector. The antenna has an overall size of $L_1 \times L_2$ ($16\times18$ mm$^2$). The fractal-like T-shaped radiator is fed using a microstrip line having dimension of $F_1 \times F_2$ ($0.5\times6.5$ mm$^2$). The major radius of the large ellipse is $R_1$ = 8 mm. The major radius of the small ellipse is $R_2$ = 4 mm. The minor radii are $R_3 = R_4$ = 0.5 mm.

The antenna was designed in three consecutive iterations. In the first iteration, an elliptical patch was designed to resonant at the central frequency of 65 GHz. To overcome the deficiency of narrow bandwidth of conventional microstrip antennas, another pair of elliptical patches were added to the structure, as shown in Fig. 2. The resultant antenna looks like a self-similar two element cascaded fractal-like structure. This structure has a broader bandwidth of 5 GHz ranging from 62-67 GHz. Another pair of elliptical patches were added to the structure to create a three-element fractal-like structure. Achieved with this antenna is a wider bandwidth of 7 GHz (60–67 GHz), as shown in Fig. 2.

For the brevity of the paper, the parametric analysis of the key parameter of the proposed antenna is discussed here. Fig. 3 shows how the return loss of the antenna is affected by the ellipse with minor radius $R_4$. It can be observed from Fig. 3 that when the optimize radius ($R_4$ = 0.5 mm) was decreased to 0.4 mm, the resultant antenna shows good impedance matching around the central frequency. However, the impedance bandwidth is reduced. Contrary to this, when the radius was increased from the optimized value, the antenna shows impedance miss-matching and a narrow impedance bandwidth.

## III. Results and Discussions

The simulation of proposed antenna was carried out using Higher Frequency Structure Simulator (HFSS), a finite element based electromagnetic solver. CST Microwave Studio EM solver was used to verify the simulated results. Fig. 4 shows the comparison between the result obtain with the two software solvers. It can be observed that antenna offers ultra-wide impedance bandwidth from 58.9–68.6 GHz for $|S_{11}|$< -10 dB. Moreover, it can also be seen from Fig. 4 there is excellent agreement in the results from the two different solvers validating the antenna's performance.

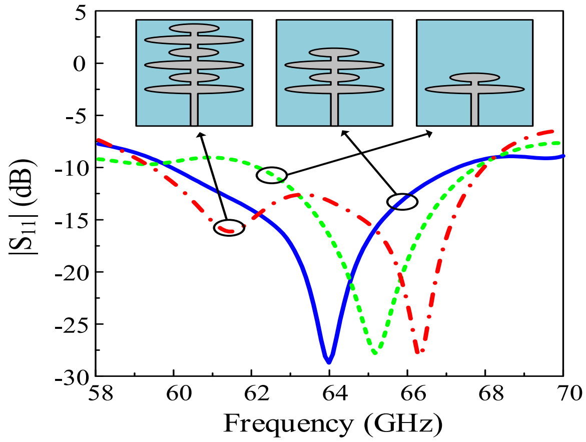


Fig.2. Return loss comparison of the three interatom stages to design the proposed antenna.

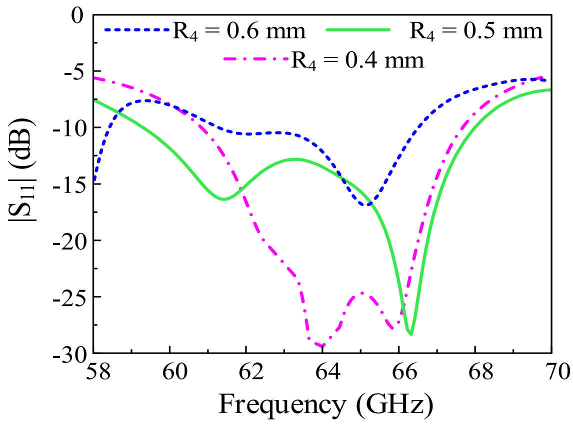


Fig.3. Parametric analysis of parameter $R_4$ on the return loss of the proposed antenna.

The Fig. 5, shows the radiation pattern of proposed antenna at the spot frequencies of 61.5 GHz and 66.5 GHz. It can be observed that the antenna radiates broadside in principle H-plane ($\theta$=90$^0$) at both the spot frequencies.

Contrary to this, the antenna offers a slightly tilted and fan beam like radiation pattern in principle E-plane ($\theta=0^0$) as shown in Fig. 5.

The surface current distribution over the antenna at the two spot frequencies of 61.5 GHz and 66.5 GHz, shown in Fig. 6, shows regions where the current density is strongest which accounts for the resulting radiation patterns.

Fig. 7 shows the peak gain and radiation efficiency of the antenna. The antenna radiates with an efficiency of more than 80% across 59–68 GHz with a peak value of 93% around 62.3 GHz. Fig. 7 also shows that antenna offers a high gain of more than 6 dBi across 59–68 GHz with the peak value of 8.1 dBi at 66 GHz.

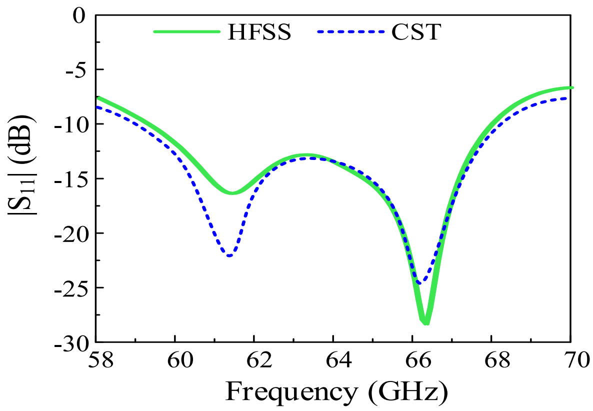


Fig.4. Return loss of the proposed T-shaped elliptical fractal-like antenna.

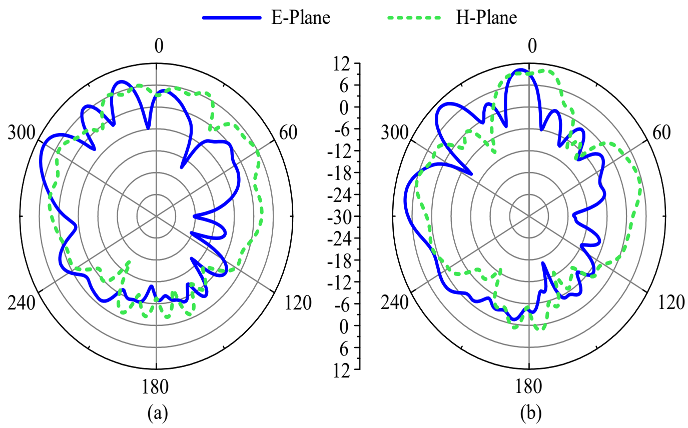


Fig.5. Radiation patterns of proposed antenna at the spot frequencies of (a) 61.5 GHz, and (b) 66.5 GHz.

Table I presents comparison of proposed antenna's size, impedance bandwidth and peak gain with other V-band antennas published in the literature. It is clear from table that proposed antenna is comparable to existing antennas however it is much of a much simpler geometry and therefore much cheaper to manufacture.

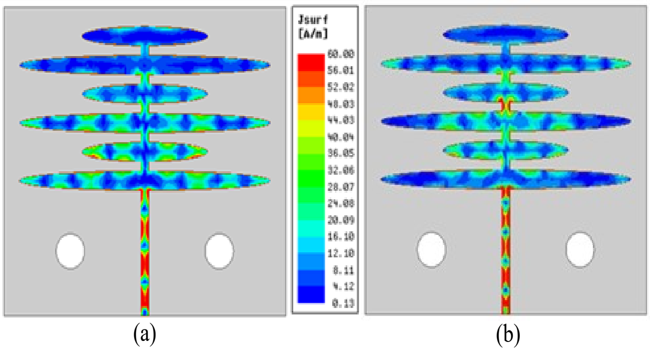


Fig.6. Surface current distribution over the proposed antenna at (a) 61.5 GHz, and (b) 66.5 GHz.

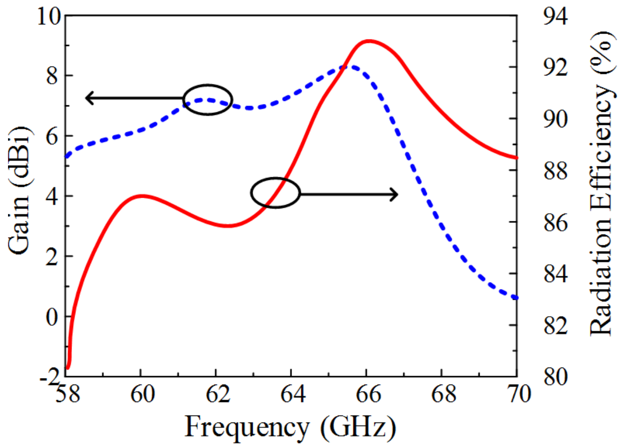


Fig.7. Peak gain and radiation efficiency of the proposed antenna.

Table I.
Comparison of proposed antenna with other V-band antennas.

| References | Size of Antenna ($mm^2$) | Bandwidth (GHz) | Peak Gain (dBi) |
|---|---|---|---|
| **[9]** | 26 × 33 | 52-67 | 10.6 |
| **[10]** | 25 × 26.5 | 54-66 | 11.8 |
| **[11]** | 6×10 | 58.5-59.6 | - |
| **[12]** | 8×10 | 58-60.5 | 5.5 |
| **[13]** | 5×5.32 | 45-65 | 3.5 |
| **[14]** | 5.2×9.5 | 61-64 | 10.7 |
| **[15]** | 17.5×14.5 | 57-66 | 18 |
| **Proposed Work** | **16 × 18** | **59-68** | **11** |

## IV. Conclusion

A geometrically simple, ultra-wideband V-band antenna having high gain and efficiency was proposed in the paper. The antenna covers globally allocated V-band spectrum and has an impedance bandwidth of 9.7 GHz. High gain and wide bandwidth performance was achieved by using a T-shape structure of elliptical fractal-like radiators stacked in a vertical plane. It is shown the fractal-like structure can significantly improve the antenna's performance. Moreover, the proposed antenna's performance is comparable to state-of-the-art V-band antennas.

## ACKNOWLEDGMENTS

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