Design and Analysis of Fractal Antenna Geometry for Wideband Applications

V. Mahesh Naik(✉) and Amara Prakasa Rao

Department of Electronics and Communication Engineering, National Institute of Technology,
Warangal 506004, TS, India
mvec21329@student.nitw.ac.in, aprao@nitw.ac.in

Abstract. In current times, there is a growing need for compact antennas that can function in multiple bands, specifically for wireless communication systems such as GSM, UMTS, and WIFI. Researchers are exploring the use of fractal geometry antennas to address this requirement. Several recent investigations have revealed that these structures possess distinct features that enhance certain properties of low-profile antennas. To attain the desired performance characteristics, a thorough examination, analysis, design, and description of the Meander-like fractal structure is conducted. The proposed antenna was created through a series of iterations ranging from the first to fourth. The imperfect ground plane was introduced in the last iteration to achieve wideband characteristics. In order to optimize performance, various aspects of the antenna including its properties, input impedance, VSWR, reflection coefficient, and radiation patterns are analyzed. The CST Design Environment was utilized for both simulation and implementation purposes. After designing the antenna, the Proposed antenna final iteration has a lower control band of (2–4.63) GHz and the bandwidth is 2.63GHz this can be considered as wideband, mid control band of proposed fractal antenna is (5.15–6.05) GHz close to the resonant frequency 5.82 GHz and upper control band of (8.15–8.66) GHz around close to the resonant frequency of 8.45 GHz [1]. There is a variety of applications in which these bands can be utilized wirelessly, including IEEE 802.11a, Wi-MAX, WI-FI, HiperLAN/2, Digital Cellular System, Personal Communications Services, UMTS, Bluetooth, IEEE 802.11 b/g/n WLAN, GSM, and GPS.

Keywords: CST Design Environment · Fractal · Gain · GSM · return loss · UMTS · WIFI

1 Introduction

Wireless communication has revolutionized human life and has become an indispensable part of daily activities. An important component of wireless communication is the antenna, which plays a crucial role in transmitting and receiving signals. The development of antenna theory can be traced back to Maxwell, who merged the concepts of magnetism and electricity and formulated Maxwell's equations in 1873. Antennas can be either directional or non-directional, and they serve as both transmitters and receivers

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[2]. Microstrip patch antennas (MPAs) and fractal antennas are two types of antennas that are widely used in wireless applications. MPAs consist of a substrate, a patch, a ground plane, and a power line. However, they have some limitations such as low efficiency, limited bandwidth, and limited resilience. Fractal antennas, on the other hand, are characterized by complex self-similar structures that can be created using recursive techniques. The proposed paper focuses on the optimal design of a fractal ground antenna that meets the criteria for small and lightweight antennas with high performance and economical cost. The proposed antenna has wide-band characteristics and achieves a bandwidth of 2.63 GHz for S11 $\leq$-10 dB in the frequency range from 0 to 9 GHz. The design parameters of the antenna are presented and discussed in detail using both theoretical and experimental results [3].

In addition to their advantages, fractal antennas have some challenges that need to be addressed. One of the main challenges is the complexity of their design and analysis, as they often involve intricate geometries that require specialized techniques and tools for their development. Another challenge is their susceptibility to interference and noise, which can affect their performance in crowded or noisy environments. Nevertheless, the potential benefits of fractal antennas make them a promising area of research and development for wireless communication systems. The unique properties of fractals offer the potential for significant improvements in antenna performance, especially in terms of miniaturization, bandwidth, and multi-band operation. As research continues to advance in this field, it is likely that new applications for fractal antennas will be discovered and their performance will continue to improve. Ultimately, fractal antennas have the potential to revolutionize wireless communication by enabling more efficient and effective communication systems that can meet the growing demands of modern technology.

Wireless communication has become an integral part of modern life, and the antenna plays a crucial role in its functioning. MPAs and fractal antennas are two types of antennas that are widely used in wireless applications. Fractal antennas offer several advantages over MPAs, including miniaturization, broadband properties, multi-band properties, and better efficiency [1, 7, 9, 10].

2 Related Work

The related work of the paper "Design and Analysis of Fractal Antenna Geometry for Wideband Applications" includes several studies that have explored the use of altered ground structures and in fractal antennas for different applications. One such study proposed a fractal antenna with an electromagnetic bandgap (EBG) ground plane for WLAN applications. The EBG structure was found to enhance the antenna's radiation characteristics by suppressing surface waves. Another study proposed a fractal antenna with a high-impedance surface ground plane for ultra-wideband (UWB) applications. The high-impedance surface structure provided a stopband for unwanted frequencies, thus enhancing the antenna's bandwidth. Several other studies have also explored different types of fractal antennas, such as Sierpinski gasket and Koch curve antennas, for various applications. Many of these studies have focused on improving the performance of fractal antennas by employing various techniques, such as adding parasitic elements, modifying the feeding structure, and altering the shape of the radiating element.

Overall, the related work of the paper highlights the importance of altered ground structures and patch in enhancing the performance of fractal antennas. It also provides valuable insights into different design techniques that can be used for various applications.

3 Antenna Design

The paper states an ideal design for a fractal antenna that utilizes a defective ground structure. To create the hexagonal patch, the design process involved using an equation that incorporated parameters such as resonant frequency and the substrate material's dielectric constant. The proposed antenna was developed using a low-cost FR4 lossless substrate with specific characteristics, including a thickness of 1.6mm, dielectric constant of 4.3, loss tangent of 0.02, and resonant frequency of 3.2 GHz [4]. Based on the design process, the patch's side length and radius were determined to be 12.6mm. Figure 1a in the paper displays the initial iteration of the hexagonal patch antenna design.

Equations:

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \tag{1}$$

$$R = \frac{F}{\left\{1 + \frac{2h}{\pi F \varepsilon_r}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{\frac{1}{2}}} \tag{2}$$

The suggested fractal antenna has been updated in its second iteration, with the addition of the six sides of the hexagonal patch have a meander-like fractal form, as shown in Fig. 1b [5]. This new design modification has been carefully crafted to be at a side scale of 1/3, with the goal of improving the antenna's overall performance. The primary benefits of this design include an increase in bandwidth and radiation efficiency. It is important to note that this design represents a significant improvement over the previous iteration, highlighting the potential advantages of incorporating fractal shapes into antenna design. The hexagonal patch length of the proposed fractal antenna's third iteration is displayed in Fig. 1c, with slots of the same scale introduced at the meander like fractal structure as shown in Fig. 1.

The proposed fractal patch antenna underwent several geometry adjustments to improve its return loss and bandwidth at frequencies ranging from 0 to 9 GHz. This was achieved by inserting 'T' shaped slots beneath each Meander element, and adding '+' and 'circle' shapes inside the patch structure with a diameter of 2 mm. The placement of the patch slots followed a specific coordinate system. The antenna's radiating patch was fed using a 50Ω microstrip feed line, and the ground plane dimensions were 45 mm × 44.92 mm, which was the same as the substrate dimensions (Fig. 2).

As shown in Fig. 3d, this part of the ground plane has been further modified by incorporating vertical and horizontal extensions. The redesigned ground plane has been carefully developed to ensure resonant characteristics in the required frequency range, as evidenced by return-loss, VSWR and gain studies. Section 3 discussed the impact of the adjustments made as well as the final shape of the planned fractal antenna with a modified ground plane (Table 1).

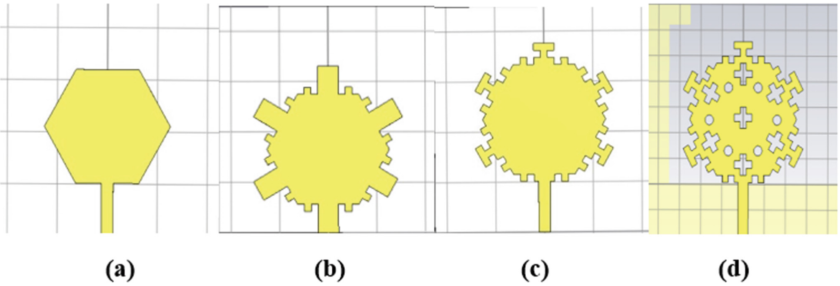


Fig. 1. Design of proposed antenna. a) 1st iteration b) 2nd iteration c) 3rd iteration d) 4th iteration

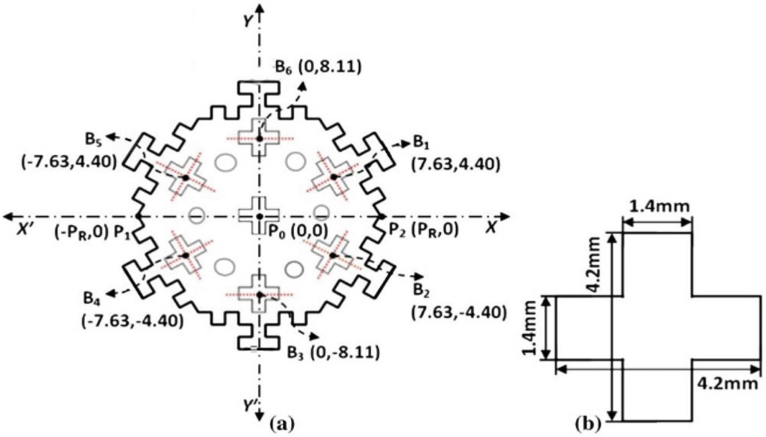


Fig. 2. a) final geometry for the proposed fractal antenna patch, b) dimensions of plus '+' shaped slots and circle with diameter of 2mm.

4 Results and Discussion

In this section, all components of the wideband fractal antenna design are presented and analyzed across the entire ground plane [6]. The performance measures are evaluated using low and high frequencies of 0 and 9 GHz, respectively, in reference to the antenna design. The suggested fractal antenna has several iterations, including the first, second, third, and fourth. Figure 5 displays the return loss versus frequency simulation charts for each iteration (1, 2, 3, and 4) of the suggested fractal antenna with ground plane dimensions of 45mm × 44.92mm. The impedance of the suggested antenna is developed by developing iterations 3 and 4 as shown in Figs. 4, 5, 6, 7.

VSWR is a measure of how effectively RF power is transmitted from a source to a load through a transmission line. VSWR values range from 1 to ∞, with values less than 2 considered satisfactory for most antenna applications (Tables 2 and 3).

The radiation pattern of a fractal antenna describes how the antenna radiates energy into space. In this case, the antenna's radiation pattern has been measured and found to have gains of 2.82dB at 3GHz, 7.16dB at 4.5GHz, and 5.05dB at 6GHz, indicating the antenna's ability to radiate energy across a range of frequencies. This wideband radiation

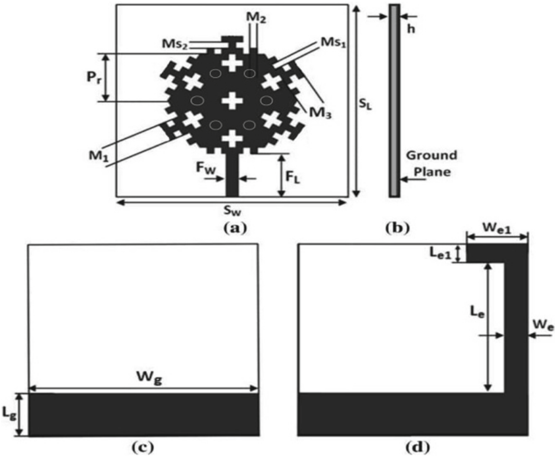


Fig. 3. The provided images include a bird's-eye view, a profile view, a rear view with a partially visible ground plane, and a view of the back of the ground plane, which has extensions.

Table 1. Measurements of designed antenna

Antenna design parameters	Description	Values (mm)
$M_1 = M_3$	Meander-like construction	4.2
M_2	Meander element	1.4
$M_{Slot1} = M_{Slot2}$	Meander slot	1.4
$P_{radius} = P_{Radius}$	Patch radius	12.6
F_W	Width of feed	2.4
F_L	Length of feed	10.15
S_W	Width of the substrate	45.0
S_L	Length of substrate	44.92
h	Height of substrate	1.6
W_g	Width of ground plane	45
L_g	Length of ground plane	10
W_e	vertical extension width	4
L_e	vertical extension length	30.92
W_{e1}	horizontal extension width	10
L_{e1}	horizontal extension length	4

pattern is a desirable characteristic for many applications, making the proposed fractal antenna a promising candidate for wideband communication systems.

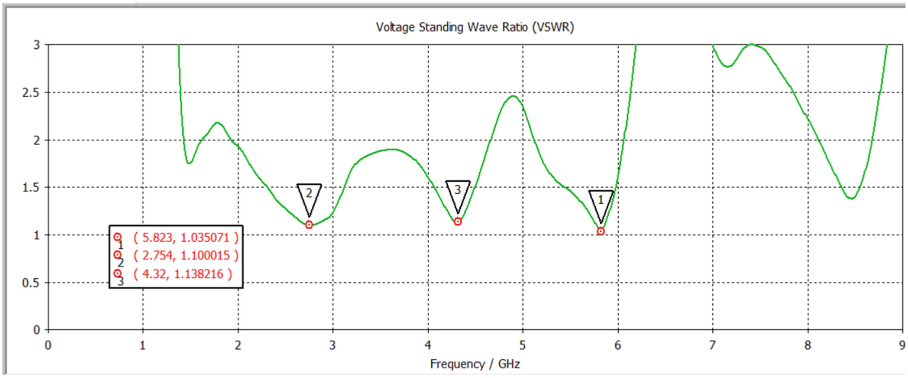


Fig. 4. VSWR plot for 4th iteration with ground plane

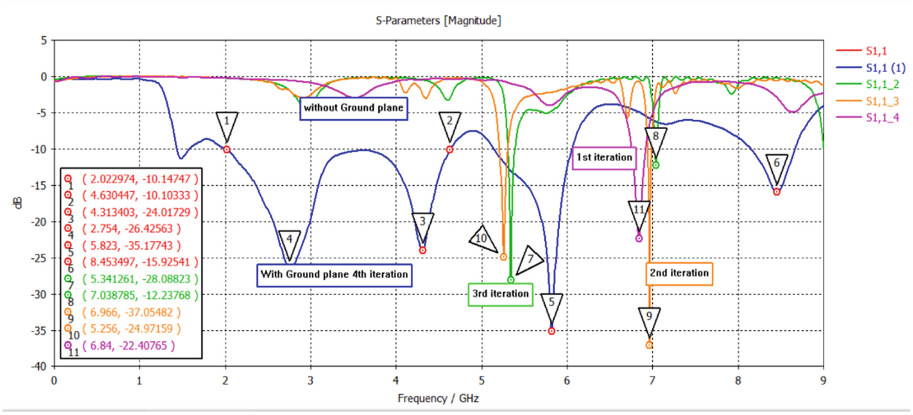


Fig. 5. A plot depicting the return loss as a function of frequency is shown for various iterations of the suggested fractal antenna design.

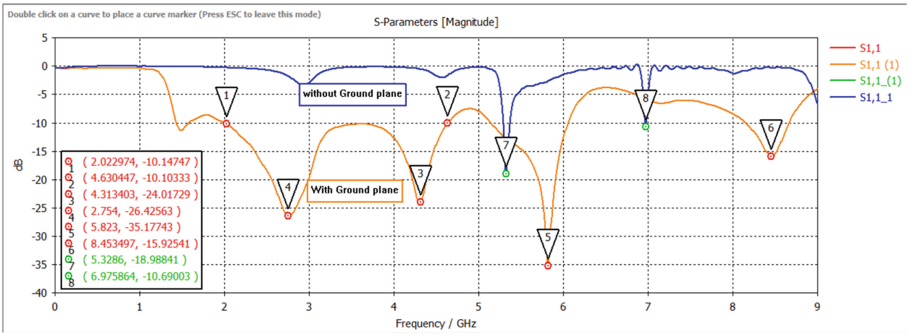


Fig. 6. Return loss plot for without ground plane versus with ground plane of fractal antenna.

Table 2. Comparison of iterations with 1,2,3,4 and reference work

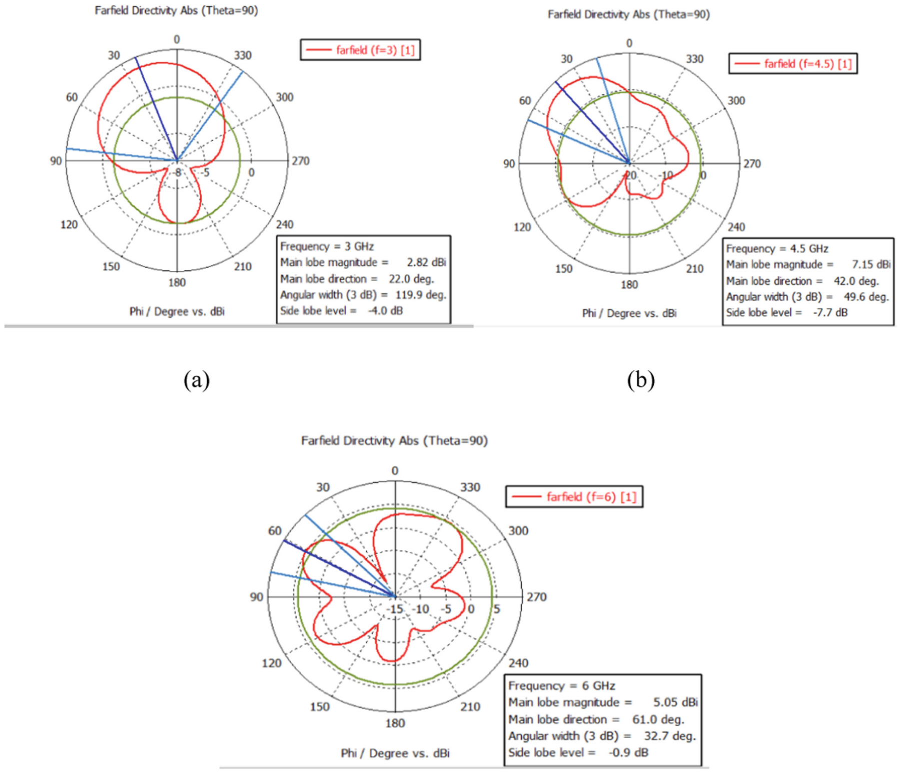
Iterations	F_L **(GHz)**	F_C (GHz)	F_H (GHz)	Bandwidth (%)	Bandwidth (MHz)
1st iteration	6.75	6.84	6.91	2.33	160
2nd iteration	5.20 6.94	5.25 6.96	5.30 6.98	1.90 0.57	100 40
3rd iteration	5.30	5.34	5.38	1.49	80
4th iteration (Proposed work)	2 5.15 8.15	3.31 5.82 8.45	4.63 6.05 8.66	79.45 15.46 6.03	2630 900 510
[2] Reference work	3	4.24	5.48	58.50	2480

Table 3. Comparison of proposed work with previous works

References	Dimensions (mm^2)	Operating frequency (GHz)	Bandwidth (MHz)	Gain (dB)
[11]	8100	1.49–1.51	113	5.41
[12]	1114	2.3/2.5/3.0/3.5	209/105/167/ 1054	5.8
[13]	900	1.76/2.55/3.85	25/32/100	2.11/- 3.9/ 2.5
[14]	3120	0.72–0.95/1.74–2.25	230.4/522.2	2.58
[15]	4900	2.4	45	2.5
[16]	1000	2.4–2.52	120	2.35
Proposed work	2021.4	3.31/5.82/8.45	2630/900/510	2.82/5.05/7.15

5 Conclusion

A novel fractal antenna design has been introduced for wideband applications, incorporating a modified patch and ground structure that spans an area of 44.92×45 mm^2. In order to increase the bandwidth, a defected ground plane was incorporated into the final version of the design [8] Simulation results indicate that the suggested antenna has a bandwidth of 2.63 GHz, rendering it suitable for a variety of wireless standards, including Wi-Fi (2.4–5 GHz), radio altimeter applications, WLAN (5.15–5.35 and 5.72–5.82 GHz), and X band (8–12 GHz). The antenna design has been optimized for maximum performance and is expected to facilitate reliable and efficient wireless communication for a wide range of applications.



(a) (b)

(c)

Fig. 7. 2D Radiation patterns of suggested fractal antenna at A)3 GHz B) 4.5 GHz C) 6 GHz.

References

1. Omar, Amjad A., Al-Hasan, Mu'ath J.B. (2011). A Dual-Band Coplanar-Waveguide Fed Slots-Coupled Dual Rectangular Dielectric Resonator Antenna. International Journal of Modelling and Simulation, 31, 90-95.
2. Bhatia, Sumeet Singh. (2018). An Optimal Design of Fractal Antenna with Modified Ground Structure for Wideband Applications. Wireless Personal Communications, 103.
3. M. -j. Song, J. -s. Li. (2011). A compact broadband microstrip patch antenna for wireless router. 2011 4th IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications.
4. S. N. Subramanian, C. Nataraj, S. Duraikannan. (2022). Multiband Fractal Antenna for 26/28 GHz Millimeter Wave Band. 2022 International Conference on Edge Computing and Applications (ICECAA). https://doi.org/10.1109/ICECAA55415.2022.9936386
5. S. Rajan and A. K. Prakash. (2015). A very compact triple band notched microstrip fed UWB antenna. 2015 Global Conference on Communication Technologies (GCCT), 906-909.
6. V. P. Sarin, N. Nassar, V. Deepu, C. K. Aanandan, P. Mohanan and K. Vasudevan. (2009). Wideband Printed Microstrip Antenna for Wireless Communications. IEEE Antennas and Wireless Propagation Letters, 8, 779-781.

7. Varghese Sheeba, Parambil Abdulla, Baby Ann Mary, Puthenveetil Muhammed Jasmine and Kunnath Kodakkat Ansha. (2021). Dual-Band Waveguide Fed Hollow Cylindrical Dielectric Resonator Antenna. Progress In Electromagnetics Research, (pp. 145–157). https://doi.org/10.2528/PIERC21103005
8. Yassen, Mahmood T. (2019). A Dual-Band Printed Antenna Design Based on Annular Koch Snowflake Slot Structure. Wireless Personal Communications, 104, 662.
9. Balanis. (1997). *Antenna theory: Analysis and design. London: Wiley.*
10. Marconi. (1912). *Titanic, Marconi and the Wireless Telegraph.* https://www.sciencemuseum.org.uk/objects-and-stories/titanic-marconi-and-wireless-telegraph
11. Prajapati, P., Patnaik, A., & Kartikeyan, M. (2016). Design and characterization of an efficient multi-layered circularly polarized microstrip antenna. *International Journal of Microwave and Wireless Technologies, 8*(7), 1101-1109. https://doi.org/10.1017/S1759078715000549
12. G. Srivatsun, S. S. Rani and G. S. Krishnan, "A Self-Similar Fractal Cantor Antennas for MICS Based Wireless Applications," *Wireless Engineering Technology*, Vol. 2, No. 2, 2011, pp. 107-111. https://doi.org/10.4236/wet.2011.22015
13. Rahimi, Maryam & Keshtkar, Asghar & Zarrabi, Ferdows & Ahmadian, Rahele. (2015). Design of Compact Patch Antenna Based on Zeroth-Order Resonator for Wireless and GSM Applications with Dual Polarization. *AEU - International Journal of Electronics and Communications*. 69. 163-198. https://doi.org/10.1016/j.aeue.2014.08.006.
14. Faruque, Mohammad Rashed Iqbal et al. "Low specific absorption rate microstrip patch antenna for cellular phone applications." *Iet Microwaves Antennas & Propagation* 9 (2015): 1540–1546.
15. Orazi, Homayoon and Hadi Soleiman. "Miniaturisation of UWB triangular slot antenna by the use of DRAF." *Iet Microwaves Antennas & Propagation* 11 (2017): 450-456.
16. Rongwei Wang, Jiuzhou Wang, Rensheng Xie, Xi Wang, Zhi Xu and Shouzheng Zhu, "A novel miniaturized microstrip antenna using interdigital capacitor based on Defected Ground Structure," 2016 *Progress in Electromagnetic Research Symposium (PIERS)*, Shanghai, 2016, pp. 450-453, https://doi.org/10.1109/PIERS.2016.7734362.