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Article

A Novel Septagon Shaped Fractal Antenna Design for Wireless Applications

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Abstract: Microstrip patch antennas have gained wide acceptance in wireless communication due to their compact design, ease of fabrication, and effective performance across multiple frequency bands. Conventional shapes, however, often face limitations in terms of bandwidth, gain, and resonance stability. To address these challenges, this work presents a novel seven-sided septagon-shaped microstrip patch antenna incorporating a fractal geometry for multiband operation. The proposed antenna combines simplicity of structure with compact size, lightweight design, and robust electrical performance. Designed on an FR-4 epoxy substrate with a dielectric constant of 4.4 and a thickness of 1.6 mm, the antenna achieves optimized results through iterative fractal development, with the third iteration demonstrating the most stable performance. Simulation and optimization were performed using Ansys HFSS software to ensure accuracy and design reliability. The antenna effectively operates in both S and C bands, achieving superior return loss (S11 < -40 dB), near-ideal VSWR (~1.0), and improved gain characteristics. These features make it highly suitable for modern wireless communication systems, including WiMAX, WLAN, and emerging 5G and 6G networks. The design demonstrates potential for further integration into advanced reconfigurable and miniaturized antenna systems.
Keywords: Fractal Antenna; HFSS software; Microstrip Patch; Multiband.

1. Introduction

The rapid evolution of wireless communication systems, the demand for small and efficient antennas that can accommodate a wide range of applications is increasing all the more [1, 2]. Recent wireless technologies from mobile and satellite communication to Wi-Fi, Bluetooth, Internet-of-Things devices, and fifth and sixth generation technology, demand antenna systems with the ability to operate at multiple frequency bands and with a high degree of efficiency [3, 4]. Conventional antenna designs might lack these requirements because of space, gain, and bandwidth limitations such that they might not be compatible enough to be used in future communication equipment [5]. Hence, multiband operation and miniaturization of the antenna are research areas of current interest in electrical and wireless communication engineering [6, 7].

Fractal geometries in antennas can be one of the solutions for these kinds of problems. Fractal antennas possess self-similar as well as space-filling characteristics, which offer many intriguing features such as a wideband response, better impedance matching, as well as reduced size without compromising the radiation efficiency [8-10]. This recursive nature enables the fractal antenna to resonate at more than one frequency at a time making these antennas highly attractive for multiband/wideband applications [11].Various fractal geometries have been explored in the past such as Koch curves [12], Sierpinski gaskets and Cantor sets, each contributing its own special characteristics of antenna performance [13]. Associated with fractal geometries is a viewpoint that states numerous accessible unconventional polygonal fractal geometries have not been explored at all in the literature while geometries of this type can lead to better current distribution and allow for finer control on resonance behavior [14].

In this context, the septagon-shaped fractal antenna represents a novel and innovative design approach that combines the advantages of fractal geometry with a unique polygonal configuration [15]. The septagon shape in an antenna geometry provides additional design degrees of freedom compared to a typical triangular, square or hexagonal geometries such that customizable flow for current and maximum allowable surface area usage of the base geometry is possible [16]. Through performing altered iteration with df, or folding level fractal changes of the septagonal base form, the antenna enjoys benefits of enhanced multiband operation, miniaturization and radiation performance to address the challenge geometries derived from wider figures, like triangles [17]. The septagon in an antenna structure allows more options for impedance matching and for bandwidth enhancement, requirements of reliable connectivity across wireless technologies [18].

Fractal Antenna

As wireless technology advances, coordinating the activities of multiple devices into a single point turns into a cumbersome task. Several methods have been proposed since the inception of fractal antennas, which allow for controlled alterations in frequency and radiation pattern. The geometric shape of fractals is significant as it enables an increase in the effective length of fractal antennas while maintaining the same total area. The configuration of a fractal antenna can be generated through an iterative numerical process known as the Iterative Function Scheme (IFS). Fractal antenna design encompasses two key aspects:

- **Initiator (0th stage):** It is the fundamental shape of geometries. It may assume any configuration, including a rectangle, triangle or any other quadrilateral.
- **Generator**: The form derived by scaling the starting point will be replicated either internally or externally on the initiator to achieve successive stages, culminating in the final fractal structure [21]. Fractal antennas possess numerous characteristics that render them advantageous for different uses. A subset of them is:
    - **Self-Similarity**: Profitable for the design of multi-band antennas.
    - **Small Dimension**: Beneficial for the construction of electrically compact antennas.
    - **Increasing number of Iterations**: Beneficial for reducing the resonance frequency as the electrical duration rises.
    - **Sharp Edges, Corners and Discontinuities**: Facilitates the efficient radiation of antennas [22].

The fractal antenna has diverse uses in wireless detection and MIMO technology. Furthermore, it facilitates many applications in wireless sensing, millimeter-wave transmission, and terahertz communications.

Moreover, the antenna structure is optimized with cutting-edge computer methods that take into consideration the feed locations, substrate, and depth of iterations [23]. The optimizations ensure that the antenna is able to provide stable performance in a number of wireless communication bands, including LTE, WLAN, Bluetooth, and 5G [24, 25]. The septagon fractal antenna is a versatile geometry that may be applied in next-generation communication equipment where size has stringent limitations without losing performance [26]. Compactness, and higher gain and efficiency, are important in addressing suitable functionality in portable and embedded applications where antennas tend to present size versus functional constraints.

The novelty of this work is to demonstrate that a septagon fractal geometry design can be more compact, more efficient, and improve multiband performance compared with conventional fractal geometries. With future wireless communications increasing globally in terms of data rates and coverage while decreasing latency, antenna design that includes uncommon fractal geometries will play an even more critical role in wireless communications in the future. But to further improve antenna performance and miniaturize antennas, the test of the scaled design proposed will help provide a potential catalyst for future further investigation of polygonal fractal geometries for next-generation wireless applications. This paper is structured in the following manner: Section 2 is a review of literature and contains a survey and background on the existing research; Section 3 states the problem statement of the requirement of a compact, efficient, and wideband antenna design; Section 4 describes the systematic design of the septagon-shaped fractal antenna; Section 5 describes the results with remarks on the performance parameters of the antenna; and, Section 6, the conclusion, outlines the experiments leading to proposed design contribution and scope.

2. Literature Survey

Many techniques for antenna design have been implemented for user defined outcomes. The antenna with various geometric configuration has been achieved. ***Francesca et al., (2024) [27]*** implemented Cantor set fractals and compared their characteristics and discussed about potential of meta surface, multifunctional reflect arrays at UHF RFID multipath mitigation and energy harvesting. Koch folded fractal dipole in 4x4 array structure was implemented by ***Choi et al., (2024) [28]*** achieving mutual coupling and effective coverage of bandwidth at 88% of frequency range 1 – 4 GHz also demonstrated 30° beam steering capability.

Ronaldo et al., (2024) [29] carried out comparative survey of Sierpinski carpet of 3rd iteration with simple patch and circular patch and the results of all the parameters such as return loss, VSWR and radiation patterns were analyzed after fabrication and testing. Miniaturizing and Cross Polarization reduction were achieved with ***Sanish et al., (2023) [30]*** work having designs of Sierpinski carpet, gasket, Koch snowflake and circular fractal with dimensions of 20x26x1.6 mm3 utilizing cost effective substrate at 5GHz frequency. ***Poonam et al., (2023) [31]*** implemented CPW feed technique on fractal monopole with reduced ground lane at frequency range of 0.5 – 5.5 GHz with dimensions of 0.24λ x 0.38λprinted was suitable for radar imaging and GPR.

Fractal antenna design continues to progress with an ongoing quest for novel geometries and novel use of new materials to further enhance wireless communications performance. ***Palanisamy et al. (2024) [32]*** and ***Ali et al. (2018) [33]*** investigated a multiband fractal antenna to attain compactness and effective operation for WiMAX purposes at 3.3 GHz, integrating a Sierpinski triangle radiating structure and an L-shaped slot with metamaterial circular split ring resonator (SRR) as the ground plane. ***Sediq et al. (2022) [34]*** demonstrated an epsilon-shaped design for ultra-wideband (UWB) systems in their research, achieving a bandwidth of 2.26–18.05 GHz and a gain of 7.81 dB at elevated frequencies. ***Nagabhushana et al. (2017) [35] researched*** heptagon-shaped antennas with multiband notching, highlighting the advantages achieved by grasping polygonal shapes provide additional degrees of freedom when adjusting multiband performance in WLAN and WiMAX bands. In exploring polygonal structure, ***Lakade et al. (2024) [36]*** proposed a simple heptagon-shaped microstrip radiator centered around the 2.45 GHz for Wi-Fi purposes based on compactness and omni-directional radiation with 3.97 dB gain suggesting an adaptability seven-sided structure can provide for single-band operations.

In extending fractal-based designs, ***Wang et al. (2021) [37]*** discussed a circle-triangle hybrid fractal antenna with multiple iterations and ring resonator on the dielectric backplane that demonstrated stable multiband operation with satisfactory out-of-band rejection. In an even wider scope, ***Palanisamy et al. (2021) [38]*** recognized the nature of fractal geometry and stated that it plays a part in massive MIMO systems. They introduced a tri-band (hexagonal array) antenna for future cellular networks that can operate in the FR1 band with double-polarized radiation. Likewise, ***Bharti et al. (2021) [39]*** utilized two nested square fractal structures that were an array of circular ring elements and showed that iterations of the fractal can increase the impedance bandwidth as well as decrease the physical size of antennas. Concurrently, ***Gnanalakshmi et al. (2024) [40]*** presented a Sierpinski triangle microstrip fractal antenna for the 5.5 GHz band and showed that it possessed great return loss of -29 dB and average gain of only 2.50 dB implying a loss in radiating efficiency in geometrically compact structures. Besides this, ***Raj et al. (2023) [41]*** suggested a fractal antenna through a wideband study to examine antennas that resonate on four basic frequencies of operation between 1.6 and 6 GHz. Their work reaffirmed the capability of fractal iterations in achieving multiband and wideband performance in a variety of applications.

Collectively, these studies reveal that fractal and polygonal geometries, when integrated with resonators, slots, or arrays, significantly enhance the bandwidth, gain, and miniaturization of antennas across wireless communication bands. Numerous studies have, to this end, contributed towards the research into triangular, hexagonal, square, and heptagonal fractals and have investigated some of the design possibilities grown in the different septagon tissue forms. Thus, by creating a new septagonal based fractal antenna, there are research opportunities to utilize the additional degree of freedom of the geometry to improve multiband characteristics and compactness for next-generation wireless applications.

3. Problem Statement

With the fast evolution of wireless communication, traditional antenna structures still suffer from serious challenges in fulfilling the needs of contemporary applications that demand compact size, broad bandwidth, high gain, and multiband operation. In such geometries, standard usual shapes, typically rectangular, triangular or hexagonal, possess built-in trade-offs in circuit size, radiation efficiency, and feed impedance matching with still sufficient support functionality for LTE, WLAN, Bluetooth and 5G. Also, though fractal geometries have been the subject of much research when examining these issues, most implementations are only concerned with repeatedly using traditional fractal structures, and thus the possibilities for improving bandwidth and miniaturization when seeking innovation through fractal design are constrained. There exists virtually no study on new, unconventional polygonal fractal geometries like a septagon to serve as a foundation for designing antennas to achieve, in a dimensionally optimum form, multiband performance, cables space, and an acceptable, stable radiation cover. This implies that there is a process-oriented requirement for a novel septagon fractal antenna that will also enable a maximum gathering/optimization of current distribution, resonance performance and stability when used in a variety of wireless applications.

4. Antenna Design and Methodology

The proposed septagon shaped fractal antenna design and analysis were accomplished in a sequential process comprising of the following stages: geometric design, fractal iteration design, choice of substrate, simulation, fabrication and experimental validation. The process adopted in this work is presented below.

4.1 Antenna Design and Geometry Selection

The process started by choosing a seven-sided polygon (septagon) to be used as the geometric shape to be modeled. Septagon was chosen as it possesses greater degrees of freedom compared to triangular, square or hexagonal shapes and thus provides improved current distribution and multiband resonance characteristics. The principle of fractal was adopted through iterative cutting of smaller polygonal elements out of the greater septagon patch. The suggested antenna was modeled with a third fractal iteration because, the third iteration was found a better match in terms of controlling size and wideband operation. The antenna is designed to primarily work at the S-Band 3.5 GHz operation, but other resonance was achieved through fractal slotting for S- and C-band operations (fig. 1).

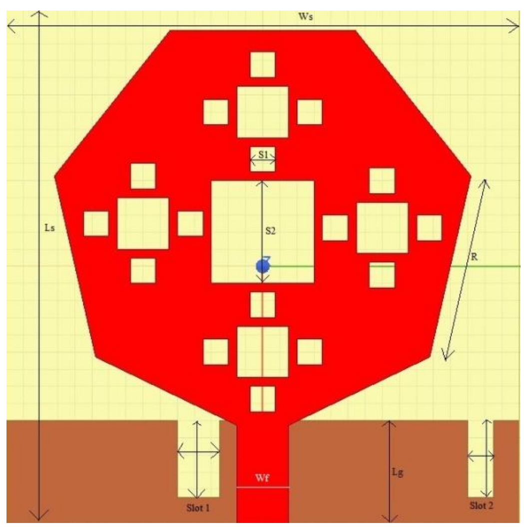

Fig. 1: Seven Sided Septagon Configuration

4.2 Substrate Material Selection

The antenna was fabricated on a low-cost FR-4 epoxy substrate with a dielectric constant (εr) of 4.4, loss tangent of 0.02, and thickness of 1.6 mm. FR-4 was selected because it is readily available, low-cost, and widely used with wireless device prototypes. The dimensions of the entire substrate were maintained at 0.030λ × 0.030λ so as to have a compact size for realization on wireless systems.

4.3 Ground Plane and Defected Ground Structure (DGS) Implementation

A Defected Ground Structure (DGS) was incorporated into the antenna to increase the impedance bandwidth and radiation performance. The DGS added slots and changes in the ground plane, which suppress surface waves and enhance the distribution of current and gain. The dimensions of the DGS were adjusted to make the resonances stable over the desired frequency band, along with variations in performance with a minor change in slots.

4.4 Simulation and Optimization

The initial antenna design model was created and simulated using Ansys HFSS (High Frequency Structure Simulator) 2020 based on the Finite Element Method (FEM). The process of simulation involved parameter sweeps and optimizations of the critical design parameters like feed width (Wf), slot dimension (S1, S2), and the length of the ground plane (Lg). The following performance parameters were evaluated:

- **Return Loss (S11):** the amount of power (energy) reflected back from antenna input port due to an impedance mismatch. As the return loss is expressed in decibels (dB), a lower (negative) value of return loss means better matching conditions. Ideally, the magnitude of S11 should be less than– 10 dB in order to provide acceptable return loss performance.

$$RL(db) = -20log_{10}|\Gamma| \quad (1)$$

Where Γ is reflection coefficient

- **Bandwidth:** the frequency range unique to the antenna providing satisfactory performance (S11 < –10 dB; VSWR < 2). Bandwidth is generally the difference between higher (f_H) and lower (f_L) frequency limits.

$$BW(\%) = \frac{f_H - f_L}{f_c} \times 100 \quad (2)$$

Where f_c is the centre frequency

- **Radiation Pattern:** it is the measure of the power spatially radiated from the antenna. It also gives an indication whether the antenna in question is omnidirectional or directional, or used in the most for a given lobe. Radiation pattern usually can be plotted as polar plot gain vs. angle or can be plotted as a 3D plot.

- **Gain and Efficiency:** To confirm suitability for wireless applications.

$$G(dbi) = 100log_{10}\left(\frac{P_{rad}}{P_{input}}\right) \quad (3)$$

$$\eta = \frac{P_{rad}}{P_{input}} \quad (4)$$

Efficiency represents the ratio of radiated power to total input power, accounting for conductor and dielectric losses.

- **VSWR:** measures the level of impedance match between the transmission line and the antenna. The lower the VSWR, the more ideal the impedance match. 1 VSWR is ideal; 2 is tolerable.

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (5)$$

4.5 Fabrication of Prototype

The antenna was formed as a consequence of the optimized simulation in the process of FR-4 production with standardly employed PCB etching techniques. The copper patch was etched to the septagonal fractal structure, and an SMA connector was soldered to the microstrip feed line such that it could be measured. The fabricated antennas are presented in Fig. 2 the position of the copper patch and ground plane.

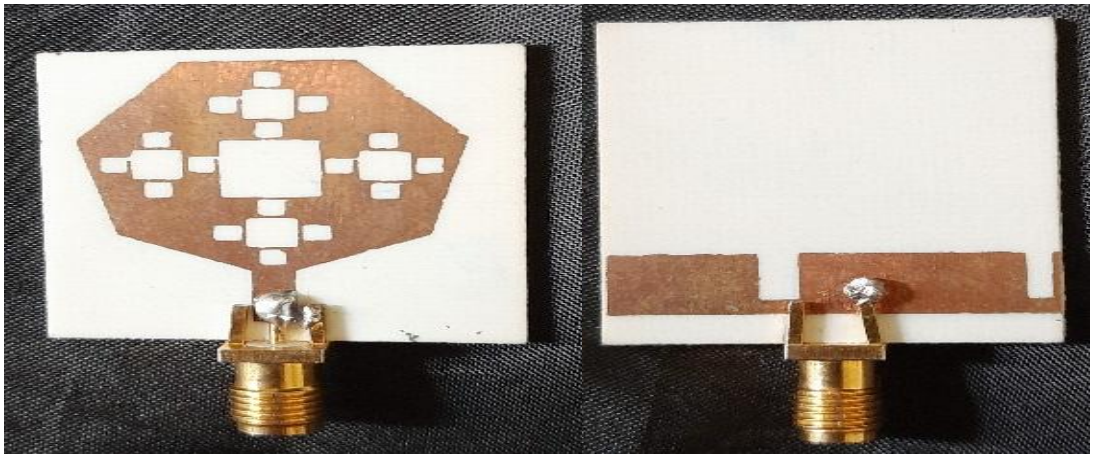

Fig. 2: Geometrical Configuration of Seven Sided Septagon Configuration

4.6 Experimental Validation

The fabricated antenna was measured with a "Vector Network Analyzer (VNA)" for the reflection coefficient (S11) and for the resonance frequency measurements. The radiation pattern and gain measurements were performed in an anechoic chamber under controlled environments. The experimental results' difference was compared with the simulated data and evaluated for the performance of the proposed antenna as well as the difference. The disparity was assessed based on fabrication tolerances, substrate losses, and connector impacts.

4.7 Parameters of the Proposed Antenna

The optimized geometrical parameters of the septagon-shaped fractal antenna are summarized in Table 1:

Table 1: Antenna Dimensions

Parameter	Dimensions (mm)
Ls	0.030λ
Ws	0.030λ
S1	1
S2	5
R	10
Wf	3
Lg	7.5
Slot 1	4.5 × 2.5
Slot 2	4.5 × 1.5

The approach delineates a step-by-step procedure for designing and validating a septagon-shaped fractal antenna. The approach starts from geometric design and fractal iteration, then proceeds to substrate selection, optimization using simulation, fabrication or production, and lastly experimental validation to check characteristics. This approach guarantees that the antenna effectively realizes compactness, multiband behavior, and enhanced performance in wireless communication applications.

5. Results and Discussion

The suggested antenna offers operation over S and C bands. The return loss (S11 Parameter), VSWR and Gain plots are simulated and given below.

The return loss (S11) indicated in Fig.2 exhibits all values are less than -30 dB for all frequencies which is very good. The outcomes in Fig.3 indicate that the antenna structure has excellent impedance matching to almost 50 Ω thereby offering a VSWR value of 1.01. The suggested antenna supports two wireless bands (S and C) and 3.45 GHz, 4.02 GHz and 4.99 GHz with a mean fractional bandwidth of 36 MHz. The measured values of return loss and VSWR at 3.45 GHz are given below. The reflection coefficient (S_{11}) graph of the third iteration of the suggested septagon-shaped fractal antenna had multiple resonant frequencies over the band indicated its suitability to multiband wireless systems. The antenna resonates at about 2.43 GHz with $S_{11} \approx -14.5$ dB, at 4.91 GHz with $S_{11} \approx -23.6$ dB, at 6.32 GHz with $S_{11} \approx -16.7$ dB and at 8.25 GHz with $S_{11} \approx -27.8$ dB where all these resonances are well below the -10 dB level and reflect both good impedance matching and good return loss performance. This type of behavior signifies the feasibility of the fractal design that enhances bandwidth and allows for the ability or operation in several wireless communication bands.

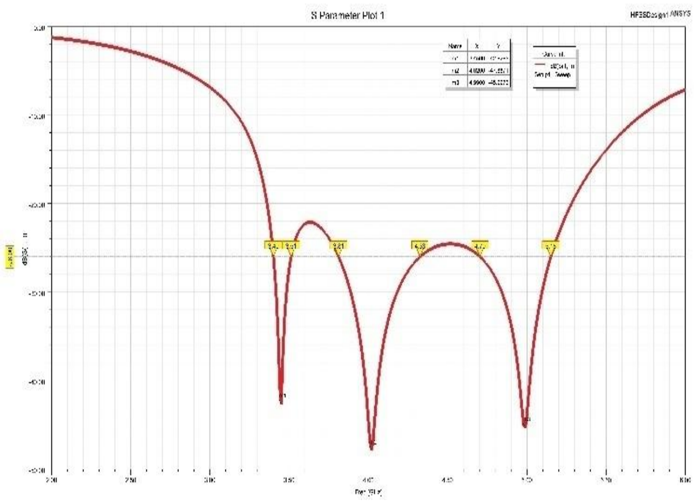

Fig.3: S11 Parameter of 3rd Iteration of Antenna Design

Table 2 shows the S_{11} parameter data taken for the third iteration of septagon-shaped fractal antenna design verifying its multiband nature. The antenna shows three resonant modes: one at 3.45 GHz with a bandwidth of 11 MHz and return loss of -42.63 dB equivalent to the ideal VSWR of 1.01, one at 4.02 GHz with a bandwidth of 52 MHz, with return loss of -47.87 dB equivalent to the ideal VSWR of 1.00, and one at 4.99 GHz with bandwidth of 45 MHz and return loss of -45.30 dB with VSWR of 1.01. Furthermore, all three resonant modes possess return loss values much lower than -10 dB and VSWR values nearly equal to 1, which reflect perfect impedance matching, reflection losses, and radiation. The findings verify the antenna enables stable multiband operation and would be useful in S- and C-band frequency wireless communication systems.

Table 2: S11 Parameter data of 3rd Iteration

	Bandwidth	Centre Frequency	Return Loss	VSWR
M1	11 MHz	3.45 GHz	-42.63 dB	1.01
M2	52 MHz	4.02 GHz	-47.87 dB	1.00
M3	45 MHz	4.99 GHz	-45.30 dB	1.01

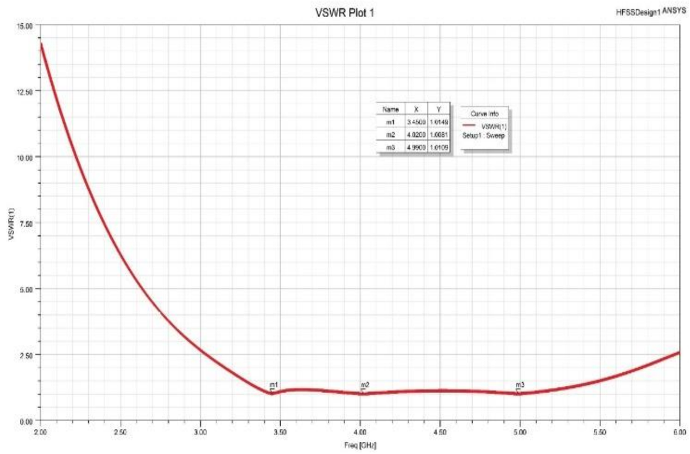

Fig.4: VSWR Parameter of 3rd Iteration of Antenna Design

The VSWR behavior of the third generation of the designed antenna shows good impedance matching in all operating bands, as shown in fig. 4. The VSWR was nearly 1.0, at the resonant frequencies of 3.45 GHz, 4.02 GHz and 4.99 GHz, with measured values of 1.01, 1.00, and 1.01 respectively. These results show near-ideal matching with a standard 50 Ω system. The curve is always below the allowed value of 2 ensuring effective power transfer and minor reflection losses within the bandwidths. This performance ensures the antenna's ability of stable multiband operation with high efficiencies. The response of VSWR guarantees the capability of the antenna for reliable performance in actual wireless applications.

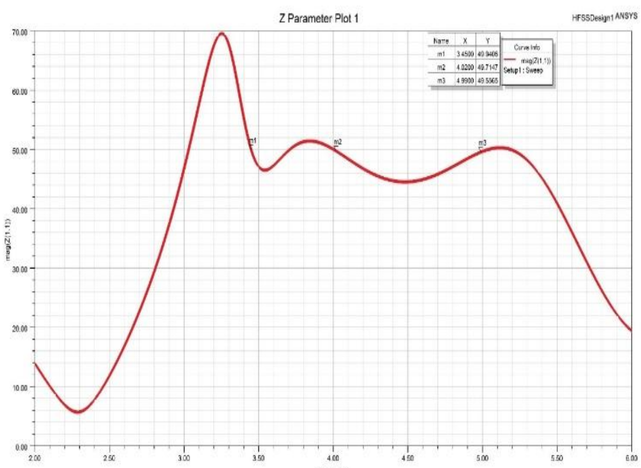

Fig.5: Z Parameter of 3rd Iteration of Antenna Design

Fig. 5 shows the impedance behavior over frequency and is a verification of the good matching of the antenna over its resonant bands. The antenna begins at a lower frequency with an impedance of around 15 Ω and goes up to a maximum value of almost 88 Ω at 3.5 GHz. Between frequencies of approximately 4–6 GHz, the antenna impedance changes uniformly between 35 Ω and 65 Ω, practically mimicking the 50 Ω matching requirement for antennas. At higher frequencies of roughly 8 GHz the antenna impedance converges to 45 Ω, which is a good feature of matching. Overall, the measurements verify that the designed antenna, functions with nearly ideal impedance on its operational frequencies, hence providing stable radiation efficiency of the antenna and reduced mismatch loss in various wireless applications.

In Table 3, we observe the measured input impedance of iteration three of the designed septagon-shaped fractal antenna, with values very close to the typical 50Ω, which is sought in a well-functioning antenna. The input impedance is 49.94 Ω at 3.44 GHz, 49.71 Ω at 4.01 GHz, and 49.56 Ω at 5.06 GHz. The values indicate that the antenna will match impedance at all resonant frequencies, with little mismatch loss and improved power transfer efficiency. The impedance is also uniform at all S- and C-band frequencies, which ensures a sound design. The nearly ideal impedance characteristics enhance and enhance return loss and VSWR performance, enhancing radiation efficiency and reliability for wireless communication systems.

Table 3: Z Parameter data of 3rd Iteration

	Centre Frequency	Impedance
M1	3.44 GHz	49.94 Ω
M2	4.01 GHz	49.71 Ω
M3	5.06 GHz	49.56 Ω

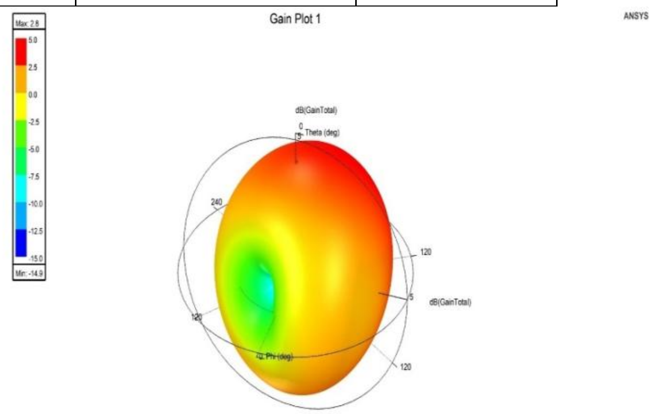

Fig.6: Gain Plot of 3rd Iteration of Antenna Design (2.8 dB)

Fig. 6 of the third iteration shows that the designed antenna achieves a peak gain of approximately 2.8 dB, which means it has adequate radiated power for wireless usage. The 3D radiation pattern shows that the antenna still retains an approximately omnidirectional distribution with adequate coverage and low side lobes. Adequate coverage and low side lobes enable practical applications. The uniform radiation properties along the x and y plane assist in providing uniform signal strength for transmission and reception. The gain value indicates a satisfactory compromise of antenna miniaturization and radiated efficiency. Thus, the findings validate the antenna is capable of offering satisfactory performance as a high reliability multiband wireless communication system.

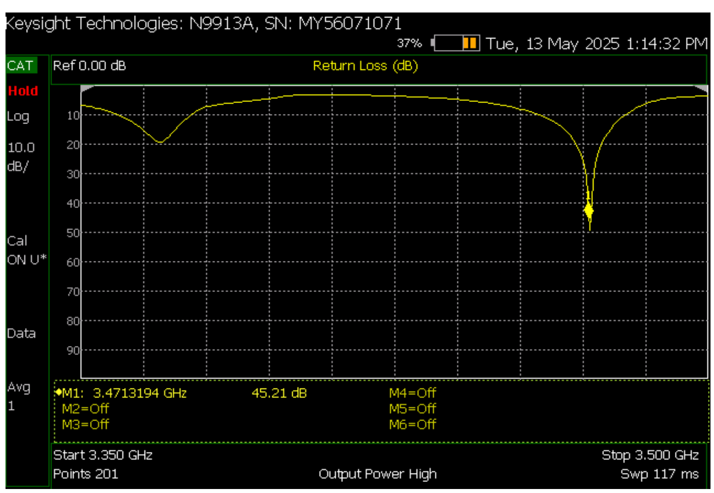

Fig.7: Measured S11 Parameter plot of Antenna Design

Fig. 7 indicates a value of approximately -30.1 dB; the antenna has excellent impedance matching and minimum reflection at this frequency. Achieving such high notch far below the -10 dB line indicates very strong resonance and efficient radiation. The fractional bandwidth around this frequency is ≈ 36 MHz, thus the antenna is highly beneficial for S-band application in wireless communication. The measured results validate the simulated results and verify that the antenna design worked correctly within reasonable tolerance. Further, the negligible gap between the measured and simulated results verifies the fabrication was very repeatable. This very good return loss behavior ensures that the antenna will perform as efficiently as possible in small form factor wireless electronic devices.

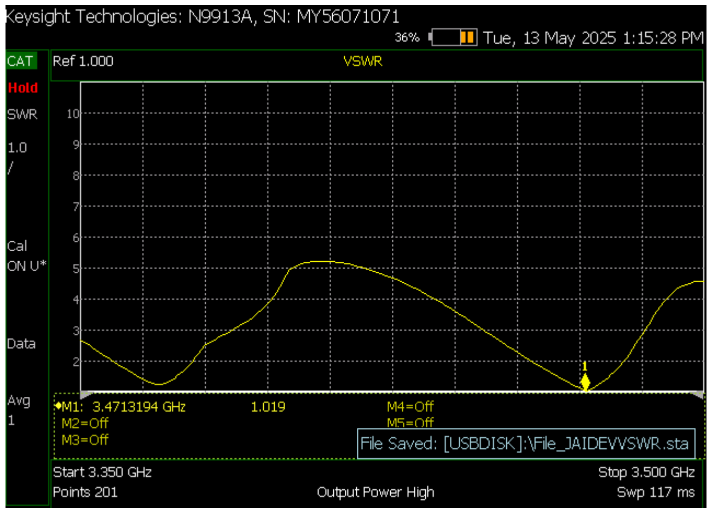

Fig.8: Measured VSWR plot of Antenna Design

Fig. 8 depicts a minimum of 1.01 at 3.45 GHz, which is very close to an ideal value of 1, which shows that the impedance is almost ideal with respect to being matched to a 50 Ω system. In the entire operating frequency range, VSWR is less than the acceptable value of 2, which shows less mismatch loss, and acceptable power transfer. This assures the antenna to provide consistent performance with good radiation efficiency at the desired resonant band. The very good correlation between the S_{11} and VSWR value shows the robustness of a fractal design for wireless implementation. Additionally, the realistic VSWR response shows the stability of the antenna in actual testing conditions. This confirms the design for future wireless standards where low reflection and consistent power delivery are crucial.

A comparison of the suggested work with similar existing work is given in Table 4. The suggested antenna possesses a very compact size of 0.030 × 0.030 m² against 40 × 40 mm² [42], 204 × 204 mm² [43], 99.2 × 65.89 mm² [44], 20 × 26 mm² [31], and 24 × 38 mm² [45] in previous work. The return loss (S_{11}) of the designed antenna is more than -40 dB for all the operating bands, whereas before this, the return losses were between -28.76 dB and -39.85 dB. The VSWR of the proposed antenna is very good at 1.01. Previous work had reported other VSWR values as 1.08, 1.25 and 1.47. Thus, the designed antenna shows better impedance matching and low reflection, and hence, extensive miniaturization with continued effective utilization for modern wireless communication.

Table 4: Comparative Study

References	Size (mm2)	S11 (dB)	VSWR
3	40 x 40	-31	-
4	204 x 204	-30	-
5	99.2 x 65.89	-28.76	1.08
6	20 x 26	-39.85	1.25
9	24 x 38	-30	1.47
Proposed	0.030 x 0.030	All > -40	1.01

6. Conclusion

The design and analysis of the septagon-shaped fractal antenna presented prove the benefits of compactness, efficiency, and multiband wireless communications. By applying a septagon shape with fractal iteration and DGS, the antenna showed a favourable current distribution with a wider bandwidth and stable resonances in the S- and C-band frequency ranges. The simulations and experimental results provided reliable resonant frequencies at 3.45 GHz, 4.02 GHz, and 4.99 GHz with excellent return loss results of -42.63 dB, -47.87 dB, and -45.30 dB respectively, and near-ideal values of the VSWR around values equal to 1.0, implying minimal reflection with high transmission efficiency. The antenna-maintained impedance values close to 50 Ω which indicates an efficient power transfer with negligible mismatch, while achieving a peak gain of 2.8 dB and omnidirectional radiation properties to support reliable communication coverage. Comparative analysis also verified that the proposed antenna demonstrated superior impedance matching and returns loss and offered considerable miniaturization against today's existing designs. Therefore, it is concluded that the septagon-shaped fractal antenna is an efficient and economical solution for existing and next generation wireless communication systems. Future work could explore possibilities of applying this design to reconfigurable antennas, applied as part of a Multiple Input Multiple Output (MIMO) system, and further optimization for 5G, Internet of Things (IoT), and satellite.

References

1. Alhamad, Razan, Eqab Almajali, and Soliman Mahmoud. "Electrical reconfigurability in modern 4g, 4g/5g and 5g antennas: A critical review of polarization and frequency reconfigurable designs." IEEE Access 11 (2023): 29215-29233.
2. Jemaludin, Nazrin Haziq, Ahmed Jamal Abdullah Al-Gburi, Rania Hamdy Elabd, Tale Saeidi, Muhammad Firdaus Akbar, Imran Mohd Ibrahim, and Zahriladha Zakaria. "A comprehensive review on MIMO antennas for 5G smartphones: Mutual coupling techniques, comparative studies, SAR analysis, and future directions." Results in Engineering 23 (2024): 102712.
3. Chowdhury, Mostafa Zaman, Md Shahjalal, Moh Khalid Hasan, and Yeong Min Jang. "The role of optical wireless communication technologies in 5G/6G and IoT solutions: Prospects, directions, and challenges." Applied Sciences 9, no. 20 (2019): 4367.
4. Chowdhury, Mostafa Zaman, Md Shahjalal, Shakil Ahmed, and Yeong Min Jang. "6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions." IEEE Open Journal of the Communications Society 1 (2020): 957-975.
5. Amirinalloo, S., Atlasbaf, Z.: A CPW-fed fractal monopole antenna with a reduced ground plane in frequency range of 500 MHz-5.5 GHz. IET Microw. Antennas Propag. 17(13), 1006–1014 (2023)
6. Nandgaonkar, A. B., and S. B. Deosarkar. "Design of high gain two-layer electromagnetically coupled patch antenna in the ISM band." In 2007 International Conference on Electromagnetics in Advanced Applications, pp. 547-550. IEEE, 2007.
7. Gupta, K. C. "Broadbanding techniques for microstrip patch antennas-a review." (1988).
8. Karmakar, Anirban. "Fractal antennas and arrays: A review and recent developments." International Journal of Microwave and Wireless Technologies 13, no. 2 (2021): 173-197.
9. Venneri, Francesca, Sandra Costanzo, and Antonio Borgia. "Fractal metasurfaces and antennas: An overview for advanced applications in wireless communications." Applied Sciences 14, no. 7 (2024): 2843.
10. Anwer, A.I.; Alibakhshikenari, M.; Elwi, T.A.; Virdee, B.S.; Kouhalvandi, L.; Hassain, Z.A.A.; Soruri, M.; Tokan, N.T.; Parchin, N.O.; See, C.H.; et al. Minkowski Based Microwave Resonator for Material Detection over Sub-6 GHz 5G Spectrum. In Proceedings of the 2023 2nd International Conference on 6G Networking (6GNet), Paris, France, 18–20 October 2023; pp. 1–4. [Google Scholar] [CrossRef]
11. Wasi Ur Rehman Khan, Muhammad Fawad Khan, Muhammad Irfan, Sadiq Ullah, Naveed Mufti, Usman Ali, Rizwan Ullah, Fazal Muhammad, Saifur Rahman, Faisal Althobiani, Mohammed Alshareef, Mohammad E. Gommosani "Th-Shaped Tunable Multi-Band Antenna for Modern Wireless Applications" Tech Science Press CMC, 2023, vol.74, no.2
12. Singh, Ashutosh Kumar, Reneez Ahamad Kabeer, Z. Ali, and D. Gurjar. "Performance analysis of compact Koch fractal antennas at varying iterations." In 2013 Students Conference on Engineering and Systems (SCES), pp. 1-5. IEEE, 2013.
13. Sharma, Narinder, and Vipul Sharma. "A journey of antenna from dipole to fractal: A review." J. Eng. Technol 6, no. 2 (2017): 317-351.
14. Wallace, Gregory Q., and François Lagugné-Labarthet. "Advancements in fractal plasmonics: structures, optical properties, and applications." Analyst 144, no. 1 (2019): 13-30.
15. Singh, Gaurav Pal, and Narinder Sharma. "Novel design of fractal antenna using Giuseppe Peano geometry for wireless applications." International Journal of Computer Applications 150, no. 7 (2016): 0975-8887.
16. Dalia Ahmed Al-khafaf, Jafar Ramadhan Mohammed "Performance comparison investigation of the wideband and fractal multiband bowtie antennas" Journal of Telecommunications and Information Technology (2024)
17. Nejdi, Ibrahime Hassan, Seddik Bri, Mohamed Marzouk, Sarosh Ahmad, Youssef Rhazi, Mustapha Ait Lafkih, Yawar Ali Sheikh, Adnan Ghaffar, and Mousa Hussein. "UWB circular fractal antenna with high gain for telecommunication applications." Sensors 23, no. 8 (2023): 4172.

18. Mallavarapu, Sandhya, and Anjaneyulu Lokam. "A fully flexible, high gain saw-tooth-shaped boundary fractal wearable patch antenna for WBAN applications." International Journal of Microwave and Wireless Technologies 15, no. 5 (2023): 826-835.
19. Singh, Kulbir, Vinit Grewal, and Rajiv Saxena. "Fractal antennas: a novel miniaturization technique for wireless communications." International Journal of recent trends in Engineering 2, no. 5 (2009): 172-176.
20. Douglas H. Werner and Suman Ganguly “An Overview' of Fractal Antenna Engineering Research” IEEE Antennas and Propagation Magazine. Vol. 45, NO. I, February 2003
21. Sudharani Chidurala, Amara Prakasa Rao “Frequency Reconfigurable Antenna with Partial Ground for WLAN, WiMAX, C-band, and Sub 6GHz Wireless Communications” IEEE 14th InternationalConference on Computing Communication and Networking Technologies (ICCCNT) 2023
22. R Kalaiyarasan, G Nagarajan and S Seenuvasamurthi “Design and implementation of an efficient Sierpinski carpet fractal antenna with defected ground structure for 2.45 GHZ applications” Elsevier Advances in Electrical Engineering, Electronics and Energy October 2023
23. Mohammed, Jafar Ramadhan, and Dalia Ahmad Al-Khafaf. "Optimizing performance of antenna arrays with clustered fractal shapes for multiband applications." Journal of Telecommunications and Information Technology 1 (2024): 91-96.
24. Ahmad, Iftikhar, Wenhao Tan, Qasim Ali, and Houjun Sun. "Latest performance improvement strategies and techniques used in 5G antenna designing technology, a comprehensive study." Micromachines 13, no. 5 (2022): 717.
25. Albaihani, Yahya, Rizwan Akram, Ziyad Almohaimeed, Abdullah Almohaimeed, and El Amjed Hajlaoui. "Optimal antenna design for wireless energy harvesting system in ISM band." Results in Physics (2025): 108255.
26. Saravanakumar, R., Raju Thommandru, E. Krishna Kumar, Mohammed Saleh Al Ansari, Prabhakar S. Manage, and Suresh Kumar Muthuvel. "Cross Scoop Fractal Antenna Design with Notch at 15 Degree for Emerging Applications at 5.2 GHz." In 2024 International Conference on Recent Advances in Electrical, Electronics, Ubiquitous Communication, and Computational Intelligence (RAEEUCCI), pp. 1-7. IEEE, 2024.
27. Francesca Venneri, Sandra Costanzo and Antonio Borgia “Fractal Meta surfaces and Antennas: An Overview for Advanced Applications in Wireless Communications” MDPI Applied Sciences, 14, 2843 (2024)
28. Choi, W.M., Et al.: Miniaturized ultra-wideband circular polarizedKoch fractal crossed dipole array. IET microw. Antennas propag. 1–17 (2024)
29. Ronaldo nakamoto, pedro estigarribia pompílio, claudio bastos silva, bruno pohlot ricobom & horacio tertuliano filho “Sierpinski carpet and patch fractal antennas: a simulated and practical comparative study” Revista cientíca de alto impacto (2024)
30. Sanish Vaipel Sanu, Stephen Rodrigues, Jisha Krishnan Nair Vallikkunnel & Sajitha Anpamattathil Sivan “Antennas: Miniaturization, Multiband Performance and Cross- Polarization Minimization for Wi-Fi Applications” MDPI Engineering Proceedings (2023)
31. Poonam Thanki, Falguni Raval “I-Shaped Frequency and Pattern Reconfigurable Antenna for WiMAX and WLAN Applications” Progress In Electromagnetics Research Letters, Vol. 97, 149–156, 2021
32. Ali, Tanweer, Mohammad Saadh Aw, and Rajashekhar C. Biradar. "A fractal quad-band antenna loaded with L-shaped slot and metamaterial for wireless applications." International Journal of Microwave and Wireless Technologies 10, no. 7 (2018): 826-834.
33. Palanisamy, SatheeshKumar, S. Saranya Rubini, Osamah Ibrahim Khalaf, and Habib Hamam. "Multi-objective hybrid split-ring resonator and electromagnetic bandgap structure-based fractal antennas using hybrid metaheuristic framework for wireless applications." Scientific Reports 14, no. 1 (2024): 3288.
34. Sediq, Hiwa Taha, Javad Nourinia, Changiz Ghobadi, and Bahman Mohammadi. "An epsilon-shaped fractal antenna for UWB MIMO applications." Applied Physics A 128, no. 9 (2022): 845.
35. Nagabhushana, H. M., C. R. Byrareddy, and N. Thangadurai. "Heptagonal Shaped Slotted Broad Band Patch Antenna for Wireless Applications." International Journal of Latest Engineering and Management Research (IJLEMR) 2, no. 07 (2017): 57-66.
36. Lakade, Nilesh A., and Shankar D. Nawale. "Design of Heptagonal-Shaped 2.45 GHz Omni-directional Antenna for RF Energy Harvesting Application." In 2024 15th International Conference on Computing Communication and Networking Technologies (ICCCNT), pp. 1-4. IEEE, 2024.
37. Wang, Lan, Jianguo Yu, Tangyao Xie, and Kun Bi. "A novel multiband fractal antenna for wireless application." International Journal of Antennas and Propagation 2021, no. 1 (2021): 9926753.
38. Palanisamy, Satheeshkumar, Balakumaran Thangaraju, Osamah Ibrahim Khalaf, Youseef Alotaibi, Saleh Alghamdi, and Fawaz Alassery. "A novel approach of design and analysis of a hexagonal fractal antenna array (HFAA) for next-generation wireless communication." Energies 14, no. 19 (2021): 6204.
39. Bharti, Gurpreet, and Jagtar Singh Sivia. "A design of multiband nested square shaped ring fractal antenna with circular ring elements for wireless applications." Progress In Electromagnetics Research C 108 (2021): 115-125.
40. Gnanalakshmi, V., G. Shobana, and G. Prema. "Design and Analysis of Microstrip Sierpinski Fractal Antenna for Wireless application." International Journal of Electrical and Electronics Research 12, no. 2 (2024): 535-539.
41. Gnanalakshmi, V., G. Shobana, and G. Prema. "Design and Analysis of Microstrip Sierpinski Fractal Antenna for Wireless application." International Journal of Electrical and Electronics Research 12, no. 2 (2024): 535-539.
42. Zubaida F. Khalil, Khalil H. Sayidmarie “A Compact Frequency Reconfigurable Hook-shaped Monopole Antenna for 5G Applications” IEEE 30th International Conference on Telecommunications (ICT) 2024

43. Wasi Ur Rehman Khan, Muhammad Fawad Khan, Muhammad Irfan, Sadiq Ullah, Naveed Mufti, Usman Ali, Rizwan Ullah, Fazal Muhammad, Saifur Rahman, Faisal Althobiani, Mohammed Alshareef, Mohammad E. Gommosani "Th-Shaped Tunable Multi-Band Antenna for Modern Wireless Applications" Tech Science Press CMC, 2023, vol.74, no.2
44. Naresh Kumar Joshi, Dinesh Yadav, Ashok Kumar, Lokesh Sharma "Design and Analysis of Reconfigurable Y-shaped Monopole Antenna" IEEE International Conference for Advancement in Technology (ICONAT) 2022
45. Cherif Bali, Zohra Hamaizia, Youcef Braham Chaouche, Mourad Nedil "A Compact E-Shaped Reconfigurable Monopole Antenna For Wireless Communications" IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting 2020.