

Miniaturized Dual-Band Antenna with Reconfigurability For Next-Gen Wireless Multi Band Fractal Patch Antenna for Implantable Cardiac Monitoring

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Abstract - The rapid evolution of wireless communication systems such as WiFi 6, WiFi 7, Internet of Things (IoT), and 5G technologies has increased the demand for compact and efficient antennas capable of supporting multiband operation. This paper presents a miniaturized dual-band reconfigurable fractal microstrip patch antenna designed for next-generation wireless and implantable biomedical applications. The proposed antenna operates in the 2.4 GHz and 5 GHz frequency bands, which are widely used in wireless communication and healthcare monitoring systems. Miniaturization is achieved using fractal geometry and meandered current paths that increase the effective electrical length without increasing the physical dimensions of the antenna. The antenna is designed on a Rogers RT/Duroid 5880 substrate because of its low dielectric constant and low loss characteristics, which improve radiation efficiency and stable high-frequency operation. The design and analysis were carried out using ANSYS HFSS 2025 R2. Simulation results demonstrate compact size, dual-band behavior, stable radiation characteristics, and suitability for biomedical and IoT-based communication systems. The proposed antenna offers a promising solution for low-profile wireless devices requiring compact dimensions, frequency flexibility, and reliable communication performance.

Keywords - Miniaturized Antenna, Dual-Band Communication, Circular Polarization, Implantable Biomedical Antenna, 5G and WiFi 6/7 Networks

I. INTRODUCTION

Wireless communication technologies have experienced remarkable growth over the past decade, enabling high-speed data transfer and reliable connectivity for applications such as WiFi, Internet of Things (IoT), wearable devices, and fifth-generation (5G) communication systems. In these

applications, antennas play a vital role in transmitting and receiving electromagnetic signals efficiently. As modern electronic devices continue to become smaller and more compact, the demand for miniaturized antennas with high performance and multiband capability has increased significantly.

In addition to conventional wireless systems, biomedical and healthcare technologies increasingly rely on wireless communication for patient monitoring and data transmission. Implantable medical devices such as cardiac monitors, pacemakers, glucose sensors, and biosensors require compact antennas capable of operating efficiently within limited space while maintaining reliable communication through biological tissues. Designing antennas for such applications is challenging because the human body absorbs electromagnetic energy, which can reduce antenna efficiency and radiation performance.

Microstrip patch antennas are widely used in wireless and biomedical applications due to their low profile, lightweight structure, ease of fabrication, and compatibility with printed circuit board technology. However, conventional patch antennas suffer from drawbacks such as narrow bandwidth, relatively larger physical dimensions, and limited frequency flexibility. To overcome these limitations, modern antenna design techniques such as fractal geometries, slot loading, meandered structures, and reconfigurable architectures are employed.

This work proposes a miniaturized dual-band reconfigurable fractal patch antenna intended for next-generation wireless and implantable biomedical applications. The antenna is designed to operate at 2.4 GHz and 5 GHz

frequency bands used in WiFi, ISM, and IoT communication systems. Fractal geometry is incorporated to achieve significant size reduction while maintaining acceptable radiation characteristics. Reconfigurability is introduced to enhance flexibility and adaptability for future wireless communication requirements.

The major contributions of this work are summarized as follows:

1. Design of a compact dual-band fractal microstrip antenna operating at 2.4 GHz and 5 GHz.
2. Implementation of fractal geometry for antenna miniaturization.
3. Integration of reconfigurable design concepts for adaptive wireless operation.
4. Performance analysis using ANSYS HFSS simulation environment.
5. Suitability evaluation for implantable biomedical and IoT communication applications.

II. RELATED WORK

A. Recent Advances in Antennas for Biotelemetry and Healthcare Applications

This paper presents a comprehensive review of modern antenna technologies used in biomedical and healthcare systems. The study discusses implantable and wearable antennas designed for wireless patient monitoring and biotelemetry applications. Major challenges such as antenna miniaturization, low Specific Absorption Rate (SAR), radiation efficiency, and stable communication near biological tissues are analyzed. The authors highlighted the importance of compact antenna structures with improved bandwidth and gain for reliable healthcare monitoring systems. The reviewed works demonstrate that fractal and compact antenna geometries can significantly improve antenna performance for biomedical applications.

B. Innovations and Challenges in RF Antenna Technologies for Implantable Medical Device Communication

This paper investigates recent developments in RF antenna technologies for implantable medical devices. The study emphasizes the importance of compact and efficient antennas capable of operating reliably inside the human body. Key challenges including biocompatibility, electromagnetic interference, SAR limitations, and power efficiency are discussed. The authors also explored advanced techniques such as reconfigurable antennas, multiband structures, and MIMO configurations to improve communication reliability in implantable systems. The work concludes that compact and adaptive antenna designs are essential for future biomedical communication technologies.

C. A Miniaturized MIMO Antenna With Dual-Band Operation for 5G Smartphone Applications

This paper proposes a compact dual-band MIMO antenna designed for 5G smartphone communication systems. The antenna achieves significant size reduction using techniques such as path extension, parasitic stubs, and compact radiator structures. The proposed design supports dual-band operation while maintaining acceptable isolation and radiation efficiency. Simulation and measurement results confirm

stable operation across the intended frequency bands. The study demonstrates that miniaturization techniques can effectively reduce antenna size without severely affecting wireless communication performance.

D. Design and Implementation of Active Antennas for IoT-Based Healthcare Monitoring Systems

This work presents a dual-band active microstrip antenna integrated into an IoT-based healthcare monitoring system. The antenna supports wireless monitoring of physiological parameters such as heart rate and body temperature. Reconfigurability is achieved using PIN diodes, enabling dynamic switching between operating frequency bands. The antenna demonstrates good radiation efficiency and stable communication performance for healthcare applications. The study highlights the importance of compact reconfigurable antennas in modern IoT-enabled medical systems.

E. A New Compact Planar UWB Monopole Antenna

This paper introduces a compact planar ultra-wideband monopole antenna designed for wireless communication applications. The antenna uses a modified radiating patch and partial ground plane to achieve wide impedance bandwidth and stable radiation characteristics. Simulation results demonstrate wideband operation with good impedance matching and quasi-omnidirectional radiation patterns. The study confirms that compact antenna structures with optimized geometries can provide improved bandwidth performance while maintaining low fabrication complexity.

III. ANTENNA DESIGN METHODOLOGY

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A. Antenna Configuration

The proposed antenna is designed as a compact fractal microstrip patch antenna intended for dual-band wireless communication applications. The antenna consists of a radiating patch, dielectric substrate, microstrip feed line, and a ground plane. Fractal slots and meandered current paths are incorporated into the radiating patch to achieve miniaturization and multiband operation.

The antenna is designed to operate at 2.4 GHz and 5 GHz frequency bands used in WiFi, IoT, and biomedical communication systems. The compact structure enables easy integration into wearable and implantable electronic devices where available space is limited.

B. Antenna Configuration

The antenna is fabricated on Rogers RT/Duroid 5880 substrate because of its excellent high-frequency performance and low dielectric losses. The substrate has a

dielectric constant of 2.2 and a low loss tangent, which improve radiation efficiency and reduce power losses during operation.

The substrate dimensions are selected to maintain compactness while providing sufficient electrical performance. The low dielectric constant also contributes to improved impedance matching and bandwidth characteristics.

IV. SIMULATION SETUP

The proposed antenna was modelled and analysed using ANSYS Electronics Desktop Student 2025 R2 with HFSS electromagnetic simulation environment. A frequency sweep ranging from 2 GHz to 6 GHz was performed to evaluate the dual-band characteristics of the antenna.

The simulation environment was configured with appropriate radiation boundaries and wave ports to ensure accurate electromagnetic analysis. Important antenna performance parameters such as return loss (S11), gain, radiation pattern, and field distribution were analysed.

The simulation process was carried out iteratively to optimize antenna dimensions and improve impedance characteristics while maintaining compact physical size.

V. RESULTS AND DISCUSSION

A. S-Parameter Analysis

The simulated S-parameter response demonstrates resonance near the 2.45 GHz region corresponding to the ISM band used in WiFi and IoT communication systems. The antenna exhibits stable resonance behavior within the intended operating band.

Although further optimization is required to improve impedance matching, the obtained response confirms the operational capability of the compact fractal structure. The dual-band behavior validates the effectiveness of the proposed miniaturization technique.

B. Radiation Pattern Analysis

The simulated radiation pattern indicates stable directional radiation characteristics suitable for short-range wireless communication systems. The antenna demonstrates acceptable field distribution and radiation coverage required for biomedical and IoT-based applications.

The three-dimensional radiation plot confirms that the proposed antenna maintains stable radiation behavior despite its compact size and fractal geometry.

C. Gain Analysis

The simulated gain characteristics indicate low-power directional radiation suitable for implantable and wearable communication systems. In biomedical applications, compactness, low power operation, and low Specific Absorption Rate are often prioritized over high gain.

The obtained gain characteristics demonstrate the feasibility of the antenna for short-range wireless communication and biomedical monitoring applications.

D. Miniaturization Performance

One of the major objectives of the proposed design is antenna size reduction. Compared with conventional rectangular patch antennas operating at similar frequencies, the proposed fractal geometry achieves significant miniaturization by increasing the effective current path within a compact substrate area.

The incorporation of fractal slots and meandered structures contributes to reduced physical dimensions while preserving acceptable electromagnetic performance. This makes the antenna suitable for compact wireless devices and implantable biomedical systems where space availability is highly constrained.

Although further optimization is required to improve impedance matching, the obtained response confirms the operational capability of the compact fractal structure. The dual-band behavior validates the effectiveness of the proposed miniaturization technique.

TABLE I. COMPARATIVE ANALYSIS

Parameter	Conventional Patch Antenna	Proposed Fractal Antenna
Physical Size	Larger	Compact
Operating Bands	Single Band	Dual Band
Reconfigurability	Not Available	Supported
Miniaturization	Limited	High
Biomedical Suitability	Moderate	High
Frequency Flexibility	Low	Improved

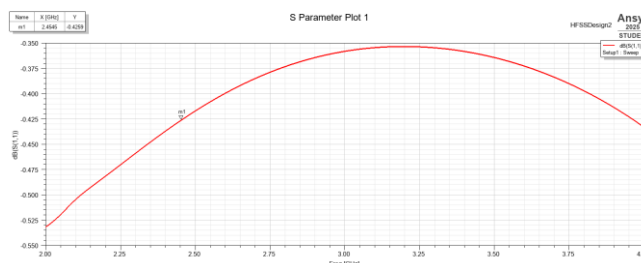


Fig. 1. S parameter plot

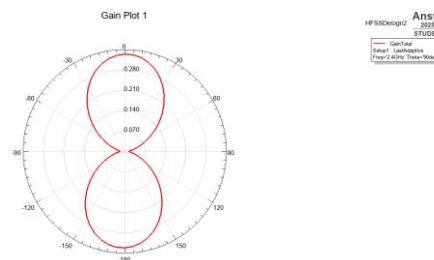


Fig. 2. Gain

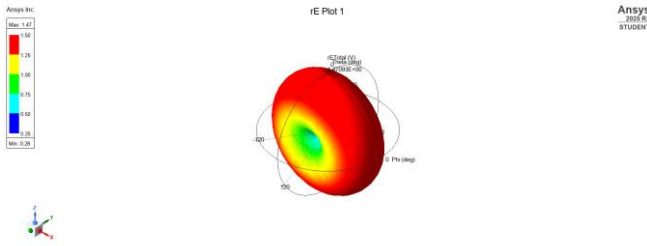


Fig. 3. Radiation pattern

VI. CONCLUSION

This paper presented a miniaturized dual-band reconfigurable fractal microstrip patch antenna designed for next-generation wireless and implantable biomedical applications. The proposed antenna operates in the 2.4 GHz and 5 GHz frequency bands commonly used in WiFi, IoT, and biomedical communication systems.

Fractal geometry and meandered current paths were incorporated to achieve significant antenna miniaturization while maintaining acceptable radiation characteristics. The antenna was designed using Rogers RT/Duroid 5880 substrate to improve high-frequency performance and reduce dielectric losses.

Simulation results obtained using ANSYS HFSS demonstrated stable radiation behavior, compact dimensions, and dual-band operation. The proposed design provides a promising solution for compact wireless communication devices requiring reduced antenna size, adaptive operation, and biomedical compatibility.

VII. FUTURE WORK

Future work will focus on fabrication and experimental validation of the proposed antenna structure. Further optimization of impedance matching and gain characteristics will also be performed. Specific Absorption Rate (SAR) analysis will be conducted to evaluate safety performance for implantable biomedical applications.

Advanced reconfigurable techniques using PIN diodes and intelligent adaptive communication systems may also be integrated in future versions of the antenna.

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