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RESEARCH ARTICLE

Compact Meander Patch Antenna at 915 MHz for Medical Implant Application

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Abstract

The present study introduces a small and efficient antenna designed specifically for medical implants. With the increasing demand for wireless and minimally invasive medical devices, there is a need for antennas that can reliably transmit and receive data within the human body. The antenna presented in this study functions within the Industrial, Scientific, and Medical (ISM) frequency band, meeting all necessary regulations with a size of 10×10×1.6 mm^3. FEM-based HFSS software has been used for simulation and using Roger 3010 substrate with relative permittivity of 10.2. We carefully selected materials and used optimization techniques to create a compact design without sacrificing performance. To overcome challenges from the body's dispersion and losses, we thoroughly evaluated the antenna's electromagnetic properties through simulations and tests. The results show outstanding performance in gain, radiation pattern, and impedance matching, making it ideal for various medical implant applications. Moreover, our design proves to be robust against detuning effects caused by tissue interactions, ensuring dependable communication within the target frequency range. By addressing the size and efficiency constraints of medical implant antennas, our work advances wireless biomedical devices, leading to improved healthcare monitoring and therapeutic solutions with enhanced patient comfort.

Keywords: human body model, medical implant, specific absorption rate (SAR), compact antenna.

1 Introduction

Internally positioned biomedical device play a crucial role in research and commercial sectors, used for various applications like brain implants, glucose monitoring, heart failure detection, retinal prosthesis, and capsule endoscopy. This device requires internally positioned antennas to communicate wirelessly with external equipment. Different frequency bands, such as Med Radio and ISM, are approved and used for medical implants. The main requirements for body-implanted communication antennas include flexibility, sufficient gain, high bandwidth, low SAR level, and miniaturized form factor. Numerous

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methods have been proposed to reduce antenna size; however, some of these approaches involve complex designs and result in low peak gain, limiting their suitability for most internally positioned biomedical devices [1].

Internally positioned biomedical devices are widely used in the biomedical industry and academia, and they often utilize the medical implant communications service band (402–405 MHz) for wireless communication. Other suggested frequency bands include the Industrial, Scientific, and Medical (ISM) bands and the Wireless Medical Telemetry Services bands. To enable wireless communication outside the body, this device requires implantable antennas, which face challenges like miniaturization, biocompatibility, channel quality, and specific absorption rate (SAR). The planar inverted-F antenna is a common choice due to its small size, simple structure, and omnidirectional pattern. However, linear polarization (LP) antennas like slot, dipole, and monopole antennas can suffer from multipath distortion based on the alignment between the transmitting and receiving antennas. Design guidelines for these implantable antennas are provided in reference [2].

The development of microelectronics and medical technologies has led to extensive research on implantable devices for various biomedical applications. These devices, like glucose monitors, cardiac pacemakers, and retinal prostheses, need to communicate wirelessly with external equipment. Designing antennas inside the human body is challenging due to factors such as tissue loss, biocompatibility, and size constraints. Human phantom models are crucial for accurate antenna behavior prediction. Previous works have used spiral or planar inverted-F antennas (PIFA) and cavity slot antennas, but they have narrow bandwidths and are sensitive to tissue property variations. To address this, wideband implantable antennas have been proposed, such as the pi-shape with double L-strip PIFA structure for dual resonance and broad bandwidth. Dual-band implantable antennas operating in the MICS and 2.45-GHz ISM bands have also been studied, allowing switching between sleep and waking modes to extend the device's lifetime [3].

Research on implantable antennas has gained significant attention in recent times. These antennas need to be broadband to minimize frequency shift effects in human tissues, but their small size inherently limits their bandwidth. Various efforts have been undertaken to enhance bandwidth, including the use of stacked multilayer designs, Planar Inverted-F Antenna (PIFA) structures, and coplanar waveguide (CPW) feeding techniques. However, these methods come with complexities and potential harm to the human body.

Most internally positioned antennas are of linear polarization (LP), which can suffer from polarization mismatch due to multipath distortion and different body postures. Circular polarization (CP) offers the advantages of orientation insensitivity, leading to better mobility, lower bit-error rates, and improved link stability compared to LP.

Consequently, there is a need to study CP antennas operating in the human body. A recent study presented a capacitive-loaded CP implantable patch antenna in the 2.4–2.48 GHz industrial, scientific, and medical band (ISM). However, these works often suffer from limited bandwidth or design complexity, motivating further research into compact and efficient implantable antennas [4, 5]. Therefore, implantable antennas must maintain reliable communication performance while achieving low SAR, stable impedance matching, and miniaturization inside biological tissues. Motivated by these requirements, this work proposes a compact meander patch antenna operating at the 915 MHz ISM band for robust biomedical implant communication applications.

2 Materials and Methods

2.1 Antenna Design

The design process begins with a thorough review of existing research and a comprehensive understanding of the specific requirements of implant applications. The meander antenna is known for its compactness. To evaluate and enhance the antenna's characteristics, the Ansys HFSS simulation tool is employed. Parameters like size, shape, and spacing of the meander segments are meticulously adjusted to achieve a resonance frequency of 915 MHz, in alignment with the widely used ISM band. The resulting compact meander antenna demonstrates outstanding performance characteristics, promising seamless and reliable wireless communication for implant applications at 915 MHz frequencies, opening up new horizons in the realm of medical technology.

Dimensions of the slots are calculated using equations (1) and (2) [6, 7]. The length of the slot is given as [8]

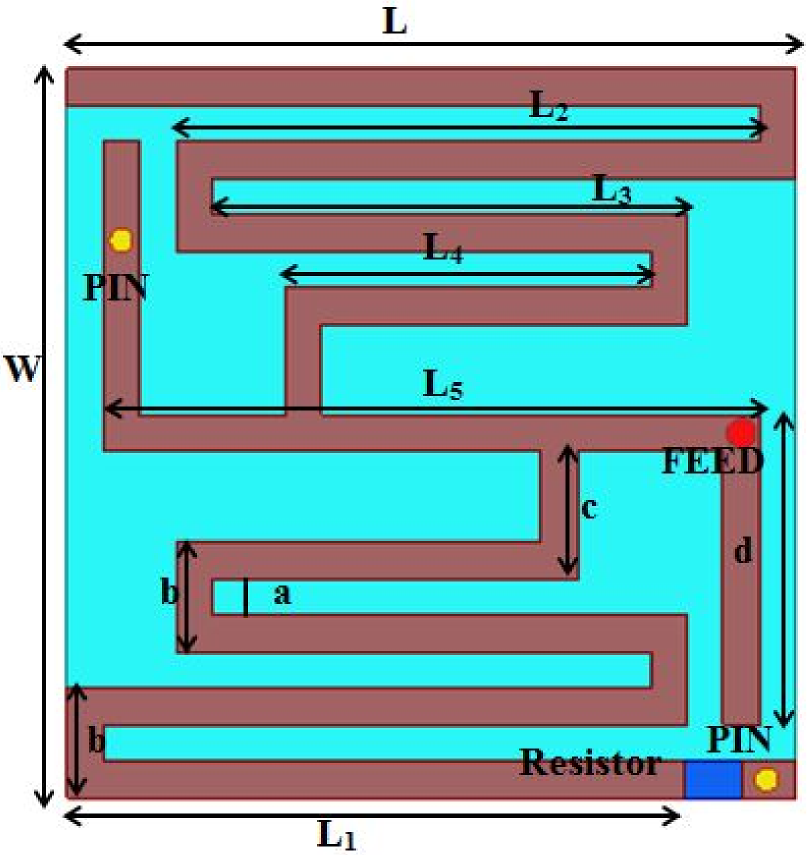

Figure 1. Proposed antenna structure.

$$L_{\text{slot}} = \frac{\lambda_g}{4} = \frac{c}{4\sqrt{2}} \quad (1)$$

The width of the slot is given as [8]

$$w_{\text{slot}} = \frac{\lambda}{60} \quad (2)$$

The proposed antenna structure is shown in Figure 1, which illustrates the compact meander patch antenna design. The detailed geometrical parameters of the antenna are summarized in Table 1, including the overall dimensions (L and W), various slot lengths (L_1 to L_5), and other critical design parameters.

Table 1. Design parameters of the antenna prototype.

Parameters	Value (mm)	Parameters	Value (mm)
L	10	L_5	8.75
W	10	a	0.5
L_1	7.95	b	1.5
L_2	8	c	1.75
L_3	6.5	d	4.25
L_4	5	R_{PIN}	0.16

2.2 Tissue Equivalent Phantom and water Phantom Model

As shown in Figure 2, the development and characterization of a novel human body tissue phantom designed for electromagnetic simulations and testing applications at 915 MHz in which the proposed antenna was inserted 2 mm inside. The TEL phantom's composition (DGBE (Diethylene glycol butyl ether), NaCl, Triton X-100, and water are 7.99, 0.16, 19.97, and 71.88 respectively) and dimensions 90×90×26.27 (mm^3) are meticulously chosen to closely resemble the complex nature of human tissues, making it a valuable tool for validating and optimizing electromagnetic devices and systems [9]. Through comprehensive measurements and comparisons with actual human tissues, the proposed phantom demonstrates exceptional accuracy and reliability, enabling researchers and engineers to perform realistic and repeatable experiments for a wide range of applications in the field of electromagnetics.

Considering its simplicity and convenience of measurement, the "Open-ended Coaxial Probe" method is frequently employed for liquid dielectric assessment. We used a commercial dielectric evaluation system that included a Vector Network

Analyzer (ZNB 8, Make: R&S), a DAK 2.4.0.814 software package, and a DAK 3.5 sensor probe (Make: S. P. E. Ag).

The dielectric properties of the tissue-equivalent phantoms used in this study are summarized in Table 2. These parameters, including permittivity (ϵ), conductivity (σ), and loss tangent ($\tan\delta$), are critical for accurately simulating the electromagnetic behavior of the antenna in biological environments.

Table 2. Dielectric properties Of phantoms.

Phantom	Permittivity (ϵ)	Conductivity (σ)	Tan (δ)
TEL	63.349	0.4489	0.141
Water	78.84	0.182	0.046

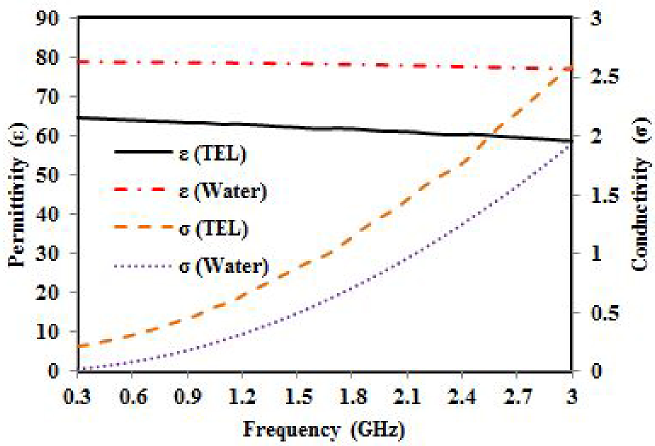

Figure 2. Permittivity and conductivity plot w.r.t frequency.

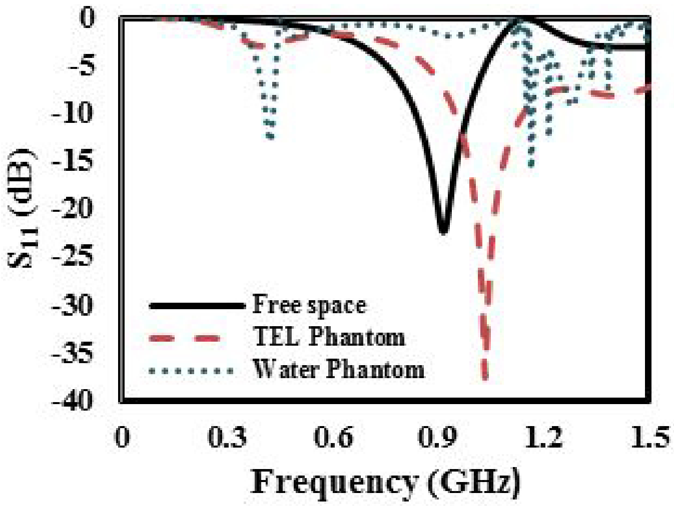

Figure 3. Simulated reflection coefficient results.

3 Results And Discussion

3.1 Evaluation of Reflection Performance

The input reflection response of the compact meander patch antenna is analyzed and compared amongst free space, TEL phantom and water phantom. The results, as shown in Figure 3, demonstrate less agreement among the three, because of dielectric loading effect. The antenna exhibits a reflection coefficient below -10 dB over the operating frequency, indicating excellent impedance matching and efficient power transfer. This performance is crucial for ensuring reliable communication in medical implant applications, where power efficiency is paramount.

3.2 SAR Analysis and Compliance

Adherence to SAR standards, such as those outlined in IEEE C95.1-1999, is paramount in ensuring the safety of electronic devices and mitigating potential health risks associated with radiofrequency (RF) exposure. The established limit of 1.6 watts per kilogram for peak average SAR values, as specified by the IEEE standard, serves as a crucial safeguard against adverse effects on human health. To practically evaluate SAR values, engineers and researchers often employ numerical analysis using specialized simulation tool, such as the ANSYS High-Frequency Structure Simulator (HFSS) [10], with simulations conducted at specific frequencies and phantom models. The TEL phantom model study at 915 MHz is crucial in confirming adherence to IEEE C95.1-1999 restrictions in the instance under discussion. A thorough evaluation of possible RF energy exposure levels and absorption patterns within the human body is made possible by this simulation [11], empowering professionals to optimize electronic device designs for safety and align them with established standards. As technology continues to advance, ongoing adherence to SAR guidelines remains vital for the responsible development of RF-emitting devices.

$$SAR = \frac{\sigma E^2}{2\rho} \tag{3}$$

Figure 4 shows the SAR distribution patterns for the proposed antenna, presenting contour plots at 2 mm depth for both (a) TEL phantom and (b) water phantom models. These visualizations demonstrate the compliance of the antenna design with safety regulations and provide insights into the electromagnetic energy absorption characteristics in different tissue-equivalent environments.

3.3 Radiation Pattern

Figure 5 shows the simulated radiation patterns in both the E- and H-planes at the operating frequency of 915 MHz. The antenna exhibits a directional pattern due to

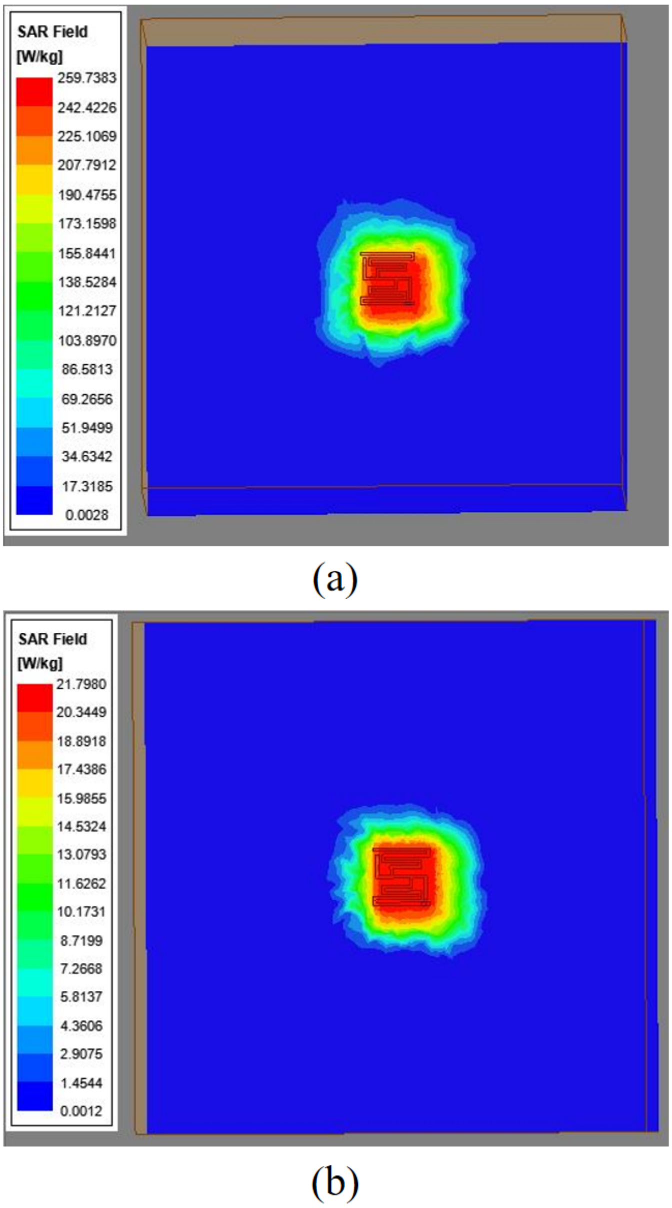

Figure 4. SAR contour plot at 2 mm (a) TEL Phantom (b) Water Phantom.

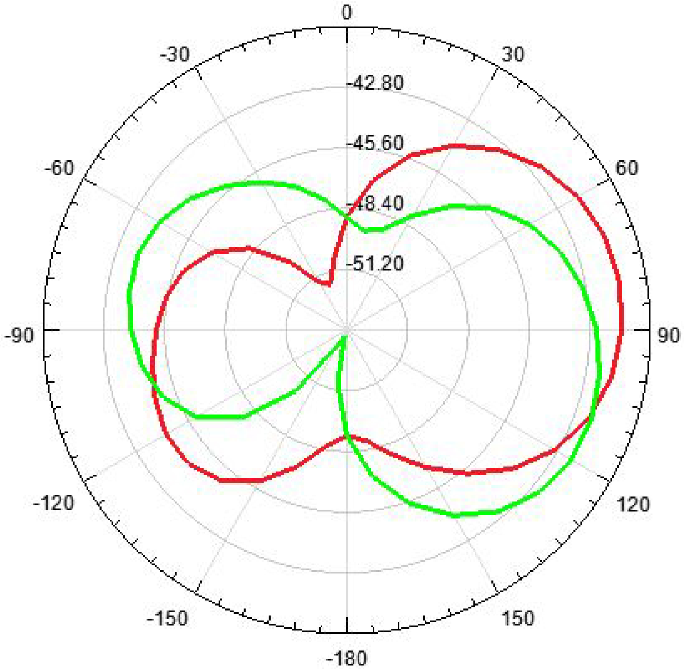

Figure 5. Simulated radiation pattern plot.

its compact meandered configuration. Such a pattern supports reliable wireless data transmission between implanted devices and external receivers, where stable radiation characteristics within biological tissues are required. The antenna maintains consistent far-field behaviour even under high dielectric loading, which is critical for dependable implant communication systems. The maximum realized gain is -48.4 dBi, a typical result for electrically small in-body antennas operating in lossy tissue environments.

4 Conclusion

This paper presents a compact meander patch antenna specifically designed for biomedical implant communication systems operating at the 915 MHz ISM band. The antenna achieves miniaturization within a $10 \times 10 \times 1.6$ mm^3 footprint while maintaining efficient impedance matching in high-loss environments. SAR analysis confirms compliance with IEEE C95.1 safety limits, ensuring safe in-body operation. The antenna's stable radiation characteristics within tissue-equivalent phantoms demonstrate its suitability for reliable wireless data transmission in implanted medical devices such as glucose monitors, neural sensors, pacemakers, and biosensors. Thus, the proposed design is a promising candidate for next-generation implantable communication systems.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflicts of interest.

AI Use Statement

The authors declare that no generative AI was used in the preparation of this manuscript.

Ethical Approval and Consent to Participate

Not applicable.

References

[1] Nguyen, D., & Seo, C. (2021). An ultra-miniaturized antenna using loading circuit method for medical implant applications. *IEEE Access, 9*, 111890-111898. [CrossRef]

[2] Li, R., Guo, Y. X., Zhang, B., & Du, G. (2017). A miniaturized circularly polarized implantable annular-ring antenna. *IEEE Antennas and Wireless Propagation Letters, 16*, 2566-2569. [CrossRef]

[3] Xu, L. J., Guo, Y. X., & Wu, W. (2012). Dual-band implantable antenna with open-end slots on ground. *IEEE Antennas and Wireless Propagation Letters, 11*, 1564-1567. [CrossRef]

[4] Li, H., Guo, Y. X., & Xiao, S. Q. (2016). Broadband circularly polarised implantable antenna for biomedical applications. *Electronics Letters, 52*(7), 504-506. [CrossRef]

[5] Xu, L. J., Guo, Y. X., & Wu, W. (2015). Miniaturized circularly polarized loop antenna for biomedical applications. *IEEE Transactions on Antennas and Propagation, 63*(3), 922-930. [CrossRef]

[6] Balanis, C. A. (2016). *Antenna theory: analysis and design*. John wiley & sons.

[7] Handbook, M. A. D. (2001). Microstrip Antenna Design Handbook. *R. Garg, P. Bhartia, I. Bahi, and A. Ittpiboon*.

[8] Khan, A., Dubey, S. K., & Singh, A. K. (2024). Corner T-slot antenna at 2.45 GHz for hyperthermia application. *Journal of Electromagnetic Waves and Applications, 38*(4), 508-521. [CrossRef]

[9] Khan, A., Dubey, S. K., & Singh, A. K. (2025). Designed and development of 2.45 GHz cross-slot microstrip patch antenna for empowering hyperthermia treatments. *Discover Electronics, 2*(1), 45. [CrossRef]

[10] Khan, A., Dubey, S. K., & Singh, A. K. (2023). An elliptical-shaped rectangular slot antenna at 2.48 GHz for hyperthermia application. *Microwave and Optical Technology Letters, 65*(8), 2425-2430. [CrossRef]

[11] IEEE Standards Coordinating Committee, 2. (1992). IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3kHz to 300GHz. *IEEE C95. 1-1991*.

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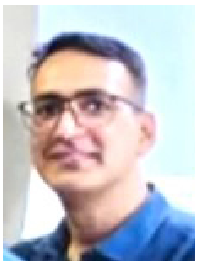

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