

FR4-Based Microstrip Radiators: Balancing Fabrication Simplicity and On-Body Resonant Stability

K. Vanitha¹, S. Jeevanantham², S. Sakthi Shri³, T. Sathya⁴

¹Professor, Dept. of Medical Electronics Engineering, Velalar College of Engineering and Technology, Tamil Nadu, India.

²Student, Dept. of Medical Electronics Engineering, Velalar College of Engineering and Technology, Tamil Nadu, India.

³Student, Dept. of Medical Electronics Engineering, Velalar College of Engineering and Technology, Tamil Nadu, India

⁴Student, Dept. of Medical Electronics Engineering, Velalar College of Engineering and Technology, Tamil Nadu, India.

Abstract - Wearable antennas play a vital role in body-centric communication systems, particularly in Wireless Body Area Networks used for healthcare monitoring, sports applications, and Internet of Things devices. However, designing antennas that maintain stable performance when placed close to the human body remains a significant challenge due to detuning effects, energy absorption, and mechanical deformation. This paper presents the design and analysis of a compact microstrip patch antenna fabricated on an FR4 substrate, operating in the 2.4 GHz Industrial, Scientific, and Medical band. The proposed antenna is developed with a focus on fabrication simplicity, cost effectiveness, and stable on-body performance. The design incorporates an optimized patch geometry and feeding structure to achieve proper impedance matching and acceptable radiation characteristics. Simulation and experimental analysis are conducted under free-space, bending, and on-body conditions to evaluate performance reliability. The results demonstrate consistent return loss, moderate gain, and quasi-omnidirectional radiation suitable for short-range communication. The antenna maintains stable operation despite mechanical deformation and proximity to human tissue. Compared to flexible textile-based designs, the FR4-based approach offers improved structural reliability and ease of fabrication while maintaining acceptable performance. This work highlights a practical balance between performance, cost, and manufacturability, making the proposed antenna suitable for integration into wearable communication systems. The study contributes to the development of efficient and low-cost wearable antenna solutions for next-generation body-centric wireless applications.

Key Words: Microstrip Patch Antenna, FR4 Substrate, Body-Centric Communication, Wireless Body Area Network, SAR Reduction.

1. INTRODUCTION

Wearable wireless communication systems have emerged as a key technology in modern applications such as healthcare

monitoring, sports tracking, military communication, and Internet of Things devices. These systems rely heavily on efficient and compact antennas to enable reliable data transmission between body-mounted devices and external networks. Wearable antennas are essential components of Wireless Body Area Networks, where consistent performance, low power consumption, and compact design are critical requirements.

However, unlike conventional antennas, wearable antennas operate in close proximity to the human body, which significantly affects their performance. The interaction between electromagnetic waves and human tissues leads to challenges such as frequency detuning, reduced radiation efficiency, impedance mismatch, and increased Specific Absorption Rate. In addition, mechanical factors such as bending, stretching, and body movement further complicate the design. Therefore, developing a wearable antenna that maintains stable performance under both free-space and on-body conditions is a major research challenge.

This paper presents the design and analysis of a compact microstrip patch antenna operating in the 2.4 GHz Industrial, Scientific, and Medical band using an FR4 substrate. The proposed design focuses on achieving a balance between fabrication simplicity, cost effectiveness, and stable on-body performance. The antenna is analyzed under different conditions to ensure its suitability for wearable communication applications.

1.1 Need for a Cost-Effective Wearable Antenna Solution

The increasing demand for wearable communication devices has created a need for antennas that are not only efficient but also affordable and easy to manufacture. Many existing wearable antenna designs use specialized textile materials or complex fabrication techniques, which increase cost and limit large-scale deployment. This creates a gap between advanced research designs and practical implementation.

A cost-effective solution using commonly available materials such as FR4 substrate offers a practical alternative. FR4-based antennas provide ease of fabrication, structural reliability, and consistent electrical properties, making them suitable for prototyping and real-world applications. By focusing on simple design and accessible materials, the proposed antenna aims to make wearable communication technology more scalable and widely usable.

1.2 Antennas in Body-Centric Communication

Antennas play a crucial role in body-centric communication systems, where devices are placed on or near the human body to enable continuous data exchange. These systems are widely used in applications such as health monitoring, fitness tracking, and smart wearable devices. Reliable communication in such systems requires antennas that can operate efficiently despite the presence of the human body.

However, the human body introduces significant challenges due to its lossy and heterogeneous nature. It absorbs electromagnetic energy, which can degrade antenna performance and alter radiation patterns. Additionally, movement and varying body positions can affect signal stability. Therefore, wearable antennas must be designed to provide consistent performance, adequate gain, and reliable radiation characteristics under dynamic conditions.

2. PROPOSED METHODOLOGY

The proposed system focuses on the design and performance evaluation of a wearable microstrip patch antenna operating at 2.4 GHz for body-centric communication applications. The methodology involves antenna design, simulation, fabrication, and performance analysis under free-space and on-body conditions. The system aims to achieve stable impedance matching, efficient radiation characteristics, and reliable operation despite the influence of the human body and mechanical deformation.

2.1 System Overview

The proposed antenna system consists of a microstrip patch structure fabricated on an FR4 substrate, along with a conductive radiating patch, ground plane, and feeding mechanism. The antenna is designed using electromagnetic simulation software to achieve resonance at the desired frequency of 2.4 GHz. Initially, the antenna dimensions, including patch length, width, and substrate properties, are calculated and optimized. The design is then simulated to analyze key parameters such as return loss, gain, bandwidth, and radiation pattern. After simulation, the antenna is fabricated using standard printed circuit board techniques. The fabricated antenna is tested under different conditions, including free-space, bending, and on-body placement. These evaluations help in understanding the practical performance and stability of the antenna when integrated into wearable applications.

2.2 Performance Analysis and Optimization

The performance of the proposed antenna is evaluated based on parameters such as return loss, radiation pattern, gain, and bandwidth. A return loss value below -10 dB is considered acceptable for proper impedance matching within the operating frequency band. When the antenna is placed near the human body, performance degradation may occur due to electromagnetic absorption and detuning effects. To address these challenges, the antenna design is optimized by adjusting parameters such as feed position, ground plane configuration, and patch dimensions. Additionally, the antenna is analyzed under bending conditions to evaluate its robustness in real-world wearable scenarios. The optimization ensures that the antenna maintains stable performance with minimal variation in resonant frequency and radiation characteristics.

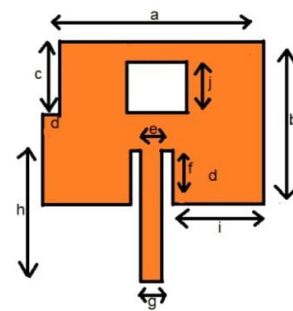


Fig - 1: Design

2.3 On-Body Evaluation and Radiation Characteristics

The proposed antenna is tested for on-body performance to analyze its suitability for wearable communication systems. When placed on the human body, the antenna's radiation characteristics, including gain and pattern distribution, are carefully observed. The results show that the antenna exhibits a quasi-omnidirectional radiation pattern, which is suitable for body-centric communication where signal transmission is required in multiple directions. The gain achieved is moderate and sufficient for short-range wireless communication in the 2.4 GHz band. Furthermore, the antenna demonstrates stable operation under bending and body-loading conditions, indicating its reliability for practical applications. The compact and low-profile design ensures easy integration into wearable devices, making it suitable for applications such as health monitoring, fitness tracking, and IoT-based systems.

3. CONCLUSIONS

The proposed wearable microstrip patch antenna demonstrates an effective and cost-efficient solution for body-centric wireless communication applications. The antenna is successfully designed and fabricated using an FR4 substrate to operate in the 2.4 GHz Industrial, Scientific, and

Medical band. The system achieves stable impedance matching, acceptable return loss, and reliable radiation characteristics, making it suitable for short-range wireless communication. Experimental and simulation results confirm that the antenna maintains consistent performance under free-space, bending, and on-body conditions. The observed results indicate that the antenna provides moderate gain and quasi-omnidirectional radiation, which are essential for reliable communication in wearable environments. Despite the challenges introduced by the proximity of the human body, such as detuning and energy absorption, the proposed design effectively minimizes performance degradation. The antenna offers a compact, low-profile, and easy-to-fabricate structure, making it practical for integration into wearable devices. The use of readily available materials and simple design techniques ensures low cost and scalability for real-world applications.

Overall, this work presents a balanced approach between performance, cost, and manufacturability. It demonstrates the feasibility of implementing reliable wearable antennas using conventional materials, paving the way for future developments in wearable communication systems, Internet of Things devices, and healthcare monitoring applications.

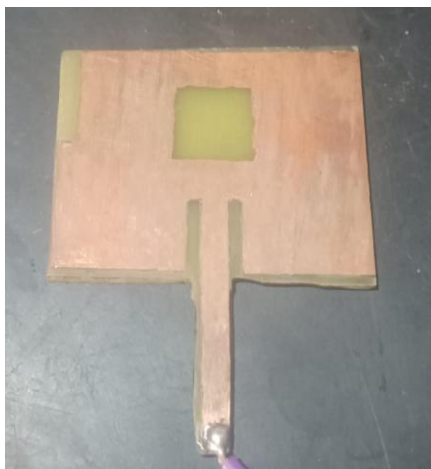


Fig -2: Setup

REFERENCES

- [1] M. Agiwal, A. Roy, and N. Saxena, "Next generation 5G wireless net works: A comprehensive survey," *IEEE Commun. Surveys Tuts.*, vol. 18, no. 3, pp. 1617–1655, 3rd Quart., 2016.
- [2] N. H. M. Rais, P. J. Soh, F. Malek, S. Ahmad, N. B. M. Hashim, and P. S. Hall, "A review of wearable antenna," in *Proc. Loughborough Anten nas Propag. Conf.*, Nov. 2009, pp. 225–228.
- [3] M. A. Shahzad, K. N. Paracha, S. Naseer, S. Ahmad, M. Malik, M. Farhan, A. Ghaffar, M. Hussien, and A. B. Sharif, "An artificial magnetic conductorbacked compact wearable antenna for smartwatch IoT applications," *Electronics*, vol. 10, no. 23, p. 2908, Nov. 2021.
- [4] H. Zu, B. Wu, P. Yang, W. Li, and J. Liu, "Wideband and high-gain wear able antenna array with specific absorption rate suppression," *Electronics*, vol. 10, no. 17, p. 2056, Aug. 2021.
- [5] B. Yeboah-Akokuwah, E. T. Tchao, M. Ur-Rehman, M. M. Khan, and S. Ahmad, "Study of a printed split-ring monopole for dual-spectrum communications," *Heliyon*, vol. 7, no. 9, 2021, Art. no. 07928.
- [6] R. Singh, P. Kumari, S. Rawat, P. Singh, and K. Ray, "Design and performance analysis of low profile miniaturized MSPAs for body centric wireless communication in ISM band," *Int. J. Comput. Inf. Syst. Ind. Manage. Appl.*, vol. 9, pp. 153–161, Jul. 2017.
- [7] H. I. Azeez, H. C. Yang, and S. W. Chen, "Wearable triband E-shaped dipole antenna with low SAR for IoT applications," *Electronics*, vol. 8, no. 6, p. 665, 2019.
- [8] S. Seneviratne, Y. Hu, T. Nguyen, G. Lan, and S. Khalifa, "A survey of wearable devices and challenges," *IEEE Commun. Surveys Tuts.*, vol. 19, no. 4, pp. 2573–2620, 4th Quart., 2017.
- [9] G. Christina, "Review on wearable antennas and their applications," *IRO J. Sustain. Wireless Syst.*, vol. 3, no. 4, pp. 259–265, 2022.
- [10] T. Tuovinen, M. Berg, K. Y. Yazdandoost, and J. Iinatti, "Ultra wideband loop antenna on contact with human body tissues," *IET Microw., Antennas Propag.*, vol. 7, no. 7, pp. 588–596, May 2013.