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Wearable Microstrip Patch Antenna for Biomedical Applications

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Abstract: This work presents a novel wideband wearable micro strip patch antenna designed for biomedical applications. The proposed antenna (60 × 44 × 1 mm3) features a monopole design with denim textile as the substrate material, offering a flexible and lightweight solution for wearable devices. Operating efficiently across an ultra-wideband frequency range of 2.4 GHz – 10 GHz, and the average gain of 3.51 dBi the antenna is well-suited for biomedical monitoring and communication systems. The performance of the antenna was rigorously evaluated through simulations and practical testing under various conditions, to ensure robustness, and reliability in real-world applications. The results demonstrate the antenna's potential for seamless integration into wearable biomedical devices, making it a promising candidate for next-generation healthcare technologies.

Keywords: ultra-wideband antenna, biomedical, jeans, gain, and wearable.

I. INTRODUCTION

An antenna is a transducer that converts electrical signals into electromagnetic waves and vice versa. It functions as either a transmitter or receiver and is crucial in wireless communication systems, eliminating the need for physical wiring in hard-to-reach areas. The same antenna can often be used for both transmitting and receiving in two-way communication. Antennas are also known as aerials and come in various shapes and sizes depending on the application.
Antennas are connected to circuitry via transmission lines, which carry current efficiently over distances. However, to radiate power, the line must be bent, truncated, or terminated. Waveguides, often used in microwave systems, are structures designed to guide electromagnetic energy and radiate it effectively. For optimal performance, certain key terms must be understood.
Input impedance must match between the antenna, transmission line, and transceiver (usually 50Ω). Return loss, measured in dB, quantifies the mismatch. Bandwidth defines the range of frequencies where the antenna performs with acceptable SWR. Directivity refers to the ability to focus energy in a direction, while gain compares the antenna's performance to a reference (isotropic or dipole). The radiation pattern shows how an antenna radiates or receives energy in different directions, often displayed in polar plots.

II. LITERATURE REVIEW

The wearable technology sector has grown rapidly in recent years, with connected devices increasing from 325 million in 2016 to over 1.1 billion in 2022. The COVID-19 pandemic accelerated the development of wearable devices and wireless sensor networks for healthcare. This growth fuels the need for flexible, lightweight, and textile-based wearable antennas that can be embedded in garments or accessories. These antennas are often placed directly on the human body and must satisfy a wide range of design requirements: electrical (e.g., bandwidth, radiation efficiency), mechanical (e.g., flexibility, low profile), manufacturing (e.g., cost, simplicity), and safety (e.g., compliance with specific absorption rate limits).

The antenna's performance must be assessed both in free space and on-body due to human body interference, often modeled using homogenous or multilayer simulations. Antenna types like patch, monopole, slotted waveguide, and loop antennas have shown potential for wearable integration. Safety is crucial, especially considering the 24/7 proximity of these antennas to the body.
Wearable technologies also provide promising solutions in medical diagnostics, offering non-invasive, continuous monitoring with low energy use. In long-term health tracking for conditions such as strokes, cancer, and fractures, wearable microwave imaging has emerged as an effective method due to its affordability and real-time capability. Yet, research on fully textile antennas for such applications is still limited. A wideband antenna (1–3 GHz) is ideal for medical imaging, offering high resolution and strong tissue penetration. Dipole, monopole, and slot antennas are common in imaging systems, but many are too large for wearable integration. Modified monopoles with defected ground structures improve efficiency but are hard to fabricate with textiles. Continued innovation and comparison of these antenna designs are essential to advance wearable biomedical technologies.

A comparison of the performance of the previous designs that also focus on biomedical application demonstrated and summarized in Table 1.

Table 1: Comparative Analysis of the reported antennas

Ref.	**Antenna Size (L × W × H) 3 (mm)**	**Operating Band (GHz)**	**Fractional Bandwidth (%)**	**Avg. Realized Gain (dBi)**
[2]	80 × 45 × 1.6	1.25-2.4	63	2.5
[3]	70 × 50 × 1	1-1.7	52	NR
[4]	167 × 134 × 0.5	1-4.3	124	NR
[10]	70 × 50 × 0.5	1.198-4.055	109	2.85
[11]	77 × 40 × 0.6	2.2–4 GHz, 5.3–10 GHz	58.06,61.43	3.37

III. PROPOSED DESIGN AND ITS EVALUATION

In this work presents the design of a novel, low-profile ultra-wideband textile antenna for wearable biomedical and Internet of Things (IoT) applications. The UWB antenna has proposed with dimensions of 60 mm x 44 mm for WBAN application. The antenna is simulated on a denim substrate have relative permittivity 1.7, and height 1 mm. CST Microwave Studio, simulation software is used for the simulation purpose.

III.1 Simulation Methodology

Antenna design plays a crucial role in improving communication and overall device performance, but it's a complex task. CST Microwave Studio provides a comprehensive solution that supports the entire antenna design process, from initial concept to final integration. However, integrating the antenna with systems like CubeSats is not straightforward in CST alone, so 3D models from external software are often imported. CST supports a wide range of CAD formats, allowing for parametric antenna modeling. By assigning appropriate materials, the software can simulate both electrical and mechanical properties accurately.

III.1.1 Solver Domain

CST Microwave Studio offers various powerful solvers, including the time domain solver with perfect boundary approximation. It also features modules like the Finite Element Method (FEM), Method of Moments (MoM), and the Multipole Method, each suited for different simulation needs. The software integrates solvers for flexibility in solving specific problems.

III.1.2 Frequency Domain

The frequency domain solver is efficient for small structures or high Q-factor devices, evaluating S-parameters, Z-matrix, and near-far field results. The Q-factor measures energy loss relative to stored energy, with higher values indicating lower damping. It allows switching from Cartesian to tetrahedral meshing for better surface accuracy. The solver features an adaptive frequency sweep for simulating multiple operations and supports both direct and indirect linear solvers.

III.1.3 Transient Solver

The transient (time domain) solver is ideal for studying field propagation and electromagnetic applications, providing results like S-parameters and antenna efficiency. It supports multiple simulations through parameter sweeps and determines results across frequencies in one run. Best for wideband or planar antennas, it's faster and uses less memory than the frequency domain solver.

Based on Maxwell's equations, it excels in simulation speed and efficiency. This makes it the preferred choice for simpler and time-efficient simulations.

III.2. DESIGN METHODOLOGY

In high-performance aerospace applications like spacecraft, missiles, and satellites, antenna systems must meet strict requirements for low profile, compact size, cost-efficiency, high performance, minimal weight, easy installation, and aerodynamic design. Microstrip patch antennas are well-suited for these needs as they are compatible with Monolithic Microwave Integrated Circuit (MMIC) designs, mechanically stable, conformable to different surfaces, and cost-effective to produce. The design begins with establishing dimensions that enable resonance at a target frequency, typically using a reference or "golden design" such as one from Balanis' Antenna Theory.

Designing a planar antenna using CST Microwave Studio involves several steps. Here's a simplified guide to help you get started:

1. Create a New Project:
2. Draw the Planar Antenna:
3. Define Excitation:
4. Meshing:
5. Simulation Setup:

6. Run the Simulation:
7. Post-Processing:
8. Optimization:

If necessary, iterate on the design by adjusting the dimensions, positions, or properties of the square slots to achieve the desired antenna performance. Perform further simulations and analyses to validate any design changes.

9. Fabrication and Testing

IV. Results and Discussions

The antenna has dimensions of 60 x 44 x 1 mm for Biomedical and IOT applications. Whereas the electrical characteristics of a wearable electronic system predominantly hinge upon the conductive materials employed, the flexibility and softness are primarily attributed to the properties of the substrates. In wearable antennas, substrates effectively insulate the antennas from direct contact with the epidermis, thereby minimizing the influence of the human body on antenna performance.

The dimensions of the slots will influence parameters such as resonance frequency and bandwidth. The effect of square slots on antenna performance can be complex and depend on various factors such as slot dimensions, spacing, and proximity to other elements of the antenna. Therefore, careful simulation and analysis are crucial for successful implementation. The proposed antenna configuration is shown in Figure 1.

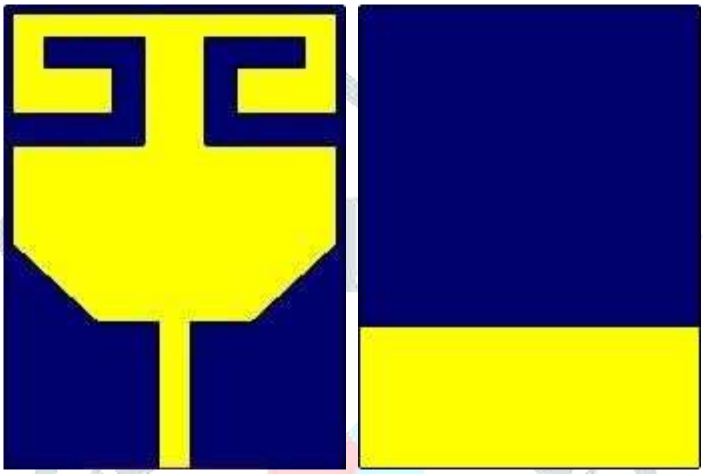

Figure 1: The proposed antenna configuration, (a) top-layer, and (b) bottom-layer

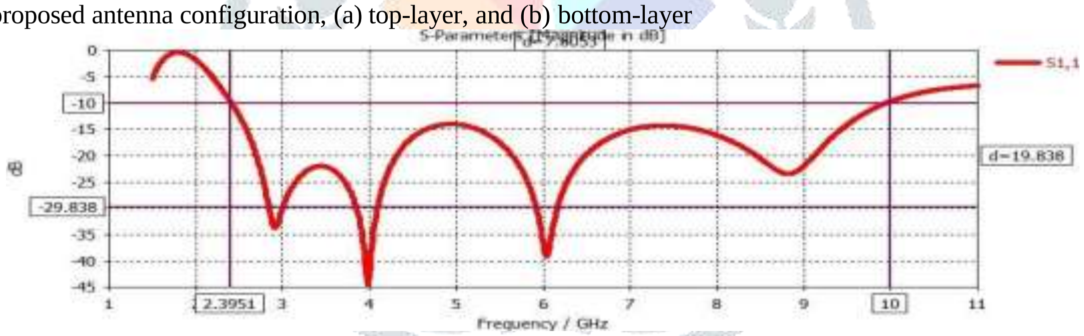

Figure 2: S-parameter plot of the proposed antenna

The simulated return loss (dB) of the proposed textile antenna is about maximum -45 dB for ultra-wide band and the range of 2.39 to 10 GHz, respectively. The simulated S- parameter graph shown in the Figure 2.

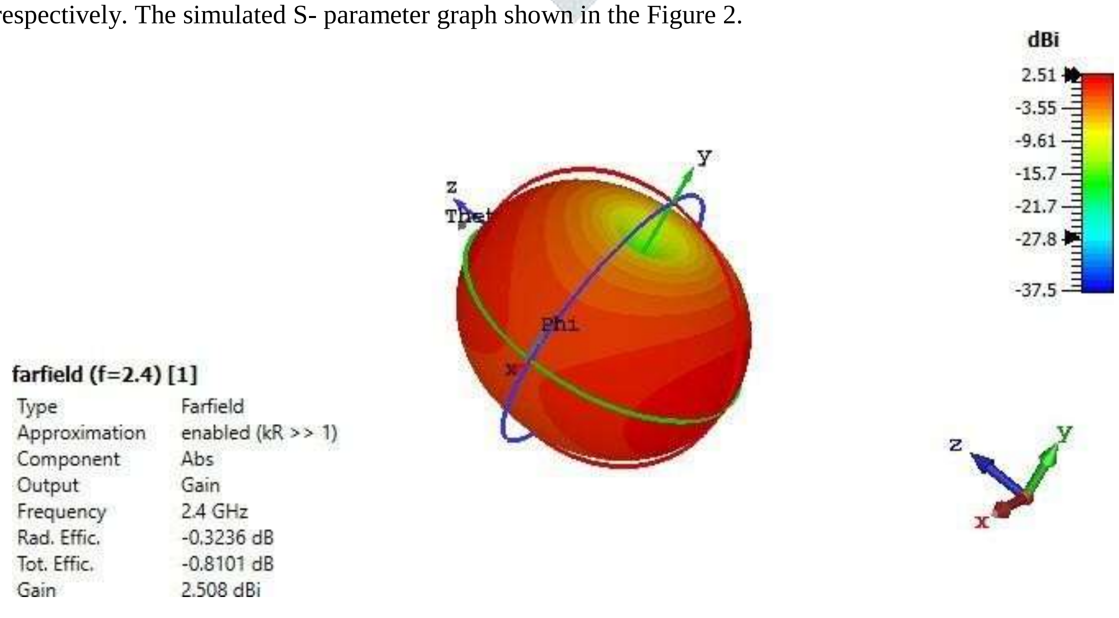

Figure 3: Gain of the proposed antenna at 2.4 GHz

The 3D view of the antenna radiation patterns at 2.4 GHz for single port is displayed in Figure 3. As shown, same radiation performances with different polarizations and also 2.83 dBi directivity are obtained for the proposed slot antenna design. It can be seen that the designed slot antenna provides dumb bell-shaped radiation patterns suitable to cover the top and bottom side of the wearable which can increase the radiation coverage of the wearable antenna design. The maximum gain (3.51 dBi) for the differently-fed single port antenna is represented in Figure. 4.4. As seen, the antenna provides high efficiencies even though it is designed on the jean's dielectric.

IV.1. Fabrication Measurement

As illustrated in Figure 1, a prototype of the single-element and dual-element antenna was fabricated and its fundamental characteristics were tested in the Antenna Laboratory at the SRM University, Chennai. As can be seen, the S-parameters of the antenna including S11 characteristics were measured using the Keysight vector network analyzer. The measured S-parameter results of the prototype are displayed in Figure 4.

As illustrated, the antenna provides very good impedance matching around 2.1 GHz to 9.4 GHz. High-isolation with more than -20 dB mutual coupling has been obtained for the fabricated sample. In addition, compared with the simulations, it can be confirmed that there is a good agreement between them.

Figure 4: S11-parameters for Fabricated Model of proposed antenna

IV.2. Performance Comparison

The geometrical dimensions, operating band, radiation efficiency, and gain and impedance bandwidth of recently reported antennas. It shows that, while subject to their clinical applicability, electrical size, overall size, gain, and fractional bandwidth, the recently reported antennas still need to be low-profile or compact compared to the proposed textile wearable antenna. Comparative Analysis of the proposed antenna with the reported antennas was summarized in Table 2.

Table 2: Comparative Analysis of the proposed antenna with the reported antennas

Ref.	Antenna Size (L × W × H) (m3)	Operating Band (GHz)	Fractional Bandwidth (%)	Max. Realized Gain (dBi)
[1]	80 × 45 × 1.6	1.25-2.4	63	2.5
[2]	70 × 50 × 1	1-1.7	52	NR
[3]	167 × 134 × 0.5	1-4.3	124	NR
[10]	70 × 50 × 0.5	1.198-4.055	109	2.85
[11]	77 × 40 ×	2.2–4 5.3–	58.06,	3.37

	0.6	10	61.43	
Proposed	**60 × 44 × 1**	**2.4 - 10**	**122**	**3.51**

V. ACKNOWLEGEMENT

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VI. CONCLUSION

Based on the obtained results, it can be concluded that, the proposed antenna has a compact size with a simple configuration, and it operated 2.4 - 10 GHz band with Maximum gain of 3.51 dBi, and high level of impedance matching, where VSWR is less than 2 and the return loss is better than -10 dB.

Therefore, the proposed textile monopole antenna can be operated with good performance at the desired band (3.1–10.6 GHz), and it can be used for Biomedical and IoT Applications. An UWB wearable textile antenna offer a combination of high performance, flexibility, comfort, and cost-effectiveness, making them ideal for various biomedical monitoring and IOT connectivity requirements.

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