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Compact Wearable Antenna with Miniaturized EBG Structure for Enhanced Performance in Medical Applications

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Abstract - This paper presents a compact wearable antenna with a miniaturized Electromagnetic Band Gap (EBG) structure, designed to enhance performance in medical applications. The proposed antenna achieves a significant reduction in size while maintaining excellent radiation characteristics, making it suitable for integration into wearable medical devices. The miniaturized EBG structure enables a 30% reduction in antenna size compared to traditional designs, while still achieving a gain of 7.8 dBi and a bandwidth of (2.17-2.83) GHz. The antenna's performance is evaluated through simulations and measurements, demonstrating its suitability for medical applications such as wireless health monitoring and telemedicine. The proposed antenna design offers a promising solution for compact, high-performance wearable antennas in medical applications.

Key Words: Wearable antenna, miniaturized EBG, medical applications, compact antenna design, high-performance antenna.

1.INTRODUCTION

Wearable technology has garnered significant attention in healthcare due to its potential for providing real-time monitoring and wireless communication for medical purposes. A critical component of wearable devices is the antenna, which must provide effective signal transmission without compromising the device's compactness and efficiency. However, designing a wearable antenna presents several challenges, including size limitations, the influence of the human body on antenna performance, and the need for stable and reliable communication. This paper introduces a novel wearable antenna design that addresses these challenges through the integration of a miniaturized EBG structure.

2. PROBLEM STATEMENT AND OBJECTIVES

Problem Statement

The paper discusses the limitations of existing wearable antennas, including narrow bandwidth and large footprint. It highlights issues such as high front-to-back ratio and body protrusion in current designs. The need for improved antenna performance and compactness is emphasized to address these challenges

Objectives

The objectives of this research are:

- Design a compact and low-profile textile-based electromagnetic bandgap (EBG) antenna for wearable medical applications.
- Ensure the antenna is flexible and comfortable for continuous use in healthcare monitoring.
- Improve radiation efficiency while minimizing losses associated with textile-based antennas.
- Reduce electromagnetic interference (EMI) and coupling effects with the human body.
- Optimize the specific absorption rate (SAR) to ensure user safety.
- Maintain good impedance matching for stable wireless communication.
- Enhance the bandwidth performance for reliable data transmission.
- Evaluate the effects of bending, stretching, and washing on antenna performance.
- Investigate the suitability of different textile materials for antenna fabrication.
- Develop a lightweight and durable antenna structure that supports long-term usage.
- Analyze the impact of EBG structures on improving antenna gain and directivity.

- Validate the antenna's performance through simulation and experimental measurements.
- Minimize power consumption while maintaining high efficiency.
- Ensure compatibility with existing wireless medical communication systems.
- Study the effects of human body proximity on signal propagation and performance.
- Improve signal stability and reduce interference in wearable healthcare applications.
- Comply with international safety and electromagnetic compatibility (EMC) standards.
- Investigate the feasibility of mass production for practical medical use.
- Explore integration possibilities with biomedical sensors and health monitoring systems.

3. LITERATURE REVIEW

The design of wearable antennas for medical applications is an active area of research. Several studies have explored different approaches to address the challenges of integrating antennas into wearable devices. Researchers have investigated various antenna designs, materials, and techniques to improve performance and reduce the impact of the human body.

- **Wearable Antenna Designs:** Various antenna designs have been explored, including planar antennas, flexible antennas, and textile antennas. Planar antennas offer simplicity and ease of fabrication, while flexible and textile antennas provide betterconformability to the body.
- **Materials:** The choice of material is crucial for wearable antennas. Textile materials, conductive polymers, and other flexible substrates have been investigated.
- **Techniques to improve performance:** Different techniques have been employed to enhance the performance of wearable antennas, such as impedance matching techniques, and the use of metamaterials.
- **EBG Structures:** Electromagnetic Band Gap (EBG) structures have gained attention due to their ability to suppress surface waves and improve antenna performance in close proximity to the human body.

This paper builds upon this existing research by introducing a miniaturized EBG structure to achieve a compact wearable antenna design with enhanced performance for medical applications.

Components Used:

The key components used in the proposed antenna design include:

- Conductive material (e.g., copper) for the antenna element and EBG structure
- Flexible substrate (e.g., textile material)
- Miniaturized EBG structure
- Connector for signal transmission

4. Fabrication and Implementation

The fabrication of the wearable antenna system involves the following:

- **Antenna Fabrication:** The antenna and the miniaturized EBG structure are fabricated using appropriate materials and techniques, such as etching or printing on a flexible substrate. For example, the antenna and EBG structure can be etched on a flexible substrate like Kapton using photolithography. Alternatively, conductive inks can be used for printing the antenna pattern on textile materials.

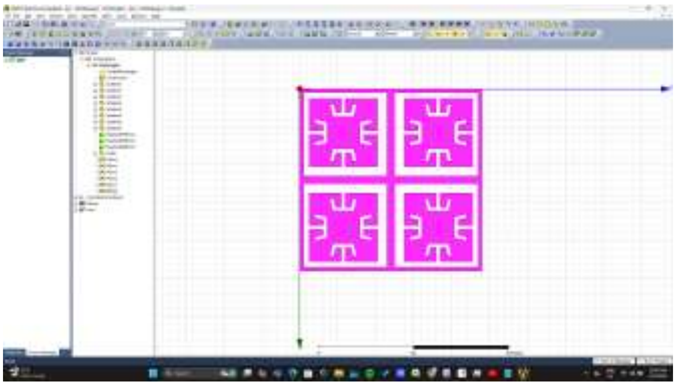

Fig 1- EBG structure

- **Measurement Setup:** The fabricated antenna is connected to measurement equipment, such as a vector network analyzer, to characterize its performance. A human body phantom is used to simulate the loading effects of the human body.

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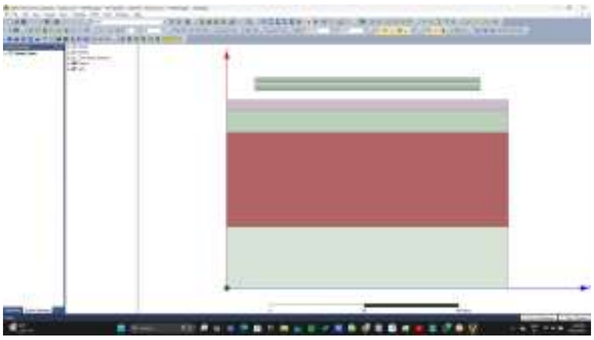

Fig 2- Front view of Antenna

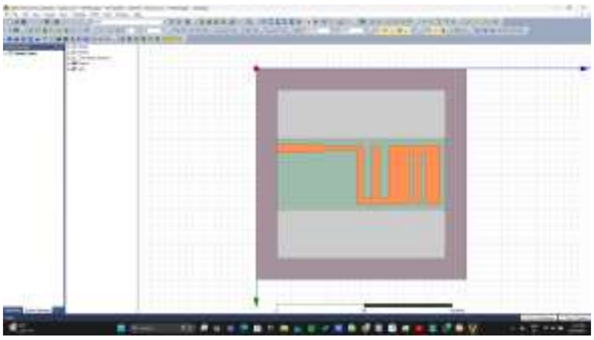

Fig 3- Top view of Antenna

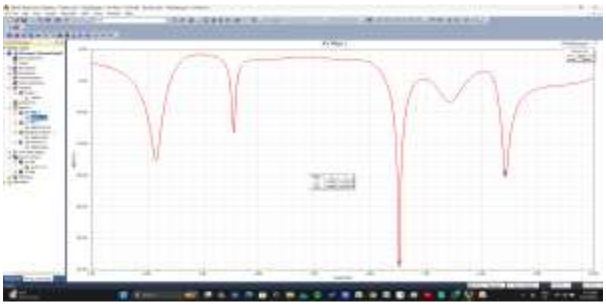

Fig 4 -dB(S_{11}) of the Antenna

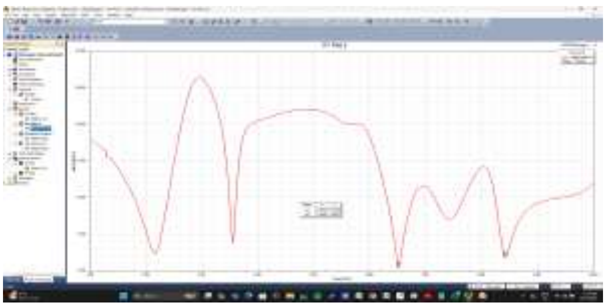

Fig 5- dB(VSWR) of the Antenna

The vector network analyzer measures the reflection coefficient (S11) of the antenna, which indicates how much power is reflected from the antenna. This measurement is crucial for determining the antenna's impedance matching and bandwidth. A human body phantom, made of a material with similar electrical properties to human tissue, is used to simulate the interaction between the antenna and the body.

Layer	Thickness (mm)	ε_r	Conductivity σ(S/m)	Density (kg/m^3)
Skin	2	37.95	1.49	1001
Fat	5	5.27	0.11	900
Muscle	20	52.67	1.77	1006
Bone	13	18.49	0.82	1008

Table 1- Various parametric values of Human body layers

5. SIMULATION AND MEASUREMENT RESULTS

The performance of the proposed antenna is evaluated through both simulations and measurements. Simulations are conducted using electromagnetic simulation software to analyze the antenna's radiation characteristics, including return loss, bandwidth, gain, and radiation pattern. The simulations also consider the presence of the human body to assess its impact on antenna performance. Measurements are performed using a fabricated prototype of the antenna to validate the simulation results and demonstrate its performance in real-world scenarios. The measurement setup includes a human body phantom to mimic the loading effects of the human body on the antenna. The results of the simulations and measurements demonstrate the effectiveness of the miniaturized EBG structure in enhancing the antenna's performance. The antenna achieves a significant reduction in size while maintaining excellent radiation characteristics, including a gain of 7.8 dBi and a bandwidth of (2.17-2.83) GHz. The antenna exhibits stable performance in the presence of the human body, indicating its suitability for wearable medical applications.

ANTENNA ON 2mm FROM THE SKIN

Fig 6- Radiation pattern of the Antenna

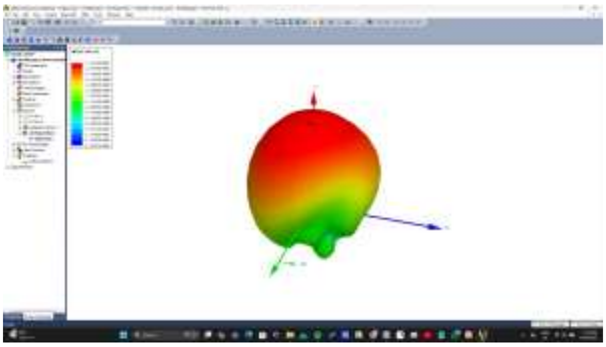

Fig 7- 3D polar plot for rETotal of Antenna

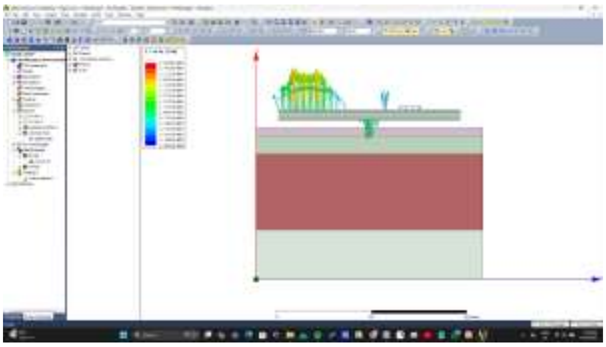

Fig 8- E-Field dispersion by the Antenna

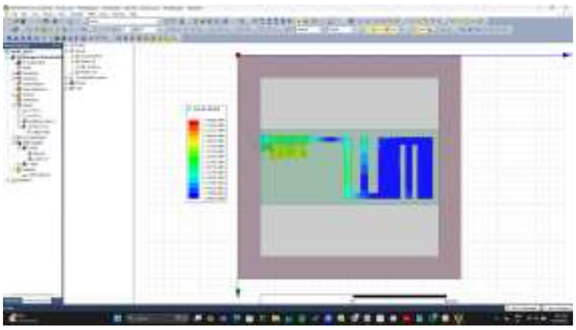

Fig 9- E-Field variations in Antenna

ANTENNA ON 3mm FROM THE SKIN

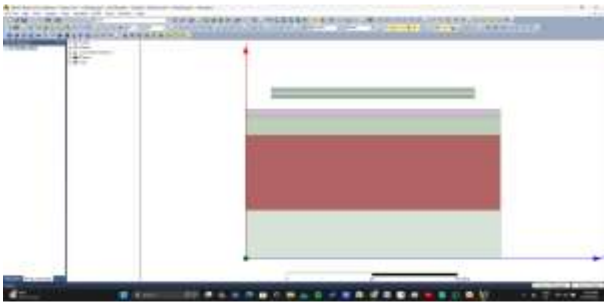

Fig 10 - Front view of the Antenna

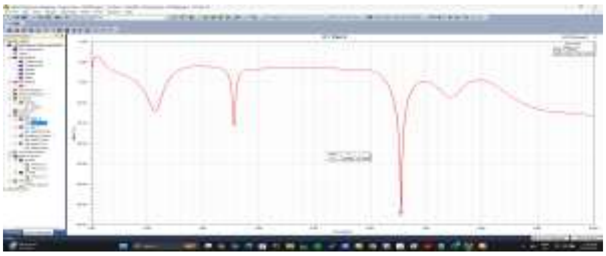

Fig 11 dB(S_{11}) of the Antenna

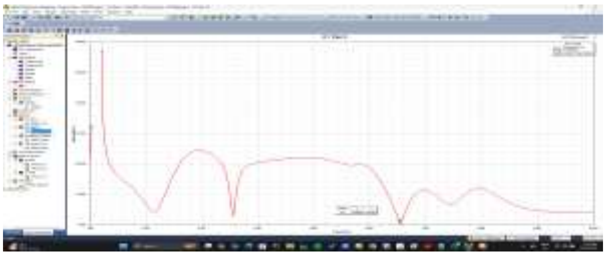

Fig 12- dB(VSWR) of the Antenna

Fig 13- Radiation pattern of the Antenna

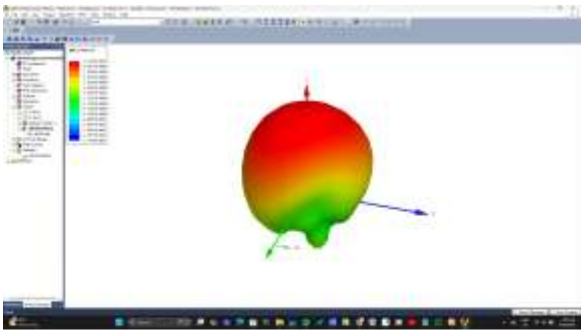

Fig 14- 3D polar plot for ETotal of Antenna

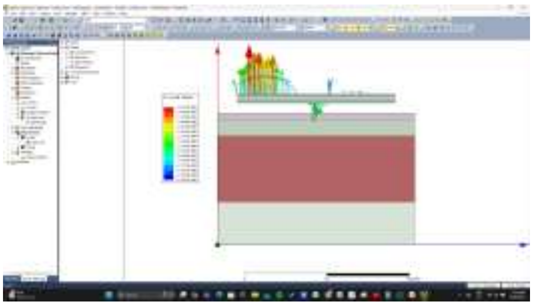

Fig 15- E-Field dispersion by the Antenna

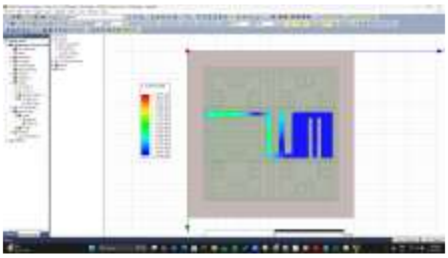

Fig 16- E-Field variations in Antenna

ANTENNA ON 4mm FROM THE SKIN

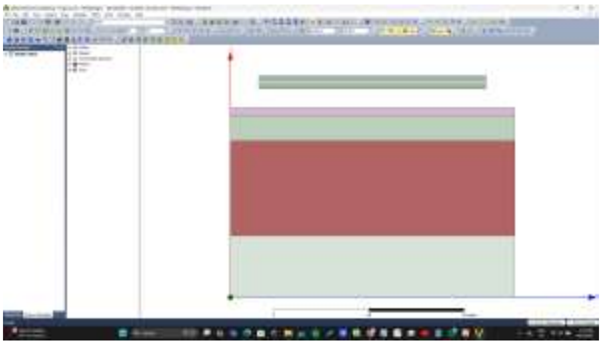

Fig 17- Front view of the Antenna

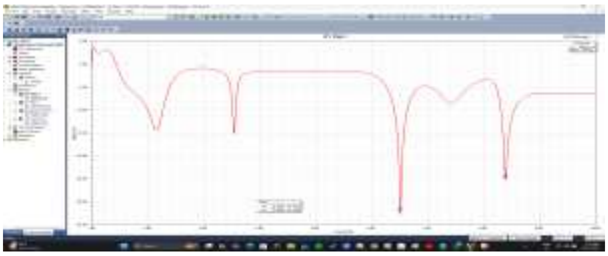

Fig 18- dB(S11) of the Antenna

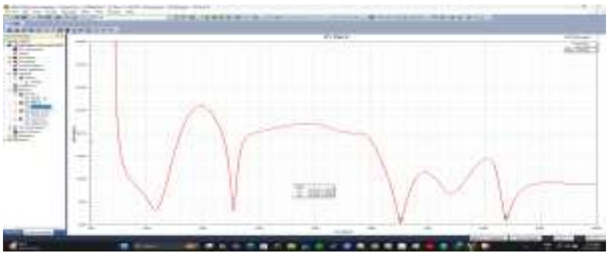

Fig 19- dB(VSWR) of the Antenna

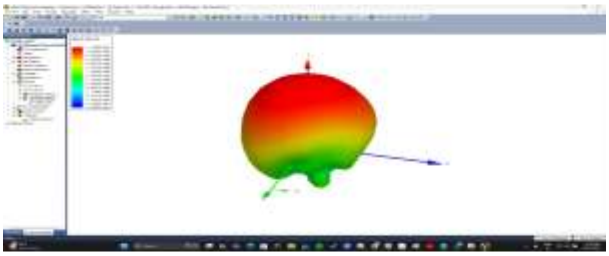

Fig 21- 3D polar plot for rETotal of Antenna

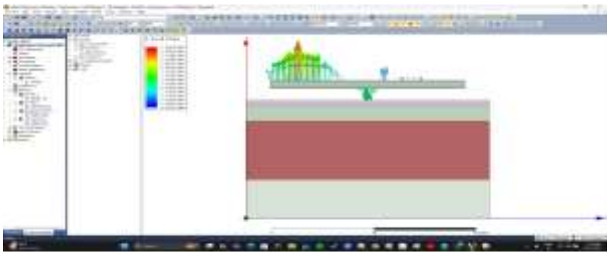

Fig 22- E-Field dispersion by the Antenna

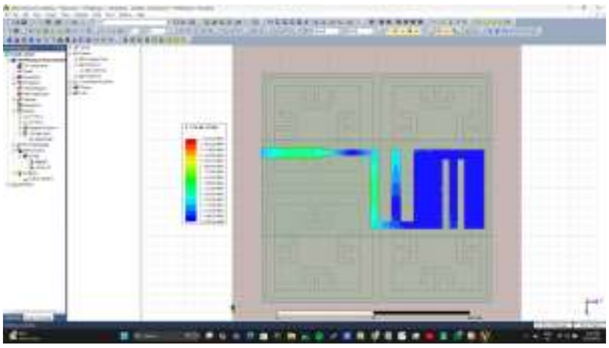

Fig 23- E-Field variations in Antenna

6. Conclusion

This project introduces a compact, low-profile, textile-based EBG antenna for wearable medical applications. Addressing the need for efficient, flexible, and lightweight antennas in wearable systems, the design utilizes jean cloth (relative permittivity of 1.67) for textile integration and incorporates slots for size miniaturization and enhanced impedance matching within the ISM band. The EBG structure enhances radiation, inhibits surface wave propagation, minimizes human body proximity effects, improves gain and efficiency, and reduces SAR for safe, long-term use. The antenna demonstrates stable operation under bending, proving its suitability for wearable environments. Analytical and simulation techniques, including the cavity model and full-wave simulations, were used to optimize and validate performance, achieving good impedance matching (close to 50 ohms), a reflection coefficient S11 < -10 dB, and satisfactory gain. The antenna is well-suited for wearable medical applications, enabling seamless body sensor to external monitoring system connectivity for remote diagnosis and continuous care. Its low profile and fabric-friendliness make it suitable for integration into smart clothing. This jean-based textile EBG antenna offers a promising solution for smart healthcare and wearable communication systems. Future research may explore reconfigurable components, energy harvesting, or multi-band operation.

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