DESIGN AND ANALYSIS OF COMPACT WEARABLE FLEXIBLE ANTENNA FOR MEDICAL APPLICATIONS

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Abstract

This study examines the optimization of suitable microstrip patch antennas for wearable healthcare applications, focusing on improving flexibility and improving throughput performance. through the change of base material and implementing the shortening method. Antenna dimensions, including ground and patch dimensions, are specified and various substrates such as Jeans, FR4, Polyimide, PDMS, Roger RT5880 and cotton are explored. After rigorous analysis, Jeans material emerged as the optimal choice, with outstanding properties such as an effective relative permeability (ε_r) of 1.5. Implementing the truncation method allows the antenna to achieve a bandwidth of 2 GHz, a notable reflection coefficient of -46.1 dB and achieved gain of 2.16 dB. This study highlights the importance of substrate selection and design techniques to improve antenna flexibility and performance for wearable medical devices, providing valuable insights for healthcare monitoring systems.

Keywords—Microstrip patch antenna, Wearable healthcare applications, Substrate materials, Truncation method, Bandwidth enhancement, Return loss

INTRODUCTION

Integration of wearable technology into healthcare applications holds immense promise for revolutionizing patient monitoring and diagnosis. Central to this advancement are flexible antennas, pivotal components that can seamlessly conform to the body's contours while maintaining robust communication links. This article delves into the intricate process of designing and optimizing flexible antennas tailored for medical applications, leveraging microstrip patch antenna technology across a spectrum of substrates.

The careful specification of antenna design parameters highlights how important flexibility is—a quality that is essential for wearable applications. After conducting a thorough investigation into various substrate materials, Jeans material is found to be an exceptional option. Its effective relative permeability (ε_r) is 1.5, indicating that it has better performance characteristics. Moreover, the pruning method's application increases antenna bandwidth

to 2 GHz, producing notable measurement gains and losses, proving the effectiveness of creative design strategies in maximizing antenna performance.

The key role that substrate selection and design techniques play in optimizing antennas for wearable medical devices is clarified by this study. The discovery of Jeans material as the ideal substrate and the effective application of the pruning method emphasize the significance of customized strategies in reaching targeted performance metrics. These results provide insightful information for healthcare monitoring systems, directing the development and deployment of antennas best suited for practical uses.

The research has significant implications for wearable technology in the medical field, offering practical recommendations for the development and implementation of antenna optimization. Practitioners and researchers can navigate the complexities of antenna design and ensure compatibility with the particular requirements of healthcare applications by utilizing the insights gained from this study. In the end, this research advances wearable healthcare technology innovation and opens the door to improved patient care and diagnostic capabilities.

LITERATURE SURVEY

A comprehensive literature survey on wearable flexible antennas for medical applications reveals a diverse array of designs and materials utilized to address specific healthcare needs. Papers such as [1] highlight the use of photo paper for flexibility, achieving high efficiency and gain suitable for wearable telemedicine applications. Others, like [2], optimize antennas for brain tumor detection using carbon- filled rubber substrates, prioritizing both bandwidth enhancement and safety through SAR simulations. Additionally, studies like [3] explore foam-based antennas, emphasizing compactness, wideband operation, and adherence to SAR safety standards. PVC flexible substrates are investigated in [4], showcasing enhanced performance and flexibility, while [5] introduces polyimide antennas optimized for S-Band applications. A focus on miniaturization and performance is evident in [6], [12], and [13], with textile-based antennas demonstrating high gain, omni-directional radiation, and compatibility with medical wearables. Reviews such as [14] and [15] provide valuable insights into design methodologies, materials, and SAR analysis, contributing to the holistic understanding of wearable antenna development. Integrating findings from these studies, a design for a wearable flexible antenna for medical applications can prioritize flexibility, wideband operation, safety compliance, and performance optimization tailored to specific healthcare needs.

ANTENNA DESIGN

Designing a microstrip patch antenna entails meticulous attention to its geometric configuration, including parameters like the width and length of the patch, substrate thickness, and material characteristics. These geometric factors directly influence the antenna's performance metrics, such as resonant frequency, bandwidth, and radiation pattern. Engineers employ sophisticated simulation tools and mathematical models to optimize these parameters, ensuring that the antenna meets the specific requirements of its intended application. The relative permittivity of the substrate material also plays a critical role, affecting the effective dielectric constant and overall electrical properties of the antenna. Through iterative design iterations, engineers refine the antenna geometry to achieve optimal performance and functionality in communication systems, radar installations, and satellite technologies.

The equation for the width of the patch (W) is given by:

$$W=\frac{c}{2fr}\sqrt{\frac{2}{(\varepsilon r+1)}}$$

where c represents the speed of light in free space, and εr denotes the relative permittivity of the material being tested. To determine the effective dielectric constant(εreff) , the equation is:

$$\varepsilon\mathrm{reff}=\left[\frac{\varepsilon r+1}{2}\right]+\left[\frac{\varepsilon r-1}{2}\right]\left[1+\frac{12h}{W}\right]^{-1/2}$$

where h represents the thickness of the substrate.

The equation for finding the actual patch length (L) is:

$$L=\left[\frac{c}{(2fr\sqrt{\varepsilon reff})}\right]-2\,\Delta L$$

where εreff represents the effective permittivity of the material under test.

Determining the extension length ΔL is done using the equation:

$$\Delta L = 0.412h\left[\frac{(\varepsilon reff+0.3)}{(\varepsilon reff-0.258)}\right]\left[\frac{\left(\frac{w}{h}+0.264\right)}{\left(\frac{w}{h}+0.8\right)}\right]$$

The proposed antenna design geometry values are given as follows

PARAMETER	CALCULATED VALUE
Substrate length(L)	35mm
Substrate width(W)	20mm
Height of substrate	1.6mm
Length of patch(LP)	22mm
Width of patch(WP)	9.9mm
Height of patch	0.035mm
Length of feed(LF)	9mm
Width of feed(WF)	1.8mm
Length of ground	8mm

Table 1. Geometric Values of Antenna

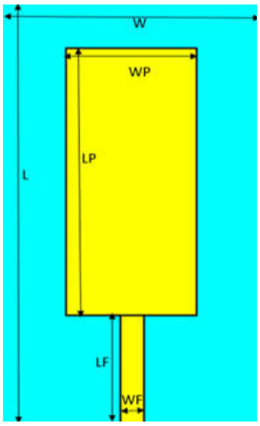

Figure 1. Front View of Antenna before Truncation

To imporove the bandwidth of a rectangular microstrip patch antenna, a strategic modification involves incorporating four rectangular cuts at the corners of the original design. This innovative approach results in a truncated version of the antenna, effectively increasing its overall bandwidth. The rectangular cuts serve to disrupt the conventional geometry of the patch, introducing additional resonant modes and modifying the current distribution along the radiating edges. As a consequence, the truncated design exhibits a broader frequency response, offering a higher bandwidth compared to the unaltered configuration. This method proves to be an efficient means of optimizing the performance of microstrip patch antennas, catering to applications where broader frequency coverage is essential for improved communication and signal reception.

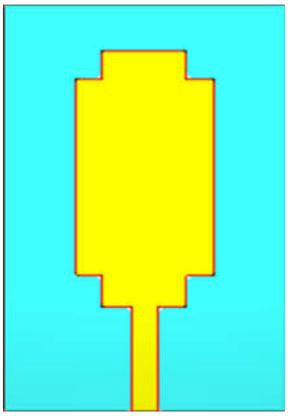

Figure 2. Front View of Antenna after Truncation

BENDING ANALYSIS

The bending characteristics of a microstrip patch antenna describe how its performance is affected by bending or flexing the substrate on which it is fabricated. Microstrip patch antennas are renowned for their flexibility, making them suitable for various applications requiring conformal or flexible designs. When bent, the antenna's resonance frequency shifts and radiation patterns vary because of modifications to the substrate's dielectric characteristics. However, careful design and optimization can mitigate these effects, ensuring consistent performance even in curved or flexible configurations. This inherent flexibility offers significant advantages in designing flexible microstrip patch antennas for applications such as wearable technology, conformal antennas for irregular surfaces, and compact wireless communication systems where traditional rigid antennas are impractical. The bending analysis conducted on the antenna, considering an angle of 50 degrees and radii of 10, 20, and 30, provided valuable insights into its performance under different bending conditions, enhancing its suitability for real-world applications.

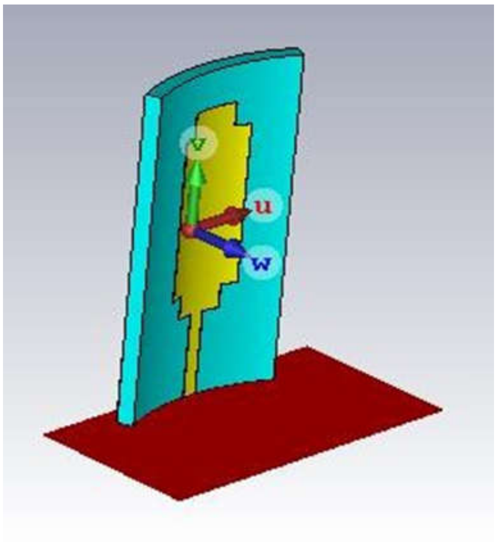

Figure 3. Side view of antenna after bending

Figure 4. Antenna top view after bending

SUBSTRATE SELECTION

Jeans is identified as the preferred substrate material owing to its advantageous performance across critical parameters. Possessing a dielectric constant (ε_r) of 1.54, Jeans mirrors the electrical properties of cotton (ε_r = 1.51) while showcasing superior return loss (-46.1dB) in comparison to cotton (-48.3dB), indicating heightened signal efficiency. Furthermore, Jeans exhibits a broader bandwidth (2 GHz) and elevated gain (2.2 dB) when juxtaposed with alternative substrates like PDMS and Roger RT5880. Additionally, Jeans demonstrates adequate directivity (2.7 dB), ensuring efficient signal transmission. Notably, Jeans presents enhanced flexibility vis-à-vis rigid substrates such as PDMS and Roger RT5880, rendering it apt for wearable applications necessitating comfort and adaptability. Hence, given its superior electrical performance, flexibility, and comfort, Jeans emerges as the optimal substrate material for the antenna design, rendering it well-suited for telemedicine and wearable applications.

Types of substrate materials	**Dielectric constant (ε_r)**	**Return loss**	**Bandwidth (GHz)**	**Gain (dB)**	**Directivity (dB)**
Cotton	1.51	-48.3dB	1.9	2.1	2.6
Proposed antenna(jeans)	1.54	-46.1dB	2	2.2	2.7
PDMS	2.65	-15.5dB	1	2.6	3.1
RogerRT5880	2.2	-18.6dB	2.1	2.5	2.9

Table 2. Substrates Comparison

RESULTS AND DISCUSSION

The modification of the microstrip patch antenna for wearable healthcare applications resulted in considerable increases in flexibility and performance. The antenna improved significantly after meticulously exploring several substrate materials and implementing the truncation procedure. Jeans material had the highest effective relative permittivity (ε_r) of 1.5, making it appropriate for wearable applications. Furthermore, bending study was performed with a radius of 20 and an angle of 50, proving that the antenna's performance remained constant in both bending and non-bending scenarios, with S-parameters yielding almost identical findings. The comprehensive study undertaken highlighted the critical importance of the truncation approach in increasing antenna performance, resulting in astounding findings such as a bandwidth of 2 GHz and a phenomenal return loss of -46.1dB and a gain of 2.16 dBi.

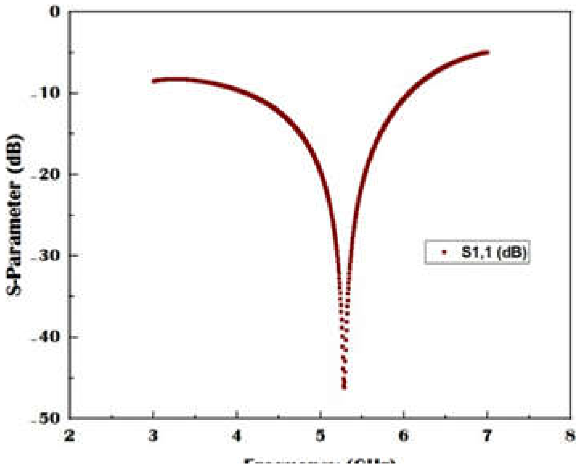

Figure 5. S-Parameter of the antenna before bending

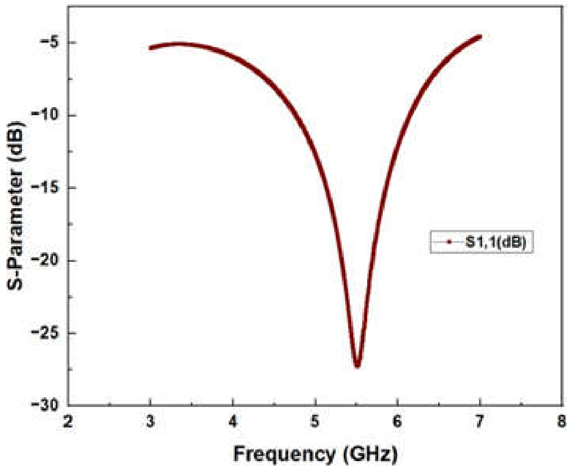

Figure 6. S-Parameter of the antenna after bending

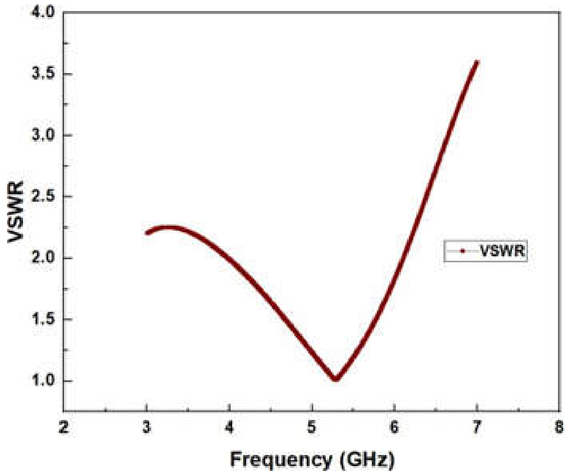

Figure 7. VSWR of the antenna

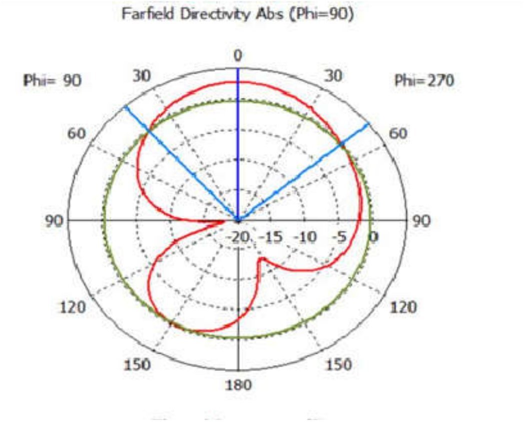

Figure 8. Directivity of the antenna before bending

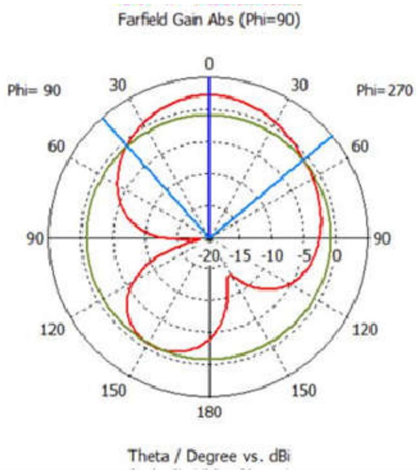

Figure 9. Gain of the antenna before bending

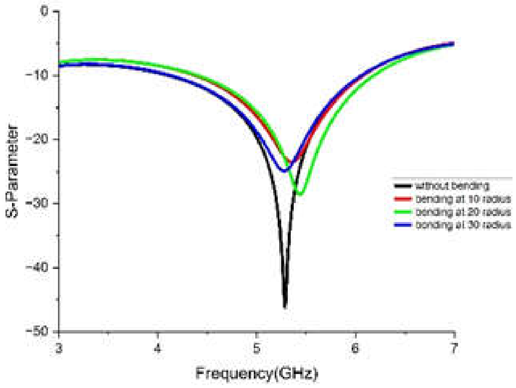

Figure 10. Comparison of the S-parameters

These results emphasise the significance of substrate selection and design techniques in optimizing the performance of antennas for wearable medical devices. By prioritizing flexibility enhancement and performance improvement, this research offers valuable insights for the advancement of healthcare monitoring systems. Moving forward, these insights will guide future developments in wearable antenna technology, with the potential to significantly enhance patient care and diagnostic capabilities in the field of healthcare. Additionally, the antenna's performance after bending analysis showed promising results, with a reflection coefficient of -28.5 dB and achieved gain of 1.56 dBi. This further validates the antenna's suitability for wearable applications, as it maintains satisfactory performance even under bending conditions.

CONCLUSION

In conclusion, our work advances microstrip patch antennas aimed at medical applications by ensuring improvements in flexibility and performance. Through a comprehensive process of testing and analysis, the denim material emerged as the best substrate, as evidenced by its remarkable effective relative permeability (ε_r) quality of 1.5. Using the clipping method, our antenna showed great performance, including a large 2GHz bandwidth, an impressive return loss of -46.1dB, and a peak gain of 2.16dBi. These results emphasise the significance of substrate selection and design strategies to improve the antenna performance of wearable medical devices and provide valuable information for the development of effective health monitoring systems. By increasing flexibility and optimizing production, our work contributes to the continued advancement of flexible antenna technology and the ability to improve patient care and diagnostic capabilities in healthcare.

Additionally, our bending analysis revealed promising results, with the antenna maintaining satisfactory performance even under bending conditions. With a reflection coefficient of -28.5dB and achieved gain of1.56dBi after bending at 20 radius, our antenna proves its suitability for wearable applications, ensuring consistent performance in real-world scenarios where bending or flexing may occur. This further underscores the robustness and reliability of our antenna design, enhancing its potential for integration into wearable healthcare devices.

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