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REGULAR ARTICLE

A Compact Slotted Wearable Wideband Antenna for Biomedical Telemetry Applications

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Wearable technologies are increasingly popular, prompting a rise in wearable antenna usage, especially in wireless body area networks (WBAN). However, constructing antennas for wearable is challenging due to the presence of the human body. Factors such as flexibility, precision, and size are crucial considerations. Researchers are actively working on these challenges and have made significant progress in the field. This work presents a compact wideband (WB), low profile and low-cost antenna, which is suitable for wearable biomedical telemetry applications. The antenna is designed using FR4_epoxy dielectric material having dimensions of $0.44\lambda_0 \times 0.44\lambda_0 \times 0.028\lambda_0$ mm^3. Two rectangular slots are engraved on the patch to improve the impedance bandwidth and gain. The proposed slotted wearable antenna achieved an impedance bandwidth of 2.26 GHz (3.58 – 5.84 GHz) with a center frequency at 5.3 GHz and high gain of 5.9 dBi. This antenna presents a solution for wearable biomedical telemetry, offering compact size, high performance, and adaptability to various conditions. The simulation results of return loss, voltage standing wave ratio (VSWR,),impedance matching, gain and radiation pattern of the proposed antenna are obtained through Ansys 2021 R2 high frequency structure simulator(HFSS) software.

Keywords: Biomedical telemetry, Wearable antenna, Wideband, Rectangle patch, WBAN.

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1. INTRODUCTION

In the areas of athletics, security, and biomedical, wearable antenna technology has gained widespread recognition in recent years for its potential benefits. Due to the extreme features like robust, flexible, ideal for integration into clothing, there is a high demand for wearable antennas. The off-body communication required the development of suitable antennas that combine flexibility, durability, and reliability [1]. Furthermore, prioritizing the reduction of strong electromagnetic interaction with the human body is necessary to support user safety and comfort standards [2].When it comes to wearable electronics, antenna design must prioritize flexibility, to allow for user mobility without reducing performance through frequency adjustment. The adaptability of antennas to the user body, orientation or posture is heavily influenced by the careful selection of conformable substrates and conductive materials. In [3], the authors explored the fundamental role of conformable substrates, also ensuring the efficiency and user comfort of wearable antennas across diverse applications. Flexible antennas can be fabricated using different materials and methods. These involve textile materials [4],[5], polyimide film[6], inkjet-printed antennas and polydimethylsiloxane (PDMS) [7].Materials like felt, denim, and Cordura in flexible garment antennas are popular because they offer comfort and respond well to the movements of the skin [8].

Consequently, these materials are increasingly favored for their ability to combine flexibility in wearable antenna design. Nevertheless, textiles exhibit a high loss tangent, leading to diminished antenna performance and reduced radiation efficiency [9].Alternative flexible substrate materials for wearable antennas include PDMS and transparent Kapton polyimide [10]. However, these materials possess inadequate mechanical properties, necessitating the selection of appropriate transparent, flexible conductors. Achieving the necessary level of formability and flexibility is not feasible with rigid or semi-rigid substrates. Now-a-days, antenna engineers are actively engaged in developing dual-band devices with superior performance and low specific absorption rate (SAR) antennas for off-body communication in wireless body area networks (WBANs) [11]. Within the wearable network, the wearable antenna plays a key role, facilitating signal transmission and reception between implanted devices and the wearable network. Considering the human body's tendency to absorb electromagnetic waves, it is essential to prioritize the

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efficiency of antenna designs. To minimize backward radiation, measured by the SAR, which is necessary to reduce any potential harm to human tissue, requiring unique design considerations [12]. Simultaneously, careful attention must be given to the overall size of the antenna [13, 14], ensuring it remains compact. A popular method in healthcare applications is to utilize flexible or conformal antennas integrated into clothing or other wearable medical devices for antenna design. [15] The proposed structure presented in this paper can be used for on-body communication system operating at 5.3 GHz. It is suitable for Wi-Fi, medical applications. This low-profile wideband antenna incorporated slots to enhance operational bandwidth and with a reflection coefficient of -23.66 dB. Mostly suitable for a wide range of wireless applications, including healthcare. A key aspect of wearable antennas is the efficiency of their manufacturing process in terms of both time and cost. Particularly for large-scale production and cost control, it's essential to prioritize manufacturing techniques that are cost-effective and scalable for industrial use. With these considerations in mind, this section explores fabrication techniques and materials that meet the main requirements of wearable antennas.

2. PROPOSED ANTENNA DESIGN

Fig. 1 illustrates the geometry and dimensional specifications of the proposed compact wideband wearable antenna. The antenna's overall physical volume is $0.44\lambda_0 \times 0.44\lambda_0 \times 0.028\lambda_0$ mm^3, where λ_0 represents the free space wavelength. Fabricated on FR4_epoxy substrate with a dielectric constant (ε_r) of 4.4 and a loss tangent (tan δ) of 0.02. The antenna consists of a patch with a small rectangular extension and two additional rectangular slots. The proposed antenna is designed and simulated using Ansys 2021 R2 HFSS software. The optimized antenna design parameters are tabulated in Table 1.

Table 1 – Principal parameters of different layers used for the simulation

Parameter	**Value (mm)**	**Parameter**	**Value (mm)**
W_s	25	a	2.5
L_s	25	b	16
W_f	2	c	1
L_f	5.525	d	12
W_g	4.5	S_1	0.5
L_g	25	S_2	1

The design evolution of the proposed compact wideband wearable antenna is depicted in Fig. 1. Initially, a solid rectangular patch with full ground plane is designed, as depicted in Fig. 1(a) (considered as reference antenna).

To match the impedance of 50 Ohms, the feed point is positioned at the edge of the patch. Further, the full ground plane of the proposed design is altered as partial ground plane as shown in Fig. 1(b), to enhance the reflection coefficient. As depicted in Fig. 1(c), a small rectangular extension having dimensions $a = 2.5$ mm and $c = 1$ mm is integrated at the top right corner of the patch. And two rectangular slots engraved on the patch to enhance the impedance bandwidth as depicted in Figs. 1(d) and 1(e) whereas Fig. 1(f) is proposed antenna. The proposed antennas achieved results and the comparative analysis of all design steps is further discussed in Fig. 2.

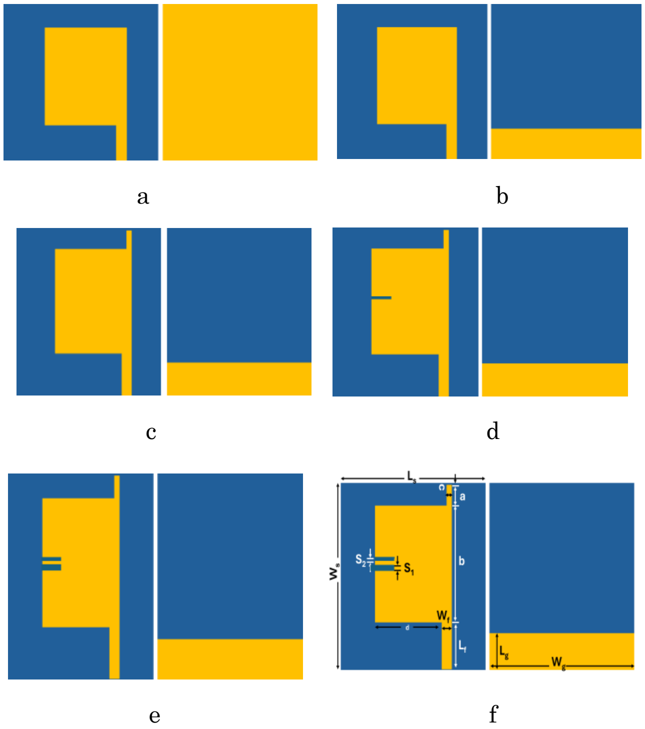


Fig. 1 – Design evolution of all steps (a-f), whereas the proposed structures (f) proposed wearable design

3. RESULT AND DISCUSSION

The proposed antenna performance in terms of reflection coefficient, radiation pattern and gain is evaluated. The attained reflection coefficient (S_{11}) at different evolution steps is depicted in Fig. 2. From Fig. 2, it is observed that the solid rectangular patch with full ground Fig. 1(a) resonated at 6.42 GHz. Subsequent alterations from full ground to partial ground Fig. 1(b) enhanced the return loss to 27.35 dB. Incorporating the small rectangular portion shown in Fig. 1(c) into the patch caused a shift in the resonant frequency from 6.4 GHz to 6.3 GHz. Engraving the first rectangular slot, measuring 0.5 mm in width and 6 mm in length, onto the patch as depicted in Fig. 1(d), enabled the antenna to resonate at the target frequency of 5.3 GHz, achieving a narrow bandwidth of 0.29 GHz ranging from 5.24 GHz to 5.53 GHz. The inclusion of the second rectangular slot, measuring 1 mm in length and 6 mm in width as shown in Fig. 1(e), expanded the impedance bandwidth from 0.29 GHz to 2.26 GHz extending from 3.58 GHz to 5.84 GHz.

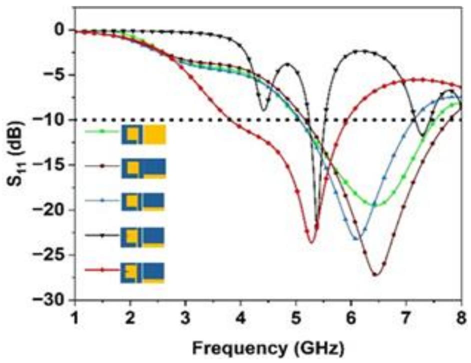


Fig. 2 – Reflection coefficient (S_{11}) at different design evolution steps

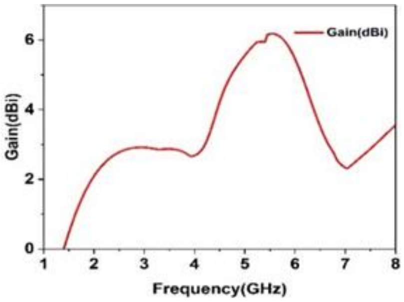


Fig. 3 – Gain of the proposed antenna

According to the data observed, the antenna design has achieved gain is 5.9 dBi at a frequency of 5.3 GHz, as shown in Fig. 3.

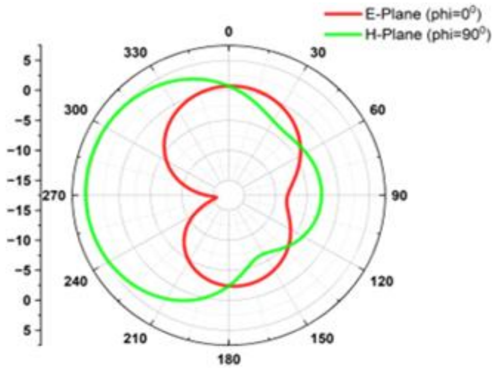


Fig. 4 – 2D far field radiation pattern at 5.3 GHz

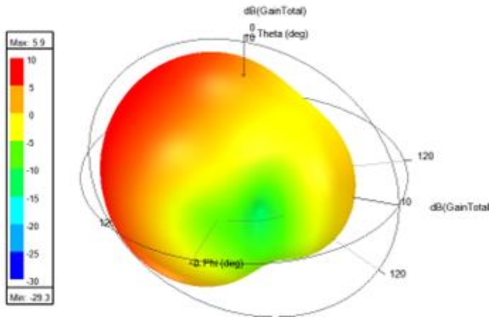


Fig. 5 – 3D radiation pattern of the proposed antenna

Orientations at 90° and 270°. Furthermore, Fig. 5 depicts a 3D radiation pattern with a gain of 5.9 dBi obtained precisely at 5.3 GHz. In Fig. 6 depicts the surface current distribution of the proposed wearable antenna at 5.3 GHz is displayed in Fig. 6.

The introduction of slots on the patch induces a moderate variation in current at the edges of the patch and feedline. From the analysis, it can be noticed that the proposed wearable antenna designed using FR4 epoxy achieved a high gain of 5.9 dBi

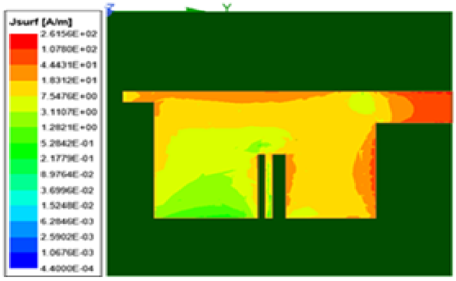
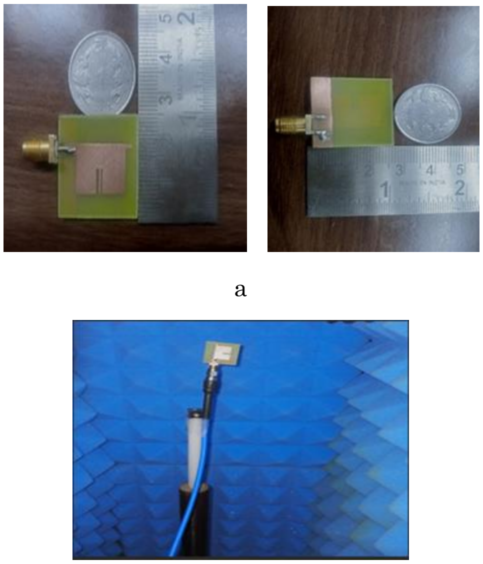


Fig. 6 – Surface current distribution at 5.3 GHz



a

b

Fig. 7 – (a) Fabricated prototype, (b) measurement

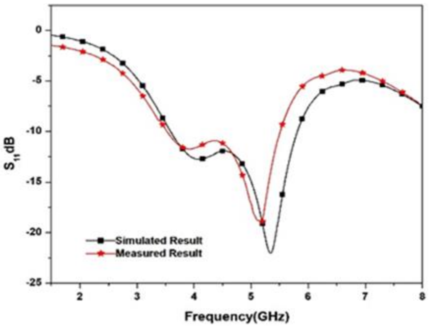


Fig. 8 – Simulated vs. Measured S_{11} (dB)

The comparative performance analysis of the proposed design with other published conventional antennas in terms of reflection coefficient, gain and VSWR is shown in Table II. From the comparison with other traditional antennas, it is noted that the proposed structure is compact in nature, also achieved wideband and high gain, which in turn make the antenna suitable for warble application at 5.3 GHz.

Table 2 – Comparative analysis with other conventional antennas

Ref.	**Dimensions (mm^3)**	**Frequency (GHz)**	**Substrate**	**S_{11} (dB)**	**Gain (dBi)**	**VSWR**
[3]	$0.786\lambda_0 \times 1.066\lambda_0$	4	Polyester fiber	– 29.9	8.85	–
[6]	$0.886\lambda_0 \times 1.181\lambda_0$	4.43 and 8.82	Flexible felt	– 23.2	4.06	–
[7]	$0.583\lambda_0 \times 0.666\lambda_0$	5	Flexible textile	– 28.0	14.54	< 2
[8]	$0.360\lambda_0 \times 0.360\lambda_0$	2.45	Flexible felt	– 33.5	7.4	–
[9]	$0.361\lambda_0 \times 0.263\lambda_0$	3.16	polyester	– 34.4	7.70	< 2
[10]	$0.490\lambda_0 \times 0.490\lambda_0$	2.45/3.45	Taconic TLY-5	– 22.2	5.1	–
[13]	$0.138\lambda_0 \times 0.20\lambda_0$	2.45	RT/Duriod 5880	– 30	2.50	1.06
This work	$\mathbf{0.44\lambda_0 \times 0.44\lambda_0}$	**5.3**	**FR4**	**– 23.66**	**5.9**	**1.1**

4. CONCLUSION

A simple, compact, low-profile wearable antenna was designed and developed. The proposed antenna design achieved a WB of 2.26 GHz (3.58 GHz to 5.84 GHz). It also achieved the maximum $|S_{11}|$ of 23.66 dB at 5.3 GHz, a gain of 5.9 dBi. The fabricated prototype measured results and the simulated results are in good agreement. The performance comparative analysis with traditional antennas was performed and tabulated in Table 2.

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Компактна широкосмугова антена з щілинами для застосування в біомедичній телеметрії

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Технології, що використовуються в одязі, стають все більш популярними, що сприяє збільшенню використання носимих антен, особливо в бездротових телемережах (WBAN). Однак побудувати антени для носіїв є складним через наявність людського тіла. Такі фактори, як гнучкість, точність і розмір, є вирішальними міркуваннями. Дослідники активно працюють над цими проблемами та досягли значного прогресу в цій галузі. У цій роботі представлено компактну широкосмугову (WB), низькопрофільну та недорогу антену, яка підходить для переносних біомедичних телеметричних застосувань. Антена розроблена з використанням епоксидного діелектричного матеріалу FR4 з розмірами $0{,}44\lambda_0 \times 0{,}44\lambda_0 \times 0{,}028\lambda_0$ мм^3. Два прямокутних слота вигравірувані на патчі для покращення пропускної здатності імпедансу та посилення. Запропонована щілинна носима антена досягла смуги пропускання опору 2,26 ГГц (3,58 – 5,84 ГГц) із центральною частотою 5,3 ГГц і високим коефіцієнтом посилення 5,9 дБі. Ця антена є рішенням для переносної біомедичної телеметрії, пропонуючи компактний розмір, високу продуктивність і адаптованість до різних умов. Результати моделювання зворотних втрат, коефіцієнта стоячої хвилі напруги (КСВН), узгодження імпедансу, посилення та діаграми спрямованості запропонованої антени отримані за допомогою програмного забезпечення симулятора високочастотної структури Ansys 2021 R2 (HFSS).

Ключові слова: Біомедична телеметрія, Переносна антена, Широкосмуговий, Прямокутний патч, WBAN.