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Kablosuz Deri Kanser Takip Sistemleri için Kot-kumaş Tabanlı Giyilebilir Çatal Şeklinde Ultra Geniş Bant Anten

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Anahtar Kelimeler
Ultra-geniş bant,
Esnek anten,
Geri dönüş kaybı (S11),
Duran dalga oranı (VSWR),
Kazanç,
Kablosuz sağlık izlemi

Öz: Son zamanlarda, insanlarla sağlık hizmeti sağlayıcıları arasında sorunsuz iletişimi kolaylaştırmak amacıyla esnek giyilebilir antenler kullanan kablosuz sağlık izleme sistemlerine olan talep hızla artmaktadır. Bu bilimsel araştırmanın temel amacı, ekonomik olarak uygulanabilir, denim üzerine özenle tasarlanmış kumaş tabanlı esnek giyilebilir bir anten tasarımının operasyonel verimliliğini değerlendirmek, özellikle de kablosuz sağlık izleme alanındaki uygulanabilirliğine odaklanmaktadır. Bu antenin önemli bir özelliği, fiziksel boyutunun minimum olmasıdır ve 50 mm × 35 mm × 1.0 mm ölçülerindedir; ayrıca, 2.44 GHz ‘de yaklaşık %96.7 ve 7.66 GHz ‘de %96.2 gibi yüksek verimliliklere sahip olarak mükemmel performans sergilemektedir. 7.66 GHz frekansında sırasıyla 4.32 dBi ve 4.87 dBi olarak ölçülen yüksek kazanç ve doğruluk özellikleri de dikkat çekicidir. Bu ultra geniş bant (UWB) antenin önemli vurguları, kompakt form faktörü, hafif yapısı, maliyet etkinliği, doğal esneklik, basit üretim süreci ve giyimle sorunsuz entegrasyonu içermektedir. Bu özel özellikler, onu kablosuz vücut alanı ağı (WBAN) sistemlerine özgü olarak özel olarak tasarlanmış bir giyilebilir insan vücut anteni olarak uygun kılan unsurları vurgular. Özellikle, yukarıda bahsedilen anten tasarımının hem simülasyon hem de ölçüm sonuçları, özellikle ultra geniş bant operasyonları bağlamında, WBAN uygulamaları için üstünlüğünü ve uygunluğunu doğrulamaktadır.

Denim-Based Wearable Fork-Shaped Ultra-Wideband Antenna for Wireless Skin Cancer Monitoring Systems

Keywords
Ultra-wideband (UWB),
Flexible antenna,
Return loss (S11),
Voltage standing wave ratio (VSWR),
Gain,
Wireless health monitoring

Abstract: Recently, there has been a burgeoning demand for wireless health monitoring systems employing flexible wearable antennas to facilitate seamless communication between individuals and their healthcare providers. The principal objective of this scholarly investigation revolves around assessing the operational efficiency of an economically viable, fabric-based flexible wearable antenna design meticulously fashioned on denim, with a specific focus on its applicability in wireless health monitoring. The significant feature of this antenna is its minimal physical size, measuring 50 mm × 35 mm × 1.0 mm, and it also draws attention as an antenna with excellent performance, boasting high efficiencies of approximately 96.7% at 2.44 GHz and 96.2% at 7.66 GHz. It exhibits commendable attributes in high gain and directivity, quantified at 4.32 dBi and 4.87 dBi, respectively, at a frequency of 7.66 GHz. The pivotal highlights of this ultra-wideband (UWB) antenna encompass its compact form factor, lightweight construction, cost-effectiveness, inherent flexibility, straightforward fabrication process, and seamless integration into clothing. These distinctive attributes underscore its suitability as a wearable human body antenna tailor-made for deployment within wireless body area network (WBAN) systems. Notably, both the simulation and measurement outcomes of the abovementioned antenna design corroborate its preeminence and suitability for WBAN applications, particularly in the context of ultra-wideband operations.

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1. Introduction

The utilization of textile antennas represents a pioneering paradigm within apparel. This innovative concept introduces multifaceted functionalities to garments, transcending their conventional roles. These enhanced attributes encompass the capacity for sensory perception and communication and the capability to effectuate actions while affording a safeguarding interface against external elements. Sensory perception entails the strategic integration of sensors directly into clothing fabric. These sensors are adept at capturing diverse physiological parameters emanating from the human body, including but not limited to temperature and respiration rate. This convergence of technology and attire engenders a symbiotic relationship between the wearer and the textile, wherein the garments become an interface for continuous physiological monitoring. The integration of wearable antennas into the fabric further amplifies the functionality of materials by facilitating wireless communication between the human body and the ambient environment. This symbiosis, often referred to as body-centric communication, transcends the boundaries of traditional communication methods, enabling a seamless exchange of information without the constraints of physical devices. This technological fusion augments the connectivity of the individual and seamlessly integrates the digital realm with the physical self.

The apex of this paradigm is realized through actuating capabilities, wherein actuators are seamlessly embedded within the fabric of garments. These actuators serve the purpose of notifying and alerting the wearer regarding specific events or triggers by employing auditory alarms or visual notifications. This proactive communication mechanism engenders heightened awareness and responsiveness, seamlessly melding the digital and human dimensions. In summation, the advent of textile antennas heralds a transformative epoch in attire. Garments evolve into intelligent interfaces that transcend traditional roles by amalgamating sensory perception, body-centric communication, and actuating functionalities. This confluence of textile engineering and cutting-edge technology expands the horizons of human-attire interaction. It exemplifies the potential of smart textiles to redefine the boundaries of both fashion and function [1]–[3].

Due to its unique composition and operational characteristics, a textile antenna is a distinct and divergent archetype juxtaposed with conventional antennas. In stark contrast to the rigidity inherent in traditional antenna construction, textile antennas are predominantly or entirely fashioned from textile materials, circumventing the necessity for inflexible substrates prevalent in conventional antenna designs. The pliability intrinsic to textile antennas is a striking departure from the established norms of antenna engineering, affording them a remarkable degree of flexibility that is inherently absent in their traditional counterparts. The composite structure of textile antennas is predicated upon the amalgamation of two distinct categories of fabrics: conductive and non-conductive. Within this construct, conductive fabrics play an instrumental role by serving as conduits for the propagation of electromagnetic waves. These fabrics are strategically employed as conductive patches, enabling efficient and effective wave transmission and reception.

Conversely, non-conductive fabrics, forming the substrates of textile antennas, engender a structural foundation that supports the functional components. These non-conductive substrates contribute significantly to the textile antenna's mechanical integrity and stability. The efficacy and performance attributes of textile antennas, encompassing metrics such as gain, bandwidth, efficiency, and reflection coefficient, are inherently contingent upon the specific fabric types employed during construction. The dielectric constant of the substrate material emerges as the pivotal determinant in this regard, exerting a pronounced influence on the antenna parameters. Notably, the choice of fabric directly governs the substrate's dielectric properties, thereby wielding a pivotal power over the ultimate operational characteristics of the textile antenna. The textile antenna represents an innovative departure from the established landscape of antenna design, redefining the conventional norms through its textile-based composition and inherent flexibility. The dichotomy between conductive and non-conductive fabrics forms the foundation for its functional architecture, with the former enabling electromagnetic propagation and the latter bestowing structural robustness. The intricate interplay between fabric selection, dielectric constants, and resultant antenna attributes underscores the paramount role of textile composition in shaping the antenna's performance landscape [2]–[5].

Crucial attributes governing the selection and application of textile materials in the context of antenna design encompass a range of factors, including the dielectric constant, fabric thickness, surface resistivity of conductive fabrics, moisture content of textiles, and the mechanical behavior exhibited by both dielectric and conductive fabric components. The interplay of these attributes significantly influences the overall performance and effectiveness of textile-based antennas. Various textile materials have found utility in constructing antennas, each harboring distinctive characteristics and potentialities. These materials include Vellux, synthetic felt, Cordura, fleece, and upholstery fabric. The composition and attributes of these materials hold implications for the resultant antenna's functionality. Concomitantly, the conductive aspect of textile antennas relies on fabrics imbued with conductive properties. Examples encompass woven fabrics endowed with nickel plating, knitted fabrics enriched with silver leaf, and woven fabrics adorned with composite silver copper-nickel plating. Additional instances contain specialized conductive fabrics such as Flectron and Zelt, contributing to the diverse material choices available for textile antenna construction (Salvado et al., 2012).

The seamless integration of antennas into textile-based garments and their optimal positioning on the human body hinge upon specific criteria. Notably, these antennas manifest compact dimensions and forms, rendering them amenable to unobtrusive placement. This diminutive stature of textile antennas is often embodied through microstrip or patch antenna configurations. These configurations, predominantly microstrip and patch antennas, have surfaced as suitable solutions for various applications, including but not limited to aviation, military hardware, and communication systems. Their discreet design and robust performance attributes render them efficacious choices for contexts where space constraints and inconspicuousness are paramount considerations [7]. The proliferation of wearable devices has garnered prominence across both civilian and military spheres, primarily attributed to their heightened utility in facilitating communication endeavors. Additionally, these devices have observed increased adoption within local area networks (LANs) and wide area networks (WANs), where the assurance of secure data transmission is paramount. Noteworthy is the application of wearable technology in the context of textile sensors, which prominently feature in monitoring physiological parameters. Of particular significance is the utilization of Bluetooth-enabled interfaces to seamlessly transmit the acquired physiological data, particularly heart rate measurements, to interconnected smart devices such as smartphones [8]. The ambit of e-textiles further expands the repertoire of physiological signals amenable to monitoring [9], [10], enriching the potentialities of wearable technology in health and performance monitoring. The fabrication process is central to successfully designing and realizing wearable textile antennas. This pivotal task encompasses a range of methodologies tailored to the textile context. Foremost among these is employing flexible copper sheets, a pragmatic and uncomplicated approach for realizing antenna patches and accompanying ground planes. This fabrication method emerges as an economically reasonable and time-efficient solution, effectively contributing to streamlining the production process [11].

In contemporary times, the integration of wireless body area networks within the domain of biomedical applications has substantially permeated everyday existence [12]–[15]. In this landscape, wearable antennas emerge as a distinctive subset of patch antennas, uniquely tailored to operate with the human form while worn [16]. The proliferation of wearable technology presents a burgeoning prospect, potentially mitigating medical errors and enhancing the overall caliber of healthcare provisions within medical facilities. The scope of this endeavor encompasses the conceptualization and implementation of a wearable antenna optimized for medical applications. This endeavor is particularly resonant in light of the imperative nature of early detection of many life-threatening ailments, whereby timely identification can be instrumental in instigating life-saving interventions [15], [17]. In recent years, the domain of ultra-wideband applications has witnessed a notable surge in interest directed towards medical imaging applications. Among these applications, ultra-wideband (UWB) microwave imaging is promising in biomedical contexts. Its capacity for profound tissue penetration and commendable resolution underscores this, positioning it as a potent modality for identifying malignancies like cancer. Within this overarching context, the present study begins designing and developing an antenna primed for delineating skin cancerous tissues, thereby capitalizing on the intrinsic capabilities of UWB microwave imaging [18].

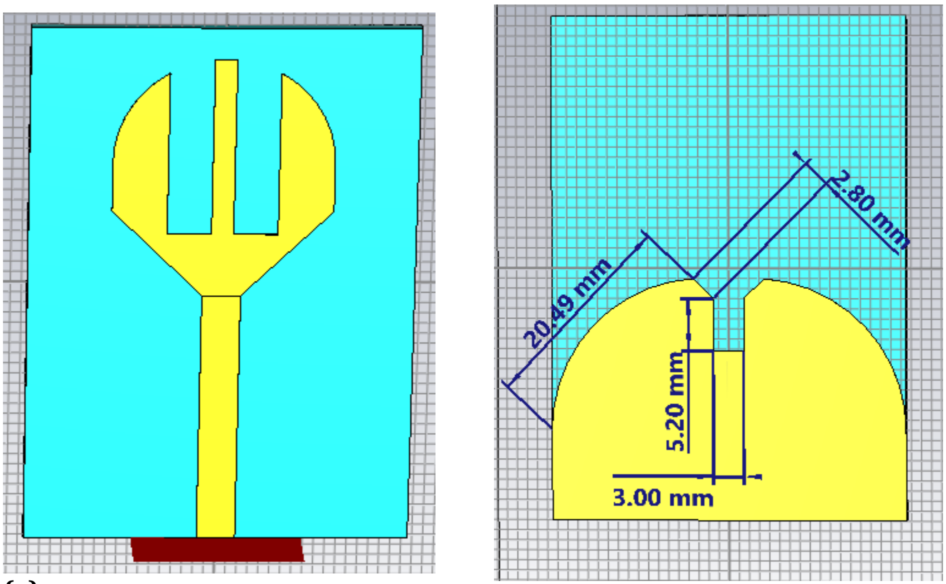
Ultra-Wideband (UWB) antennas are types of antennas that enable communication over broad frequency bands and facilitate high-speed data transfer. These antennas play a significant role, particularly in the field of wearable technology. In this context, the design, simulation, and production of a flexible UWB antenna integrated into denim fabric can offer various advantages in wearable technology applications. The flexible structure of denim fabric provides an ideal material for the design of wearable devices, offering comfort and freedom of movement. Integrating a UWB antenna into this fabric can provide communication capabilities that are discreetly embedded in the clothing the user wears. This represents a crucial step in the design of wearable technology devices, emphasizing aesthetics and functionality. The simulation process plays a critical role in optimizing the design and improving antenna performance. The simulation of the UWB antenna integrated into denim fabric takes into account factors such as material properties, antenna dimensions, and placement to achieve the best performance. During the production phase, considerations include the availability of flexible materials and their compatibility with wearable technology. Flexible Printed Circuit Board (PCB) technologies and specialized production processes enable the manufacturing of UWB antennas integrated into denim fabric. This facilitates better integration of wearable technology products into industrial production processes. Flexible UWB antennas integrated into denim fabric find applications across a wide range of wearable technology, including health monitoring, location tracking, and interactive wearable applications. For instance, health monitoring devices can continuously track vital signs such as body temperature and heart rate. In location tracking applications, precise location data can be transmitted to determine the user's exact whereabouts. In conclusion, flexible UWB antennas integrated into denim fabric play a significant role in making wearable technology more functional and user-friendly. These designs, by combining fashion and technology, have the potential to enhance the user experience and integrate wearable technology seamlessly into daily life.

This paper comprehensively explores the development, simulation, and fabrication of a flexible Ultra-Wideband (UWB) antenna seamlessly integrated into denim fabric, with a specific focus on its applicability in wearable technology. The study entails a systematic investigation aimed at optimizing the geometric configuration of the antenna through a parametric analysis, shedding light on the influence of dimensional variations on its overall performance. The simulation results of the designed antenna closely align with the empirical findings obtained from the physical prototype. Remarkably, the fabricated antenna exhibits exceptional fidelity to the simulation data, achieving an impressive 96.2% accuracy in the S11 parameter and a 96.7% accuracy in the gain value when compared to the simulated outcomes. The antenna's peak simulated gain and directivity reach noteworthy levels at 2.4 dBi and 4.87 dBi, respectively, while offering a substantial impedance bandwidth spanning 1.8 GHz, ranging from 2.12 to 10.04 GHz. This remarkable bandwidth maintains a minimum impedance matching of -47.64 dB for S11 and -42.65 dB, showcasing its outstanding performance. Notably, the physical dimensions of the fabricated antenna are compact, measuring 50 mm × 35 mm × 1.0 mm, with a peak gain of 4.4 dB. It is worth emphasizing that this UWB antenna design surpasses the performance of comparable antennas documented in existing literature, establishing its suitability for applications in wearable technology, particularly within the context of Wireless Body Area Networks (WBANs) used for wireless health monitoring. As a prospective avenue for further investigation, the antenna presented in this study can be subjected to tests involving various antenna parameters to accommodate a range of human body movements and positions. This endeavor holds the potential to enable diverse applications in the realms of human body movement recognition and classification.

2. Material and Method

In the suggested configuration of the Fork-shaped microstrip patch antenna, the fundamental structure involves a denim substrate between the upper conductor, functioning as a Fork-shaped radiating patch, and the lower conductor, serving as a ground. Fabrication of the designed antenna takes place on a denim substrate with dimensions measuring 35 mm × 50 mm × 1 mm. Using denim as a substrate presents an optimal selection for a wearable and pliable antenna within a wireless health monitoring system. This preference stems from its ability to manifest sought-after attributes, encompassing cost-effectiveness, elevated flexibility, minimal mass, substantial mechanical resilience, and requisite radiation properties. This substrate possesses a relative permittivity of 1.7 and a loss tangent of 0.025. The ground plane and the radiating patch are constructed utilizing adhesive copper tape, which exhibits a conductivity of 5.88×10^7 S/m and has a thickness of 0.035 mm. A microstrip feed line is integrated to achieve impeccable impedance matching of 50 Ω for the fabricated antenna. This feed line features 13.5 mm × 2.85 mm dimensions and is connected to a Sub-Miniature Version A (SMA) connector. The design framework of the proposed antenna, encompassing the radiating patch, substrate, and ground, is visually represented in Figure 1. Specific antenna design measurements are outlined in detail in Table 1.

Optimization and parametric exploration are undertaken by subjecting various parameter specifications to variation. This comprehensive approach is aimed at attaining the ultimate design configuration. These tasks are executed employing the Computer Simulation Technology (CST) Microwave Studio, which serves as the designated software for antenna simulation. The optimized design incorporates strategically placed slots within the radiating patch and the ground to enhance the antenna's performance. This innovative addition contributes to superior impedance matching, expanded bandwidth, minimal bending impacts, reduced electromagnetic deposition, and decreased overall size due to eliminating excess metallic components.



(a) (b)

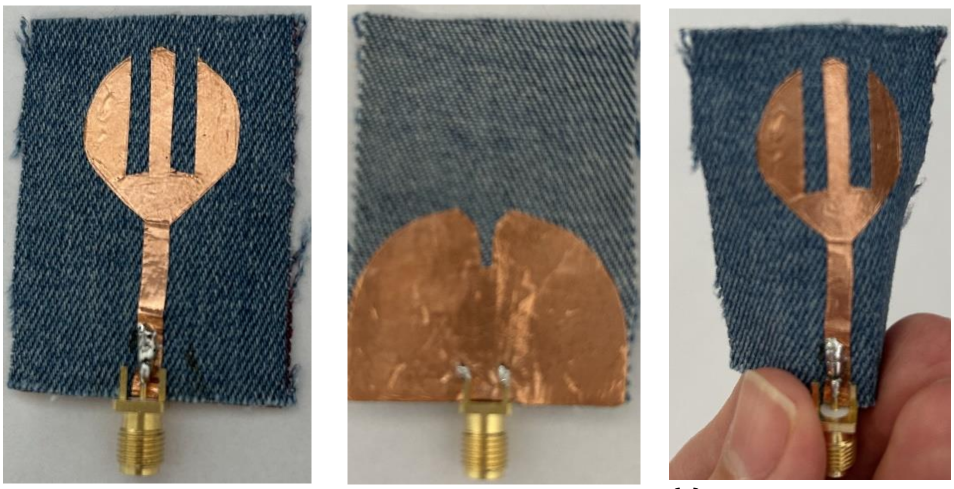
Figure 1. Fork-shaped UWB-antenna in CST Simulation (a) Radiating patch geometry (b) Ground structure.

Table 1. Dimensions of the proposed antenna.

Antenna Design Parameters	Dimensions (mm)
Substrate width (Ws)	35
Substrate length (Ls)	50
Patch width (Wp)	20
Patch length(Lp)	23
Feed length (Lf)	24
Feed width (Wf)	3.5
Slot length (Ls1, Ls2)	16.95
Slot width (Ws1, Ws2)	4
Ground width (Wg)	35
Ground length (Lg)	24
Thickness of substrate (h)	1
Thickness of copper tape (t)	0.035
Blend radius (Br)	10
Blend ground (Bg)	15
Chamfer ground (Cg)	2

The procedure encompassing the conceptualization and production of a pliable antenna intended for wearability involves several sequential stages. Firstly, the choice of substrate material takes place in tandem with the consideration of other design factors aligned with the particular requisites of the application. Subsequently, determining the antenna's geometry and dimensions is established, a pivotal step in achieving the desired functionality. The deployment of an electromagnetic (EM) simulator, such as CST, is then executed, engaging in iterative simulations until the targeted performance metrics are attained, signifying the antenna's operational efficiency. Following this, preparing a textile-based adaptable substrate tailored to the application's specifications takes precedence, ensuring optimal compatibility. The manufacturing stage entails the precise crafting of the antenna. This entails the accurate segmentation of self-adhesive conductive copper tape and the chosen substrate material (in this case, denim), with the subsequent adhesion of the copper tape onto the substrate's surface. Integrating the SMA connector ultimately culminates the process, facilitating seamless connectivity and finalizing the wearable, flexible antenna's assembly. The testing and measurement of the designed antenna parameters were carried out using a handheld LITEVNA (24) vector analyzer.

In this study, the selection of textile denim fabric as the substrate for designing and realizing a flexible wearable UWB antenna is exemplified in Figure 2 (a). The antenna of focus is meticulously planned, virtually simulated, and refined using CST simulation software, employing a frequency-domain solver. The technique of employing copper tape is harnessed for the antenna's construction, wherein a 0.035 mm thick adhesive copper tape is affixed to serve as both the radiating patch element and a ground plane structure on the denim fabric substrate. This highly conductive material is well-suited for the antenna's economical fabrication. To facilitate the operational capacity of the constructed antenna, a 50 Ω SMA connector is linked with a microstrip feed line. As depicted in Figure 2 (b), the flexible fabric-based wearable antenna spotlighted in this work exhibits high suitability for applications involving body-worn setups, attributable to its inherent conformability and resilience that enable its attachment to non-planar, bent, or curved surfaces.



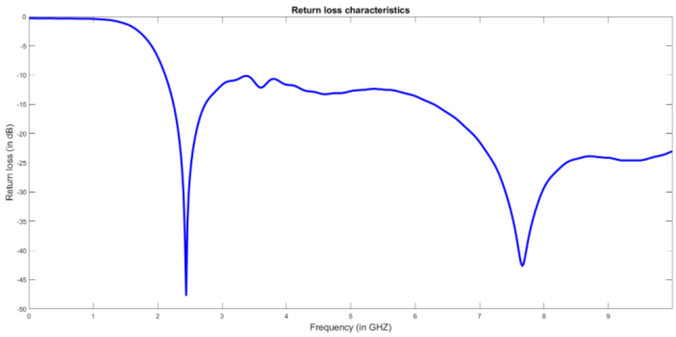
(a) **(b)** **(c)**

Figure 2. Front view of the produced antenna (a), Photo of the backside or ground side of the produced antenna (b), and Flexible denim-based wearable antenna (c).

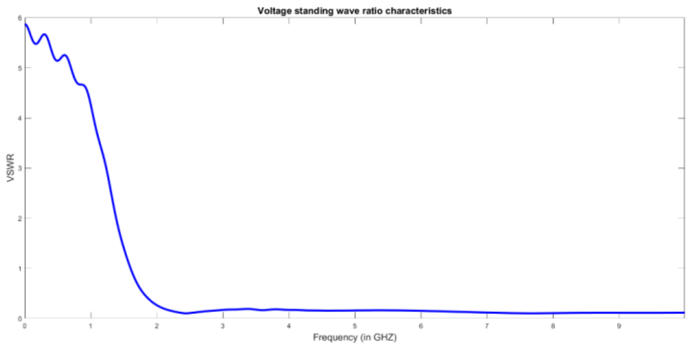
3. Simulation outcomes and parametric study findings

Return loss, also known as reflection coefficient or S_{11}, and Voltage Standing Wave Ratio (VSWR) represent critical metrics for assessing antenna performance and analyzing power losses within the antenna system. In an ideal scenario, conditions are perfect, and the antenna should reflect no power. However, practical situations often involve imperfections, discontinuities, or impedance mismatches between the feed line and radiating patch, resulting in some power being reflected.

For reliable performance, it is generally accepted that S_{11} should have a minimum value of -10 dB and a VSWR value of around 2.0 is considered suitable. In the simulation of our design, we observed an S11 of -47.64 dB and –42.65 dB at frequencies of 2.44 GHz and 7.66 GHz, respectively. The corresponding VSWR values were measured at 1.22 and 1.12 for 2.44 GHz and 7.66 GHz, respectively. Visual representations of these metrics are provided in Figure 3.



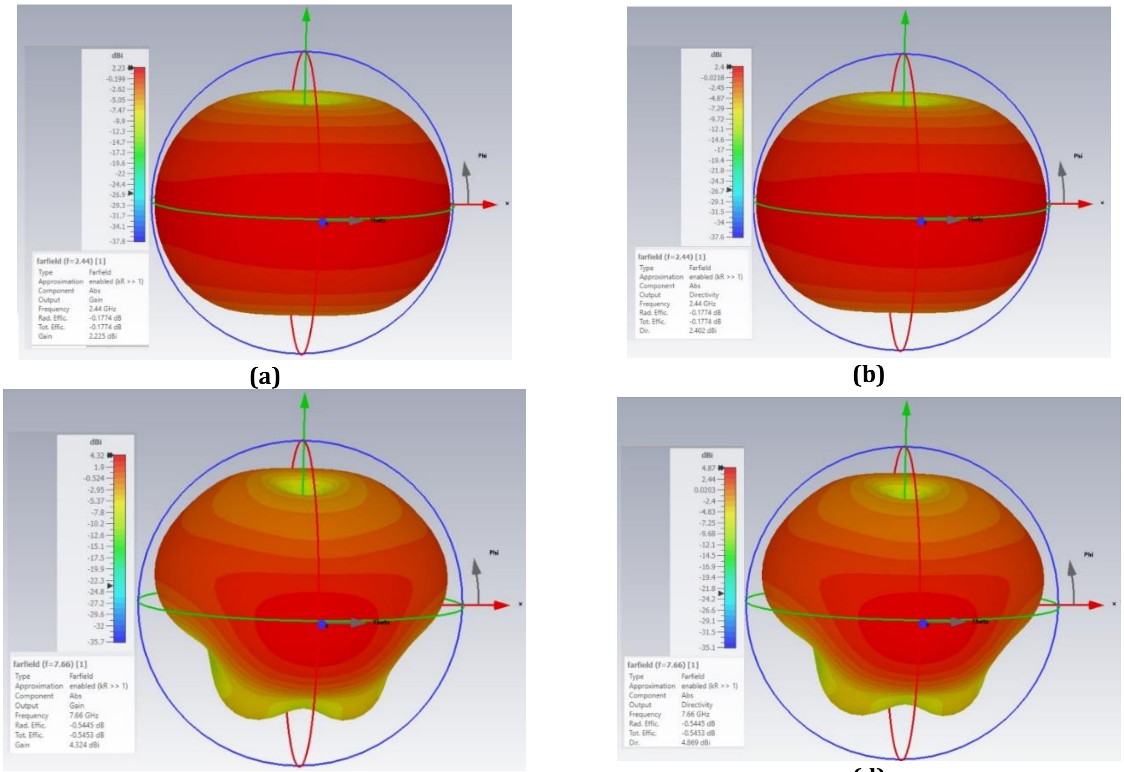
(a)



(b)

Figure 3. Simulated return loss (a) and VSWR (b) characteristics.

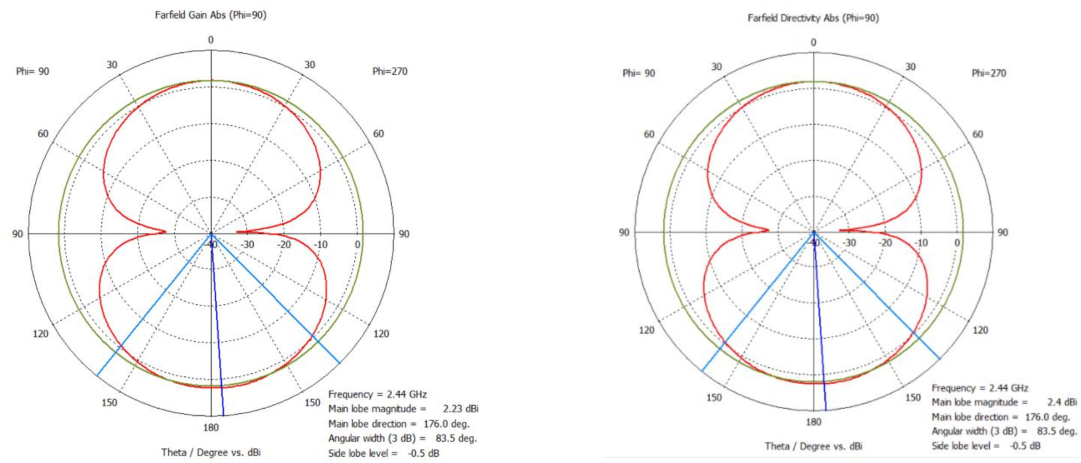
Radiation patterns illustrate the variation of radiation power in different directions from the antenna. In our analysis, we present 3D radiation pattern plots in Figure 6 to depict gain and directivity at frequencies of 2.44 GHz and 7.66 GHz. Additionally, 2D polar fields of radiation patterns are displayed in Figure 5 for the resonance frequencies of 2.44 GHz and 7.66 GHz. Figure 4 shows that at 2.44 GHz, the simulated gain and directivity are 2.23 dBi dB and 2.4 dBi, respectively. At 97.66 GHz, the gain and directivity of the proposed antenna measure at 4.32 dBi and 4.87 dBi, respectively.



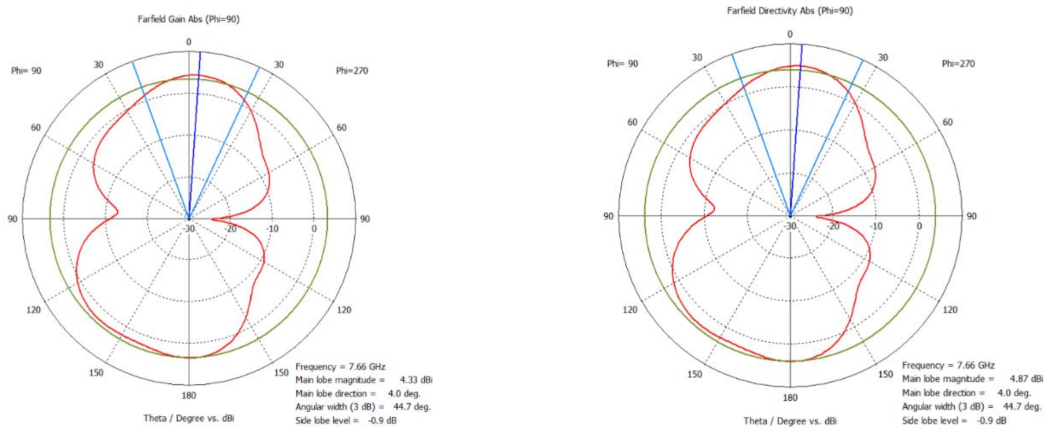
(a) (b)

(c) (d)

Figure 4. Simulated gain and directivity graphs at resonance frequencies. (a) Gain at 2.44 GHz, (b) Directivity at 2.44 GHz, (c) Gain at 7.66 GHz, (d) Directivity at 7.66 GHz.



(a) (b)

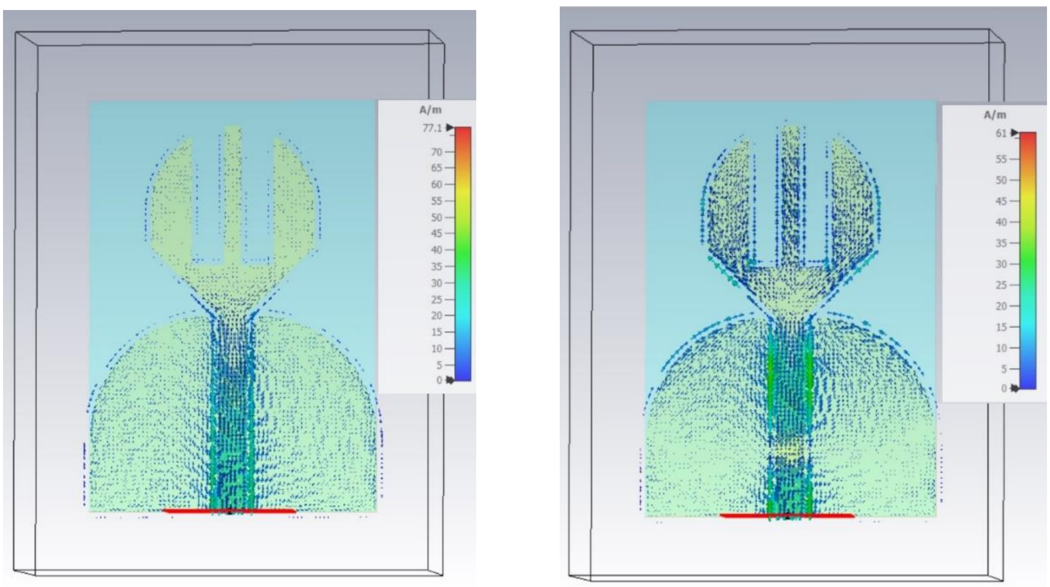


(c) **(d)**

Figure 5. Radiation pattern graphs at resonant frequencies. (a) Radiation pattern gain at 2.44 GHz, (b) Radiation pattern directivity at 2.44 GHz, (c) Radiation pattern gain at 7.66 GHz, (d) Radiation pattern directivity at 7.66 GHz.

To demonstrate the influence of slots on the designed antenna, we comprehensively analyze the simulated surface current distributions at two distinct frequencies, namely 2.44 GHz and 7.66 GHz. These simulations were conducted at the phase of 0°, and the results are meticulously showcased in Figure 6.

A thorough examination of these figures reveals that the electric dipole exhibits maximum surface current concentration primarily along the feed line, the edges of the slots, and the truncated ground. Moreover, it is noteworthy that the surface current distribution undergoes significant variations with the phase change. Furthermore, to offer a comprehensive overview of the antenna's performance characteristics, we have compiled a detailed summary of the simulation outcomes in Table 2. This table encapsulates crucial data of the presented antenna's performance parameters, providing a holistic perspective on its performance under different conditions.



(a) **(b)**

Figure 6. Surface current distribution at phase 0° (a) at 2.44 GHz and (b) at 7.66 GHz.

Table 2. Simulation-based evaluation of antenna performance.

Antenna performance parameteres	F1	F2
Resonant frequency (GHz)	2.44	7.66
Return loss S_{11} (dB)	-47.64	-42.65
VSWR	1.22	1.12
Gain (dBi)	2.23	4.32
Directivity (dBi)	2.4	4.87
Efficiency (%)	96.7	96.2
Impedance bandwidth (GHz)	1.18	-

4. Experimental Results and Discussions

The S_{11} parameter of the presented antenna was measured using a handheld Vector Network Analyzer (LiteVNA) with a frequency range from 1 GHz to 6.3 GHz. Figure 7 (a) illustrates the proposed denim-fabric-based flexible antenna measurement using the VNA. This new research specifically examined and demonstrated the on-body effect of wearable UWB antenna design on return loss (S_{11}) characteristics for potential use in skin cancer detection studies. The antenna was placed on the body's right arm to illustrate the on-body return loss effect of the wearable antenna, and measurements were repeated, as shown in Figure 7 (b).

(a) **(b)**

Figure 7. Return loss (S_{11}) measurement using a vector network analyzer (a), measurement of on-body influence (b).

The present study delved into exploring the impact of wearable UWB antenna design on S_{11} characteristics when positioned on the human body. The antenna was affixed to the left arm to elucidate the on-body return loss effect of the wearable antenna, as depicted in Figure 7 (b). Figure 8 illustrates simulated and measured S_{11} characteristics in two distinct settings: free-space and on-body wearable conditions.

As evident from Figure 8, a marginal discrepancy was discernible in the S_{11} measurements between free-space and on-body conditions. These disparities in measurements were primarily attributable to the dynamic movements of the human body, encompassing bending and twisting, as well as the partial absorption of radiated energy by bodily tissues. Furthermore, there was a commendable convergence between the simulated and assessed reflection coefficients in free-space conditions, demonstrating an accuracy rate of 90.5%. In contrast, the accuracy rate of the presented fabricated antenna under on-body conditions was 72.4%.

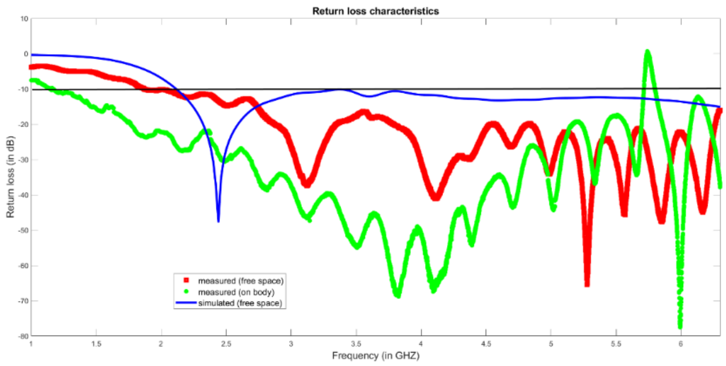


Figure 8. A comparison graph of return loss characteristics for measurements in a simulation environment (free space, measured (free space), and measured (on body).

5. Conclusion

This paper provides a comprehensive account of developing, simulating, and fabricating a flexible Ultra-Wideband (UWB) antenna integrated into denim fabric for wearable applications. The research encompasses a parametric study to optimize the antenna's geometric configuration and elucidate the impact of dimensional variations on its performance. The simulation results for the designed antenna exhibit a remarkable congruence with the empirical outcomes derived from the fabricated prototype. The fabricated antenna demonstrates a noteworthy level of fidelity to the simulation data, boasting an impressive 96.2% accuracy in the S_{11} value and a 96.7% accuracy in the gain value compared to the simulated results. The peak simulated gain and directivity reach values of 2.4 dBi and 4.87 dBi, respectively, accompanied by a substantial impedance bandwidth spanning 1.8 GHz, ranging from 2.12 to 10.04 GHz, representing an impressive -47.64 dB and -42.65 dB, respectively, as the minimum impedance matching of S11 over the bandwidth. The physical dimensions of the fabricated antenna exhibit a compact form factor, measuring 50 mm × 35 mm × 1.0 mm, and the peak gain measures 4.4 dB. Importantly, this UWB antenna design demonstrates superior performance characteristics compared to similar antennas referenced in the literature (Table 3), underscoring its suitability for wearable applications in wireless health monitoring within the context of Wireless Body Area Networks (WBANs). As a prospective avenue for further research, the antenna, as presented in this study, can be tested for various antenna parameters to accommodate different human body movements and positions. This exploration holds the potential to facilitate diverse applications in human body movement recognition and classification.

Table 3. Analyzing Antenna Performance: A comparative study between the presented antenna and similar WBAN textile antennas found in the literature.

[Ref.]	Antenna Dimensions	Substrates	Resonant Frequency (GHz)	S_{11} (dB)	Gain	Directivity (dBi)	Impedance bandwidth (GHz)
[19]	50 x 50 x 1.5 mm³	Rogers RO4003	4.0 6.0 9.0 11.0	Minimum impedance matching of /S11/ over the bandwidth: -25	4.3 dBi 10.8 dBi	Not reported	3.1 to 10.6 UWB
[18]	36 x 48x 6.12 mm³	nylon-based substrate	Not reported	Minimum impedance matching of /S11/ over the bandwidth: -22	7.04 dB	Not reported	8.2 to 13 UWB
[20]	30 x 30 x 0.75 mm³	a cloth with 100% cotton	Not reported	Minimum impedance matching of /S11/ over the bandwidth: -30	Not reported	Not reported	3.0 to 16 UWB
[21]	45 x 35	Denim	3.0 7.0 9.0	-12.0 -18.0 -35.0	2.74 4.17 4.074	Not reported	4.2 to 10.6 (86.48 %) UWB
[22]	86 x 90 x 1.06 mm³	Denim	2.1366 4.756 11.49	-22.23 -38.10 -20.79	Not reported	3.3 4.2 5.19	4 to 6, 11 to 12 (87.4 %, 89.6 %)
[23]	30 x 35 x 1.2 mm³	Denim	3.82 9.80	-26.41 -15.0	3.45 4.63	3.61 4.86	3.2 to 11.8 (114.6 %) UWB
This Study	35x50x1 mm³	Denim	2.44 7.66	-47.64 -42.65	2.23 (dBi) 2.4 (dBi)	4.32 4.87	2.12 to 10.04 UWB

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