Design and Analysis of Wearable Textile UWB Antenna for WBAN Communication Systems

Bhawna Tiwari, Sindhu Hak Gupta, and Vipin Balyan

Abstract In present scenario, with application-centric approach of all the modern communication devices, integration of electronic gadgets with wearable accessories is in high demand. This research paper presents design and simulation of wearable antenna using flexible textile substrate and analysis of various performance antenna parameters. The design and simulation of proposed jeans substrate-based textile antenna have been performed using CST 2018 Microwave Studio. Main emphasis of the current research work is to demonstrate a small-sized UWB antenna design having overall antenna size 20 mm × 22 mm × 1.07 mm. The resonant frequencies of the designed dual-band antenna are observed to be 4.45 and 8.75 GHz and have a wide fractional bandwidth of 103.5% in the ultra-wide band range. The presented microstrip patch textile antenna is compact, robust and flexible that makes it perfect choice to be utilized as body worn antenna for WBAN communication systems for wireless health monitoring systems.

Keywords WBAN · UWB · Textile antenna · Gain · VSWR · Efficiency

1 Introduction

Wireless body area networks (WBAN) is research trend nowadays that makes wireless health monitoring systems feasible. The design and implementation of wide variety of flexible textile fabric-based wearable antennas are preferred in recent research trend that are light weight, malleable and conveniently portable in

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comparison to rigid substrate-based traditional antennas for wireless communication systems. The antenna's impedance bandwidth and therefore antenna performance can be significantly improved by using textile fabric materials having low values of dielectric constant which helps in reduction of antenna losses associated with the antenna's proximity electromagnetic waves. On-body antenna radio frequency wave propagation and radiation is explained that finds application in different fields such as WBANs, medical sensor networks, personal and industrial communication, etc. The frequency range from 3.1 to 10.6 GHz has been authorized for implementing ultra-wide band (UWB) systems for commercial utilities. Wearable textile UWB antennas incorporating different designs patterns using fabric materials were implemented and discussed. Fabric material finds perfectly suitable to be used for flexible textile antenna for on body worn applications as these can be easily embedded into person's clothing [1, 2].

Motivation behind the current work is to incorporate microstrip patch antenna utilizing the advantage of dielectric properties of jeans fabric substrate for WBAN communication systems as body worn, flexible UWB antenna. The major aim of this presented work is based on development and simulation of a compact dual-band UWB textile-based antenna using jeans fabric which provides superior antenna performance and analysis of various antenna performance parameters when worn on human body.

The remaining paper is categorized as described. Related work in context to antenna designs as mentioned in references is discussed in Sect. 2. Proposed textile antenna design structure with dimensions and the CST simulation model is demonstrated in Sect. 3. Section 4 characterizes designed antenna simulation results and discussion. Section 5 concludes the current research work.

2 Related Work

A novel technique of monitoring, recognition and classification of different human activities that involves hand movements is described in [3]. Transmission and reflection coefficients parameter of on body antennas are observed and extract different characteristics, and machine learning approach is applied for various hand movement classifications with high classification accuracy. The application of on body antenna parameters S_{11} and S_{21} to classification of various human activities like sitting, boxing, etc. by using deep convolution neural network approach (DCNN) is also presented.

Martin Frank et al. in [4] demonstrate highly reliable in body UWB antenna communication and its effect on human tissues by utilizing different layer of human tissues embedded in biomedical human model. A small-sized UWB antenna design in terms of electrical dimensions and its electrical equivalent model is described in [5]. Analysis of jeans-based textile antenna is performed by considering both the antenna design theory and circuit theory analysis. Fabricated antenna results are compared with simulation result in context to antenna performance as well as specific absorption rate (SAR) characteristics. A low-profile low-weight UWB antenna optimized for WBAN purpose is fabricated on printed circuit board (PCB) and proposed in [6]. The tremendous improvement in antenna performance in terms of very high impedance bandwidth (21.5 GHz) shown in antenna simulation results. A compact circular patch antenna having dimensions in micrometers with terahertz band operation optimized for WBAN applications is designed and presented. A highly efficient and flexible wearable body worn antenna is designed using CST 2016 software. Specific absorption ratio (SAR) analysis is also performed for the proposed electro textile-based antenna [7–10]. In a review paper [11], mathematical modeling analysis of wide-band and ultra-wideband antennas is shown by considering WB patch, WB monopole, slotted antennas, tapered slotted and many other design geometries. Enabling technologies of WBAN applications are discussed in by Cao et al. [12] A novel technique to demonstrate the properties of textile materials with low values of electrical permittivity for flexible antennas has been explained. Mishra B. et al. in the research work [13] proposed a rectangular-shaped slotted circular patch antenna geometry designed for Wi-Fi/WLAN wireless utilities.

A novel design of the high-performance textile antenna with three resonant frequency bands and large fractional bandwidth has been designed and analyzed in [14] which is optimized for various wireless communication operations. Textile antennas can be used in wide variety of application which includes military, medical fields, etc. The proposed jeans- and copper-based antenna is preferred as wearable textile antenna as this fabric substrate material possesses many properties like its washability, wearability, flexibility, cost effectiveness, and very less maintenance requirements. The implemented natural rubber substrate-based compact and flexible UWB antenna is presented in [15] and preferred as suitable option as flexible antenna for WBAN applications. Its flexibility and less weight can incorporate any bending or twisting of human body without deforming antenna characteristics while wearing it on any part of the human body. Wang et al. in [16] demonstrate the various antenna geometries of multi-band UWB body worn antennas with jeans textile material as antenna substrate. Different design technical issues and associated challenges of wearable antennas for WBAN utility are also highlighted in their research work. The research work in [17] considers fabrication and simulation results of the novel design of compact textile antenna with different optimization techniques. The presented antenna for UWB wireless applications is operable on multiple channels that can incorporate all bending, twisting, curves, etc. conditions of human body for body communication.

3 Proposed Antenna Design

Wearable antennas can be classified into two categories. One is non-textile antennas that provide in-built antennas embedded in accessories like glasses, etc., and other is textile antennas that can be perfectly integrated into clothing. Current works focus on design and simulation of wearable textile antenna in which jeans fabric is taken as substrate material and copper is utilized as conducting part. Textile material exhibits relatively lower value of loss tangent and lower value of electric permittivity that leads to reduction of surface wave losses and bandwidth enlargement. Because of its flexibility and light weight, textile antennas are preferred as wearable antenna integrated into clothing without compromising wearability and user comfort. Table 1 represents applicable notations used in the paper and its description.

Table 2 describes the characteristics of the substrate material used in proposed antenna design. Radiating patch, substrate and partial ground with defective ground structure (DGS) with optimized dimensions are presented in Fig. 1, and antenna parameters values are depicted in Table 3.

The designed geometry of the proposed wearable textile antenna consists of a radiating patch with an asymmetric microstrip feed line and a partial ground plane with DGS structure as shown in Fig. 2. Defects or slots are inserted on the ground plane of antenna to improve various antenna parameters like enhancement of gain, impedance bandwidth, etc. The optimized dimensions are attained through optimization performed in CST Microwave Studio simulator. Three slots in radiating patch are introduced with dimensions $W_3 \times L_3$, $W_4 \times L_4$ and $W_5 \times L_5$, defective ground structure is utilized with slots dimensions $W_1 \times L_1$, $W_2 \times L_2$ in partial ground and adjustment of feed dimensions $W_f \times L_f$ leads to improved impedance matching thereby enhancing antenna performance.

Table 1 Table of notations

Notation	Description	Notation	Description
L_{sub}	Length of substrate	L_p	Length of patch
W_{sub}	Width of substrate	W_p	Width of patch
L_f	Length of feed line	h_s	Height of substrate material
W_f	Width of feed line	S_{11}	Return loss or reflection coefficient
L_g	Length of ground	Tanδ	Loss tangent of substrate material
W_g	Width of ground	εr	Relative permittivity of substrate material

Table 2 Substrate material properties

Textile substrate material	(εr)	(Tanδ)	(h_s)
Jeans	1.7	0.025	1

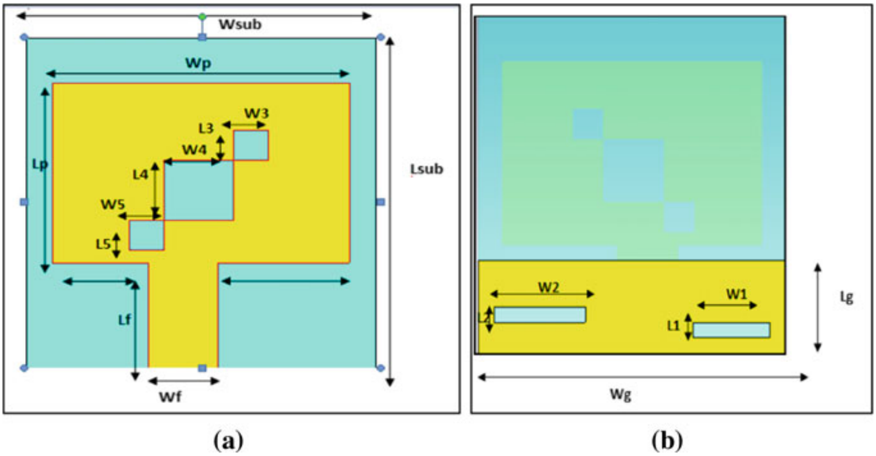

Fig. 1 Proposed antenna design geometry with dimensions. **a** Radiating patch and substrate. **b** Partial ground with DGS structure

Table 3 Dimensions of proposed antenna geometry

S. No.	Antenna parameter	Dimension (mm)	S. No.	Antenna parameter	Dimension (mm)
1	L_{sub}	22	8	W_p	17
2	W_{sub}	20	9	h_s	1
3	L_f	7	10	$L1 \times W1$	1×6
4	W_f	4	11	$L2 \times W2$	1×5
5	L_g	6	12	$L3 \times W3$	2×2
6	W_g	20	13	$L4 \times W4$	4×4
7	L_p	16	14	$L5 \times W5$	2×2

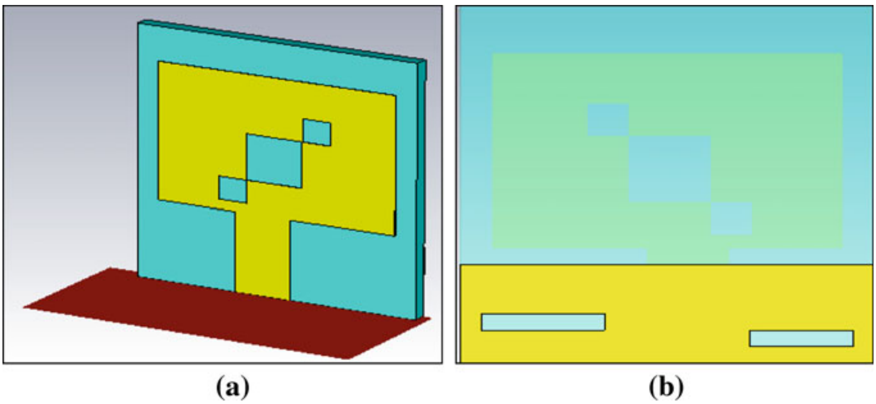

Fig. 2 CST model of proposed antenna. **a** Radiating patch design. **b** Partial DGS structure ground design

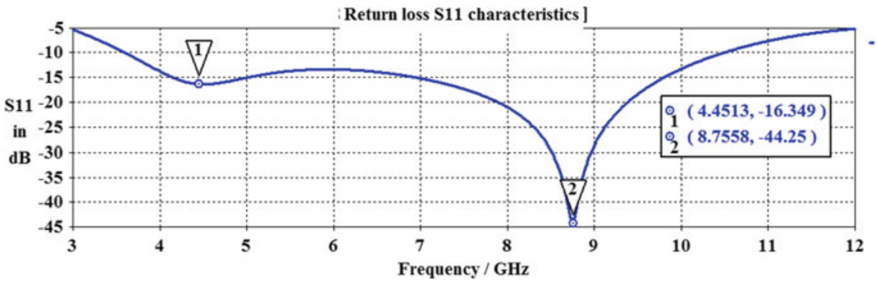

Fig. 3 Return loss characteristics (S_{11} vs. frequency plot)

4 Simulation Results and Discussion

4.1 Return Loss Characteristics

Return loss characteristics signify reflection coefficient or S_{11} value which indicates the quantity of power which gets reflected by the antenna. It has been observed from simulation result that values of S_{11} at resonant frequency 4.45 GHz and 8.75 GHz is −16.349 dB and −44.25 dB, respectively. Figure 3 demonstrates return loss characteristics for developed antenna having jeans as substrate material which confirms its suitability for UWB operation as S_{11} lies below −10 dB for the whole UWB frequency band as desired.

4.2 VSWR Characteristics

Voltage wave standing Ratio (VSWR) is an indication of how properly an antenna is matched with its attached feed line. It is ascertained from Fig. 4 that the observed values of VSWR lies in its desired value range that is 2 or lesser than 2. The simulation

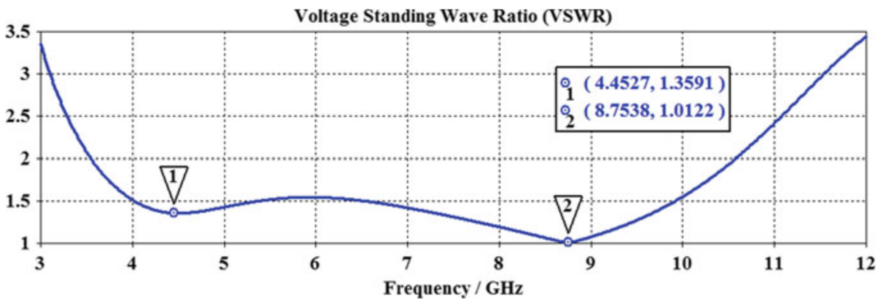

Fig. 4 VSWR characteristics (VSWR vs. frequency plot)

result shows VSWR values of 1.35 and 1.0122 at resonant frequency 4.45 GHz and 8.75 GHz, respectively.

4.3 Radiation Pattern Characteristics

Radiation patterns describing antenna radiation characteristics in terms of gain and directivity 3D plot for designed textile antenna at resonant frequencies are shown in Fig. 5. The simulation results show that the observed gain and directivity at resonant frequency 4.45 GHz are 1.89 dB and 3.4 dBi, respectively. At resonant frequency

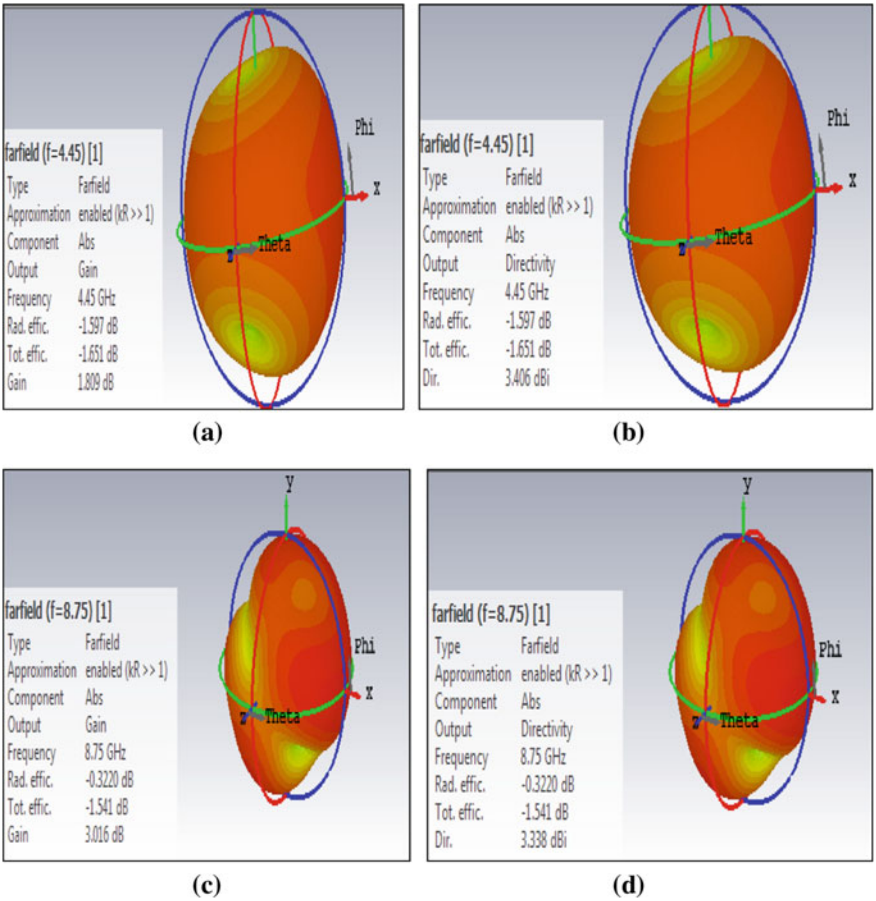

Fig. 5 Radiation pattern characteristics. **a** Gain plot at resonant frequency 4.45 GHz. **b** Directivity plot at 4.45 GHz. **c** Gain plot at resonant frequency 8.75 GHz. **d** Directivity plot at 8.75 GHz

Table 4 Antenna performance parameters of proposed antenna design

Resonant frequency (GHz)	Return loss S_{11} (dB)	Gain (dB)	VSWR	Directivity (dBi)	Efficiency (%)	Impedance bandwidth (GHz)	Fractional bandwidth (%)
$F1 = 4.45$ $F2 = 8.75$	−16.349 −44.25	1.89 3.0166	1.35 1.01	3.4 3.338	55.8 90.3	3.4–10.7 (7.2 GHz)	103.5

Table 5 Comparison of antenna geometry dimensions of proposed antenna design with comparable antennas mentioned in reference

Ref. No.	Substrate used	Overall antenna size (in mm)	Substrate dimension (in mm)	Ground dimension (in mm)	Patch dimension (in mm)
[14]	Jeans	86 × 90 × 1.06	86 × 90	86 × 30	Circular with radius 14 mm
[15]	Rubber and FR4	–	42 × 34	42 × 10	17 × 21.4
[16]	Jeans	45 × 35	45 × 35	38 × 28	20 × 10 × 1
[17]	Felt	39 × 42 × 3.34	39 × 42 ×	39 × 42	32 × 39
Proposed	Jeans	20 × 22 × 1.07	20 × 22 × 1	20 × 6 × 0.035	17 × 16 × 0.035

8.75 GHz gain and directivity is observed to be 3.016 dB and 3.338 dBi, respectively. Maximum antenna radiation efficiency of 90.3% is observed at 8.75 GHz.

Antenna parameters observed from antenna simulation are summarized in Table 4. The operating frequency range spans from 3.4 to 10.7 GHz, therefore, providing 7.2 GHz impedance bandwidth and 103.5% fractional bandwidth in UWB range.

The comparative study of the antenna dimensions and antenna performance parameters of presented antenna with existing comparable antenna designs is presented in Tables 5 and 6, respectively. Results demonstrate improvement of proposed antenna in context to compactness, impedance bandwidth and return loss characteristics and thus superiority in comparison to other antenna designs presented in literature.

Table 6 Comparison of antenna performance characteristics of proposed antenna design with comparable antennas mentioned in reference

Ref. No.	Resonant frequency (GHz)	S_{11} (dB) at resonant frequency	Gain (dB)	Directivity (dBi)	Impedance bandwidth
[14]	2.1366, 4.756, 11.49	22.23, −38.10, −20.79	–	3.3, 4.23, 5.19	4–6 GHz 11–12 GHz
[15]	5.5, 7.5	−18, −24	–	–	–
[16]	3, 7, 9	−12, −18, −35	2.7, 4.17, 4.074	–	6.4 GHz (86.48%)
[17]	3.5, 8.3	−17, −15	–	–	3.6–4.3 GHz 6.3–10.1 GHz
Proposed	4.45, 8.75	−16.349, −44.25	1.89, 3.0166	3.4, 3.338	3.4–10.7 GHz (103.5%)

5 Conclusion

The major objective of this work is to design and simulate a novel small-sized wearable antenna based on jeans textile substrate in UWB frequency range. The slotted radiating patch and partial ground with DGS structure is designed using adhesive copper, and jeans fabric is utilized as substrate material for antenna design. The dual-band textile UWB antenna using jeans fabric has been designed and simulated that is compact and possess large impedance bandwidth and high efficiency. The research paper also presented the comparative analysis of the antenna performance characteristics like reflection coefficient, VSWR, directivity, impedance fractional bandwidth, gain and radiation efficiency. The simulation results of presented jeans textile substrate-based antenna show return loss S_{11} values of −16.349 dB and −44.25 dB at resonating frequency 4.45 GHz and 8.75 GHz, respectively. The highest gain of 3.016 dB and peak efficiency of 90.3% is observed at the resonant frequencies 8.875 GHz, respectively. The proposed compact antenna has overall dimensions of 20 mm × 22 mm × 1.07 mm. The return loss characteristic shows that the designed antenna operating frequency lies from 3.4 to 10.7 GHz, therefore providing 103.5% fractional bandwidth in UWB range. Integration of flexibility, light weight, compact size, mechanically robust, efficient with the desired antenna performance characteristics are the key features that confirm its suitability for on body wearable application for wireless body area network communication systems.

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