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Design and comparative analysis of compact flexible UWB antenna using different substrate materials for WBAN applications

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Abstract
In the present scenario, smart devices are using flexible wearable wireless technologies to enable interaction among people and their surrounding equipments. Due to the commercialization of these flexible electronic devices and systems, these systems require the integration of flexible antennas. The compactness and flexibility of the antenna are the major objectives of the current research. This paper highlights the comparative study of a small-sized swastika-shaped slotted patch ultra-wideband (UWB) antenna. The designed microstrip patch antenna is simulated using Rogers RT 5880 as a substrate mounted on the partial ground structure. A rectangular substrate with a size of 24.56 × 22.48 mm × 1.575 mm is placed between the partial ground and patch. The dimensions of the radiating patch are 13 mm × 10.5 mm × 0.035 mm. The resonant frequencies of the designed antenna are 4.43 GHz and 8.84 GHz and have a large fractional bandwidth of 110% in the range of 3.1 to 10.7 GHz. The maximum observed gain and directivity of the proposed antenna are 5.9 dB and 6.8 dBi at 4.43 GHz. The simulation of the presented antenna design is performed in CST Microwave Studio 2018. The proposed antenna performance metrics are comparatively analyzed using different substrate materials like Rogers RT 5880, Jeans, and rubber substrates. The developed dual-band antenna can be useful for WBAN communication applications in the UWB band.

Keywords Compact · Antenna · Efficiency · Gain · UWB · VSWR · WBAN

1 Introduction

Flexible and compact antennas are required for wide variety of modern applications like medical wireless monitoring, WLAN, for wearable head imaging systems, UWB communication, etc. Recent research has the main emphasis on the design and simulation of compact and flexible UWB antenna to be utilized for wireless body area networks area (WBAN) applications. Antennas are an essential part of a wireless communication system that efficiently radiate or receive electromagnetic radiation in the desired direction. Monopole planar antenna is generally preferred for UWB antenna design due to its simple structure, wide bandwidth and cost-effectiveness [1].

Peter et al. [2] described on-body electromagnetic wave propagation and antenna radiation. It is gaining interest in different applications including WBANs (wireless body area networks), personal communication and many more. The frequency spectrum ranging from 3.1 to 10.6 GHz was approved for ultra-wideband (UWB) systems by the Federal Communications Commission(FCC) for commercial usage.

Wearable textile UWB antennas with different designs structure using clothing materials were fabricated and discussed in [3] which enable it for wearable usage. Fabric substrate materials are used for flexible antennas, because textile antennas can be easily attached to clothing. Various antennas having flexible metal-based patches on fabric textile substrates have been designed and implemented as wearable antennas. Impedance bandwidth of antenna can be significantly improved with the use of textile material that has less dielectric constant which minimizes losses associated with

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the antenna’s surface wave [4–6]. A new design of reduced size highly directional antenna with an added reflector is presented and through simulations various antenna structural parameters were determined to achieve the directionality required for various wireless applications [7].

The design and development of cotton and polyester fabric on-body antennas for 2.45 GHz WLAN applications are described by Sankaralingam et al. [8]. Performance characteristics of wearable antennas under bent conditions are also observed. Flexible antennas can be implemented using wearable substrates such as jeans, cotton, and leather and can be implanted on dress materials. A dual-band micro strip patch antenna using jeans substrate is designed and simulated in [9] which operates at 0.9 GHz and 2.4 GHz. A new method to elaborate on the properties of fabric materials has been demonstrated in [10]. For flexible antennas, textile materials are preferred as a substrate with low dielectric constants.

Mishra B. et al. in the research work [11], proposed a circular patch structure of antenna design having four rectangular-shaped slots designed for Wi-Fi/WLAN utility. The characteristics of dual-band antenna have been evaluated in terms of antenna specifications like VSWR, return loss, radiation patterns representing gain. The highest gain of 3.93 dB and 3.09 dB are achieved at a resonating frequency of 3.71 GHz and 5.51 GHz, respectively. Many researchers are gaining interest in wearable antennas due to high demand usage of wireless body area networks that enables interaction among devices by wearing them on our body. The performance of different textile materials has been evaluated. Antenna using textile materials has enhanced efficiency and flexibility which makes them suitable for on-body applications [12].

Textile antennas are developed for wearable products with the capability of continuously monitoring and tracking in case of healthcare wireless systems, therefore, reducing manpower and other required facilities. The proposed textile-based UWB antenna is implemented particularly for the healthcare sector that helps patients with adaptive, on demand and comfortable health tracking procedures [13]. An annular-slotted antenna applicable for the WLAN and healthcare field is shown in [14], which gives moderate bandwidth and gain. Therefore, to improve antenna characteristics, antenna arrays are used. Conductive textiles and copper-coated polyester are utilized for implementing antenna-radiating patches. A low-profile low-weight UWB antenna suitable for wireless body area networks is presented in [15] which can be implemented on a printed circuit board. An enhanced impedance bandwidth from 2.50 to 24 GHz is shown in simulated and observed results.

A wearable UWB antenna for WBAN purpose is presented that demonstrates very low values of low-specific absorption rate (SAR), flexibility, and meta-materials embedded characteristics. The designed antenna is based on jeans as substrate and meta-material UWB reflector design is based on the felt textile substrate to improve antenna performance by minimizing the antenna’s SAR. Research results verify superior characteristics and suitability of designed antenna as safe and appropriate for wearable wireless systems [16]. In [17], a rectangular microstrip patch antenna design is presented that operates at 2.0–2.8 GHz frequency range. This FR4 substrate-based antenna is a probe feed and with a reduced ground and exhibits a good impedance matching. The proposed antenna can be conveniently fabricated on the substrate due to its small size and thickness. In a review paper [18], materials and numerical analysis of wideband and ultra-wideband antennas are shown.

The considered antennas geometries include WB (wideband) patch antenna, WB monopole antenna, slotted antenna, mutilated patch UWB antenna, tapered slotted geometry, meta-material-based UWB antennas, elliptical printed monopole UWB antenna, and adjustable, on-body UWB antenna used for wireless communication. The antenna’s realization is compared with respect to size and their applications for portable communication device applications. A very small-sized circular patch antenna with terahertz band operation is designed in [19]. The fabricated antenna has a substrate of dimensions $100\ \mu m \times 100\ \mu m \times 10\ \mu m$ with $40\ \mu m$ as patch radius. Small size in the range of micrometers and working frequency in the range of terahertz makes it applicable for WBAN. SNR and BER are explored at the defined frequency for transmission channel link by determining path loss and absorption coefficient, etc.

For implementing wireless body area networks (WBAN) systems, various frequency spectrums are allotted and approved that are listed as (a) MICS (Medical Implant Communication System) with 402 MHz to 405 MHz frequency span, (b) ISM (Industrial Scientific Medical) with 2.45 GHz (ranging from 2.4 to 2.485 GHz) and 5.80 GHz (ranging from 5.725 to 5.825 GHz) frequency bands, (c) UWB (ultra-wideband) utilizing frequency from 3.1 to 10.6 GHz and (d) Terahertz frequency band which is emerging nowadays and can be explored for the next generation WBAN applications.

Modified design of the textile antenna having three resonant bands and wide impedance bandwidth has been presented and analyzed in [20] which is best suited for different wireless communication operations. The monitoring and alerting for military and medical field, satellite communication, etc. are some of the applications where textile antennas can be used. The proposed design used jeans clothing material as substrate and copper is utilized for designing patch and ground. Jeans is utilized as a substrate as it is wearable, launderable, flexible, very cost-effective, and requires little maintenance.

The implemented malleable UWB antenna in [21] based on natural rubber substrate has a lot of benefits and utilities. Rubber as raw material for the substrate is available in bulk to minimize the overall production cost of antenna. As substrate having a very high value of permittivity is used, the size of the antenna gets reduced; therefore, find suitable for WBAN applications. Due to its flexibility and light weight, the designed antenna can be wearable on any part of the body and capable to bear the body associated bending and twisting. In comparison to FR4, natural rubber gives more immunity to wear and tear in high-temperature conditions. The antenna works in complete UWB frequency which is optimized for WBAN functions.

Wang et al. [22] review the different designs of dual-band UWB wearable antennas based on textile materials. Various design considerations and challenges of wearable antennas for WBAN applications are also discussed in their research work in which flexible textile jeans as substrate material and adhesive copper as metallic radiators are used for the fabrication of wearable antenna. A body worn microstrip patch antenna operable at 5.80 GHz with great efficiency and flexibility is designed with the help of CST 2016 antenna simulation software and demonstrated in [23]. Existing metals associated with e-textile material is used as conducting materials used, while jeans textile has been used as substrate material. Two different methods are used to determine the values of the relative permittivity ($\mathcal{E}_r$) and loss tangent (tan δ) of the jeans material. The specific absorption ratio (SAR) is also measured for the proposed wearable antenna. Microstrip patch flexible antennas are usually preferred due to their lightweight and ease in fabrication. To enhance the flexibility of the antenna, circular patch and hexagonal patch shapes were designed. The implemented structure is compared for various substrate materials.

Different antenna specifications like return loss, VSWR, gain, etc. are compared and discussed. The comparison results show that patch antenna having polyamide substrate gives better results with respect to return loss, VSWR, gain, and directivity for both circular and hexagon shaped patch than all other substrate materials used for proposed antenna design [24].

The research paper [25] demonstrates the textile antenna design for UWB operation specified by the wireless standard. The designed antenna incorporates a novel and minimized radiator on the top side of the antenna geometry with an entire ground plane on its backside. The patch based on multiple miniaturizations and broad banding techniques yield a compact size antenna.

The implemented antenna design is the most effective low size textile antenna based on UWB in comparison to other antennas discussed in the literature. Cost-efficient, ease of fabrication, and accessibility are some criteria to choose commercial textile material for substrate. The proposed antenna not only operates in channels of low and high bands of WBAN-UWB, but also operates in five other optional channels during on-body operations especially under bending and curves. In the manuscript [26], a compact UWB antenna having a bandwidth of 1.5 GHz is presented and its results after simulations are discussed for human in body WBAN communication applications. The designed low-profile antenna is based on an antenna inserted inside the human body used for biomedical transmission. The bio model available in CST software presenting different human body tissues and its layers is utilized for presented work. Its geometry includes a circular patch of diameter 25 mm. The impact of various tissues on antenna characteristics has been studied.

In the presented work, UWB is preferably chosen as a suitable candidate for antenna design to be used for wireless body area networks operations as it has several benefits like enhanced channel capacity, immune to jamming, remarkable penetration characteristics, capable to perform in low SNR, excellent performance in multipath transmission and many more.

In the presented research work, major objectives are listed as follows:

1. To design and simulate a compact UWB antenna using Rogers RT 5880 substrate.
2. To perform a comparative analysis of simulation results as antenna performance metrics such as reflection coefficient, VSWR, gain, directivity, efficiency impedance bandwidth as well as overall antenna size using different substrates like Rogers RT 5880, Jeans and Rubber and to find a most suitable substrate for the presented design.
3. To compare the illustrated slotted UWB antenna design with related antennas presented in references to confirm its superiority and suitability of the application for WBAN application.

The remaining paper is structured as described. The proposed antenna design geometry is explained in Sect. 2. Sections 3, 4, 5, 6 demonstrates Simulation results and discussion. Section 7 summarizes the current research work.

2 The proposed antenna design geometry

2.1 Antenna geometry

An antenna is an important subunit of any hand held or wireless mobile device. The efficiency of these devices depends on the performance characteristics of the antenna. Microstrip patch antennas are generally preferred for on-body applications, because these have a lot of benefits such as low size, weight and volume, low profile, a planar composition that is conformal to the host surface, cost-effectiveness, and ease of fabrication. General structure of the micro strip patch antenna is shown in Fig. 1. Table 1 provides a comparative

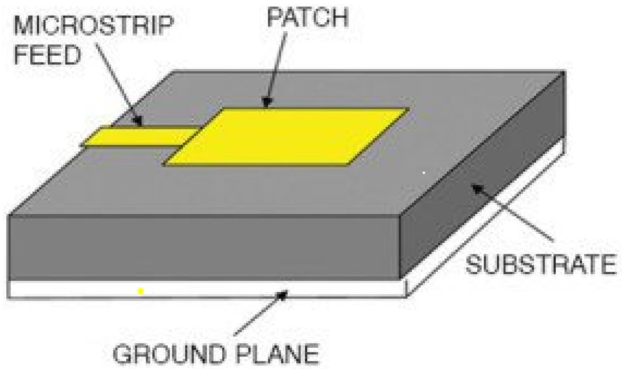


Fig. 1 General structure of microstrip antenna

study of proposed antenna structures with comparable antennas geometry available in the literature.

The proposed microstrip patch antenna consists of parallel copper conductors that are isolated by a dielectric substrate of Rogers RT 5880 at initial design and jeans and rubber materials in the later designs. Lower conductor and upper conductor is a partial ground plane and radiating plane, respectively.

To improve impedance matching, particularly at higher frequencies, the slots are incorporated on the patch structure. The proposed antenna consists of one rectangular and one swastika-shaped slot in a radiating patch. These irregularly shaped slots grooved from the radiating patch may vary the current distribution, which changes the current path length and impedance at the input point changes. The addition of different multiple slots in patch leads to the creation of resonance and ultimately leads to larger bandwidth. Dimensions of the radiating patch are optimized to reduce the size of the antenna's geometry, and rectangular and swastika-shaped slots in the patch along with reduced partial ground are introduced to enhance the bandwidth. Table 2 describes the structural dimensions of the designed antenna.

Table 2 Dimensions of the presented antenna

Antenna dimensions	Optimized values
Overall dimension of the antenna	22.48 mm × 24.56 mm × 1.645 mm
Substrate dimensions	22.48 m × 24.56 mm × 1.575 mm
Patch dimensions	13.8 mm × 10.5 mm
Ground dimensions	22.48 mm × 6.28 mm
Feed dimensions	7.28 mm × 3 mm

The presented slotted antenna simulation design using Rogers RT 5880 substrate including antenna design geometry, partial ground, and patch design is presented in Fig. 2a–c, respectively.

2.2 Substrate

While designing a microstrip patch antenna, a pertinent selection of suitable substrate material is very crucial. The permittivity of the substrate is a parameter that affects bandwidth, efficiency, and radiation patterns of the microstrip patch antenna and by choosing them appropriately these performance parameters can be significantly improved. In this paper, a comparative investigation of the effect of different substrate materials on antenna performance parameters is demonstrated. The designed swastika-shaped slotted patch antenna is primarily implemented using Rogers RT 5880 substrate and further jeans and rubber substrates are used for comparative analysis. Table 3 describes the material characteristics of different substrate materials used.

Table 1 Comparison of the proposed antenna with comparable antennas geometry available in the literature

[Reference Paper No.] Year of publication	Substrate material used	Operating frequency band	Ground plane	Antenna geometry
[20] 2015	Jeans	UWB	Partial ground	Slit loaded patch
[21] 2016	Natural Rubber and FR4	UWB	Partial ground	Rhomboid geometry
[22] 2016	Jeans	UWB	Partial ground	Slots and truncation techniques
[23] 2018	Jeans	5.5–6 GHz	Full ground plane	Electro textile patch design
[24] 2018	Rubber	UWB	Full ground plane	Circular and hexagon patch
[25] 2019	Felt	WBAN-UWB	Full ground plane	Multi-resonance overlapping and parasitic coupling with compact radiator
Present work	Rogers RT 5880	UWB	Partial ground plane	Partial ground plane, swastika-shaped and rectangular-shaped slotted patch

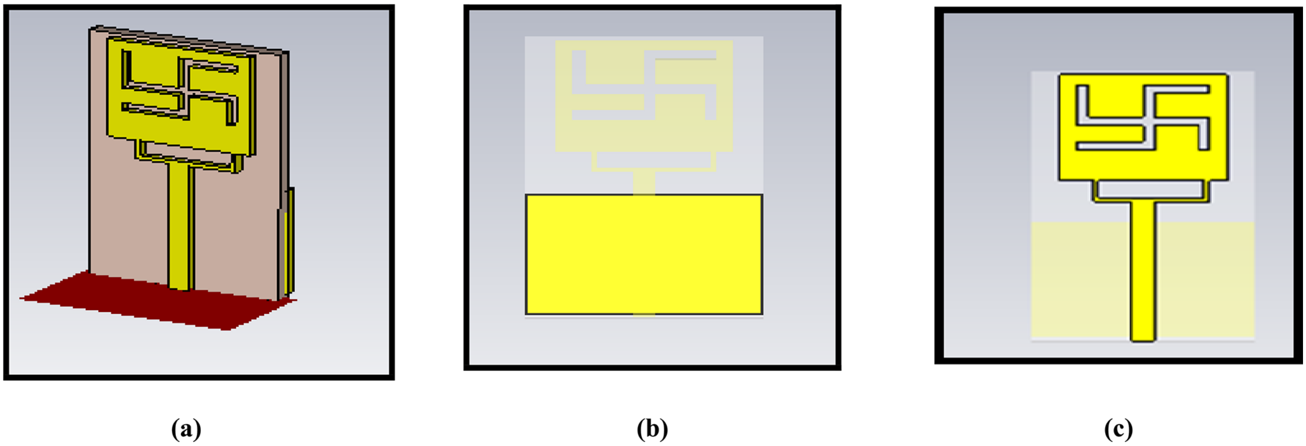


Fig. 2 CST simulation model of the designed antenna. **(a)** Proposed antenna design **(b)** partial ground design **(c)** radiating patch design

Table 3 Comparison of different substrate materials characteristics

Substrate material used	Relative permittivity ($\mathcal{E}_r$)	Loss tangent (tan δ)	Height (h) of substrate (in mm)
Rogers RT5880	2.2	0.0009	1.575
Jeans	1.7	0.025	1
Rubber	3	0.015	1.6

3 Simulation results and discussion

The simulation of the proposed antenna was performed using CST microwave simulation software 2018 version and antenna characteristics are studied and comparatively analyzed for RT 5880, jeans textile, and rubber substrates.

3.1 Return loss characteristics

Return loss or reflection coefficient or S_{11} specifies the quantity of power which gets reflected by the antenna and is numerically determined by

$$S_{11} = 10 \times \log\left(\frac{p_r}{p_i}\right), \tag{1}$$

where p_r is reflected power from the antenna and p_i is incident power on to the antenna.

Antenna's fractional bandwidth (FBW) is a mean to describe how wideband the antenna is and it is calculated by dividing impedance bandwidth by center frequency. For calculation of antenna's bandwidth, the return loss plot showing a variation of S_{11} with respect to frequency is taken into account. It is considered as the frequency span over which S_{11} value is below − 10 dB. From the return loss plot, − 10 dB line is identified. This line intersect S_{11} curve in two points which are known as f_{lower} and f_{higher}. The frequency range between this minimum frequency (f_{lower}) and maximum frequency (f_{higher}) is known as impedance bandwidth.

If the antenna operates at center frequency f_{center} between minimum frequency f_{lower} and maximum frequency f_{higher}, then mathematically it is expressed by

$$\text{fractional bandwidth} = \frac{\left(f_{\text{higher}} - f_{\text{lower}}\right)}{f_{\text{center}}}, \tag{2}$$

$$\text{where } f_{\text{center}} = \frac{\left(f_{\text{higher}} + f_{\text{lower}}\right)}{2}. \tag{3}$$

The antenna with a fractional bandwidth larger than 50%, is known as UWB antenna i.e. any antenna must possess bandwidth at least 50% to be termed as ultra-wideband.

3.2 VSWR characteristics

Voltage standing wave ratio (VSWR) specifies how properly an antenna is matched with its connecting feed. The desired value of VSWR is 2.0 or lesser than 2.0. VSWR value 2 signifies that the antenna is closely 90% matched to its connected feed line and only 10 percent power is there which gets reflected from an antenna. The value of voltage standing wave ratio (VSWR) lies between 1 and ∞.The minimum value of VSWR is 1.0 for which no power is reflected from the antenna, which happens in an ideal situation (in a perfect system). In real practical situations, imperfections in transmission with mismatched impedance causes power to be reflected back to the source. The

VSWR lesser than 2 is considered suitable and acceptable in most antenna applications for the communication system in practical conditions. In general, if VSWR is under 2, the antenna match is considered fairly good.

3.3 Radiation pattern characteristics

Radiation pattern diagrammatically represents the antenna's radiation characteristics as a function of space. Radiation pattern 3D plots indicate a variation of gain and directivity with respect to frequency over a complete specified frequency range. Efficiency is an important parameter to describe how efficiently an antenna transmits and receives RF signals which can be expressed as

$$\text{efficiency in\%} = \left(\frac{\text{gain}}{\text{directivity}}\right) \times 100. \tag{4}$$

4 Simulation results using rogers RT 5880

4.1 Return loss characteristics

The desired value of S_{11} should be below − 10 dB for the whole UWB frequency band. It has been observed that simulated values of S_{11} at operating frequency 4.4 GHz and 8.8 GHz are − 32.742 dB and − 16.116 dB, respectively. The designed antenna provides − 10 dB bandwidth (impedance bandwidth) value 7.6 GHz over a span covering 3.1 GHz to 10.7 GHz which utilizes the whole frequency spectrum of the UWB band and delivers 110% as fractional bandwidth. Figure 3 demonstrates return loss characteristics for an antenna having Rogers RT 5880 as substrate material.

4.2 VSWR characteristics

It is ascertained from Fig. 4, that specific values of VSWR at resonant frequency 4.43 GHz and 8.84 GHz are 1.053 and 1.371 respectively.This value is in the desired range (i.e. < 2).

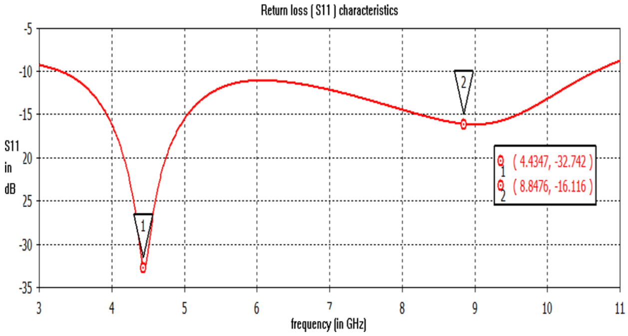


Fig. 3 Return loss (S_{11}) characteristics

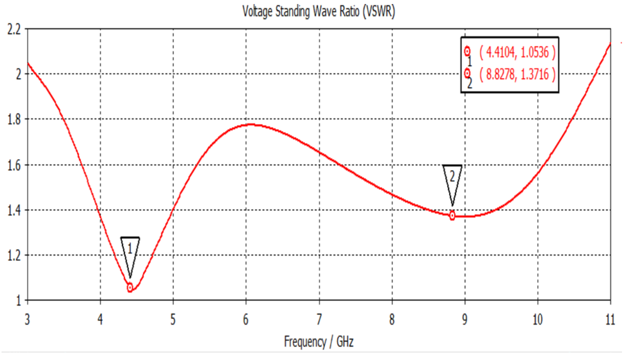


Fig. 4 VSWR characteristics

4.3 Radiation pattern characteristics

Figure 5 displays the gain and directivity magnitude plot for an antenna having RT 5880 as a substrate at resonant frequencies. At 4.43 GHz, gain and directivity are observed to be 5.9 dB and 6.80dBi, respectively. Gain and directivity at resonant frequency 8.843 GHz are observed to be 4.006 dB and 4.257 dBi respectively. Maximum efficiency of 95.3% is observed at 8.84 GHz.

5 Simulation results using jeans substrate

5.1 Return loss characteristics

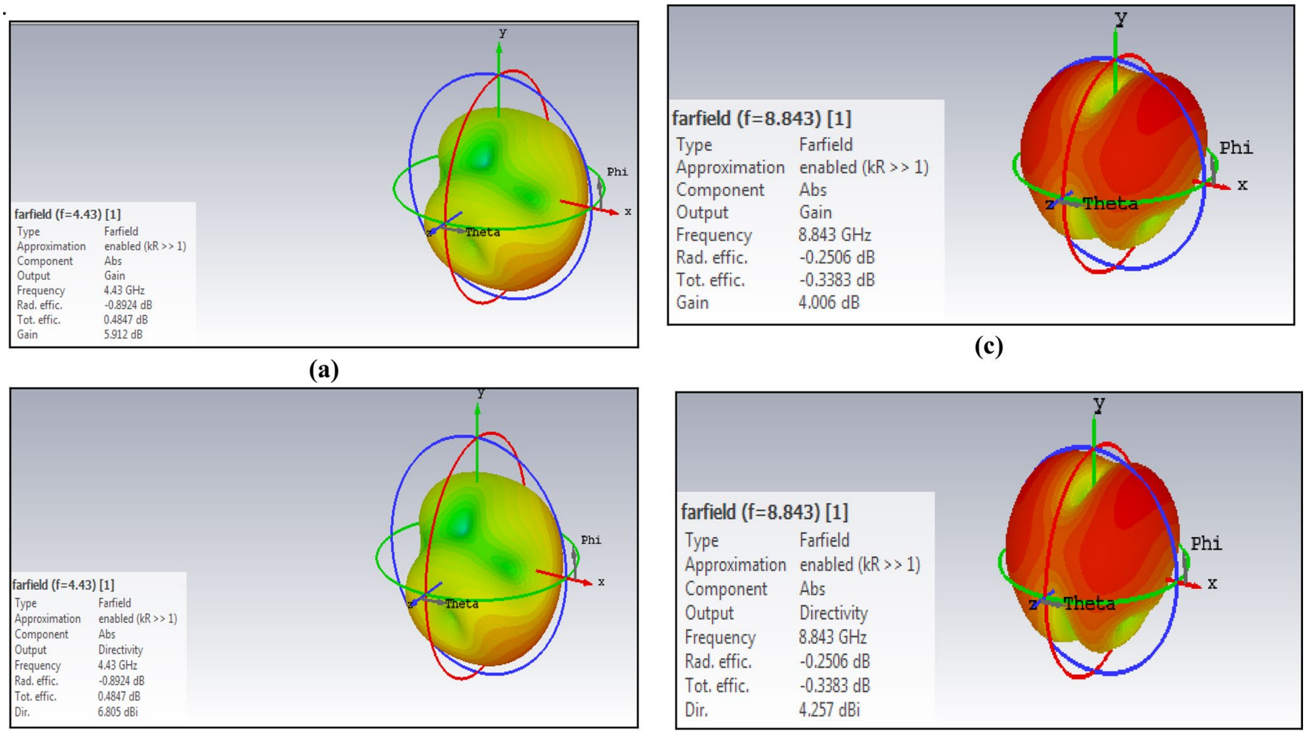
Simulated values of S_{11} at resonating frequency 4.28 GHz and 8.58 GHz are observed to be − 21.09 dB and − 34.84 dB, respectively. The antenna geometry using jeans substrate possesses an absolute bandwidth of 7.0 GHz which lies between 3.5 and 10.5 GHz and provides 100% fractional bandwidth as shown in Fig. 6.

5.2 VSWR characteristics

It is depicted from Fig. 7, the simulated VSWR at resonant frequency 4.28 GHz and 8.58 GHz are 1.19 and 1.03, respectively, showing VSWR value is in the desired range (i.e. < 2).

5.3 Radiation pattern characteristics

Figure 8 displays the gain and directivity plot for an antenna having jeans substrate at resonant frequencies. Gain and directivity at resonant frequency 4.28 GHz are observed to be 2.45 dB and 3.72 dBi, respectively. At 8.58 GHz, gain and directivity are observed to be 4.11 dB and 5.50 dBi, respectively. Maximum efficiency of 75% is observed at 8.58 GHz.



farfield (f=4.43) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	4.43 GHz
Rad. effic.	-0.8924 dB
Tot. effic.	0.4847 dB
Gain	5.912 dB

(a)

farfield (f=4.43) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	4.43 GHz
Rad. effic.	-0.8924 dB
Tot. effic.	0.4847 dB
Dir.	6.805 dBi

(b)

farfield (f=8.843) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	8.843 GHz
Rad. effic.	-0.2506 dB
Tot. effic.	-0.3383 dB
Gain	4.006 dB

(c)

farfield (f=8.843) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	8.843 GHz
Rad. effic.	-0.2506 dB
Tot. effic.	-0.3383 dB
Dir.	4.257 dBi

(d)

Fig. 5 Radiation pattern characteristics. **a**, **b** Gain and directivity plot at 4.43 GHz. **c**, **d** Gain and directivity plot at 8.843 GHz

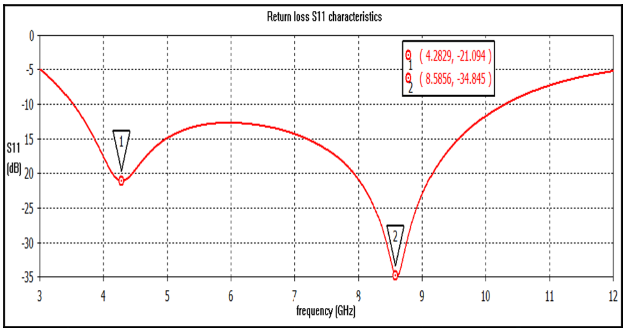


Fig. 6 Return loss (S_{11}) characteristics

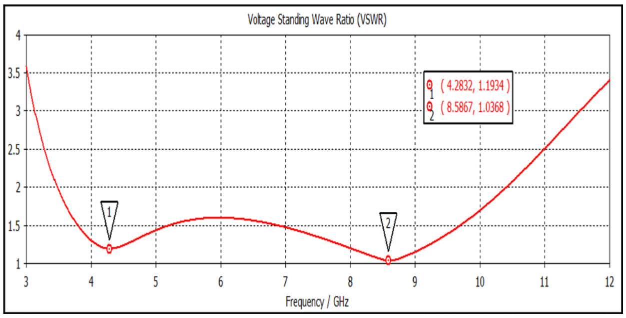


Fig. 7 VSWR characteristics

6 Simulation results using rubber substrate

6.1 Return loss characteristics

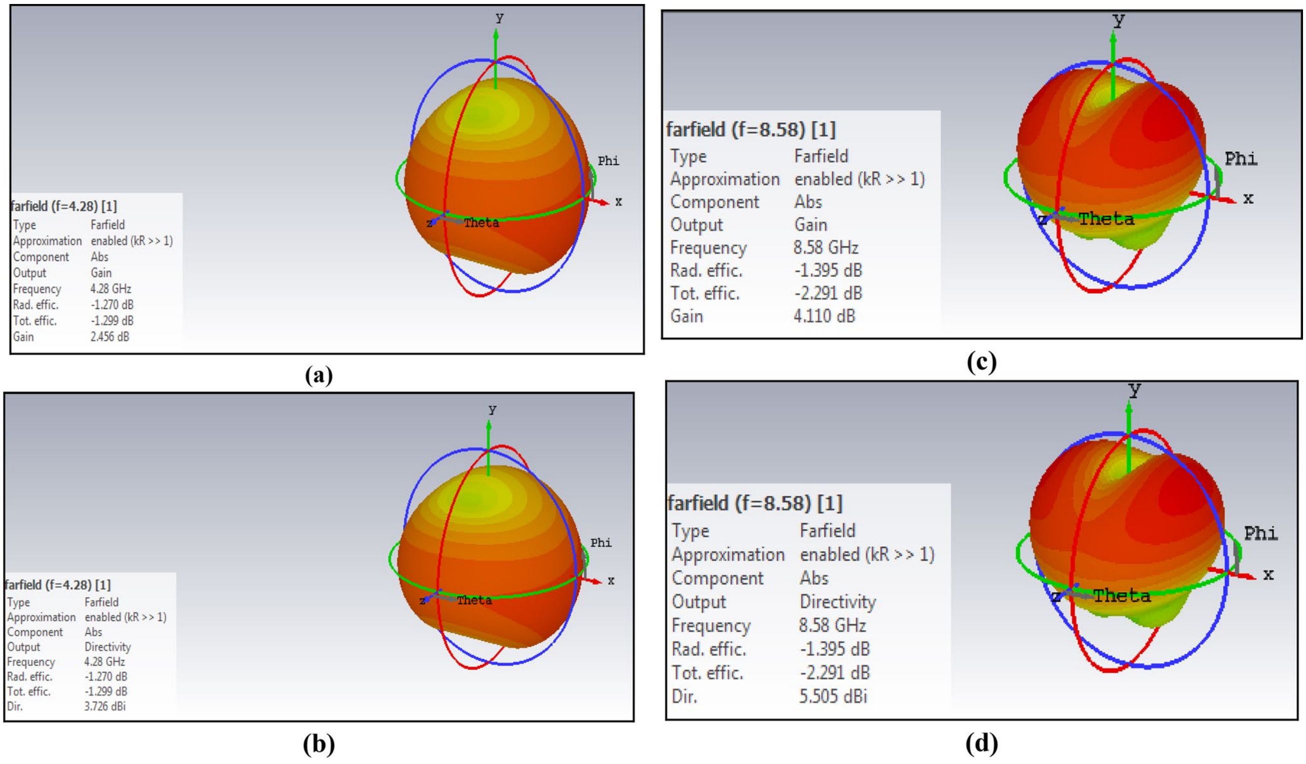
Simulated values of return loss at resonant frequency 5.50 GHz and 7.87 GHz are observed to be − 43.6 dB and − 32.0 dB, respectively. The proposed antenna using rubber substrate possesses absolute bandwidth of 5.05 GHz that spans from 4.20 to 9.25 GHz and provides 75% fractional bandwidth as shown in Fig. 9.

6.2 VSWR characteristics

Simulation results of Fig. 10 show that the observed values of VSWR obtained from the simulation at resonant frequency 5.50 GHz and 7.87 GHz are in the desired range i.e. less than 2 and have magnitude 1.01 and 1.05, respectively.

6.3 Radiation pattern characteristics

Radiation patterns illustrating the gain and directivity plot for an antenna having Rubber substrate at resonant frequencies is shown in Fig. 11. Gain and directivity at resonant frequency 5.50 GHz are observed to be 2.08 dB and 2.8 dBi, respectively.



farfield (f=4.28) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	4.28 GHz
Rad. effic.	-1.270 dB
Tot. effic.	-1.299 dB
Gain	2.456 dB

(a)

farfield (f=4.28) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	4.28 GHz
Rad. effic.	-1.270 dB
Tot. effic.	-1.299 dB
Dir.	3.726 dBi

(b)

farfield (f=8.58) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	8.58 GHz
Rad. effic.	-1.395 dB
Tot. effic.	-2.291 dB
Gain	4.110 dB

(c)

farfield (f=8.58) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	8.58 GHz
Rad. effic.	-1.395 dB
Tot. effic.	-2.291 dB
Dir.	5.505 dBi

(d)

Fig. 8 Radiation pattern characteristics. **a**, **b** Gain and directivity plot at 4.28 GHz. **c**, **d** Gain and directivity plot at 8.58 GHz

At 7.87 GHz gain and directivity are observed to be 3.983 dB and 4.426 dBi, respectively. Maximum efficiency of 89.9% is observed at 7.87 GHz. Table 4 summarizes the comparative analysis of various performance parameters for the presented swastika-shaped slotted patch antenna using different substrates. From the above discussion, minimum return loss (– 43.6 dB) and minimum VSWR (1.01) were found in the case of rubber substrate. At the same time, maximum impedance bandwidth (7.6 GHz),maximum gain (5.9 dB) maximum directivity (6.80 dBi) and maximum efficiency (95.3%) was observed using Rogers RT 5880 substrate material, therefore giving better result in context to fractional bandwidth, 3D radiation patterns describing gain and directivity and efficiency in comparison to jeans textile and rubber substrate for the current antenna design.

From the comparative analysis, it has been found that the designed antenna with all three substrate materials i.e. Rogers RT5880, jeans and rubber satisfies the requirements for UWB application and comparatively Rogers RT 5880 seems to be most appropriate for UWB application for the current antenna design.

The comparison study of the performance parameter of the presented antenna with existing comparable antenna design available in the literature is presented in Table 5.

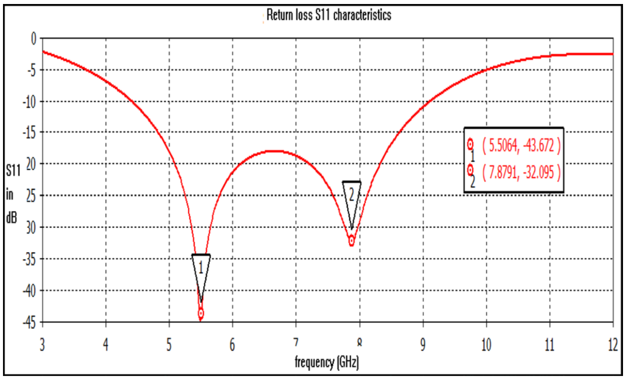


Fig. 9 Return loss (S_{11}) characteristics

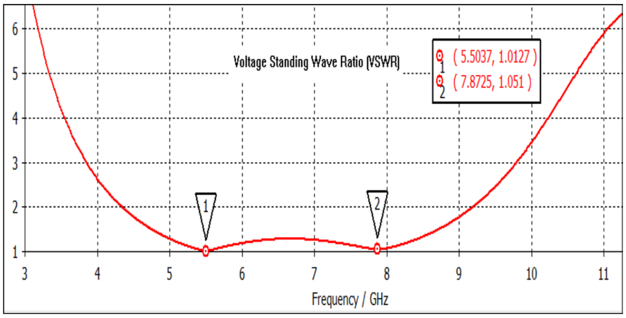
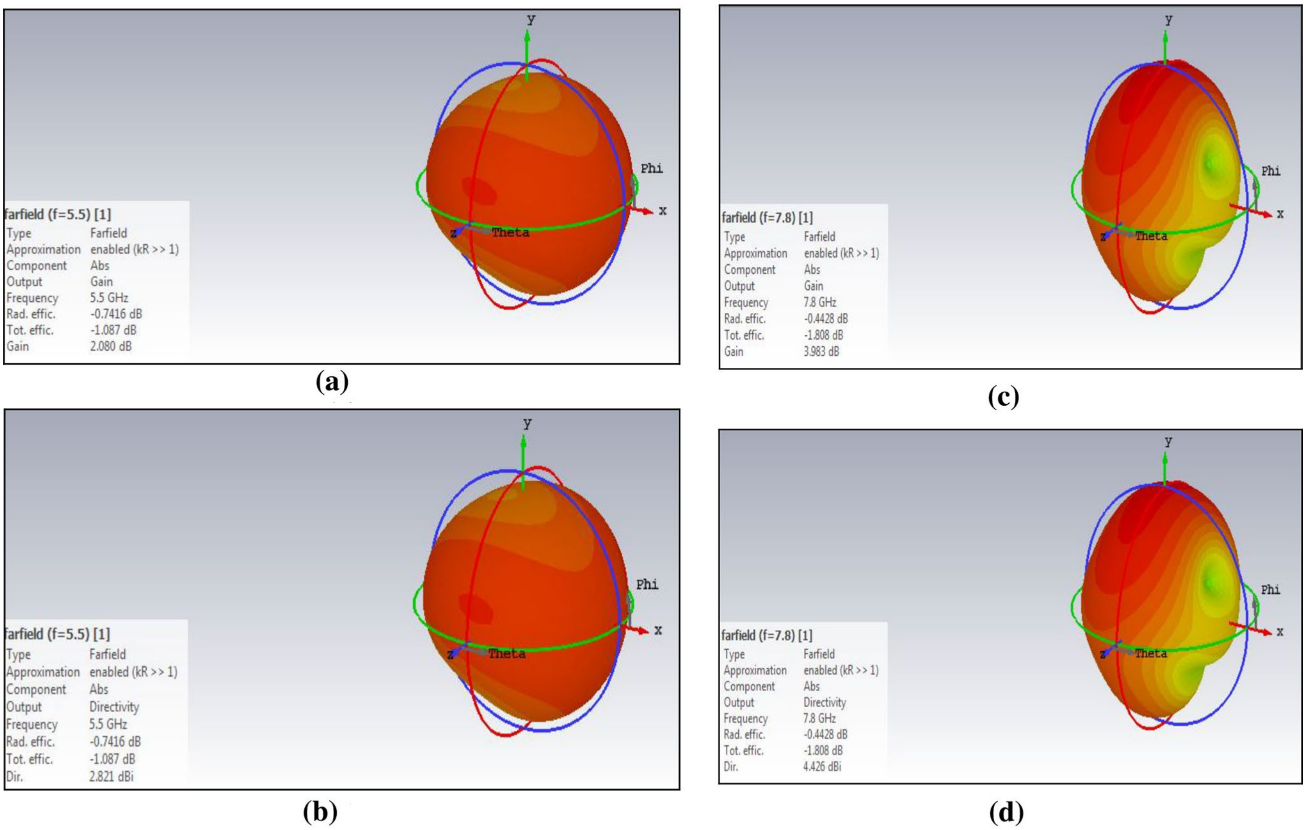


Fig. 10 VSWR characteristics



(a)
arfield (f=5.5) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 5.5 GHz
Rad. effic. -0.7416 dB
Tot. effic. -1.087 dB
Gain 2.080 dB

(b)
arfield (f=5.5) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 5.5 GHz
Rad. effic. -0.7416 dB
Tot. effic. -1.087 dB
Dir. 2.821 dBi

(c)
farfield (f=7.8) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 7.8 GHz
Rad. effic. -0.4428 dB
Tot. effic. -1.808 dB
Gain 3.983 dB

(d)
farfield (f=7.8) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Directivity
Frequency 7.8 GHz
Rad. effic. -0.4428 dB
Tot. effic. -1.808 dB
Dir. 4.426 dBi

Fig. 11 Radiation pattern characteristics. **a**, **b** Gain and directivity plot at 5.50 GHz. **c**, **d** Gain and directivity plot at 7.8 GHz

Table 4 Comparative analysis of performance parameters of proposed antenna design using different substrate materials

Substrate material used	Antenna overall size	Resonant frequency (GHz)	Return loss S_{11} (dB)	Gain (dB)	Voltage standing wave ratio (VSWR)	Directivity (dBi)	Efficiency (%)	Impedance bandwidth (GHz)	Fractional bandwidth (%)
Rogers RT 5880	22.48 mm × 24.56 mm × 1.645 mm	F1 = 4.43	− 32.7	5.9	1.05	6.80	86.7	3.1–10.7 (7.6 GHz)	110
		F2 = 8.84	− 16.11	4.06	1.37	4.257	95.3		
Jeans	20 mm × 22 mm × 1.07 mm	F1 = 4.28	− 21.09	2.45	1.19	3.72	66	3.5–10.5 (7 GHz)	100
		F2 = 8.58	− 34.84	4.11	1.03	5.50	75		
Rubber	20.2 mm × 22.4 mm × 1.27 mm	F1 = 5.50	− 43.6	2.08	1.01	2.8	74.2	4.2–9.25 (5.05 GHz)	75.3
		F2 = 7.87	− 32.0	3.983	1.05	4.426	89.9		

Simulation results reveal that the proposed antenna is better than related antennas presented in references in relevance to compactness, gain, operating bandwidth and efficiency. Simulation results confirmed UWB characteristics and its suitability to be used as a UWB antenna for various WBAN applications.

Table 5 Comparison of performance parameters of proposed antenna design with antenna designs mentioned in references

[Reference Paper No.]	[20]	[21]	[22]	[23]	[24]	[25]	Proposed
Year of publication	2015	2016	2016	2018	2018	2019	
Antenna parameter							
Antenna overall dimension	86 mm × 90 mm × 1.06 mm	–	45 mm × 35 mm	–	–	39 mm × 42 mm × 3.34 mm	22.48 mm × 24.56 mm × 1.645 m
Substrate dimension	86 mm × 90 mm	42 mm × 34 mm	45 mm × 35 mm	40 mm × 40 mm	21.5 mm × 50.7 mm	39 mm × 42 mm	22.48 mm × 24.56 mm × 1.575 mm
Ground dimensions	86 mm × 30 mm	42 mm × 10 mm	38 mm × 28 mm	40 mm × 40 mm	21.5 mm × 50.7 mm	39 mm × 42 mm	22.48 mm × 6.28 mm
Patch dimensions	Circular patch of radius 14 mm	17 mm × 21.4 mm	20 mm × 10 mm	20 mm × 19.2 mm	Circular with 17 mm radius	32 mm × 39 mm	13.8 mm × 10.5 mm
Resonant frequency (GHz)	2.1366, 4.756, 11.49	5.5, 7.5	3.0, 7.0, 9.0	5.80,5.86,5.89	5.78	3.5, 8.3	4.43,8.84
S_{11} (dB) at resonant frequency	− 22.23, − 38.10, − 20.79	− 18, − 24	− 12, − 18, − 35	− 38.53, − 37.8, − 21.52	− 13.08	− 17, − 15	− 32.11, − 16.11
Gain (dB)	–	–	2.74, 4.17, 4.074	6.6, 4.52, 3.05	2.9	–	5.9, 4.06
Directivity (dBi)	3.3, 4.23, 5.19	–	–	–	7.8	–	6.8, 4.25
Impedance bandwidth	2 GHz, 1 GHz	–	6.4 GHz (86.48%)	300 MHz	500 MHz	650 MHz 3.8 GHz	7.60 GHz 110%
Operational frequency range	4–6 GHz, 11–12 GHz	–	4.2 GHz–10.6 GHz	300 MHz	5.5 GHz–6 GHz	3.65 GHz–4.30 GHz, 6.3 GHz–10.1 GHz	3.10 GHz–10.7 GHz
Efficiency (%)	87.4%, 89.6%	93%	–	–	–	–	86.7 %, 95.3%

7 Conclusion

The major aim of this presented work is to develop and simulate compact dual-band UWB antenna design using Rogers RT 5880 which can support large impedance bandwidth, compact in size, having high gain and directivity. The research effort also targeted on the comparative analysis of various performance parameters of antenna such as reflection coefficient, VSWR, directivity, impedance bandwidth, gain, and antenna's radiation efficiency. Rogers RT 5880, jeans and rubber substrates are considered for comparative study. The presented Rogers RT 5880 substrate-based antenna simulation result shows return loss S_{11} of -32.7 dB and -16.1 dB at resonating frequency 4.43 GHz and 8.84 GHz, respectively. The gain of 5.9 dB and 4.06 dB are observed in the resonant frequencies 4.43 GHz and 8.84 GHz respectively. The proposed compact antenna has overall dimensions of 22.48 mm × 24.56 mm × 1.645 mm. The S_{11} value below -10 dB was obtained from simulation results for frequency ranging from 3.1 to 10.7 GHz; therefore, confirming ultra-wideband operation. The performance metrics of the presented antenna design confirms its superiority with respect to other related antennas mentioned in references and satisfies the requirements to be used for body worn applications. It can be used for WBAN applications in the UWB range as it balances the trade-offs between antenna performance and its size. Compactness and flexibility further confirm its suitability for portable UWB devices.

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