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Wearable Ultra Wide Dual Band Flexible Textile Antenna for WiMax/WLAN Application

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Abstract In this paper, a novel compact dual-band textile printed slot antenna with partial ground plane is proposed. The substrate of the designed antenna is prepared from jeans fabric material while the patch and ground plane are made from copper tape. The proposed antenna offers an experimentally measured impedance bandwidth of 46 %, i.e. from 3.01 to 5.30 GHz and 41 %, i.e. from 8.12 to 12.35 GHz. The antenna is further characterized by a peak gain of about 5.7 dB and a comparatively stable radiation pattern in the useful band. The antenna is compact in size and useful for WiMax (3.25–3.85 GHz), WLAN (5.15–5.35 GHz) and X-band (8–12 GHz) applications. Also, a comparison of simulated results is discussed with the measured results of the fabricated prototype.

Keywords Textile antenna · UWB · Dual bandwidth · Wearable antenna · X-band

1 Introduction

The key considerations for wearable electronics devices are to be robust, flexible, small size, consume a small amount of power, and comfortable to wear. Ultra Wide Band (UWB) devices do not require transmitting a high-power signal to the receiver and these devices can have a longer battery life. For flexible textile antennas, textile materials form attractive substrates, because fabric antennas can be easily incorporated into clothes. In this paper, by

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merging the UWB technology with textile technology, an improved UWB antenna using Clothing materials is fabricated and presented. By means of emerge of body-centric wireless communications and the potential and possibilities of wearable healthcare and monitoring systems have made a need for fabric-based antennas which could be seamlessly integrated with clothing [1–4]. With body-worn antennas, it is possible to conceal the technology that often frightens patients, while discreetly providing support. Unobserved monitoring instruments are needed in involuntary treatment and dementia care, where the patients may search for to remove suspicious devices [5, 6].

In welfare industry, there is a sprouting need for on-body sensing with unnoticeable and well-fixed sensor components namely wearable sensors. For instance, the lack of personnel in nursing homes is a significant problem. Instead of replacing human tangency, technology should be helpful and take care of certain monitoring responsibilities, thus saving the time of the staff for more important tasks [7–9]. The recent trend is to assist the elderly live at home instead of caring homes. For giving assistance, technology is needed to improve the feeling of security, for instance, sensing of breathing, regular actions, body temperature, sleep, or body limb movement can help in spontaneous monitoring of well-being. In rehabilitation process, sensors could monitor that the permitted exercises are performed but not too hard training is done. Rapid exploitation of antenna enhances wireless communication technology day by day. The wearable textile antenna is mostly used in health monitoring of vital signs of the wearer such as heart rate, respiration rate, temperature, military application, mobile communication, monitoring pilot or truck driver tiredness [10–17]. Flexible wearable systems need the integration of flexible antennas to provide wireless connectivity operating in specific frequency bands which are extremely demanded by today's information-oriented society. Smart fabrics or e-textiles have attracted growing interest in the last 10 years, particularly for wearable system applications. The practical use of flexible textile antennas is most suited as soon as they are integrated into clothing. As this can be accomplished easily and unobtrusively, the integration of such an antenna system into a rescue worker's garment is no clogging for the operations to be performed. Hence the essential requirements of wearable antenna designing are flexible conductive materials in the patch and ground plane, and flexible dielectric materials [18–25].

Micro electromechanical systems (MEMS) are the incorporation of mechanical elements such as sensors and actuators and, diodes with electronics on a common silicon substrate through utilization of micro fabrication technology. Micro electromechanical systems technology can offer improved performance over solid-state devices for instance semiconductor switches, sensors, and varactor diodes [26–28]. There are a number of prominent examples of antennas that employ RF MEMS devices. These can be classified into two distinct categories: generic RF MEMS antennas and RF MEMS antenna circuits.

The first category has radiating elements that physically move under some form of mechanical actuation mechanism. The second category has fixed position radiating elements that employ RF MEMS switches and/or variable capacitors to alter their electrical length [26–28].

2 Antenna Design and Configuration

In this article, an octagonal slot loaded circular-shaped textile antenna is fabricated on 40×40 mm^2 substrate textile. The jeans textile material is used as substrate and conducting (patch and ground) part of the antenna is fabricated by copper tape. The copper tape consist a copper foil is self adhesive and the tape has dual conductivity so current will flow through both sides and the adhesive. Jeans material characteristics such as thickness, relative permittivity, loss tangent are experimentally measured with the help of 1 × 1 m^2 jeans textile. The partial antenna ground plane of 40 × 20 mm^2 plays a most important task of tuning matching circuit in realizing the antenna to function as UWB application. The patch radius is 8 mm which is calculated by Eq. (1) whereas the length and width of line feed is deliberated using basic equations for the patch antenna. The realistic use of textile antennas is most convenient when they are incorporated into clothing. The SMA connector has been directly soldered to the feed line of the textile antenna. The simulation results are accomplished in the CST simulation software. The shape of the proposed antenna is shown in Fig. 1. The height of substrate and conductive sheet is taken 1.0 and 0.03 mm respectively. The ground plane of proposed textile antenna is made of copper adhesive tape with a thickness of 0.03 mm. All fabrication and measurements are performed at the Indian Institute of Technology (IIT) Kanpur Microwave Lab. All design parameters and dimensions of the slots are shown in Table 1.

$$a = \frac{87.94}{fr\sqrt{\varepsilon_r}} \tag{1}$$

3 Results and Discussion

3.1 S_{11} Parameters of the Desired Antenna

Figure 2 shows the simulated reflection coefficient of circular-shaped UWB textile antenna with octagonal slot. Under tolerable S_{11} of <-10 dB, the simulated antenna design using copper conducting sheet with octagonal-slot structure has achieved, which meet the design specifications of Ultra Wide Band application at the concern frequency range of 3.1–10.6 GHz. Table 2 shows reflection coefficient (S_{11}) and gain at different resonant frequencies after simulation on CST studio. The efficiency is 94 % at resonant frequency 18.30 GHz and the gain is 5.685 dB at 13.20 GHz.

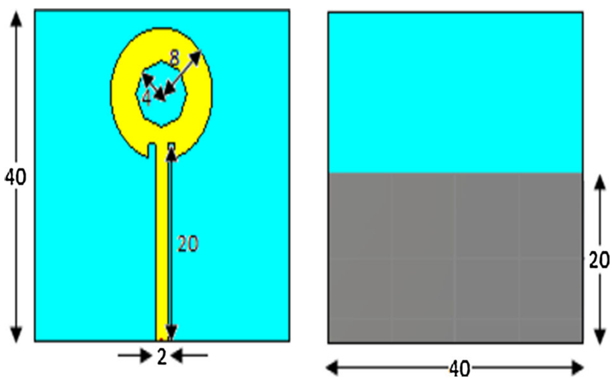

Fig. 1 Geometry octagonal slot loaded circular patch textile antenna

Table 1 Design parameters and dimensions of proposed antenna

Relative permittivity (ε_r)	1.67
Loss tangent	0.025
Substrate thickness (mm)	1.0
Substrate dimension (mm)	40 × 40
Partial ground plane (mm)	40 × 20
Patch radius (mm)	8.0
Centre octagonal slot dimensions (mm)	4.0
Microstrip feed line	20 × 2

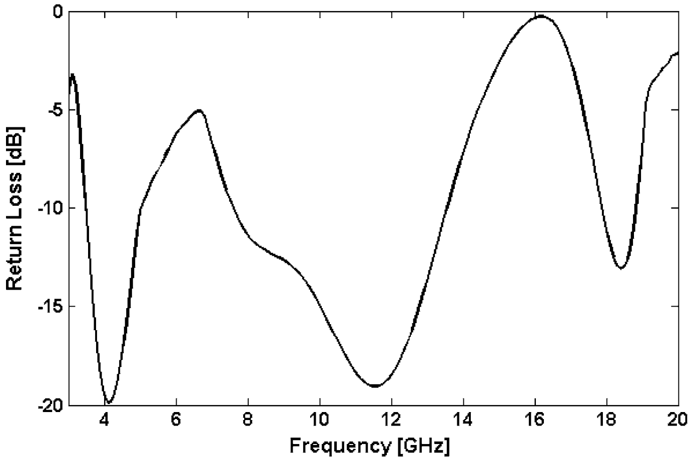

Fig. 2 Simulated S_{11} parameter versus frequency of proposed textile antenna

Table 2 Gain and efficiency of proposed antenna

Frequency (GHz)	Gain (dB)	S_{11} (dB)	Efficiency (%)
4.00	3.693	−19.61231	89
8.90	4.530	−12.10352	92
13.20	5.685	−11.81001	92
18.30	5.461	−16.41123	94

3.2 Simulated Gain and Efficiency

The variation of frequencies versus gain of the wearable textile Ultra Wide Band antenna are demonstrated in Table 2. The maximum gain achieved was about 5.685 dB at 13.2 GHz while the highest percentage of efficiency reached 94 % at 18.3 GHz. However, the lowest efficiency was about 89 % at 4 GHz. Accordingly, results showed that proposed design has low power consumption due to the high gain results that was more than 4 dB in most span of frequencies between 6 and 20 GHz which is shown in Fig. 3. A photograph of the measured gain environment is depicted in Fig. 8 where the antenna is located in an anechoic chamber. Furthermore, Fig. 9 shows the measured gain vs frequency of proposed textile antenna.

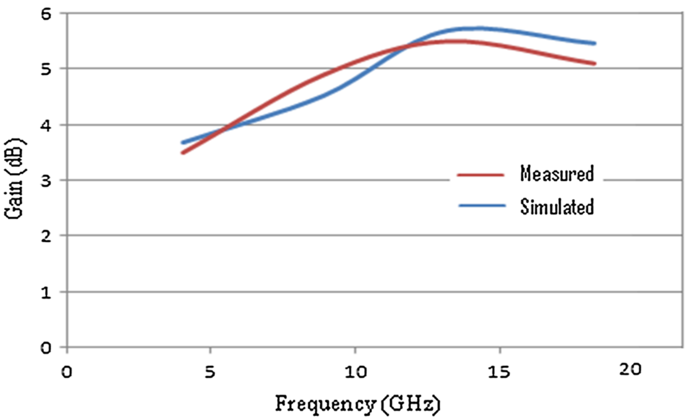

Fig. 3 Measured and simulated gain versus frequency of proposed textile antenna

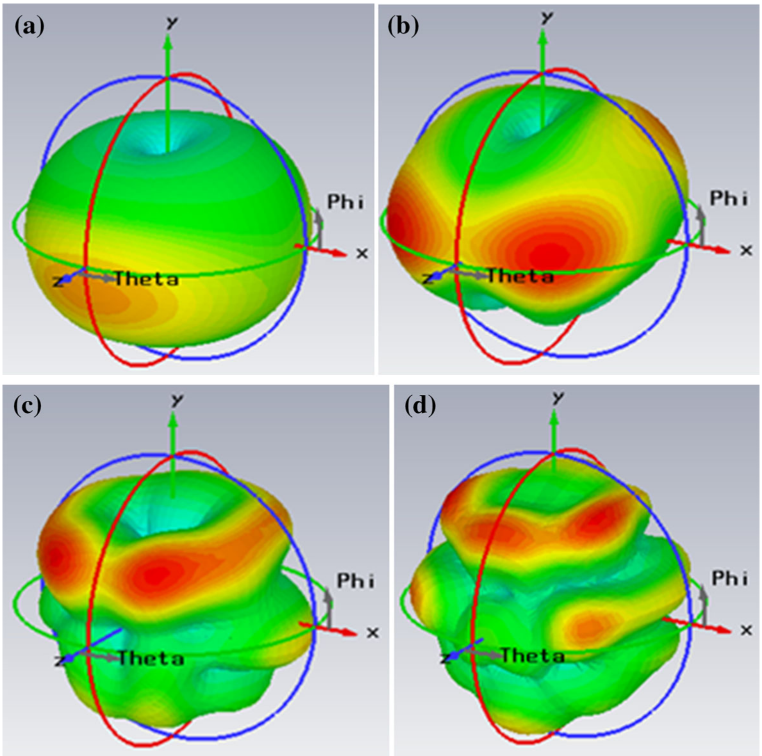

Fig. 4 Radiation pattern of proposed textile antenna at frequency **a** 4 GHz, **b** 8.9 GHz, **c** 13.2, **d** 18.3 GHz

3.3 Radiation Pattern of Desired Antenna

In Fig. 4 it is clear that radiation pattern is different at different frequencies. At frequency 4 GHz the gain is about 3.693 dB which is good for medical purpose. At frequency

8.90 GHz gain is about 4.53 dB having the efficiency 92 % which can be used for wearable wireless body area network (WBAN) sensor applications in the military. The omnidirectional pattern is essential for the reason that when we are wearing an antenna it can be in any orientation during sleep or if a patient is wearing it, it might not be directional towards base station as it is impossible for a human to be in single orientation during the day and night, as a result, omnidirectional pattern is chosen. Furthermore, at frequency 13.2 GHz, the gain is about 5.685 dB and efficiency is about 92 % which is quite remarkable and at frequency 18.3 GHz the gain is 5.461 dB with maximum efficiency of 94 %. The total efficiency, radiation efficiency, and gain are shown in Table 3.

4 Antenna Testing

In Fig. 5, Photograph of hardware of proposed textile antenna with SMA connector soldered carefully on the conductive patch. Jeans substrate is taken as substrate as it is formed of 99 % cotton and easily available and the cheapest clothing material. Conductive fabric is copper fabric purchased from the market. It is a fabric of conductive threads which makes it vigorous for use it wherever necessary.

Table 3 Radiation characteristics of proposed antenna

S. no.	Frequency (GHz)	Radiation efficiency (dB)	Total efficiency (dB)	Gain (dB)
1	4.0	−0.01537	−0.06439	3.639
2	8.9	−0.03303	−0.3376	4.530
3	13.2	−0.1925	−0.2683	5.685
4	18.3	−0.3386	−0.4348	5.461

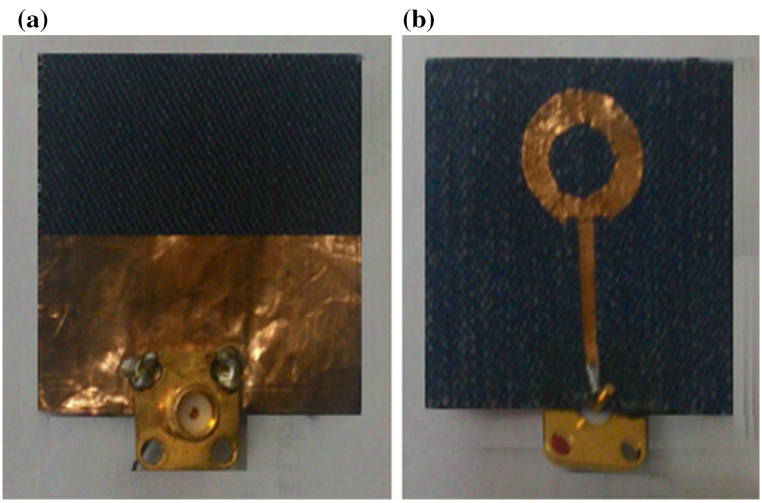

Fig. 5 Photograph of fabricated antenna using textile substrate. **a** Front face, **b** Back face

4.1 Antenna Measurement and Measured Results

The proposed Textile Antenna is kept straight with transmission line of vector network analyser due to continuous fluctuations in results on screen due to change in its orientation with slight movement as shown in Fig. 5. To measure the reflection coefficient (S_{11}) results of the fabricated UWB prototype antenna, a network analyser is used. Figure 6 demonstrates a snapshot of the fabricated prototype using jeans fabric. In addition, reflection coefficient (S_{11}) & gain measurement environment of UWB antenna prototype using jeans fabric is illustrated in Figs. 7, 8.

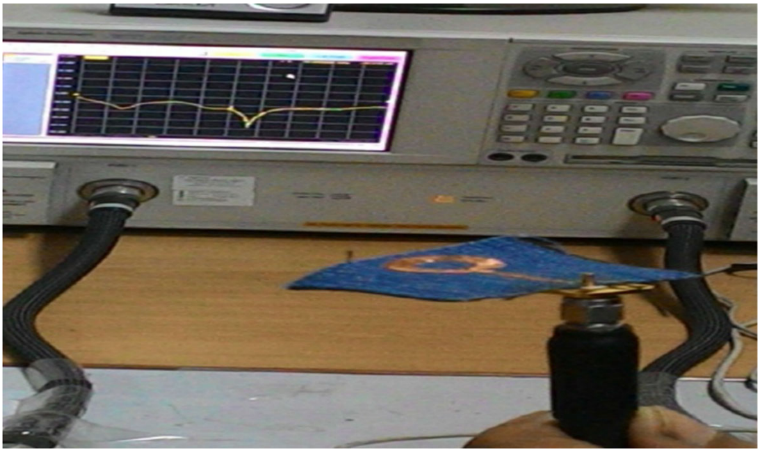

Fig. 6 Proposed antenna while measuring S_{11} on vector network analyser in IIT Kanpur lab

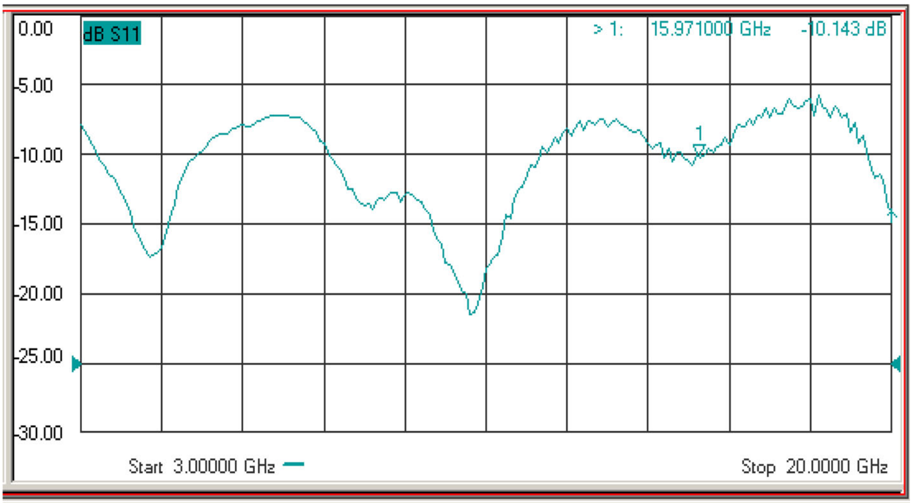

Fig. 7 Measured S_{11} result on vector network analyzer in IIT Kanpur microwave lab

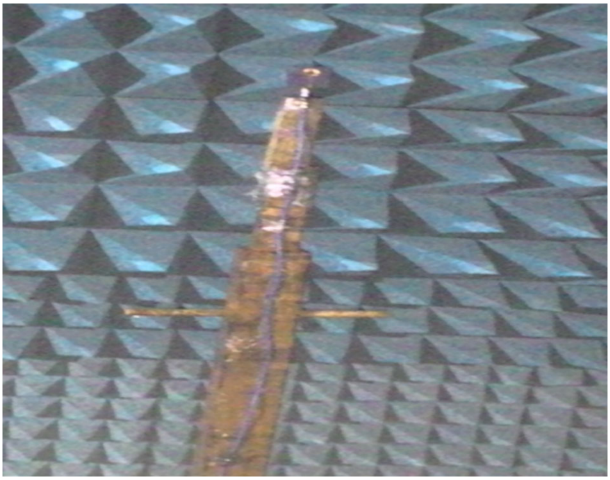

Fig. 8 Experimental setup of gain measurement in IIT Kanpur microwave lab

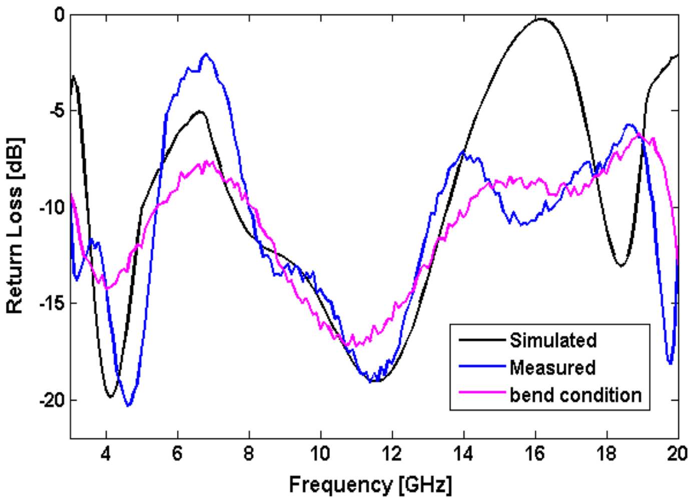

Fig. 9 Comparison of measured results of proposed antenna on vector network analyzer under bending condition

4.2 Analysis of Circular Patch Textile UWB Antenna

Figure 9 shows a comparison of simulated and measured results in terms of reflection coefficient and bandwidth of proposed textile antenna. The slight change between simulated and measured result is due to the flexibility of the textile material, fabrication tolerance, humidity and temperature effect on cotton. However, simulated and measured results show a good correlation. Significant characteristics of designed antenna are given as below Figs. 10, 11 & described in Tables 4, 5.

- Dual Measured bandwidth = 46 % (3.01–5.30 GHz) and 41 % (8.12–12.35 GHz).

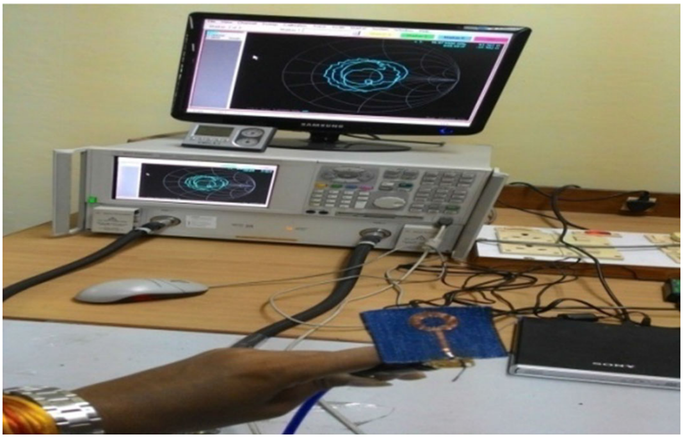

Fig. 10 Proposed antenna while measuring input impedance on vector network analyser in IIT Kanpur lab

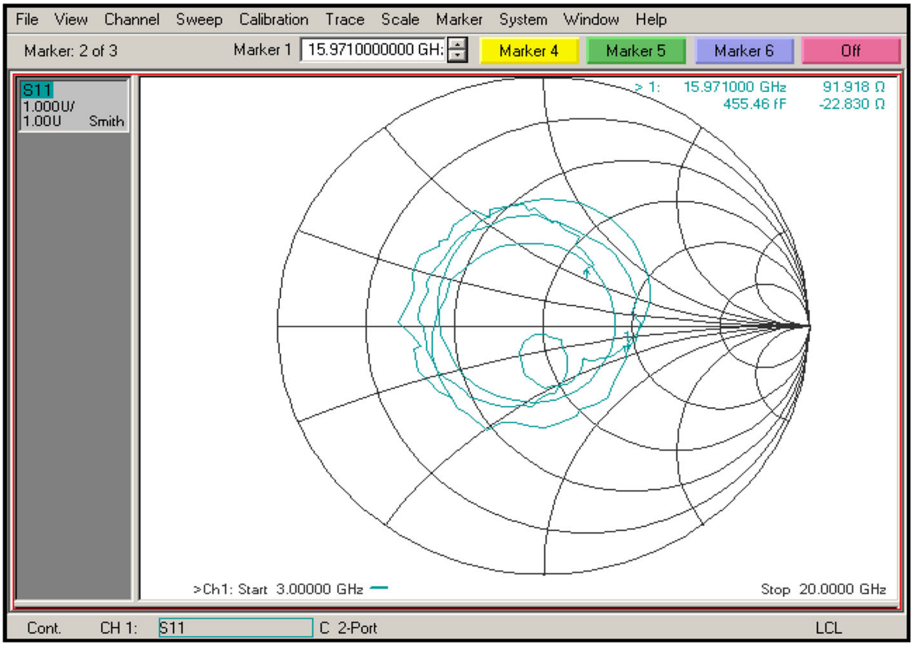

Fig. 11 Measured plot of smith chart versus frequency of proposed textile antenna

- Frequency range of the first band is 3.01–5.30 GHz is used for WiMax application.
- Frequency range of the second band is 8.12–12.35 GHz is used for earth exploration satellite service.
- At frequency 13.2 GHz the maximum gain is about 5.685 dB.

Table 4 Characteristics of proposed textile antenna

Parameters	Proposed antenna	Reference antenna [4]
Dual band width	46 and 41 %	4 and 16 %
Frequency range	3.01–5.30 and 8.12–12.35 GHz	2.45–2.51 and 5.15–5.82 GHz
Application	First band for WiMax/WLAN application	First band for wireless application
	Second band for X band application	Second band for WLAN application

Table 5 Performance comparison between the proposed antenna and some existing antennas

S. no.	References	Substrate	Frequency range	Dimension (mm × mm)	BW (%)	Applications
1	Rawat and Sharma [12]	FR4	4.04–7.28 GHz	30 × 30	60.3	C-band
2	Mourad and Essaaidi [13]	FR4	6.80–7.30 GHz	30 × 21	7.09	C and X-band
3	Samsuzzaman and Islam [14]	FR4	8.69–9.14 GHz	20 × 17.2	5.02	X-band
4	Ansari et al. [15]	FR4	6.48–9.5 GHz	32 × 32	37.79	C and X-band
5	Proposed antenna	Textile	3.01–5.30 and 8.12–12.35 GHz	40 × 40	46 and 41	C and X-band

5 Conclusion

The proposed design consists of jeans substrate while the radiating element and ground plane were made from copper self-adhesive tape. The proposed UWB antenna with partial ground plane is successfully designed, fabricated and measured. The operating frequency of measured results of the existing manuscript designs span from 3.01 to 5.30 GHz is for WiMax application and the second band is 8.12–12.35 GHz for X-band application. The reflection coefficient ($|S_{11}|$) results indicated that jeans fabric acted as a good candidate for textile wearable applications. The simulated and measured results have a good agreement and showed that the proposed antenna has high gain, high efficiency and constant radiation pattern over its whole range of frequencies. However, the very compact size of the antenna further confirms its appropriateness for portable UWB devices.

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