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ORIGINAL RESEARCH

Compact textile UWB antenna with hexagonal for biomedical communication

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Abstract
This paper introduces a small-sized, low profile, planar and flexible ultra-wide band (UWB) antenna using Jeans, a textile material as the substrate. A novel shape of hexagonal slot in rectangular step shape patch with partial ground plane is developed with bandwidth of 12 GHz is proposed. It is the primary approach in using natural textile as the substrate for UWB antenna which operated in a wide range of bandwidth. The UWB antenna is designed for short range applications including wireless body area network (WBAN), which is the current revolution with growing demands in wireless sensor networks. The antenna operates from 2.8 to 10.9 GHz, which is a suitable candidate for WBAN operation.

Keywords Ultra wide band antenna · Biomedical communication · Wireless body area network · Polymethylsiloxane

1 Introduction

Textile antennas are recently getting attention towards the medical applications such as patient monitoring, body diagnosis, and wireless body area network between patient and doctor. Hence the short range communication particularly ultra wide band (3.1–10.6 GHz) frequency operation is needed. The main requirements of textile UWB antenna are the wearability (Indumathi and Bhavithra 2017), compactness (Osman et al. 2011a, b; Sanz-Izquierdo et al. 2007), compatibility with human body (Hassan and Shehab 2015), low specific absorption rate (SAR) (Soh et al. 2014), backward wave reduction (Yimdjo Poffelie et al. 2016) and high gain (Oshin and Amit 2017).

Several materials have been used in the development of textile antennas. Indumathi and Bhavithra (2017), designed antenna with cordurafabric and Taffeta fabric which are used as substrate and conductor materials, respectively. However, the fabrication is less feasible. Mohan and Suriyakala (2017) studied the performance characteristics of UWB antenna with different kind of substrates such as FR4 and Jeans. For the application of green cloud computing a modified polymer textile antenna was developed by a crew (Mustafa et al. 2013). A circular patch antenna was designed and various materials such as Rogers, Flannel and Polyester are considered as substrate material and results were compared (Kango and Oza-Rahurkar 2017). The antenna was made of conductive threads which are available in market (Kiourti et al. 2016). A flexible polymethylsiloxane (PDMS) substrate based spiral shape antenna with permittivity and loss tangent of 3 and 0.004 was introduced.

In the design aspects of UWB antenna, different shapes have been tried to achieve wider bandwidth. Shikder and Arifin (2017) studied about the icon based shape in their UWB antenna. The power shape icon was resembled for WBAN application.

A small size hexagonal shape antenna was designed in the work (Krishnaveni et al. 2015). The simulation studies were performed with human body models. Baidda et al. (2019) explained about the UWB antenna with modified circular shape antenna with partial ground plane. The circular monopole antenna was designed for the lower band of UWB application. In this work a conductive copper thread was implemented as a patch antenna (Dey et al. 2011). A novel funnel shape antenna was designed as a button antenna using flexible metallic patches by the team of researchers in Yu et al. (2012). Shaad Mahmud and Dey (2012) developed a

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logo based textile antenna for their university name American International University—Bangladesh. An EEE shape logo type UWB antenna (Shikder and Arifin 2016) for body area network by using Fleece fabric was developed. In this antenna a square slot was introduced in the partial ground plane for the improvement (Lal and Joe Prathap 2020) of bandwidth. In Shehab et al. (2014) the Dacron fabric was used with the dielectric of 3 and the ground and patch are made with copper tape in the development of UWB antenna. Jalil et al. (2012) explained about their CPW fed UWB antenna in jeans substrate. The shape of the antenna was elliptical.

A diagonal cut was introduced in order to reduce the size of the antenna without compromising the bandwidth improvement. The authors Verma and Singh (2015) studied about two different antennas as comparative cases. A complete textile antenna was introduced by the team (Yan et al. 2016) with full ground plane as a shielding element. With full ground plane the antenna (Sakthidasan Sankaran et al. 2020) used as a protective cover from back ward radiation from the antenna. The advantage of the antenna was its robustness (Samal et al. 2014). Using jeans material as a substrate, a kite shape textile antenna was introduced with three different triangle shapes in Ramesh et al. (2017). Osman et al. (2011a, b) designed a UWB circular patch antenna with partial ground plane and it was fabricated with jeans material.

2 Materials and methods

2.1 Materials

The proposed antenna is fabricated with Jeans (Denim) substrate of thickness i 2 mm and dielectric constant 1.67. The length and width of the antenna are 40 mm and 42 mm, respectively. A unique conductive material namely, copper tape in adhesive nature with thickness of 0.75 mm has been used to perform as the radiating element. At the center of the radiating patch hexagonal shaped closed loop slot (HSCS) is introduced to achieve band notch operation in the UWB band. HSCS is embedded as the removal of copper in full patch shape.

2.2 Methods

The dielectric constant of the Jeans material is found using the antenna resonant method originally introduced by a team. In this method the conventional antenna with bandwidth of 2.45 GHz is designed with similar material of Jeans substrate and copper tape based conducting element. As a first step, the return loss value is measured and it is compared with the simulation return loss was changed. The procedure is repeated varying the dielectric value and loss tangent of the same antenna, till good agreement between the measured and simulation result of return loss is achieved. And the corresponding dielectric and loss tangent value are observed to be the 1.67 and 0.0035, respectively (Fig. 1).

In the designing of the antenna, the top side is embedded with the hexagonal slot which introduces the band notch function in the range of UWB. Moreover, the step shape truncation is incorporated in the design for the betterment of the current flow at the corners. The rectangular feed is positioned at the center of the antenna element hence the magnetic field is uniformly distributed of observed in the antenna body. Partial ground plane has been placed beneath the Jeans substrate for the enhancement of the? A rectangular slot is positioned in the partial ground plane to increase the bandwidth.

The three steps in the antenna design enable the antenna to operate in three resonant bands and thus multiband resonant occurs. At the top of the patch two rectangular shaped slots are included to improve the current density at the corners of the antenna and hence the bandwidth. The Jeans material which is textile in nature has 99% cotton and 1% polyester (Fig. 2; Table 1).

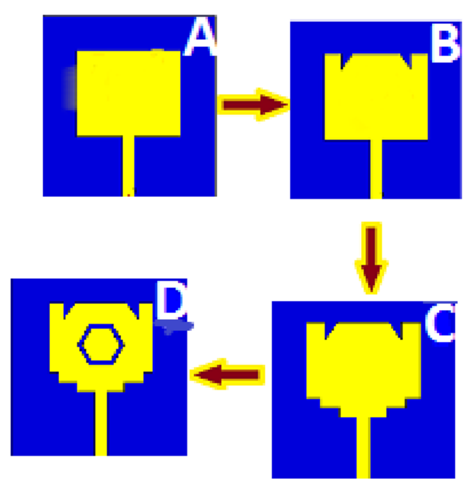

Fig. 1 Evolution step of antenna design **a** Plain rectangular patch. **b** Rectangular truncation in the top corners of the patch. **c** Three step shapes introduced in the bottom corners of the patch. **d** Hexagaonal slot introduced in the center of the patch

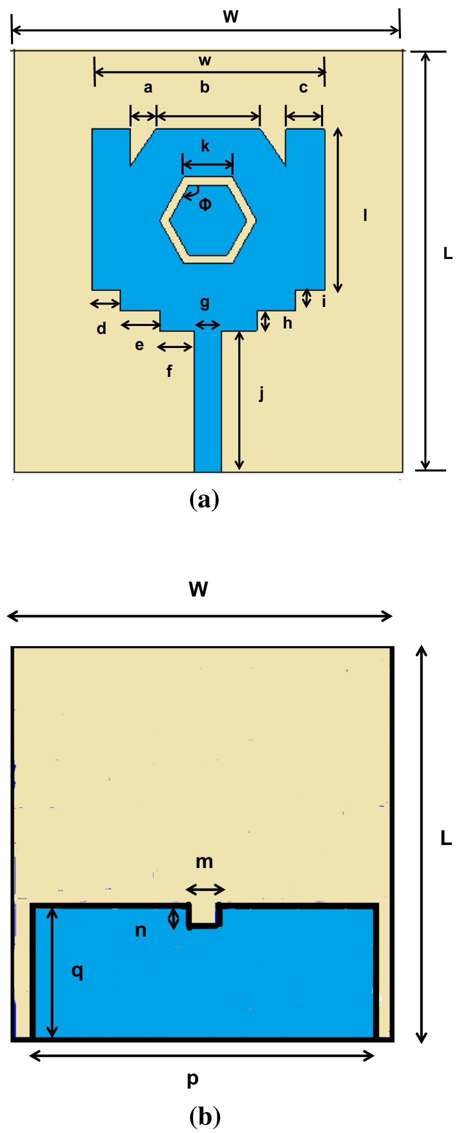

Fig. 2 The details of the dimensions of the proposed antenna **a** Top and **b** bottom dimensional details

Table 1 Dimensional details of the proposed antenna

Dimensional notation	Values	Dimensional notation	Value	Dimensional notation	Values
L	42	E	4	k	5
W	40	F	3.75	l	16
a	2.6	G	2.5	m	3
b	20.8	h, i	2	n	2
C	4	J	14	p	36
D	3	Φ	60º	q	14

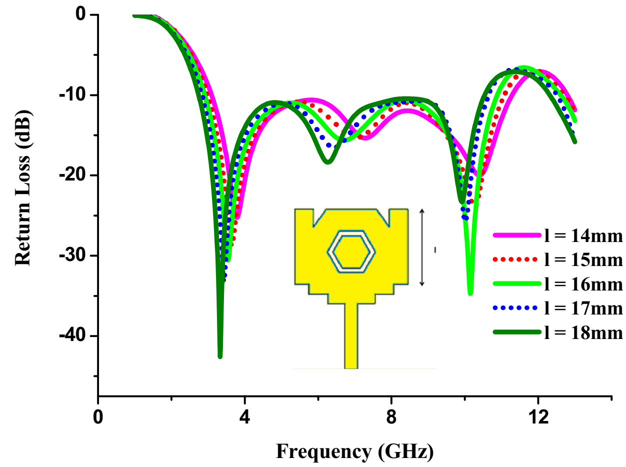

Fig. 3 Comparative study on the length of the rectangular patch varies from 14 to 18 mm

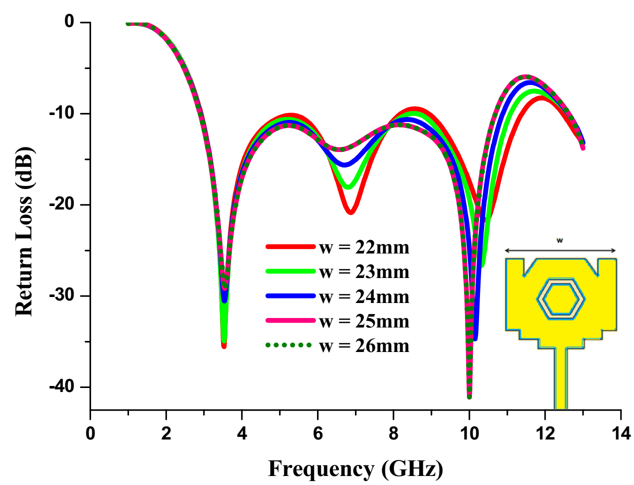

Fig. 4 Comparative study on the width of the rectangular patch varies from 22 to 26 mm

3 Results and discussion

The optimised dimensional details are obtained by trial and error method in which the length and width and other parameters are varied and optimum value has been found as shown in Fig. 3, 4, 5, 6, 7, 8.

3.1 Parametric study on varies dimensions

From Fig. 3, it shown that the length varies the resonance frequency and also the impedance matching. In Fig. 4, the width of the patch shape influences the bandwidth.

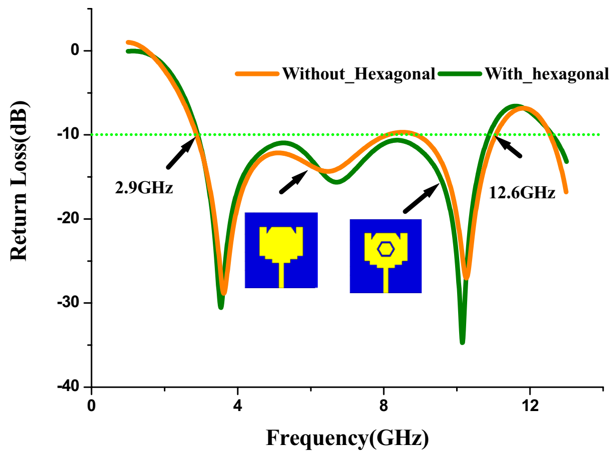

Fig. 5 Comparative study on the effect of the hexagonal slot at the center of the patch

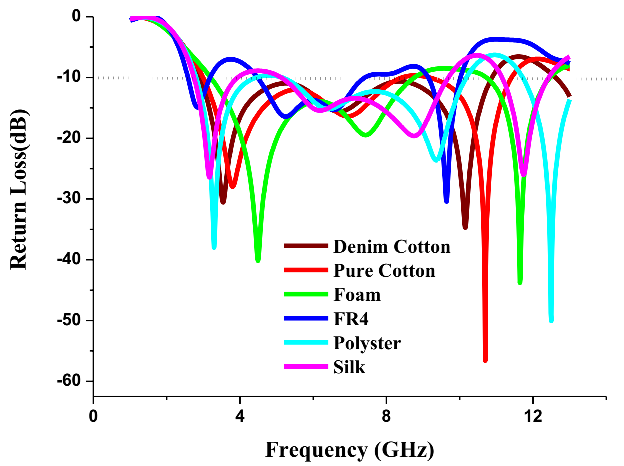

Fig. 6 Comparative study on effect of different substrate materials

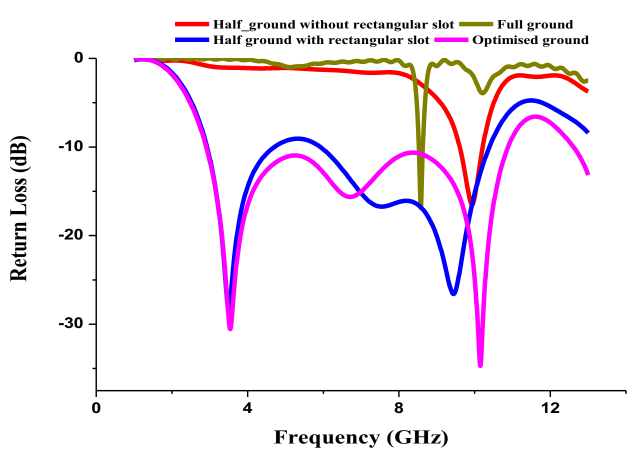

Fig. 7 Comparative study on the effect of ground plane in which partial ground, full ground and partial ground with rectangular slot

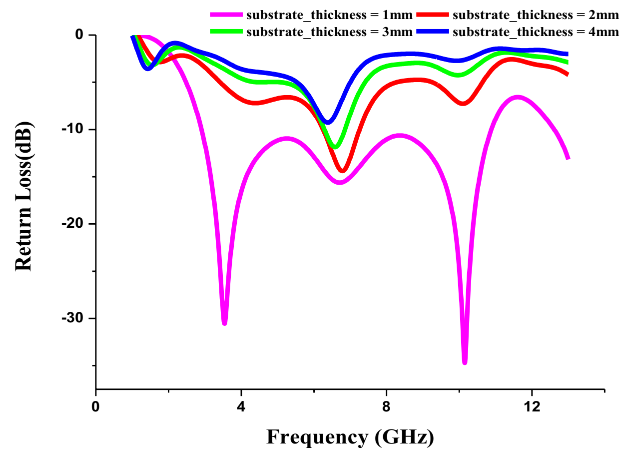

Fig. 8 Comparative study on the effect of the substrate thickness varies from 1 to 4 mm

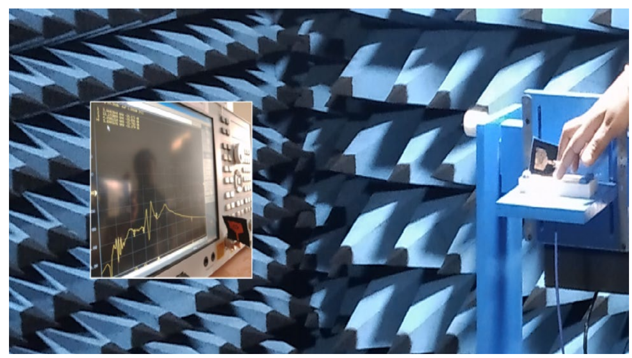

Fig. 9 Anechoic Chamber setup for testing return loss and field patterns

From Figs. 5, 6, effect of hexagonal slot is identified as the band notch function in the UWB band and the substrate material with low permittivity enhances the bandwidth of the antenna, respectively.

The return loss of the designed antenna is illustrated in Fig. 7, explaining the effect of the ground plane in further enhancement of the bandwidth. The thickness of the substrate influences the impedance matching of the radiating element with feed line. Moreover, the wideband width result with more than five band notch points is obtained with the insertion of the step shape in the antenna. The step shapes in the antenna induces the response peak with acceptable bandwidth. And also the ground shape also influences the noticeable bandwidth improvement with combined notification in rectangular slot.

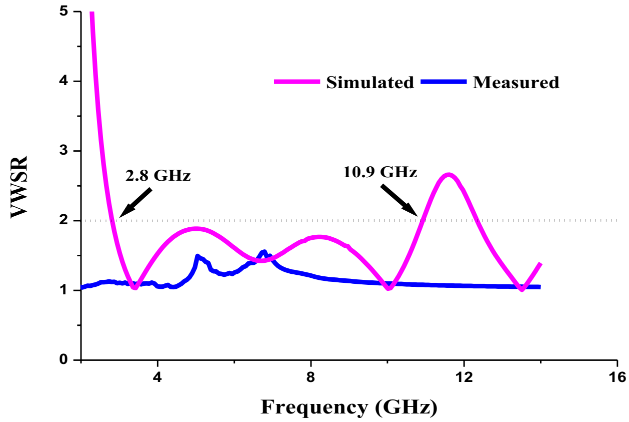

Fig. 10 Comparison on simulation and measured VSWR values

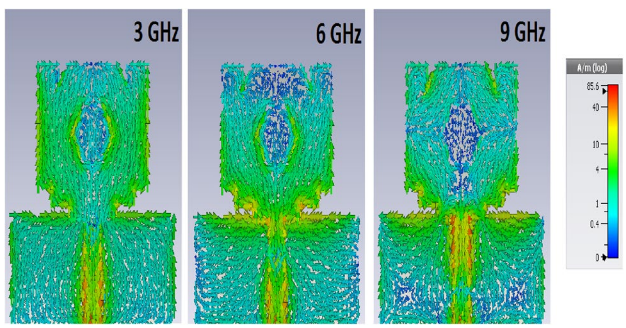

Fig. 11 Current distribution with respect to the frequency of 3 GHz, 6 GHz and 9 GHz

3.2 Experimental set up

Anechoic chamber is the quite zone which has no losses due to the null reflection inside the room. The return loss and VSWR are measured with respect to the reference horn antenna as a transmitter as depicted in Figs. 9, 10.

As shown in Fig. 11, the current is denser at the bottom edge which comes near the feed lines. Owing to the hexagonal slot the current flow circulates around the patch, and hence a circular polarisation can be achieved.

As shown in Fig. 12, the H field pattern is obtained as omnidirection pattern and in Fig. 13, the doughnut shape E-plane indicates the maximum radiation is transmitted and received in all directions.

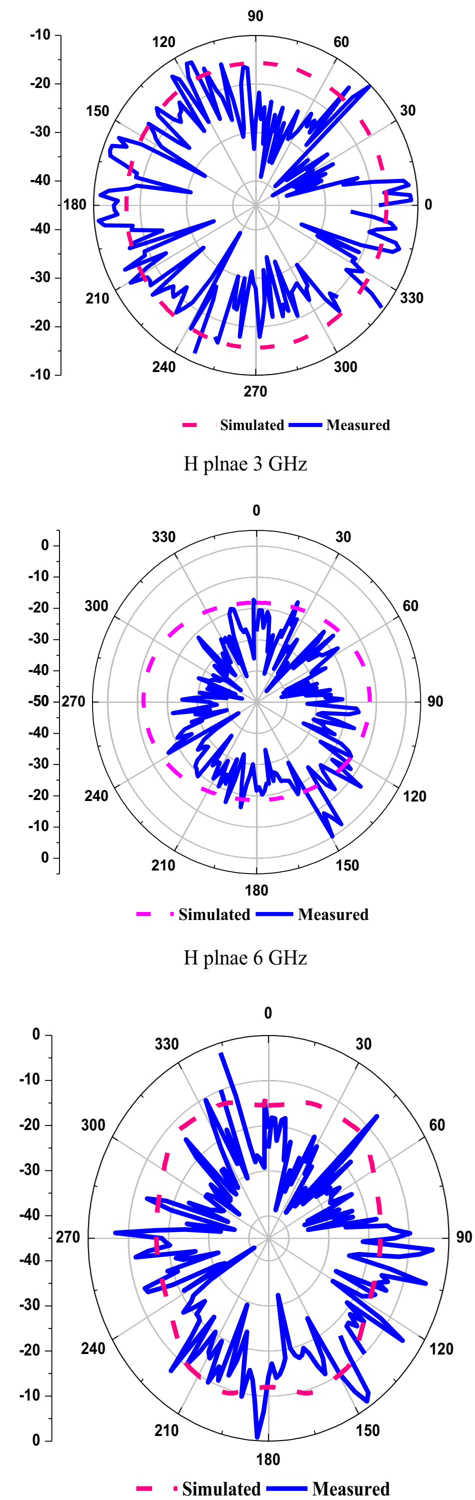

Fig. 12 H plane radiation with respect to the frequency of 3 GHz, 6 GHz and 9 GHz

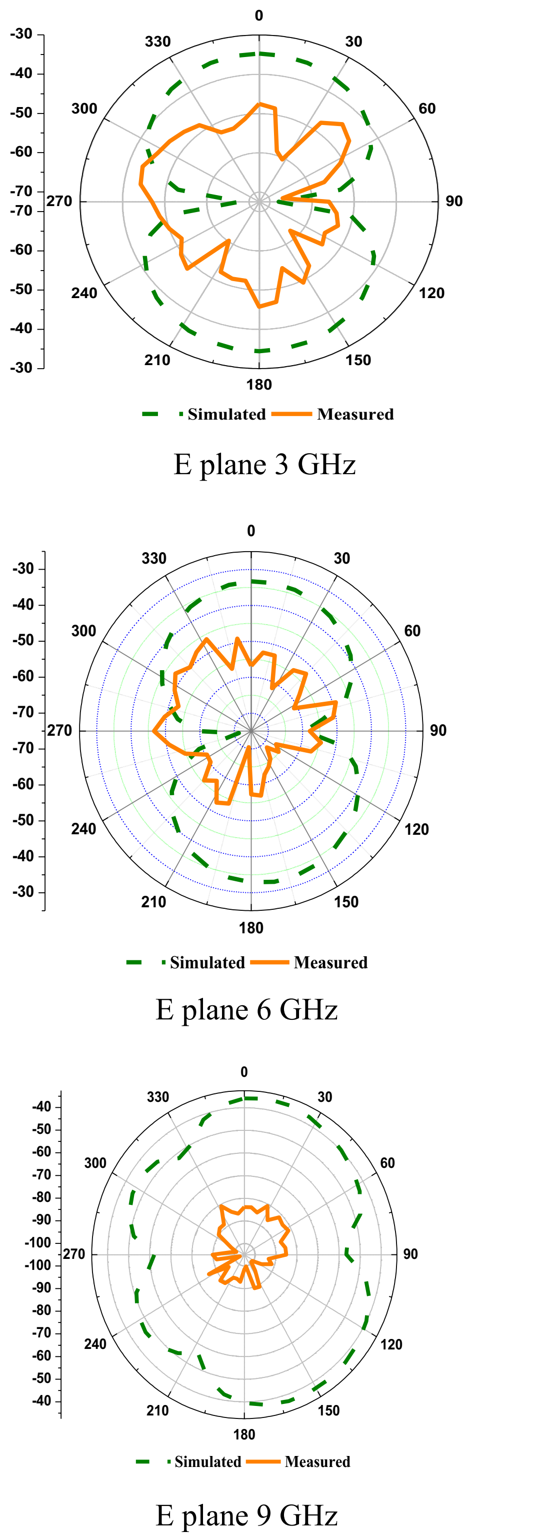

Fig. 13 E plane radiation with respect to the frequency of 3 GHz, 6 GHz and 9 GHz

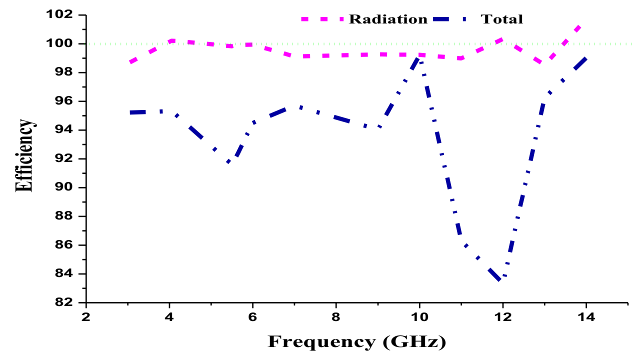

Fig. 14 Comparative study on the radiation efficiency and total efficiency

From the Fig. 14, the radiation efficiency is reached up to the level of 100% while the total efficiency varies from 2.9 to 10.9 GHz randomly. In the Table 2, the same jeans material based antenna as in reference 20, is designed and obtained the bandwidth of 10 GHz. However, the size of the antenna is reduced in the proposed work as 42×40 mm^2.

4 Conclusions

In the proposed work, a compact UWB textile antenna with operating frequency 10.9–2.9 GHz to covering the UWB band (3.1–10.6 GHz). The size of the antenna is reduced by using the textile material Jeans with permittivity of 1.67. The ground plane is reduced to partial to increase the impedance bandwidth. The hexagonal slot is embedded for the improvement of bandwidth by increasing the electric field distribution more at the edges. The fabrication is done with Denim material as substrate in the dimension of 2 mm (thickness) and the feed is conventional microstrip feed. The reflection characteristics and gain characteristics of the developed antenna are acceptable.

The proposed antenna can be used in short range communication devices and the textile substrate enables the antenna to used for BAN. In future the patch material can be implemented as conductive textile and the antenna becomes wearable antenna.

Table 2 Comparison of performance of the proposed antenna with other UWB band antennas

Permittivity of substrate	h (mm)	Methodology	BW (MHz)	Size (mm^2)
RT duroid (2.2)	0.650	Stub	400	20 × 2
Jeans (1.7)	1	Partial ground	10,000	60 × 60
FR3 Epoxy (3.9)	3.8	Metamaterial and cavity	2000	55 × 55
Jeans (1.67)	2	Multidimensional feed	10,000	42 × 40

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Declarations

Conflict of interest The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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