# Chapter 8
# Design and Analysis of an All-Textile Antenna Integrated Within Human Clothing for Safe Bio-medical Wireless Communication

**D. Ram Sandeep, B. T. P. Madhav, S. Salma, and L. Govinda**

**Abstract** This study presents the design and development of a portable textile antenna for bio-medical wireless communication at a 5.8 GHz ISM band application. The proposed antenna is built on a highly sustainable, low-cost, and flexible jute substrate. The famous Tai-Chi symbol inspires the present textile antenna design and operates in three frequencies 3.5, 4.9, and 5.8 GHz. The circular polarization characteristic is also achieved in the operating frequencies. This feature enables the antenna to receive the signal without proper orientation between the receiver and transmitter, thus enabling a stable wireless link for wireless bio-medical communication applications. The developed antenna was methodologically investigated on the three-layer body model and the real human tissue to access SAR ranges. All the ranges were under the safe limits of US and EU standards. The obtained results have remarkably proven that the antenna is safe to use on the human body in all the functioning frequencies.

**Keywords** Textile antenna · Bio-medical communication · Circular polarization · SAR analysis · Three-layer body model

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## Introduction

Wearable electronics are devices worn on or implanted in the human body. At the same time can also be concealed in the wearer's outfit (Düking et al. 2016). Wearable gadgets have the potential to connect to other devices through cellular connection or directly with each other. These devices consist of various components such as processing units, memory modules, sensors, transmitting and receiving modules, batteries, and antennas. The antennas are significant among these multiple components because they are vital in establishing the wearable wireless link.

In all the wearable devices, traditional rigid microstrip antennas are not found because they are difficult to mount on the user's body, and their sharp edges severely damage the skin. Wearable antennas are a particular kind where the antenna is made up of wearable materials specially designed to function while worn. The most common applications of these antennas are in the bio-medical radio frequency systems and on-body wearable wireless communication systems. Usually, the Wireless Body Area Networks (WBAN) connect these wearable antennas, and all these antennas are under the context of WBAN. The WBAN links IoT nodes, actuators, and sensors on the human skin or clothes of the wearer or other human body tissues and establishes a wearable wireless connection through a proper communication channel, as illustrated in Fig. 8.1 (Wang et al. 2017; Paracha et al. 2019).

All modern wearable devices are devised with compact wearable antennas. The antenna topology has relied on several requirements like radiating performance, electrical performance, size, efficiency, gain, bandwidth, polarization, and the wearable device's particular application. The daily used antenna topologies are planar inverted-F antennas (PIFAs), slot antennas, printed loops, monopole, printed dipole,

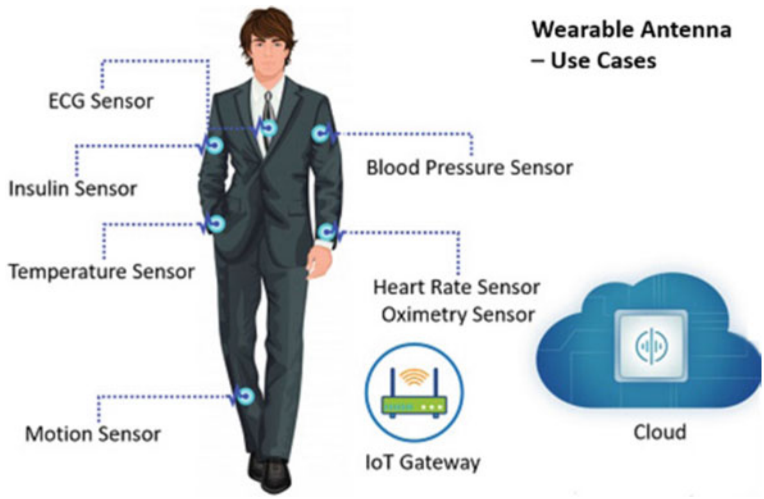



**Fig. 8.1** Applications of wearable antennas

and microstrip antennas. The microstrip topology is the right choice for wearable antennas because of their compact size, ease to fabricate, flexibility and conformability, and ease of integration with wearers' clothing or wearable wireless devices (Balanis 2015; Kanitthika et al. 2016). For realizing a textile antenna, the insulating parts are made with various dielectric materials. At the same time, the radiating and ground structure is made up of electro-textiles or other fabrication techniques (Dong et al. 2022; Mahmood et al. 2020). This work considers the evolving methods in practice to develop a sustainable, safe, and circularly polarized multi-band textile antenna for Bio-Medical Wireless Communication applications.

## Evolution Steps of the Proposed Textenna

The very famous Tai-Chi symbol inspires the present textile antenna design. Here in the sign, two equal forces acted upon each other, ultimately leading to the system's harmony. The design characteristics of the proposed antenna were done in Ansys High-Frequency Structure Simulator (HFSS) 19.0 software. Three iterations are carefully designed to achieve the Tai-Chi topology in the present antenna model, as seen in Fig. 8.2. For that purpose, together with simulation and practical development, the dimensions of the jute substrate are considered as 20 × 16 × 1.5 mm$^3$ (20 mm of length, 16 mm of width, and a height of 1.5 mm) (Ram Sandeep et al. 2020). The antenna consists of a circular patch and ground elements in the first iteration. This design has an operating frequency of 4.8 GHz, as seen in Fig. 8.3. Later in design step-2, the circular elements were converted into half circles, and this model resonated at 2.2, 5.2, and 6.9 GHz. In the final step, the half circles were converted into crescent-shaped elements, and this design operates at 3.5, 4.9, and 5.8 GHz. The overall antenna design with geometry is shown in Fig. 8.4.

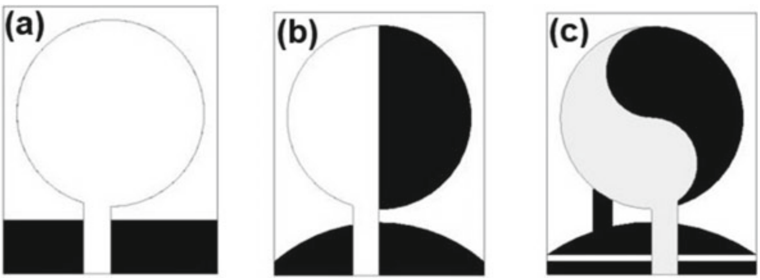



**Fig. 8.2** The design procedure of the textenna: **a** step-1, **b** step-2, and **c** step-3

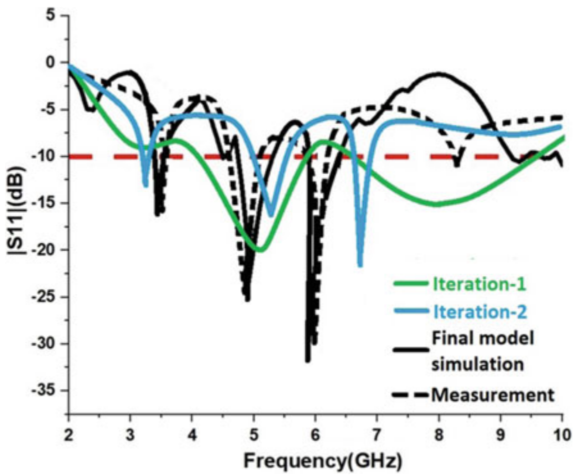



**Fig. 8.3** The reflection coefficient concerning iterations

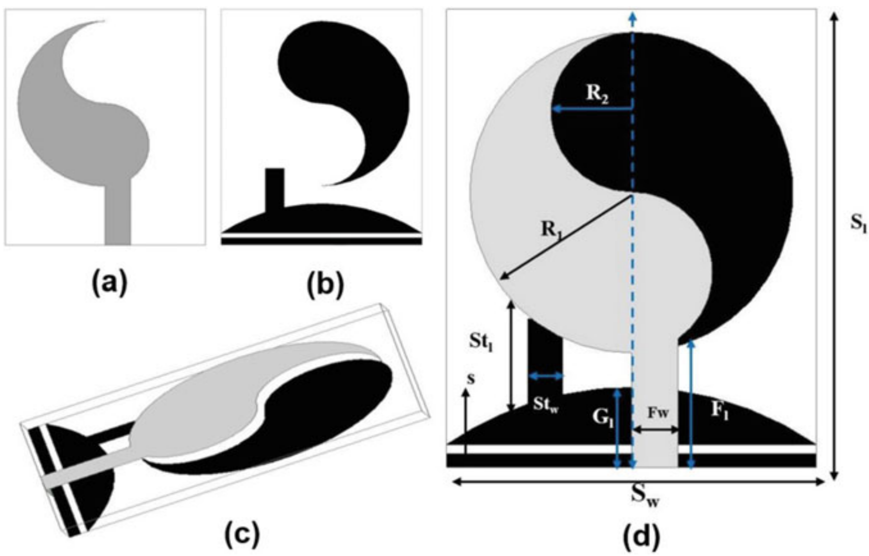



**Fig. 8.4** The topology of the textile antenna: **a** patch perspective, **b** ground perspective, **c** lateral perspective, and **d** overall geometry

## Validation of the Proposed Textenna

The fabricated prototype on a jute substrate is illustrated in Fig. 8.5; the patch and ground layers were realized through conductive paint. It is validated in an anechoic chamber to test its radiating behavior and circular polarization feature in the operating frequencies. To accomplish this task, initially, the resonating frequencies at the

**Fig. 8.5** The photographic images of the prototype: **a** patch and **b** ground

operating bands were tested. This is followed by testing antennas' circular polarized features through the Axial ratios.

## Reflection Coefficient |S11|

As seen in Fig. 8.6, the developed prototype is operating successfully at 3.5, 4.9, and 5.8 GHz. Also, there is a decent match that was observed between the practical measurement and the simulation.

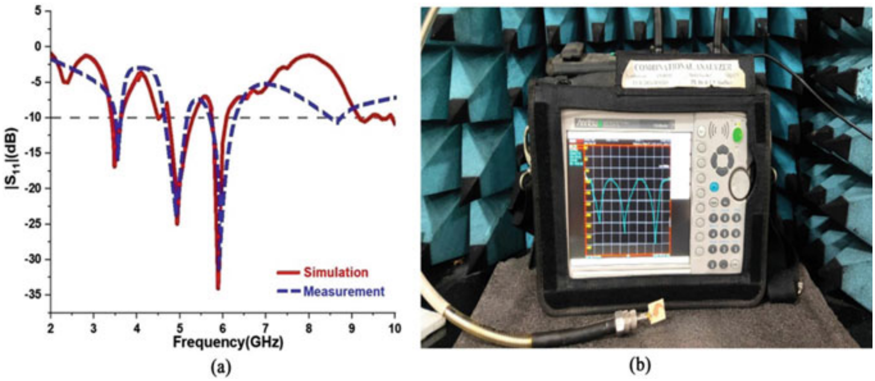



**Fig. 8.6** |S11| measurement of the proposed textenna: **a** plot and **b** measurement setup

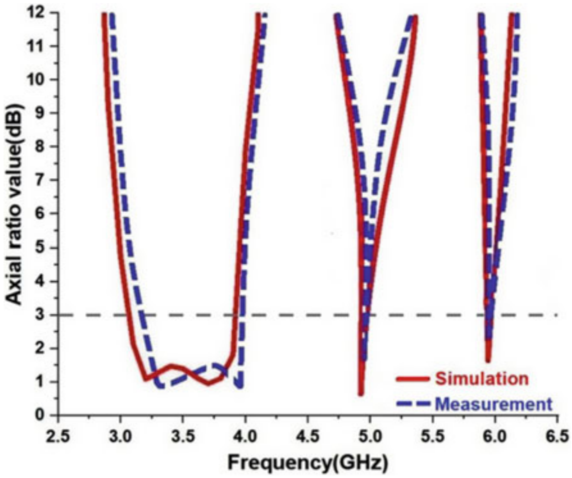



**Fig. 8.7** Simulated and measured axial ratio (ARs) values of the proposed antenna

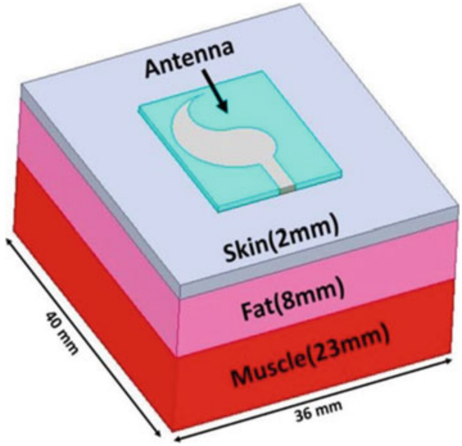
## Axial Ratios

The circular polarization is primarily investigated by observing the Axial ratios. Axial ratios are described as the ratio of the major and minor axes of the polarization ellipse. Ideally, ARs value has to be one. In practice, the axial ratio values can't be unity (1) because the energy is emitted in a slightly elliptical form. So a value of less than three is widely considered as a standard limit for practical measurement of axial ratios. As seen in Fig. 8.7, the axial ratio values of the proposed model, both in the simulation and measurement, were under the 3 dB line; hence the antenna is operating with CP.

## Specific Absorption Rate (SAR) Analysis

The human body is highly dispersed, lossy, and complex tissue. The performance of the antenna will be varied when it's operated in proximity to human tissue. The textenna's radiation behavior also changes, and long-time exposure to electromagnetic radiation will cause an adverse effect on human health. A proper investigation should be carried out on the textile antenna when it is designed for wearable applications. This study on the proposed textile antenna evaluates the SAR value and antenna's resonating behavior on the three-layered phantom model and also assesses directly the human body. As illustrated in Fig. 8.8, the body model comprises muscle, fat, and skin.

**Fig. 8.8** Illustration of the textile antenna on top of the three-layer body phantom model




## Proposed Textenna: Functional Behavior while Operating on the Human Body

As seen in Fig. 8.9, the textenna was placed directly on the human body and assessed in an anechoic space. Both in the simulation and measurement, a decent match has been noted. While placing the prototype jute antenna on the human body, a slight variation in the resonating frequencies is reported, and they are resonating at 3.45, 4.93, and 5.78 GHz. These reported variations are due to human tissue lossy and conductive behavior.

The IEEE standards (IEEE/IEC std 62,704) and European standards-International Commission on Non-Ionizing Radiation Protection (ICNIRP) have issued the guidelines for the safe SAR limits (IEEE Standards 1992). The threshold limit for

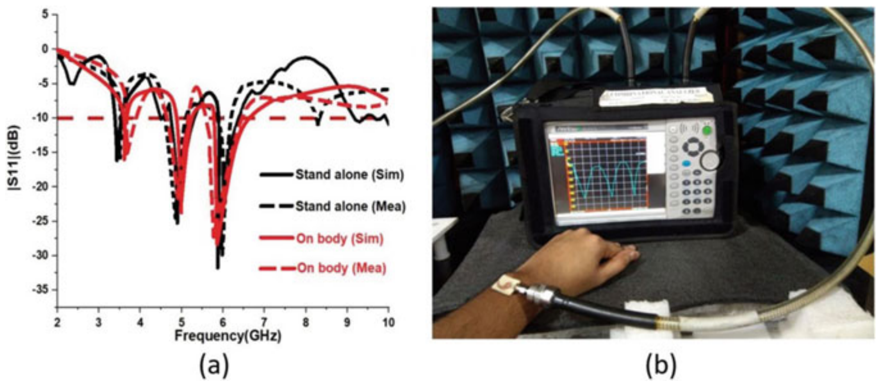



**Fig. 8.9** The proposed textennas: **a** simulation and measurement of |S11| on the human body and **b** measurement setup

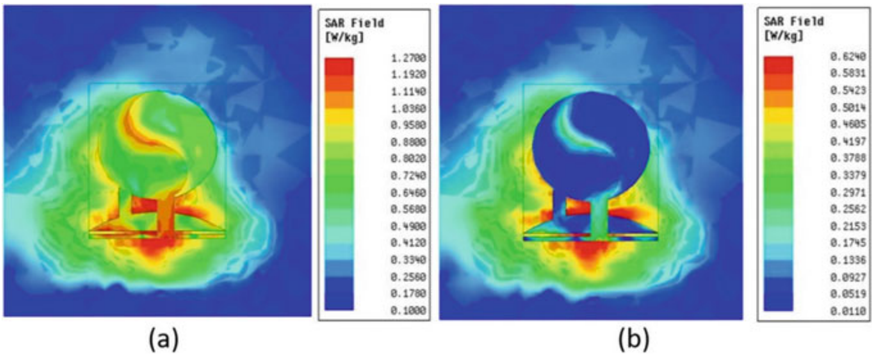



**Fig. 8.10** The proposed textennas SAR analysis on body model at 3.5 GHz for **a** 1 and **b** 10 g of tissue

maximum SAR in 1 g of tissue is 1.6 W/Kg; the threshold limit for 10 g of tissue is 2W/Kg.

## SAR Analysis at 3.5 GHz (Wi-MAX)

As illustrated in Fig. 8.10a, at 3.5 GHz frequency for 1 g of tissue, the SAR value is 1.270 W/Kg. Its corresponding value for 10 g of tissue is 0.6240 W/Kg, as shown in Fig. 8.10b. These values are under the IEEE and European standards' safe limits. So the proposed antenna has safe operating SAR limits at 3.5 GHz frequency of Wi-MAX band applications (Sandeep et al. 2021). Tiwari and Malik (2021), Failed (2021), Kaur and Malik 2021.

## SAR Analysis at 4.9 GHz (WLAN)

As illustrated in Fig. 8.11a, at 4.9 GHz frequency for 1 g of tissue, the SAR value is 1.010 W/Kg. Its proportionate value for the 10 g of tissue is 0.5160 W/Kg, as shown in Fig. 8.11b. It concluded that the proposed antenna has safe operating SAR limits at 4.9 GHz frequency of WLAN band applications.

## SAR Analysis at 5.8 GHz (ISM Band)

As illustrated in Fig. 8.12a, at 5.8 GHz frequency, for 1 g of tissue, the SAR value is 0.7300 W/Kg. Its equivalent value for the 10 g of tissue is 0.386 W/Kg, as shown

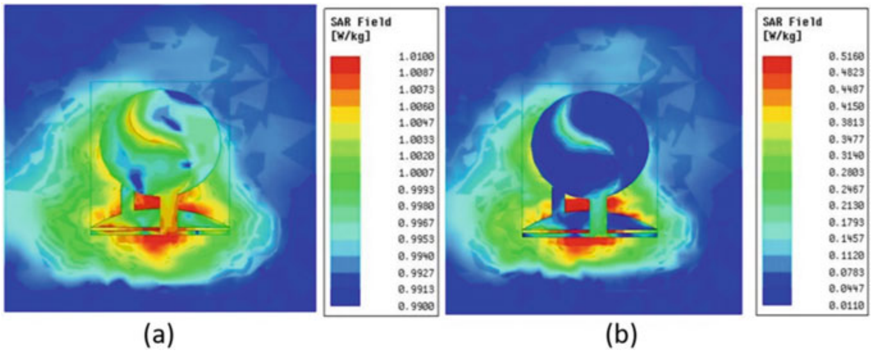



**Fig. 8.11** The proposed textennas SAR analysis on body model at 4.9 GHz for **a** 1 and **b** 10 g of tissue

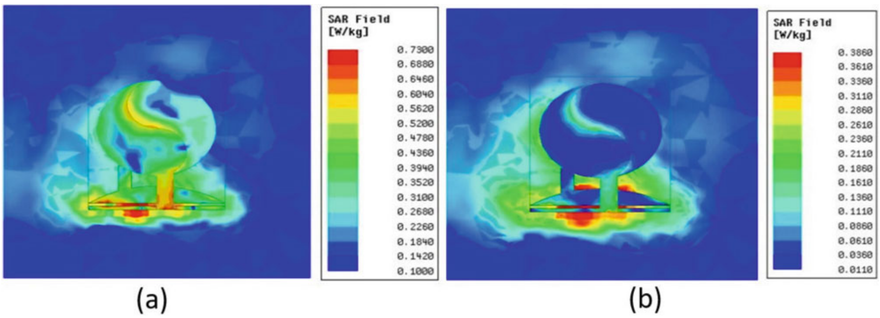



**Fig. 8.12** The proposed textennas SAR analysis on body model at 5.8 GHz for **a** 1 and **b** 10 g of tissue

in Fig. 8.12b. Hence, it concluded that the proposed antenna has safe operating SAR limits at 5.8 GHz frequency of ISM band applications.

## Conclusion

In this communication, a highly portable circularly polarized textile antenna was proposed and developed on a flexible jute substrate. The antenna is intended for bio-medical on-body wireless communication at 5.8 GHz. A safe SAR value is a must for such on-body communication since high SAR values possibly damage the human tissue on long exposures. So the antenna's SAR value is methodologically analyzed for 1 and 10 g of tissue. This analysis of the developed textenna concluded that for all the three operating frequencies, both at 1 and 10 g of tissue, the textenna performs well with safe SAR limits as prescribed by IEEE standards (IEEE/IEC std

62,704) and European standards (ICNIRP). So it is determined that this antenna is found safe to apply for on-body wireless communication applications as a whole.

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