SAR Analysis of Jute Substrate based Tri-band Antenna for Wearable Applications

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Abstract: In this communication, a textile-based circularly polarized monopole antenna was developed on jute material. The proposed textile antenna functions in the tri bands of WiMAX, WLAN, and ISM bands at the frequencies of 3.5, 4.9, and 5.8 GHz. This design was also resonating with the circular polarization. The proposed antenna was fabricated on the jute fabric and has shown an excellent characteristic in terms of resonating frequencies and axial ratios. The proposed antenna aims to work in the nearness of the human; for that purpose, we also investigated the antenna’s performance by employing it on the human body. The on-body simulation analysis was performed on a three-layer body phantom model, which was developed by considering the electrical characteristics of muscle, fat, and the skin. A good agreement in terms of the operating frequencies was observed between the measurement values in stand-alone conditions and on body placement. Specific Absorption Rate (SAR) investigation was also performed on both 1 gram and 10 grams of tissue. The results obtained from the simulation are within the SAR standards’ limits, which shows the textile antenna's excellent performance.

Keywords: Monopole textile antenna, on-body applications, SAR analysis.

1. Introduction

In the last decade, the on-body communication system has gained popularity because of its vast applications in rescue, healthcare, and entertainment [1]. To design these body-centric wireless communication systems, the antennas must accommodate the human body environment. The absorption power of the antenna should be low by being more efficient and flexible. In real-time applications, these antennas must maintain a secure connection with other devices even if they function on the human body. The antenna’s performance can be affected by deformation and movements of the body [2]. So, designing the body-mounted antennas for real-time applications is more complicated than traditional antennas [3].

In the recent past, there has been a special interest shown towards wearable antennas for off-body communication. Which is designed using different fabrication techniques like polydimethylsiloxane (PDMS) [4], liquid metal [5], and embroidered textiles [6], but the developing attention for on-body communications demands antennas to be flexible and must be fit on the human body. While realizing the wearable antennas, the textile material is the perfect option because of its properties, low cost, easy integration with garments, and flexibility (essential in practical applications) [7]. For on-body communication, numerous models have been developed on textile antennas using different approaches [8]. It’s also reported that the artificial magnetic conductor (AMC) and electromagnetic bandgap (EBG) antenna designs help reduce the electromagnetic coupling to the human body, reducing the damage when comparing with the conventional antennas [9]. Feeding methods must also be carefully designed; feeding methods like probe-fed [10] and aperture coupled methods [11] are not suitable for the on-body applications. Textile antennas have shown a low SAR value; when compared...
to traditional rigid antennas. The backward radiations affect the human body and can be reduced by carefully selecting the textile materials as an appropriate substrate [12].

Several studies have examined the antenna's behavior, which was developed for off-body communication applications. In this study, we have developed a textile antenna intended for on-body communication. Section 2 presents the antenna design procedure. Section 3 validates the antenna behavior while placing it on the human body. Section 4 analyses the SAR of the proposed antenna in the operating frequencies for 1 gram and 10 grams of tissue. This unique antenna can work concurrently in both on and off-body approaches.

2. The Antenna Design

The Yin-yang symbol inspires the proposed design. The propounded antenna is developed on the natural fiber-based jute textile with a thickness of 1.5 mm, a length of 20 mm, and a width of 16 mm. Upon the vast availability of the natural fibers, jute material is selected as the substrate because of its skin, environmental and mechanical properties [13]. The conductivity was eventuated using the copper paint, and it was applied by the traditional brush painting method. Fig. 1(a) illustrates the proposed antennas' topology. In stand-alone conditions, the proposed model operates in WiMAX, WLAN, and ISM bands at the frequencies of 3.5, 4.9, and 5.8 GHz.

Fig. 1. (a) The antenna topology, and (b) textile antenna mounted on three layers human body Phantom model.

2.1. Antenna behavior on Flat-Body Phantom

Textile antennas are designed to work in the human body's proximity, which will affect the antenna's performance because of the lossy and heterogeneous nature of the human body. To evaluate the antenna's behavior on the human body, a three-layer body model was created in the commercially available ANSYS HFSS software, which comprises skin, fat, and muscle and is demonstrated in Fig. 1(b). The three-layer body phantom model's conductivity and average permittivity are as follows; for the skin layer with a thickness of 2 mm, the values are $\sigma = 5.0138$, and $\varepsilon_r = 31.29$. For the fat layer of thickness 8 mm, the values are $\sigma = 0.1$, and $\varepsilon_r = 5.28$; for the muscle layer with a thickness of 23 mm, its values are $\sigma$
=1.705 and εr=52.79. As illustrated in Fig. 2(a), compared with the stand-alone condition, in the on-body simulation, the resonating frequencies were varying slightly in all three bands and operating at 3.45, 4.93 5.78 GHz. These shifts in the operating frequencies are observed because of the human body's conductive and lossy nature. The prototype is fabricated and tested in an anechoic chamber by placing it on the human body.

3. SAR Analysis
The proposed tri-band textennas Specific Absorption Rate (SAR) on the three-layer body phantom model was analyzed in this section. The IEEE standards (IEEE/IEC std 62704) were taken as the SAR analysis threshold limits. SAR calculation was calculated on both 1 gram of tissue and 10 grams of tissue. For 1 gram of tissue, the standard's safe level is 1.6 W/Kg, and for the 10 grams of tissue, the safe limit is 2W/Kg as per the European standards (ICNIRP). Traditional rigid antennas are detuned when operated in the proximity of the human body. This happens because of the human body's conductive nature, and impedance mismatch results in the backward reflection of the available power. This back reflection increases the SAR value in traditional antennas. In this study, Jute fabric has been used as the substrate. The physical and mechanical properties of jute show its highly flexible nature. The textile's air voids help absorb the back radiation and reduce its impact on the human body.
3.1. SAR analysis for 3.5 GHz
The proposed antenna SAR values at 3.5 GHz for 1 gram of tissue are shown in Fig. 3(a). The SAR values are 1.270 W/Kg and are in the safe range and within the IEEE standards threshold. As illustrated in Fig. 3(b), for 10 grams of tissue, the SAR values are 0.624 W/Kg, which falls under the IEEE standards. Both for 1 gram and 10 grams of tissue, the antenna resonates in WiMAX bands with a safe SAR value range.

3.2. SAR analysis for 4.9 GHz
The proposed antenna SAR values at 4.9 GHz for 1 gram of tissue are shown in Fig. 4(a). The SAR values are 1.010 W/Kg and are in the safe range and within the IEEE standards threshold. As shown in Fig. 4(b) for 10 grams of tissue, the SAR values are 0.516 W/Kg, which falls under the IEEE standards.
For both 1 gram and 10 grams of tissue, the antenna resonates in WLAN bands with a safe SAR value range.

3.3. SAR analysis for 5.8 GHz

The proposed antenna SAR values at 3.5 GHz for 1 gram of tissue are shown in Fig. 5(a). The SAR values are 0.730 W/Kg and are in the safe range and within the IEEE standards threshold. As illustrated in Fig. 5(b) for 10 grams of tissue, the SAR values are 0.386 W/Kg, which falls under the IEEE standards. For both the 1 gram and 10 grams of tissue, the antenna resonates in ISM bands with a safe SAR value range.

4. Conclusion

In this study, a compact tri-band antenna was proposed and fabricated on the jute fabric. The proposed model is operating in 3.5, 4.9, and 5.8 GHz frequencies with circular polarization. The proposed antenna was developed for on-body communication applications, so it's analyzed on a three-layer human body phantom model containing skin, fat, and muscle. An acceptable shift in the resonating frequencies is observed after placing it on the phantom model. To validate the antenna's radiating performance, a prototype was built on jute material and tested on the body in an anechoic chamber. The measurement results have shown a decent agreement with the simulation values. SAR investigation was also performed for 1 gram of tissue and 10 grams of tissue. The SAR values of the proposed antenna are within the safe limits and are within the threshold values of the IEEE standards (IEEE/IEC std 62704). These values furtherly confess the textile antenna's excellent performance by adapting the jute material as a substrate.

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