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Conformal Wearable Antennas for WBAN Applications

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***Abstract*—Increasingly recent research about wearable antennas has been provoked widespread concern for wireless body area network (WBAN) application. This paper reviews the state-of-the-art wearable antennas on textile materials focusing on the design with dual band and UWB. This paper also presents the challenges and considerations when designing a suitable wearable antenna.**

***Index Terms*—Wearable antennas，patch antennas，textile antennas，WBAN applications**

I. Introduction

WIRELESS body area network (WBAN) technology has the potential to provide an unprecedented opportunity for ubiquitous real-time healthcare and fitness monitoring in ambulances, emergency rooms, operating theatres, postoperative recovery rooms, clinics, homes and even on the move; such that many diseases could be prevented through early detection and doctors could give patients efficient advice on improving their health [1]. In recent years, there has been increasing concern about the safety of WBAN systems, particularly wearable electronics, over a multitude of applications including medical, entertainment and military. A key feature of these wearable electronics is that they have to allow wireless communications from or to the body via conformal and wearable antennas. Therefore, wearable antennas play a pivotal role in wireless on-body centric communications and arouse significant attention in research. Since wearable antennas operate in close proximity to the human body, the loading effect due to the lossy nature of body tissues coupled with their high dielectric constants and conductivity makes the design of a high radiation efficiency antenna challenging. This is compounded by the desire and requirement for such antennas to be light weight, low cost, be maintenance-free and require no installation.

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One of the dominant research focuses in wearable antennas for WBAN applications is the patch antenna, due to its relatively high directivity, as a result of the large ground plane used in its design. Besides the directivity, microstrip patch antennas have some significant advantages for on-body wearables, the three major ones being: their ease of construction, their cost effectiveness and the relative isolation achieved between the radiating element and the body due to the ground plane, which leads to a significant reduction in energy absorbed by the body. [2]. However, patch antennas tend to be low bandwidth and may need to be relatively large if they are to be robust against perturbation by the body [3].

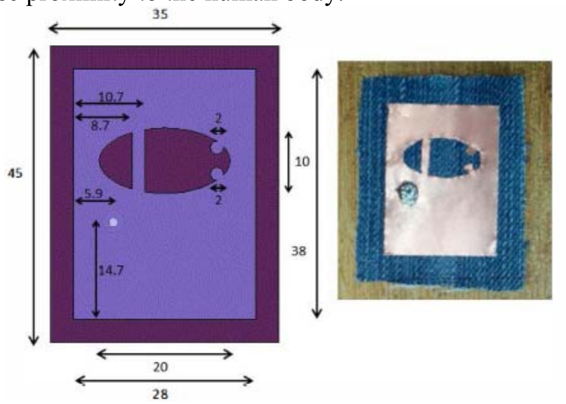
With the development of wearable antennas, studies on patch antennas have mainly focused on flexible materials. The properties of the materials used can influence the behavior of the antenna employed. For example, the bandwidth and the efficiency of a planar microstrip antenna are mainly determined by the permittivity and the thickness of the substrate [4]. The use of textiles in wearable antennas requires the characterization of their properties. Electro-textiles are conductive fabrics constructed by mixing conductive metal or polymer threads with normal textiles. These fabrics, which are wearable, durable and flexible, make it suitable for wearable contexts. The conductive textile is expected to have low and stable electrical resistance to minimize losses. The flexibility of the materials is also needed so that the antenna can be deformed over the cloth. Substrate selection is a critical step in designing a textile or wearable antenna, in order to be robust for a specific application. In general, textiles present a considerably low dielectric constant that reduces the surface wave losses and increases the impedance bandwidth of the antenna [5].

In this paper, a review of wearable textile antennas with patch structures will be presented in Section II. Section III and IV provide some challenges or considerations for wearable antennas and the conclusion of this paper, respectively.

II. Wearable Patch Antennas

A. *On-body Textile Antenna*

A microstrip on-body antenna with probe-feed excitation is presented in [6]. The design of a proposed planar on-body antenna along with its dimensions is shown in Fig. 1(a), and the manufactured prototype is shown in Fig. 1(b). The antenna has been designed and fabricated using jean as the substrate and copper tape as the patch radiating element and ground, to provide flexibility to the conformal antenna. The jean material used has a relative permittivity of l.68, a loss tangent of 0.01 and a thickness of 1 mm. Slots in an antenna have been designed to attain adequate bandwidth, high gain and to have minimum antenna parameter variation when in close proximity to the human body.



(a) Simulated Design (b) Fabricated Prototype
Fig.1. Proposed Antenna with dimensions in millimeters

For near body effects analysis in HFSS, an antenna of average clothing thickness has been placed at a 5 mm distance from a body phantom. Air has been used between the textile antenna and body model (skin, fat, muscle and bone), but this air spacing size has very little effect on antenna performance. The near body performance analysis setup is shown in Fig. 2.

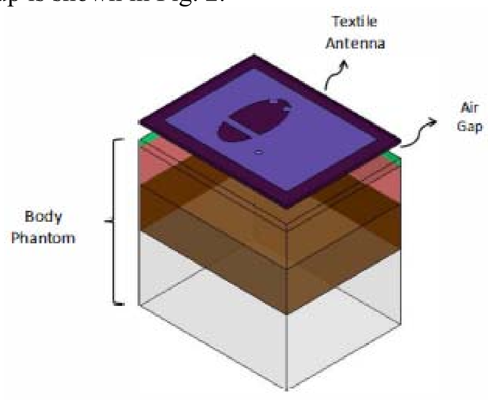


Fig. 2. Near body performance analysis setup

Simulated and Measured return loss results for the proposed antenna both with and without the presence of a body phantom are presented in Fig. 3.

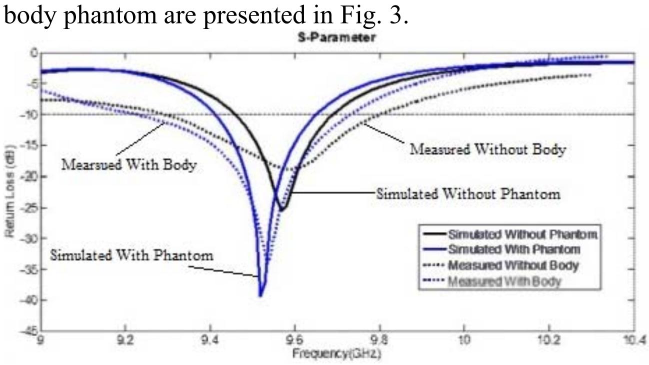


Fig. 3. Simulated and Measured S-11 of proposed antenna with and without near body effects

The results show that the antenna is suitable for function and is efficient over a 200 MHz band from 9.45 to 9.65 GHz. Over this band, the proposed antenna achieved reasonably high gains of 12.8 dB and 13.2 dB with and without body phantom respectively [6].

B. *Dual Band Diamond Textile Wearable Antenna*

The diamond-shaped dipole antenna is another option for wearable applications, able to offer improved bandwidth and efficiency over the standard dipole. The combination of two diamond-shaped dipole antennas offers the possibility for dual band use and increased bandwidth. Fig. 4 shows the commercially available electro textile diamond-shaped dipole dual antenna, it has a dielectric constant of 1.7, copper foil tape, which has high conductivity of 5.88×10^{7} and a thickness of 0.035 mm as the conducting element [7].

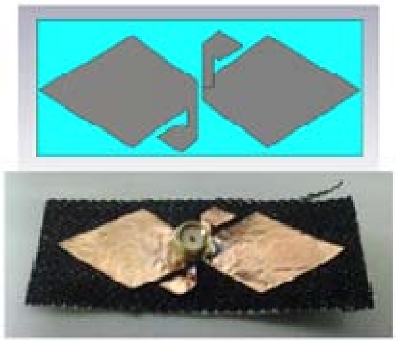


Fig. 4. Dual wideband textile antenna design using CST and prototype of denim antenna

Using the CST software with its built in Gustav male model, a simulation is developed to investigate the performance of the textile antenna. The antenna performance is investigated under three conditions: free space (no body phantom), 3 mm from the backside of the phantom (shown in Fig. 5) and in the same position but with the 3 mm gap filled by a layer of wash cotton (clothes) (permittivity 1.51 and loss tangent of 0.021 at 2.45 GHz) [8].

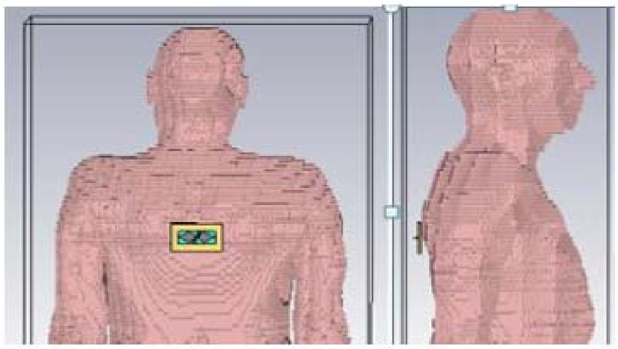


Fig. 5. Location of antenna at the backside of Gustav body

Fig. 6 shows that, the presence of the phantom and clothing (wash cotton) exhibits little frequency detuning or fluctuation in bandwidth around the dual designed resonances at 2.45 GHz and 5.8 GHz. Placing the antenna on the backside of the body results in an immediate 85% drop (from 99% to 14%) in efficiency at 2.45 GHz and 23.5% (from 96% to 72.5%) at 5.8GHz [7].

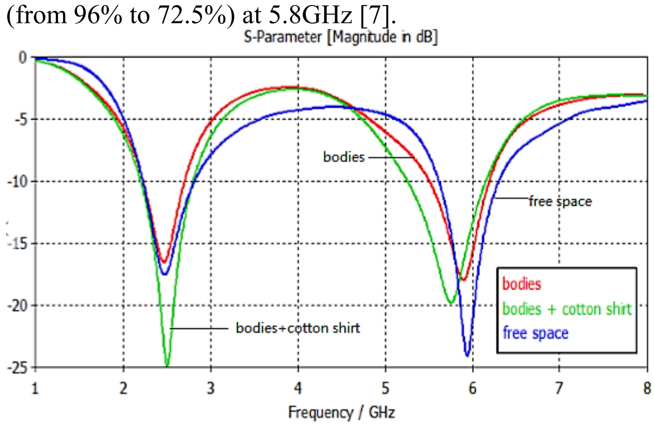


Fig.6. Simulated return loss result of the textile antenna blue (with bodies and cotton clothes), red (free space) and green (with bodies)

C. *Polygon-Shaped Slotted Dual-band Antenna*

To reduce the patch area and increase the electrical length, a polygon-shaped patch antenna with a ring-shaped slot was proposed in [9] to operate within the two mobile frequency bands, GSM-900 and GSM-1800. The designed patch antenna consists of a substrate located in between ground plane and patch. The material used for ground plane and patch is copper. The substrate is jean fabric that has a thickness of 1 mm, dielectric constant 1.7, and loss tangent 0.025 [10]. The photograph of the handmade prototype is given in Fig. 7.

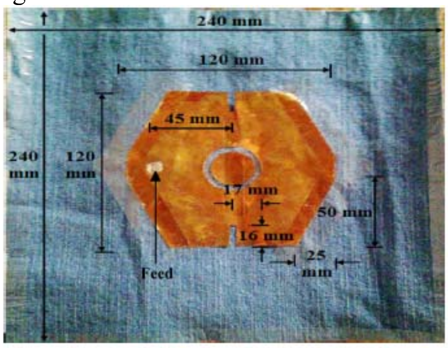


Fig. 7. Fabricated prototype of the proposed dual-band antenna

The simulated and measured plots for free space and on-body measurements are shown in Fig. 8. The directivity values at the higher and lower resonant frequencies are 8.1 and 7.4 dBi, respectively. The corresponding radiation (total) efficiencies are 20.5% (16.7%) and 10.3% (4.7%) [9].

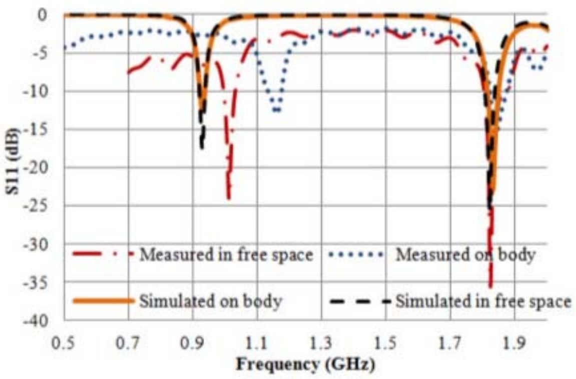


Fig. 8. Simulated and measured (free space and on-body) S11 response

D. *Small Planar UWB Wearable Antenna*

A small planar UWB wearable antenna proposed in [11], consists of a substrate made of jean and a metallic radiator (adhesive copper tape). The average values of the dielectric constant and loss tangent are 1.76 and 0.078 respectively. Fig. 9 shows the fabricated antenna.

(a) (b)

Fig. 9. Prototype of the proposed antenna, a) front and b) back views

A portion of the human arm was selected as the antenna location and the appropriate phantom section chosen for simulation in CST. Fig. 10 illustrates the top and front view of the phantom with four layers (skin, fat, muscle and bone). The resulting S_{11} parameters are shown in Fig. 11 with acceptable bandwidth achieved from 3 to 4.5 GHz and from 6.5 to 11.5 GHz. The antenna achieves a good efficiency reaching higher than 65% at the higher end of the UWB band [11].

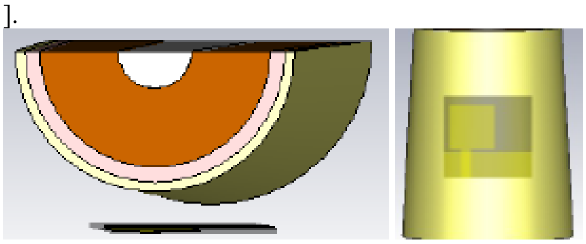


Fig. 10. Human arm model developed in CST MWS, a) top view, b) front view

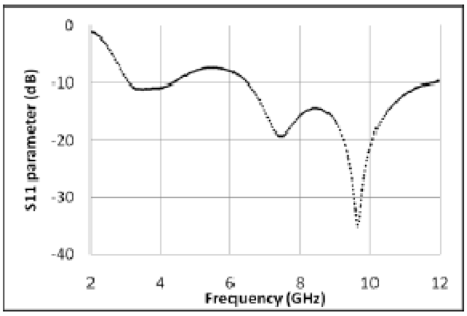


Fig.11. S11 parameter at 5 mm far from the arm model

E. *Compact UWB Wearable Antenna*

By combining slot and truncation techniques, the impedance bandwidth of the proposed patch antenna has been improved in [12]. A flexible textile substrate (jean) with metallic radiator (adhesive copper tape) is used for construction of the wearable antenna with a dielectric constant of 1.76 and loss tangent of 0.078. The fabricated antenna is shown in Fig. 12.

(a) (b)

Fig. 12. Prototype of the proposed antenna (a) front view (b) back view

Fig. 13 shows the simulated return loss for the antenna in the presence of the human body. The human body phantom here is a conical-shaped arm model consisting of skin, fat, muscle and bone. Taking the upper frequency limit as 10.6 GHz and lower frequency as 4.2 GHz, the improved bandwidth covers up to 86.48% [12]. The gains at the maximums are 2.74 dB at 3.0 GHz, 4.17 dB and 4.07 dB at 7.0 GHz and 9.0 GHz respectively.

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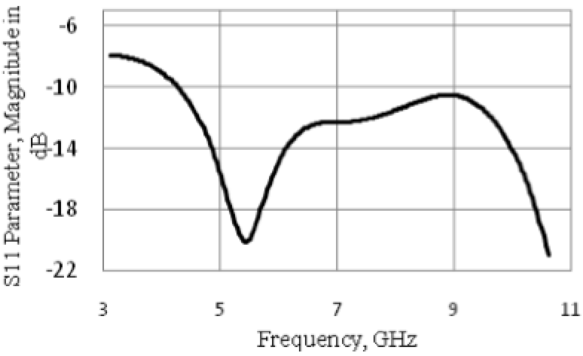

Fig. 13. S11 parameter at the presence of human body

III. Some challenges and Considerations

The patch antenna is a good candidate for wearable devices, since it is usually low profile and easy to fabricate. Using textile materials as substrates helps reduce surface wave losses and enhances the overall bandwidth. When a wearable textile antenna is worn on the human body, long term electromagnetic radiation poses potential health risks. Minimization of Specific Absorption Rate is therefore a challenge for wearable patch antennas. On the other hand, metamaterials such as artificial magnetic conductor (AMC) surfaces, high impedance surfaces (HIS) or the electromagnetic bandgap (EBG) structures have emerged as promising designs for wearable antennas owing to their wider bandwidth, reduction in backward wave energy and hence good SAR values [13-14]. The problems in the design of these structures, however, are the increasing overall antenna size and antenna fabrication complexity.

Additionally, antenna performance and robustness under deformations (bending, crumpling, wrinkling, wetting) have to be investigated and incorporated into the design of wearable antennas to meet conformal requirements.

IV. Conclusion

The antenna is an essential element in wireless body-centric networks for WBAN applications. Its complexity depends on the radio transceiver requirements and also on the propagation characteristics of the surrounding environment. Not only textile patch antennas but also antennas with metamaterial structures for wearable devices have their own merits and demerits. It is important to the continued improvement of WBAN applications to design optimized wearable antenna, balancing the trade-offs between an antennas performance and its size and complexity.

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