Compact UWB Wearable Antenna with Improved Bandwidth and Low SAR

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Abstract— SAR calculation for UWB textile antenna is reported in this paper. This paper presents simulation results of the antenna performance at the conditions of free space and placement at a distance from a portion of a human body. A summary of measurement results of the return loss of the antenna is also included. The simulated $S_{11}$ parameter shows that the antenna operates within the range 2.25 GHz and 12.19 GHz. The measured return loss has shown that the antenna can operate within 3.04 GHz-10.3 GHz giving a bandwidth of 108%. The performance antenna near to a human body has been simulated and examined. The SAR (10g) has been evaluated using a four-layer body model.

Keywords— SAR (specific absorption rate), textile, tissue, smart clothes, phantom

I. INTRODUCTION

Since the time when the Federal Communications Commission (FCC), was convinced that the emissions from UWB devices would not interfere with narrow frequency bands devices, ultra-wideband communications have been revived and received renewed interest. There has been a lot of work dedicated to the development of UWB communication systems and there has been an intense research on small UWB antennas and applications [1].

UWB has featured wireless technologies with its merits in high data rate communications, high accuracy radars and imaging systems. UWB technology has been employed for military sector communication systems for decades [2]. Opening the unlicensed spectrum of UWB (3.1GHz – 10.6GHz) for commercial use has brought us variety of systems, for example indoor applications that employ ultra wideband such as wireless multimedia data communication between home appliances (player, screen and PDA and many more) and different area networks like personal area networks (PANs) and wireless area network (WLAN) [3].

The combination of the recent development in wearable applications and miniaturization of electronic devices have led into the creation of small devices that can be carried in pockets or attached to the body [4]. There has been a growing interest in wearable antennas and electronics in the areas of civil, medical, sport and military. This growth has been serving the demands of replacing wired systems with wireless systems creating flexibility and portability. The very recent development has aimed to integrate UWB wearable systems and textile technology [5], [6].

The utilization of textile materials as antenna substrates has allowed designing body-worn antennas systems embedded into the so-called “smart clothes” which offers a host of entertainment possibilities. In most cases, textile antennas can come as fully textile as in [7], while fabric antenna refers to that the substrate is a textile material such as fleece fabric. Textile materials have attractive properties such as very low dielectric constant, which helps reduce surface wave losses and enhances the overall bandwidth [8]. Textile and fabric UWB antennas have been studied in [9], [5] or a metallic radiator on a textile substrate as in [10].

After all of this growth in the technology, the scientific community has been giving a considerable attention to the impact of the interaction between electromagnetic (EM) fields and the human body as in [11-14]. The interaction between human head and cellular phones has been presented in [15], [16] and interaction between human head and terminal antennas has been studied in [17], [18]. In general, the research was made so that the antenna does not radiate over the limit set by the standards [19], [20], which may lead to possible hazards to human health from radio frequency (RF) exposure.

General studies have been conducted on the evaluation of the power absorbed by the human body and the Specific Absorption Rate (SAR). Kuster [15] has evaluated the absorption mechanism for homogenous body model while Kivekas [22] has considered homogenous and layered body model.

Klemm [21] has further studied the interactions of UWB antennas used in wearable applications on homogenous and layered human body models. SAR results of very near antennas to the body have been computed in order to investigate the influence of the body. The first evaluation of SAR was on a simple homogenous model composing one tissue (muscle of 50 mm thickness). The second model consisted of three-layers (skin: 0.5, 1 and 2 mm; fat: 1, 3 and 6 mm; muscle: 50 mm). The study assumed all models to be planar neglecting the curvature of the body.

This paper studies a UWB antenna made on textile substrate for wearable applications. This includes studying the performance of the antenna in free space and SAR.
evaluation when placing near to the human body. Portion of a human body consisting of four-layer model (skin, fat, muscle and bone) has been considered for the evaluation. Curvature of the body part (human arm) has been approximated.

II. ANTENNA DESIGN

The proposed antenna has been designed to fit in UWB wearable applications. Therefore geometry and materials used have been considered. The following is the summary of the details of the proposed antenna.

A. Antenna Materials

The antenna is consisting of a flexible textile substrate (jeans) with metallic radiator (adhesive copper tape). In order to insure that the properties of the jeans used in fabrication are known, an experimental study has been conducted to measure the dielectric constant and loss tangent using Agilent 85070E Dielectric Probe Kit, 200 MHz to 50 GHz. Figure 1 and 2 illustrate the behavior of the material in the range of 3-10 GHz.

![Figure 1: Jeans dielectric constant with respect to UWB frequency range.](image)

![Figure 2: Jeans loss tangent with respect to UWB frequency range.](image)

The value of epsilon $\varepsilon$ and loss tangent have been averaged to 1.76, 0.078 respectively.

B. Antenna Geometry

The dimensions of antenna were initially calculated as a rectangular patch antenna. Adjustments to the geometry have been required in order to enhance the bandwidth. The patch of the antenna has been optimized by combining slot as in [23] and truncation techniques as in [24], which helped improve the impedance bandwidth with keeping size to less than previous proposed UWB antennas on jeans substrate. While ground plane was adjusted to partial and notched across the feeding line to an optimum length as in [25]. Figure 3 shows the finalized design of the antenna.

![Figure 3: Geometry of the proposed antenna (a) front view (b) back view.](image)

The proposed antenna is fabricated on jeans substrate with thickness of 1 mm and dimensions of $L \times W$ (46 × 46 mm$^2$), while the patch has dimensions of $l \times w$ (25 × 21.6 mm$^2$). The patch has been truncated at the two lower corners with a rectangular of radius $r = 4$ mm. The slot of the patch is $S_l \times S_w$ (2 × 11 mm$^2$). The antenna is fed using a strip line of $l_f = 18$ mm and $w_f = 3.64$ mm. The ground plane has been reduced to $l_g \times W$ (13.8 × 46 mm$^2$) and notched with $l_n \times w_n$ (8 × 2.6 mm$^2$).

![Figure 4: Prototype of the proposed antenna (a) front view (b) back view.](image)

III. RESULTS AND DISCUSSIONS

The performance of the proposed antenna has been simulated using CST. Return loss has been carried out within the frequency range 2.0 GHz-13.0 GHz. Figure 5 illustrates the simulated and measured S11 parameter of the antenna at free space. The simulated result shows that the proposed antenna can operate from 2.25 GHz and 12.19 GHz which indicates that the antenna covers the entire range of UWB spectrum at free space condition with improved bandwidth up to 137% according to equation 1 [1].

![Figure 5: Simulated and measured S11 parameter of the antenna at free space.](image)

It is noticeable to see that the measured S11 parameter of the antenna at free space also operates in a wide bandwidth (3.04 GHz-10.3 GHz). In spite of the fact it is less than the simulated one; the improved bandwidth is larger than 108%. The curve of the measured S11 parameter appears with slight difference from the simulated one for many reasons. The antenna was simulated on smooth jeans represented by solid planes, while the texture of the real material has different composition. In addition, cutting the copper tape to match the design will involve errors while tracing the edges and slots of both of the patch and the ground planes.
The radiation pattern of the proposed antenna at far-field has been simulated in 2D plot mode. The plot indicates that the gain increases as the frequency increases. The direction of the radiation tends to be intense at the upper region of the antenna as the frequency goes higher (the antenna is considered to be vertically oriented as in Figure 3). It is seen that the radiation pattern has a maximum gain of 2.74 dB at 3.0 GHz surrounding the antenna. The antenna also has a maximum gain of 4.17 dB and 4.07 dB at 7.0 GHz and 9.0 GHz respectively at the upper region of the antenna (phi~10°-180°, theta~10°-150°). Figure 6 illustrates the simulated radiation pattern in 2D plot mode.

IV. ANTENNA PERFORMANCE AT THE PRESENCE OF THE BODY

The model was developed in CST Microwave Studio. It simply represents a portion of the human body; that is the arm. Four-layer model (skin, fat, muscle and bone) has been considered for the evaluation. Curvature of the body part has been approximated to a conical shape with top and bottom radiuses. The thickness of each layer is taken as skin = 2 mm, fat = 3 mm, muscle = 8 mm and bone = 10 mm (radius) as in [21] and [26].

Body tissue dielectric parameters have been obtained from Body Tissue Dielectric Parameters Tool provided by FCC official website [27]. The antenna has been placed at approximately 1.5 mm from the origin (in this case the bottom of the substrate). Figure 7 shows the simulated return loss for the antenna with the presence of the human body. Considering the higher frequency as 10.6 GHz and lower frequency as 4.2 GHz, the improved bandwidth can reach up to 86.48% according to equation 1.

\[
\text{Fractional bandwidth} = \frac{f_u - f_l}{f_c} \quad \text{(1)}
\]

\[
\text{f_c} = \frac{f_u + f_l}{2} \quad \text{(2)}
\]

The simulated 2D radiation pattern illustrated in Figure 9 shows how the antenna operates at frequencies 3.1, 5.0, 7.0 and 9.0 GHz at body presence. It is noticed that the antenna has very low gain at lower frequencies. It can be seen that the gain for 3.1 GHz has dropped from a maximum of 2.74 dB (at the absence of the body) to a maximum of -1.46 dB
(at the presence of the body). This can be explained due to the distortion, reflection and absorption caused to the EM waves by the body tissues (note that the patch is facing the free space while the ground plane is facing the body). The efficiency of the antenna tends to improve as the frequency increases; this can be found from the computed Total Efficiency provided from 1D Results of CST in Figure 8.

![Figure 7: S11 parameter at the presence of human body.](image)

![Figure 8: Total efficiency at the presence of the body.](image)

**V. SPECIFIC ABSORPTION RATE (SAR)**

Table 1 summarizes the peak 10-g SAR for the body model. The values of SAR change at each different frequency due to the contrast difference of the dielectric constant between skin and fat layers, where the model consists of different internal structure which causes different distribution of the penetrating radiation. The skin has the highest conductivity followed by muscle and bone layers, while the fat has the lowest. This explains that most of the absorbed power occurs on the skin. The highest SAR in the body model occurs at 5.4 GHz and 9 GHz while the lowest at 7 GHz. One way to reduce the SAR value is to place the antenna a bit farther which reduces the amount of radiations that travel toward the body.

**Table 1: Peak 10 g SAR [W/kg] in the 4-layer body model, accepted power = 1W for all frequencies except 3.1 GHz (0.5 W).**

<table>
<thead>
<tr>
<th>Peak 10 g (W/kg)</th>
<th>3.1 GHz</th>
<th>5.4 GHz</th>
<th>7 GHz</th>
<th>9 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 g</td>
<td>1.18</td>
<td>2.21</td>
<td>0.84</td>
<td>1.95</td>
</tr>
</tbody>
</table>

![Figure 9: 2D radiation pattern for the proposed antenna at the presence of the body.](image)

**VI. CONCLUSION**

This paper has introduced the evolution of UWB antenna technology integrated with body-worn systems. The merits of UWB such as high data rate and accuracy have made it the best candidate for wearable antennas.

The recent development of wearable antennas has combined flexibility and portability to the systems attached to the body with the help of textile technology. The production of such “smart-clothes” has brought the concern...
of the scientific community concerns about the interaction between worn systems and the human body in terms of electromagnetic fields.

The proposed antenna was made on jeans substrate whose dielectric constant has been measured. The antenna was designed with different techniques in order to achieve a high bandwidth. The simulated results of the antenna at free have shown that the antenna has 137% improved bandwidth, while the measured results showed 108%. The radiation patterns showed that the gain of the antenna improves with the increase of the frequency.

This paper has summarized some previous efforts on the evaluation of the effects of EM fields on the human body caused by communication systems. Some studies have evaluated the power absorbed by the human body and the specific absorption rate by using homogeneous and inhomogeneous phantom models. The proposed model consists of four-layer body tissues approximating the curvature of the layers. The antenna performance at the presence of the body has shown that the return loss has lower values at low frequencies. The SAR results for 10 g change with the frequency. This could be regarded to the fact that human tissues are anisotropic mediums. The difference in the internal structure of the model has caused the different response of the penetrating radiations. The conductivity of the skin is the main player in the absorption of the radiated power. The future work will focus on investigating methods of reducing the SAR values in order to provide an antenna that meets with the safety level.

REFERENCES