Experimental Study of Optimal UWB Antenna Location for ECG Application

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Abstract—In this paper, the RF transmission performance on the human body for ultra-wideband wireless body area network (UWB WBAN) applications will be evaluated. The UWB pulse that is generated by the transmitter sensor node has a bandwidth of 500 MHz and centered at 4 GHz. The received signal passes through a receiver frontend circuitry before entering the high speed oscilloscope. In this study, the transmission performance measurement will involve placing the printed omni-directional monopole antenna at various receiver locations near/on human body. An identical transmitter antenna will be positioned on the left chest area which corresponds to the electrocardiography (ECG) location. The peak-to-peak amplitude and waveform from the oscilloscope were recorded. From the study, it was found that the optimal receiver location to receive the strongest signal is at the waist area of the human body when the transmit antenna is vertically polarized and receive antenna is horizontally polarized.

I. INTRODUCTION

Applications using Ultra-Wideband (UWB) technology have been extensively researching in recent years, especially in portable computing devices to be worn on the human body. The UWB communication provides the advantages of a potentially high transmission capacity and a low effective isotropic radiated power of less than -41.3 dBm/MHz, which results in a longer battery life for body-centric networks [1]. The UWB antenna should be designed with special considerations to provide the typical parameters such as bandwidth, efficiency, and gain within the limited antenna specifications [2].

Due to growing demands in electrocardiogram (ECG) analyses, the transmitter and receiver transmission performance must not be neglected. ECG research plays an important role in medical research, pharmaceutical research, medical education, training, and health care. Communications from in-body implants and on-body sensors will allow for better diagnoses and improve therapy [3].

A wireless body area sensor network system can be implemented to gather the ECG signals of the human body. They consist of fixed sensor nodes and are a specific type of network structure. Initially, it may be possible to achieve excellent communication within the network. However, various factors such as body movements and varying body orientations and environment may degrade the network coverage [4-6]. A key element of the wireless body area network is the antenna. Therefore, other than to achieve the required impedance and radiation parameters, the antenna must also meet the basic requirements of being biocompatible, compact size, insensitive to the body, mobile, and light weight. The computed antenna characteristics influenced by the human body are very useful for ECG diagnoses [7]. Although the human body is not an ideal medium for the transmission of radio waves, however, it is still partially conductive and consists of materials of different conductivity, dielectric constant, and thickness. Therefore, depending on the frequency of operation, the presence of the human body can lead to high losses caused by power absorption, shift in the resonant frequency, and distortion in the radiation patterns. In order to achieve the optimum overall system performance for ECG applications, the effects of the polarization and position of the receive antenna on the body with respect to the polarization of the transmit antenna will be studied in this paper.

II. MEASUREMENT SETUP

The measurement setup for a transmit-receive antenna system on the body inside the anechoic chamber is shown in Fig. 1(a). In the setup shown in Fig. 1(b), both the transmit and receive antennas were mounted on wooden tripods and oriented face-to-face with each other. The received waveforms when the transmit and receive antennas were separated by 10 cm, 50 cm, and 100 cm in free space were recorded using an oscilloscope and used as a reference. The measurements were taken with the transmit antenna vertically polarized and with the receive antenna vertically and horizontally polarized. The transmitter which generates the UWB signal was passed through the transmit antenna and picked up by the receiver frontend circuitry.

Next, the transmit antenna was placed on the left chest area corresponding to the ECG location and the receive antenna was placed 10 mm away from the human body at three different locations, namely the waist, arm, and chest as shown in Fig. 1(c). From the results, the optimal receive antenna location and orientation with respect to the transmit antenna can be obtained.
**A. Transmitter and Receiver Architectures**

The transmitter module generates the UWB pulse using the 2 ns pulse generator. It is battery operated and can last for 4 hours, which is sufficient for data collection at a particular receiver location. An overview of the transmitter circuitry is as shown in Fig. 2. The ECG electrode is amplified at the input of the microcontroller. The pulse and 4 GHz voltage-controlled oscillator (VCO) will be combined to form the UWB signal centered at 4 GHz with a 500 MHz bandwidth before passing through a pulse-shaping bandpass filter. The digital output of the microcontroller and the UWB signal are passed through the logic gates and will be transmitted using an omni-directional monopole antenna. The received signal passes through a receiver frontend circuitry as shown in Fig. 3, where the baseband signal is recovered and the waveform is recorded using the oscilloscope.

**B. Antenna Design**

Fig. 4 shows the geometry of the omni-directional printed UWB antenna. The overall size of the antenna is 25 mm × 35 mm. The radiator and ground plane are etched on the opposite sides of a PCB (RO4003, εr = 3.38 and 0.813 mm in thickness). The radiator consists of an open-ended vertical rectangular notch of 1 mm × 16 mm located at the center of the radiator such that it is symmetrical about the y-axis. Two horizontal strips of 2 mm × 4 mm are extended from the top left and right corners of the radiator, respectively. The radiator is fed by a microstrip line of a 1.86-mm width located at the center with a 1.5-mm feed gap. The ground plane has a vertical length of 13.5 mm.

**III. RESULTS AND DISCUSSIONS**

**A. Free space Measurements**

The output of the transmitter was directly connected to the oscilloscope and the waveform is shown in Fig. 5(a). The peak-to-peak amplitude of the pulse is 190 mV with a pulse width of 2 ns. In order to observe the effect of the antenna on the pulse characteristics, the transmit antenna was connected to the transmitter and placed in free space while the receive antenna was connected directly to the oscilloscope. The distance between the vertically polarized transmit and receive antennas is 3 cm. From the received waveform shown in Fig. 5(c), no significant pulse spreading was detected, which implies that the antenna system bandwidth is larger than 500 MHz. The
peak-to-peak amplitude of the received pulse has been reduced to 24 mV due to the effect of the free space path loss.

The measurements in free space were performed by mounting the antennas face-to-face on the tripods and separated by \( d = 10, 50, \) and 100 cm. A maximum separation distance of 100 cm was chosen since the distance between the transmitter and receiver on the body is typically less than 100 cm for ECG application. The receive antenna was connected to the receiver frontend circuitry with a low-noise amplifier so as to ensure that the generated baseband signal is large enough to be detected. The transmit antenna is vertically polarized and the peak amplitude of the baseband signal was recorded for the vertical and horizontal polarizations of the receive antenna. Since the antennas are directly facing each other, the peak amplitudes when both the antennas are vertically polarized (V-V) and horizontally polarized (H-H) can be assumed to be the same. Similarly, the amplitudes when the antennas are orthogonally polarized with respect to each other can be assumed to be equal, i.e. V-H=H-V. The results are shown in Table 1.

### Table 1. Effect of antenna polarization and separation on the received signal in free space

<table>
<thead>
<tr>
<th>( d ) (cm)</th>
<th>V-V/H-H</th>
<th>V-H/H-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>80 mV</td>
<td>60 mV</td>
</tr>
<tr>
<td>50</td>
<td>40 mV</td>
<td>10 mV</td>
</tr>
<tr>
<td>100</td>
<td>15 mV</td>
<td>&lt; 5 mV</td>
</tr>
</tbody>
</table>

From the results as shown in Table 1, it can be observed that the signal strength attenuates as the antenna separation increases. The test was carried out using the UWB pulse as shown in Fig. 5(a). A sample of the received baseband signal is shown in Fig. 6 for the case when the transmit and receive antennas are 10 cm apart and vertically polarized.
antennas were placed 10 cm apart and vertically polarized. It can be seen from Table 1 that when both the transmit and receive antennas have the same polarization, a stronger signal can be obtained. Also, as the distance increases, the cross-polarized antenna orientation (V-H/H-V) experiences a greater attenuation. This is due to the signal being too weak before entering the amplifier.

B. On-Body Measurements

The transmission performance on the body was compared at the various receiver locations shown in Fig. 1(c). The transmit and receive antennas were placed 10 mm away from the surface of the human body of height 1.7 m in order to reduce the effect of the body on the antenna. The peak amplitude of the waveforms at the output of the receiver for the various locations were recorded and tabulated in Table 2.

It can be seen that when the receiver was placed at the waist, it is possible to consistently register ECG signals for the different antenna orientations, although the amplitude is generally lower as the signal needs to propagate a longer distance from the chest to the waist. A sample of the received waveform on the waist when the transmit antenna is vertically polarized and receive antenna is horizontally polarized is shown in Fig. 7. On the other hand, when the receiver was located at the arm, weak signals were obtained for most of the antenna orientations despite the closer proximity between the antennas. This is mainly because of the non-line-of-sight between the antennas due to the blockage by the arm. When the receiver was placed on the chest, strong signals can be experienced for most of the antenna orientations due to the closer proximity between the antennas, except for the case where the transmit antenna is horizontally polarized and the receive antenna is vertically polarized, i.e. (H-V). The weak received signal can be possibly due to difference in the polarization as well as the occurrence of radiation nulls due to the presence of the body. Generally, for all the three possible receiver locations, reasonable signal strength can be obtained when the receive antenna is horizontally polarized. As compared to Table 1, the peak amplitude of the received signals has been reduced due to the absorption by the lossy human body.

Table 2. Effect of antenna polarization and location on the received signal

<table>
<thead>
<tr>
<th></th>
<th>V-V</th>
<th>H-V</th>
<th>H-H</th>
<th>V-H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist</td>
<td>6 mV</td>
<td>8 mV</td>
<td>5 mV</td>
<td>10 mV</td>
</tr>
<tr>
<td>Arm</td>
<td>&lt;5 mV</td>
<td>&lt;5 mV</td>
<td>8 mV</td>
<td>8 mV</td>
</tr>
<tr>
<td>Chest</td>
<td>22 mV</td>
<td>&lt;5 mV</td>
<td>12 mV</td>
<td>16 mV</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

This paper presents an experimental study to locate the optimal position of the receiver on the human body for ECG applications. A UWB omni-directional monopole was used as the transmit and receive antennas. Three possible receiver locations, namely the waist, chest, and arm were selected in this study. The transmit waveform is generated at 4 GHz and has a bandwidth of 500 MHz. Using a receiver, the peak amplitude of the waveform of the recovered baseband signal was recorded. The lossy human body has caused the signal strength to be attenuated due to the absorption by the body. The measured results have shown that in order to achieve a more consistent and reliable signal strength for ECG diagnosis, the receiver should be placed at the waist, however, a stronger signal strength can be obtained if the receiver was placed on the chest. Also, with the transmit antenna placed at the left chest area, acceptable signal strength can be obtained for the three proposed receiver locations when the receive antenna is horizontally polarized.

REFERENCES