IEEE International Conference on Ultra-Wideband, 2007. ICUWB 2007. 24-26 Sept. 2007 Page(s):220 - 224

Antennae Polarization for Effective Transmission of UWB Signal around Human Body

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Abstract — **Ultra wideband (UWB) is an emerging technology with promising applications in wireless body area networks (WBANs). Detailed understanding of the propagation mechanism of UWB signal around human body is essential for the development of wearable sensors. However there are currently limited studies describing UWB signal propagation around human body. In this paper, the favorable antennae polarization for effective transmission of signal to receiver is investigated through numerical simulations. The results showed that antennae oriented in perpendicular polarization with respect to body surface provide a lower path loss as compared to horizontal polarization.**

Index Terms — **Body area network, polarization, propagation, ultra wideband.**

I. INTRODUCTION

As the technology in device miniaturization and mobile communications advances, development of health monitoring devices that can be made available for general use has attracted increasing attention in recent years. Wireless body area network (WBAN) [1] is a new enabling system for continuous monitoring and logging of vital physiological parameters such as heart rate, blood pressure, respiratory rate and body temperature. In a WBAN, several wearable sensors are placed in close proximity to the human body and data is transmitted wirelessly. Since prolonged continuous monitoring of patients is paramount and in order to minimize concerns on possible radiation hazards, the sensors have to be very energy efficient and must be able to operate at very low power.

In order to make WBAN ubiquitous and affordable, there is a big interest in searching a proper transmission technology for wireless connectivity and ultra wideband (UWB) [2] appears to be a promising technology. UWB is an unconventional type of electromagnetic pulse with a wide bandwidth of several gigahertz. It is also known as micropower impulse, carrierless, non-sinusoidal, baseband and super wideband signal. It can provide very high resolution, operate at very low power, and is ideal for short-range communication (within 10 m range). Furthermore, with the legalization of a 7.5 GHz wide swath of unlicensed spectrum between 3.1 and 10.6 GHz for UWB communication by the Federal Communications Commission (FCC) in year 2002, many new technologies involving UWB are expected to become widely available soon.

Up to now, although a significant amount of studies have been carried out on UWB channel propagation in wireless communications, they are more focused towards propagation in indoor environment [3]-[4]. There are limited investigations on the transmission mechanism of UWB signal in WBAN [5]-[7]. For example, calculation models of transmitter and receiver attached to an arm using the finite-difference time-domain (FDTD) method have been proposed for clarification of transmission mechanism of wearable devices using human body as a transmission channel [5]. From these models, it was found that transmitter electrodes oriented in longitudinal direction is much more effective for sending signal to receiver as compared to transversal direction [6]. It was also found that the dominant signal transmission channel is not inside but on the surface of arm because signal seems to be distributed as a surface wave [6]. However, to date no work has been done to analyze the signal transmission efficiency for electrodes oriented perpendicular to the human body.

In this paper, the transmission mechanism of UWB signal around human body is investigated using the CST Microwave Studio simulation software. As an initial study, a simple human arm model with dipole antennae representing the transmitter and receiver placed in close proximity to the arm surface is proposed. Two different antennae orientations are considered in the investigation: (a) vertical polarization, i.e. both transmitting and receiving dipole antennae oriented perpendicular to human arm, and (b) horizontal polarization, i.e. both transmitting and receiving dipole antennae oriented parallel to human arm. The favorable antenna polarization for effective transmission of signal to receiver is determined based on the S_{21} transmission coefficient results obtained. In order to achieve more realistic and broadband analysis, simulations are then carried out by replacing the dipole antennae with disc cone antennae.

II. SIMULATION MODEL

The CST Microwave Studio simulation software is used to carry out three-dimensional computations of UWB signal propagation around human arm in this paper. Fig. 1 shows the simulation model of a human arm used in this paper, where D is the separation distance between the feed points of transmitter and receiver (D = 10-30 cm, in increment of 5 cm) and d is the distance from the dipole antenna feed points or the

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distance from the base of the disc cone antenna to the surface of human arm.

In the simulations, the human arm is simplified as a muscle-equivalent homogeneous rectangular parallelepiped of dimensions 5 cm × 5 cm × 40 cm. The relative permittivity and conductivity of the muscle tissue are approximately 53.3 and 1.2 Sm^{-1} respectively at 6 GHz. The transmitter and receiver are modeled either as 2.2 cm long dipole antennae (approximately half-wavelength at 6 GHz in free space) or as disc cone antennae [8]-[9], all located in close proximity to the human arm.

By using this model, the transmission can be determined and the antennae polarization giving the lowest S_{21} coefficient denotes the orientation for most effective UWB signal transmission to receiver.

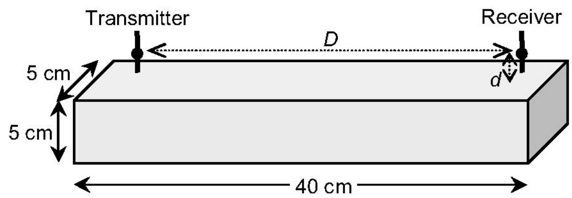

Fig. 1. Numerical model for investigation of UWB signal transmission mechanism in close proximity to the human arm.

III. Signal Propagation In Relation With Polarization Of Dipole Antennae

The positioning of dipole antenna with respect to the human arm for vertical and horizontal polarizations is described in Fig. 2. The distance from the antenna feed point to the surface of human arm, *d*, is kept at 1.2 cm at all time.

The change in antenna performance due to the presence of human arm is determined by examining the S_{11} return loss coefficient. The S_{11} coefficients for single dipole in free space, as well as dipole oriented in vertical and horizontal polarizations with respect to human arm are given in Fig. 3. It is shown that the magnitude of S_{11} coefficient for vertical polarization at resonant frequency is significantly different from those in free space and horizontal polarization and is approximately 6 dB higher. However the resonant frequency is only marginally affected by the presence of the human arm, regardless of the antenna polarization.

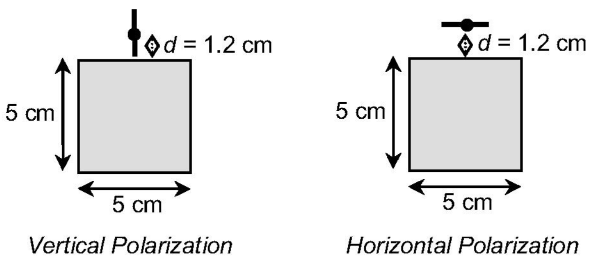

Fig. 2. Cross sectional view showing position of dipole antenna with respect to human arm.

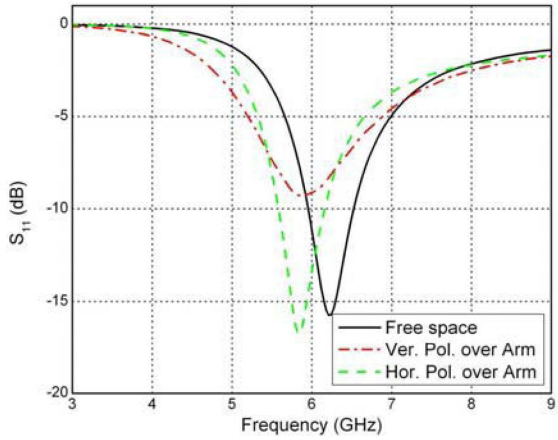

Fig. 3. S_{11} return loss coefficient of transmitting dipole oriented in vertical and horizontal polarizations with respect to human arm.

A. One Receiver

Before further simulations are being carried out, the accuracy of the simulation is first verified by comparing the S_{21} coefficient obtained for dipole antennae in free space with Friis transmission equation [10]. A good agreement is obtained and the comparison is depicted in Fig. 4.

The S_{21} coefficient is also illustrated in Fig. 4 for different separation distances between the transmitting and receiving dipole antennae feed points, *D*, for two different antennae settings: (a) vertical polarization, i.e. both transmitting and receiving dipole antennae oriented perpendicular to human arm, and (b) horizontal polarization, i.e. transmitting and receiving dipole antennae oriented parallel to human arm. It is found that the S_{21} coefficient for vertical polarization is at least 5 dB lower than in free space, but on the other hand, it is more than 10 dB higher in comparison to horizontal polarization. This implies that the presence of human arm in close proximity to the dipole antennae deteriorates the transmission efficiency, and that vertical polarization is able to provide a more effective signal transmission than horizontal polarization.

Another simulation is carried out for dipole antennae oriented in vertical polarization, but the rectangular parallelepiped human arm is now replaced by a cylindrical arm of 5 cm in diameter. It is interesting to note that the transmission is poorer for cylindrical arm and this phenomenon escalates at larger separation distance between the transmitting and receiving dipole antennae. These results suggest that the polarization of antenna and shape of human arm both play a vital role in determination of the transmission efficiency.

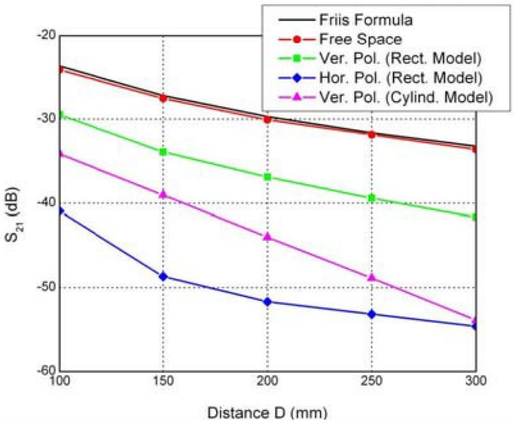

Fig. 4. S_{21} transmission coefficient for different separation distances D between transmitting and receiving dipole antennae: vertical polarization and horizontal polarization. The free space transmission is compared to the analytical solution.

B. Four Receivers

Once the antenna polarization for efficient transmission to receiver has been determined, the number of receiving dipole antenna included in the simulation model is increased to four. The positioning of receivers (R1 to R4) with respect to the human arm is demonstrated in Fig. 5. Note that R1 is the receiver located above the same human arm surface as the transmitter. The transmitter is oriented in vertical polarization whereas the receivers are all oriented parallel with respect to the transmitter. Hence, for the configuration shown in Fig. 5, R1 and R2 are in vertical polarization whereas R3 and R4 are in horizontal polarization with respect to the human arm.

The S_{21} coefficient for the receiving dipole antennae configuration in Fig. 5 is presented in Fig. 6. The results show that the signal is transmitted most effectively to R1, followed by R3 and R4, and R2 has the lowest S_{21} coefficient. The reason R3 and R4 have the same results is because they are in symmetrical location in relative to the transmitter, and their S_{21} coefficient is between 8-12 dB lower than R1 for all separation distances considered.

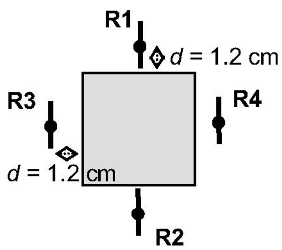

Fig. 5. Cross sectional view showing position of receiving dipole antennae with respect to human arm: receivers parallel to transmitter. (R1 is placed above the same human arm surface as transmitter).

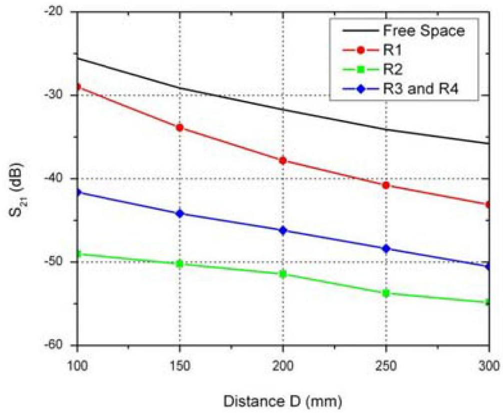

Fig. 6. S_{21} transmission coefficient for different separation distances D between transmitting and receiving dipole antennae shown in Fig. 5.

IV. Signal Propagation In Relation With Polarization Of Disc Cone Antennae

The investigation described in Sec. III is performed at a single frequency of 6 GHz, exemplarily taken approximately in the center of the UWB spectrum. For a more realistic investigation, a broadband disc cone antenna [8] is employed for further studies. The disc cone was used in [9] in WBAN measurements in the frequency range of 3 to 6 GHz. Since the disc cone antenna shows a dipole-like radiation pattern, similar characteristics to the ones found in the previous section are expected. Therefore, only the orientation of the disc cone resulting in a vertical polarization of the radiated electromagnetic field with respect to the human arm is considered in the following. Figure 7 depicts the arrangement of the transmitting and receiving disc cone antennae above the rectangular human arm model with width and height of $a = 5$ cm and a length of $L = 40$ cm. The arm is modeled with a second order Debye dispersive model of muscle tissue ($\varepsilon_\infty = 11.05$, $\varepsilon_{s1} = 51.67$, $\varepsilon_{s2} = 43.35$, $\tau_1 = 8.56$ ps, $\tau_2 = 0.23$ ns) in the investigated frequency band from 3 to 6 GHz. The height of the base of the antenna above the surface of the arm is fixed at $d = 1$ mm.

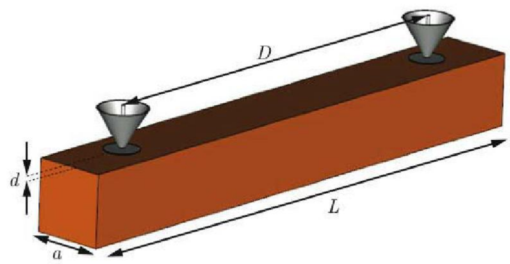

Fig. 7. Rectangular model of the human arm ($a = 5$cm, $L = 40$cm) including a dispersive approximation of the human muscle tissue. The two disc cone antennae are positioned at a distance D with respect to each other and at a height $d = 1$mm over the arm.

The S_{11} coefficient of a single disc cone antenna in free space and above the arm is plotted in Fig. 8. It is observed that the return loss is noticeably influenced by the arm, however, S_{11} coefficient is still staying at -10 dB and below throughout the frequency band.

The S_{21} transmission coefficient at the center frequency $f_0 = 4.5$ GHz for distances of $D = 10$-30 cm between the two disc cone antennae is shown in Fig. 9. The free space transmission (red line with circular markers) shows a good agreement with the theoretical value (black solid line) obtained by the Friis transmission equation [10]. Compared to free space, the transmission above the arm (green line with rectangular markers) exhibits a higher attenuation. A broadband analysis of the transmission coefficient is depicted in Fig. 10 showing the increasing loss for higher frequencies at different separation distances *D*.

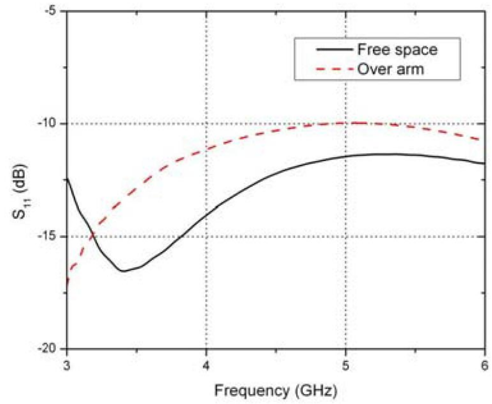

Fig. 8. S_{11} return loss coefficient of a single disc cone antenna in free space (black solid line) and with the presence of the human arm (red dashed line).

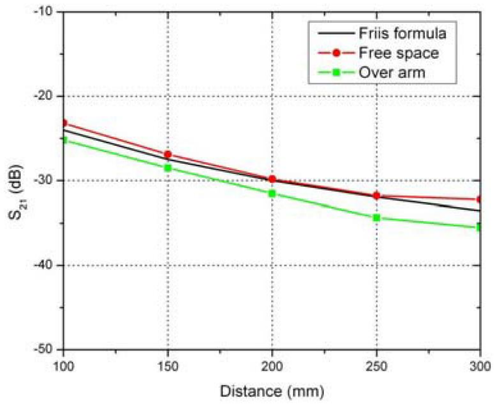

Fig. 9. S_{21} transmission coefficient between the two disc cone antennae at $f_0 = 4.5$ GHz. The free space transmission (red line with circular markers) is compared to the analytical solution (black solid line). Compared to free space, the transmission above the human arm (green line with rectangular markers) shows a higher attenuation.

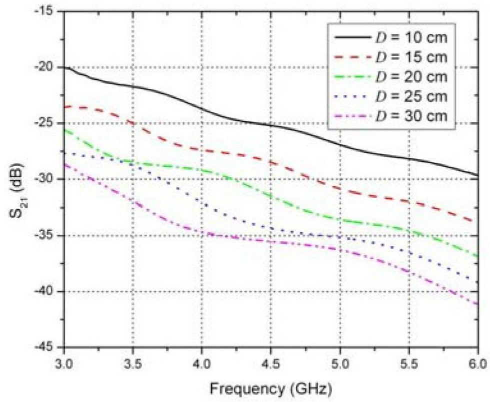

Fig. 10. Transmission coefficient S_{21} between two disc cone antennae as a function of frequency: The frequency dependent transmission is plotted for different distances *D* between the two antennae.

V. Conclusion

In this paper, investigations of the received signal level in relation to the polarization of transmitting and receiving antennae placed in closed proximity to a human arm have been carried out using the CST Microwave Studio simulation software. A rectangular parallelepiped is used to represent the human arm, whereas dipole or disc cone antennae are used to represent the wearable sensors worn around.

The results obtained for dipole antennae showed that the presence of the human arm only lowered the resonance frequency marginally from that in free space. However, the transmitted signal is found to experience a higher attenuation due to the presence of the human arm. The transmitting and receiving dipole antennae oriented in vertical polarization with respect to the human arm is found to be more effective than horizontal polarization for transmission of UWB signal. Besides, the signal transmission for a cylindrical human arm is found to be poorer than a rectangular parallelepiped human arm. These findings suggest that the polarization of antenna and shape of human body must be considered carefully for the WBAN antenna design in order to achieve effective transmission and accurate results.

For a more realistic investigation, the dipole antennae are then replaced with broadband disc cone antennae. As opposed to the observation obtained for dipole antenna, the return loss for disc cone antenna is noticeably influenced by the presence of the human arm. Also, increasing transmission loss is observed for higher frequencies at different separation distances between the disc cone antennae which are placed in close proximity above human arm.

More realistic human model will be applied in the future studies and comparison between simulated results and measurement on real human body will be carried out.

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