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In Vivo Wireless Communication Channels

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***Abstract* — In this paper we perform signal strength and channel impulse response simulations using an accurate human body model and we investigate the variation in signal loss at different RF frequencies as a function of position around the human body. It was observed that significant variations in received signal strength (RSS) occurred with changing position of the external receive antenna at a fixed distance from the internal antenna. The variations were even more profound at the highest frequency, where just a 5º of movement causes an increase of RSS up to 20 dB. Wideband scattering parameters were also obtained and the channel impulse response was calculated. A greater amount of dispersion through the abdomen has been observed than was expected based on human body geometry.**

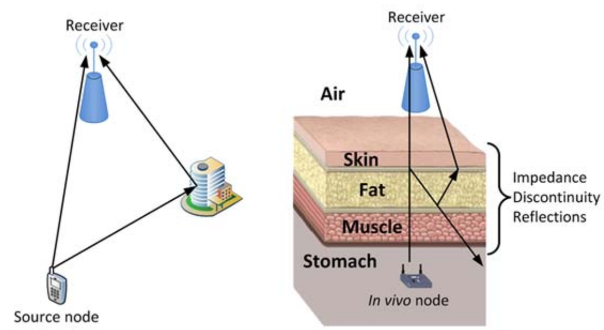
***Index Terms* — Biotechnology, biomedical communication, wireless communication, channel models, MIMO, *in vivo*, electromagnetic propagation in absorbing media.**

I. Introduction

Wireless communication for biomedical technology is a research topic that has recently experienced a significant amount of attention [1]-[2]. Body surface and internal sensors (and actuators) for medical applications have the potential of being critical components in advanced health care delivery by reducing the invasiveness of a number of medical procedures. Such applications include, but are not limited to, internal health monitoring [3], internal drug administration [4], and minimally invasive surgery [5]. Therefore, wireless communication from *in vivo* sensors/actuators to body worn/surface nodes will play a crucial role in advancing health care delivery.

A significant amount of work has already been done to characterize the performance of communications and channel models on body [6] while the study of *in vivo* wireless transmission, from inside of the body to external transceivers, is just starting to get traction. Characterization of the *in vivo* channel is still in its infancy [7], but the importance of obtaining accurate channel models is instrumental to the design of optimum communication systems and protocols for advanced bio-medical applications. Accurate *in vivo* channel models are especially important for high data rate communication, such as wireless high definition (HD) video transmission.

The *in vivo* channel is very different from the classic multipath communication medium (Fig. 1a). Since the electromagnetic wave is passing through different media that have vastly different electrical properties, the wave propagation speed is significantly reduced in some organs and may induce significant time dispersion that varies with each organ and body tissue (Fig. 1b). Also in many cases, far field assumptions used to develop channel models will have to be removed and the total electromagnetic fields will have to be taken into account due to the proximity of body and its organs to antenna near fields.



(a) (b)

Fig. 1. (a) Classic multipath RF channel, and (b) *In vivo* RF channel.

This paper presents preliminary results in the development of accurate *in vivo* channel models through numerical simulation using a human body model for high data rate applications. One goal of this research is to utilize the channel models so that the external receivers can be placed optimally for high performance communication from inside the human body. Subsequently using these models, optimized transmitter and receiver design for *in vivo* channels can be achieved. The results can also be applied to the case of using multiple antennas at the transmitter and at the receiver (Multiple Input -

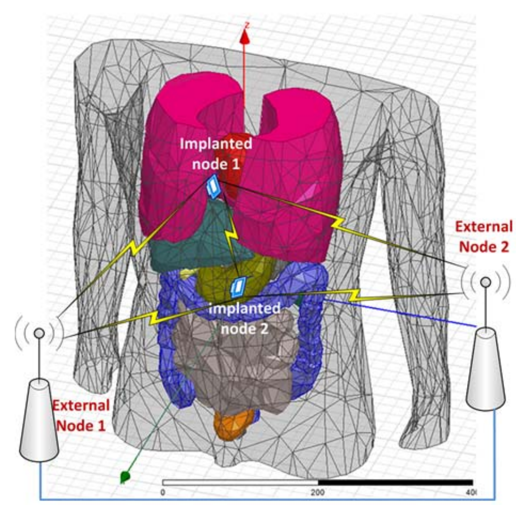


Fig. 2. MIMO *in vivo* communication links.

Multiple Output, dubbed *MIMO in vivo*), Fig. 2, to increase the channel capacity. MIMO is a communication technology that has already been proven to significantly enhance the quality of land-based wireless communication in a multi-path environment [8].

The paper is organized as follows. In section II, we describe the software and numerical model used in this research, after which the setup of the simulation and antenna description and placement is discussed. The simulated results showing the received signal strength (RSS) as a function of angular change around the human body at a fixed distance and height are presented in Section III. In section IV we derive and show channel impulse responses calculated from the simulated S-parameters for a 0.5 to 2 GHz channel. Finally, in Section V we present our conclusions.

II. Simulation and Human Body Model

In this investigation, we used ANSYS HFSS 13.0.2 [9], which is a 3D full-wave electromagnetic field simulator that utilizes a full-wave frequency domain electromagnetic field solver based on the Finite Element Method (FEM) to compute the electrical behavior of RF components, and the ANSYS human body model. ANSYS provides a human body model of a detailed adult male with over 300 muscles, organs, and bones with a geometrical accuracy of 1 mm. Frequency dependent material parameters (conductivity and permittivity) for each organ and tissue are included in the models which were derived for human tissues from 20 Hz to 20 GHz.

In the simulation, we used the model of a simple monopole antenna located in a fixed position inside the abdomen of the human body model to transmit a continuous wave (CW) signal with a 100 MHz bandwidth and centered at three different frequencies; 0.5, 1.0, and 2.0 GHz. The receiver antenna, which is identical to the implanted monopole, was placed 300 mm from the internal antenna and at the same planar height as shown in Fig 3. This antenna was rotated around the human body in the X-Y plane and S-parameter measurements were made at 5° increment of rotation during the simulation. From the S-parameter data, we extracted the RSS as a function of angular position and derived the channel impulse response for three positions using the Impulse Writer function in Agilent ADS [10].

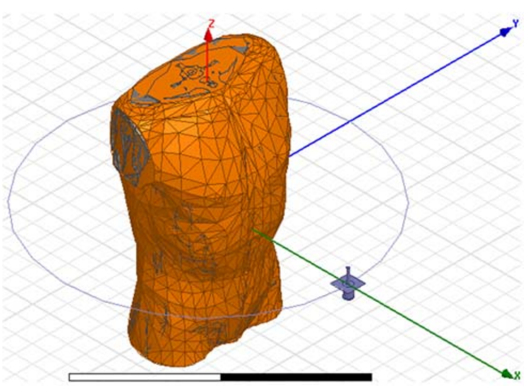
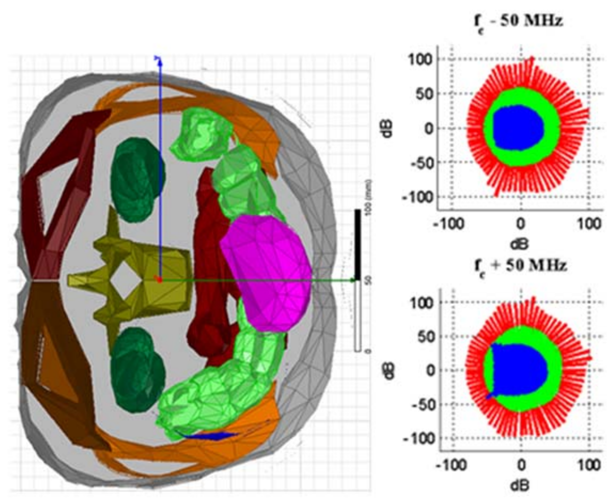


Fig. 3. HFSS human body model (with arms, head, and lower body removed) with receive antenna. The antenna is rotated 360° in 5° increments around the body with a constant radius during the simulations.

III. Results

As mentioned above, we investigated the frequency dependency of the *in vivo* RSS in three different frequency bands (0.5, 1 and 2 GHz for a 100 MHz bandwidth). Fig. 4a shows a cross sectional cut at the center of the abdomen. When viewed from the top of the body, the non-uniformity of the organs can clearly be seen. From the simulations, it can be observed that the RSS is extremely high in the body and, as expected, increases with higher frequency, as shown in Fig. 4b. In this figure, the two-dimensional angular RSS is plotted at four different frequency points within the bandwidth of each simulated frequency band to observe the RSS variations within each band. From the figure, it can be clearly seen that there is significant variation in RSS as a function of the receive antenna's angular position and it also does appear that the frequency dependence at different angles within a frequency band is more significantly in the 500 MHz band. What is even more interesting is the fact that at the highest frequency band, significant variations in RSS can be observed with only very slight variations of angular position (by as much as 20dB) ---a motivation for using MIMO. A noteworthy change in RSS with angular position can be expected since the location of the various organs and tissues in the body are not uniform and symmetrical. Since the absorptive effects of electromagnetic signals due to the



(a) (b)

Fig. 4. (a) Top-down view of the human body showing locations of internal organs, muscles, and bones, and (b) RSS as a function of the angle for the human body (without arms). The distance between transmitter and receiver is 300 mm with center frequencies (f_c) of: Red=2GHz (outer circle), Green=1 GHz (center circle), Blue=0.5 GHz (inner circle).

frequency dependent conductance of the tissues becomes more significant with increasing frequency, a greater variation in RSS at the 2 GHz band can be anticipated. It can be noted that there is enough distance between the body and the receive antenna to not have a near field effect in RSS with position since no significant changes in antenna return loss with position were observed in the simulations.

IV. Channel Impulse response

For the *in vivo* channel impulse calculation, we picked three receive antenna locations, obtained the wideband (0.5-2 GHz) S-parameter transfer function, and used the Impulse Writer feature in Agilent ADS to compare the impulse response at the different receiver locations; one impulse response with the antenna placed in front of the abdomen, one impulse response with the antenna placed to the right side (when viewed from the front), and one impulse response with the antenna placed behind the back of the body. The calculated channel impulse response for each case is shown in Fig. 5. From these simulations, we can observe that there is much greater dispersion through the abdomen than through the side and back. The higher dispersion is most likely due to the fact that the RF signal encounters more organs (stomach, intestines, bladder, etc.) as it traverses through the abdomen which present a greater amount of frequency dependent variations to the signal, then when the signal is passing through the side or the back, which again is clearly illustrated in Fig. 4a.

V. Conclusion

We used a full wave numerical RF simulator, ANSYS HFSS 13.0, and its highly accurate human body model, to observe variations in RSS as function of position around the human body for *in vivo* communications. The simulations were performed at 100 MHz frequency bands with center frequencies of 0.5, 1.0 and 2.0 GHz. It was observed that great variations in RSS exist with only slight changes in angular position at the highest frequency bands and can become even more significant with even higher frequency bands of operation. We also found through channel impulse calculations, that the dispersion through the body is greatest when the signal passes from the inside through the abdomen of the body. These results show the importance of developing highly accurate channel models for the human body as a RF transmission medium which will allow us to refine and utilize these channel models so that external receivers can be optimally placed, and optimal radio transmitter and receivers can subsequently be designed. Furthermore, the results obtained in this preliminary study of the *in vivo* channel will be used as a building block for further investigation into developing parametric models for the *in vivo* channel response and therefore can provide a beneficial effect on the optimization of advanced communication techniques such as the use of MIMO technology (MIMO *in vivo*) for improved communication reliability and performance.

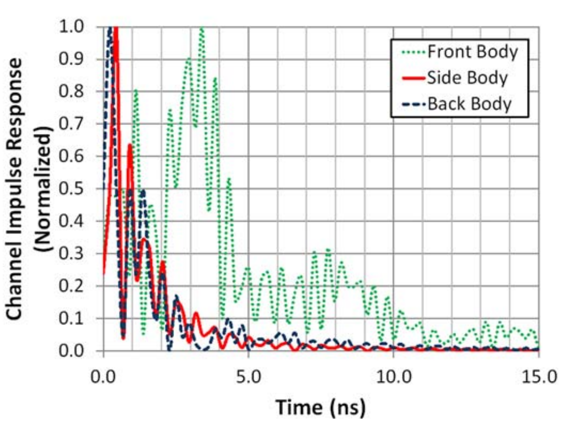


Fig. 5. Channel impulse response for the human body for different locations of the receiver.

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