A study on the receiving signal level in relation with the location of electrodes for wearable devices using human body as a transmission channel

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Abstract – Studies of wearable computers have attracted public attention in these days. And one of the area of interest is the communication system adopted in those wearable computers. As an example, wearable devices which use the human body as a transmission channel, have been developed. This communication system uses near field region of the electromagnetic wave generated by the device which is eventually coupled to human body by electrodes. Hence, the structure of electrodes is one of the key issues for the transmission using human body. However, little is known about the transmission mechanism of such devices in the physical layer [1-3]. In this paper, we propose calculation models of the transmitter and the receiver attached to the arm using the FDTD method. From this model, we estimated the difference in the received signal level due to the electrode structures of the transmitter and the receiver under various conditions. Moreover, in order to verify the validity of these calculation models, we compared the calculated received signal levels to the measured ones by using the biological tissue-equivalent phantom [4] with the transmitter and the receiver. The result shows a good agreement of the calculated and measured received signal levels. In addition, it is found that the GND electrode of the transmitter strengthens the generated electric field around the arm. However, the existence of a GND electrode for the receiver reduces the received signal level.

1. Introduction

Studies of wearable computers have attracted public attention in these days. It is thought that the computing in near future will be mainly performed in the interaction between wearable computers and ubiquitous computers. As one of these studies, Fig. 1 shows the communication system that uses the human body as a transmission channel. When a user wearing the transmitter shown in Fig.2 (from Sony Computer Science Laboratories, Inc. http://www.csl.sony.co.jp/IL/projects/wearable_key/index_j.html) touches the electrode of the receiver, a transmission channel is formed via human body. In this case, the receiver recognizes the user's ID and it can be personalized [3]. The transmitter has two electrodes. One is the signal electrode fed by an excitation signal (3 V, 10 MHz, sine wave), and the other is the GND electrode which is connected to the ground level of the electric circuit. Similarly, Fig. 3 indicates the exterior of the receivers. The receivers have two electrodes. One is the receiving electrode, and the other is the GND electrode.

In a previous study, the transmission mechanism of the transmitter has been evaluated from the viewpoint of impedance matching [5]. However, little is known about the reception mechanism of such devices using the human body as a transmission channel. Therefore, the

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difference in the receiving sensitivity caused by the electrode structures of the transmitter and the receiver needs to be considered in detail. In this paper, we propose calculation models of the transmitter and the receiver attached to the arm using the FDTD method to clarify the mechanism of transmission via human body. Also, in order to verify the validity of these calculation models, we compared the calculated receiving signal levels to the measured ones by using the biological tissue-equivalent phantom [4] and the mobile receiver which can measure the receiving signal voltage.

Fig. 1 Transmission system using human body.

Fig. 2 Exterior of the transmitter.

Fig. 3 Target mobile receivers.

2. Calculation model of the transmitter and receiver attached to the arm

Figure 4 shows the calculation model of the arm with the transmitter and receiver to investigate the difference in the received signal level according to the electrode structures. In Fig. 4, both of the transmitter (TX) and receiver (RX) have a GND electrode. The electrodes and the circuit boards have been modeled as perfect conductor sheets, and a continuous sine wave (3 V, 10 MHz) feeds the signal electrode. The size of the electrode is 2×3 cm^2 and the circuit boards of the transmitter and receiver are 3×8 cm^2 and 7×13 cm^2, respectively. The arm has been modeled as a rectangular parallelepiped (5 × 5 × 45 cm^3) and the electrical parameters are equal to the muscle (relative permittivity $\varepsilon_r = 81$ and conductivity $\sigma = 0.62$ S/m). The size of the cells is $\Delta x = \Delta y = \Delta z = 1$ cm. The absorbing boundary condition is assumed to be as Liao, and the time step is 19.2 ps that satisfies the Courant stability condition. "d" is defined as the distance between the signal electrode and the receiving electrode.

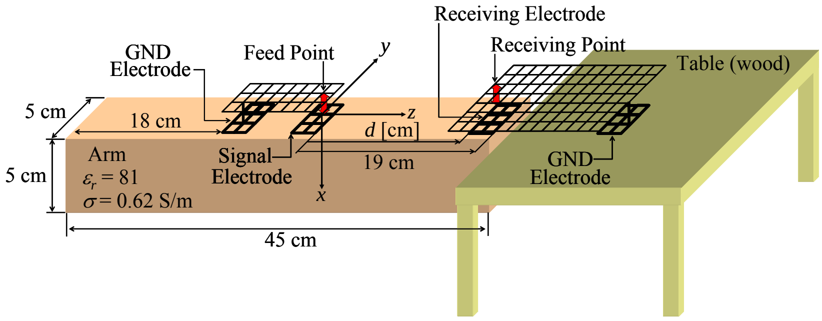

Fig. 4 Calculation model of the received signal voltage.

3. Receiving signal level in relation with the location of electrodes

Figure 5 shows the result of the received signal level of the receiver and (a), (b), (c), (d) indicate TX and RX with GND, TX with GND and RX without GND, TX without GND and RX with GND, TX and RX without GND, respectively. In case of Fig. 5 (a), the received signal voltage decreases as the distance d is increased between 0 and 6 cm. However in the region of $d \geq 8$ cm, where the GND electrode of the receiver does not contact the arm, the received signal voltage increases as distance d is increased. When $d = 19$ cm, the received signal voltage drops rapidly because the receiving electrode does not contact the surface of the arm. This means that the GND electrode of the receiver prevents from receiving signal and the primary transmission channel seems to be the human body. In case of Fig. 5 (b), the fluctuation of the received level is less than (a) when d is varied. Moreover, the tendency of the received signal voltage vs. d is same as (a) at the position $d \geq 8$ cm. Therefore, the difference of received level of (a) and (b) is caused by the presence of the GND electrode. In case of Fig. 5 (c), the received signal voltage is the lowest of all patterns of the electrode structure. The received signal voltage is approximately less than 40 mV where the GND electrode of the receiver does not contact the surface of the arm (the region of $d \geq 8$ cm). Moreover, compared with (a), this result indicates that the presence of the GND electrode of the transmitter is effective to send the signal from the transmitter to the receiver. In case of Fig. 5 (d), the tendency of the received signal voltage vs. d is almost same as (c) at the position $d \geq 8$ cm. However, in the region of $d \leq 7$ cm, the received signal voltage decreases rapidly as d is increased and this result shows disadvantage for the practical use.

Figure 6 shows the electric field distributions in and around the arm with the transmitter and the receiver for which d is set to 17 cm to investigate the influence of the presence of the GND electrode. In Fig. 6, the wooden table of the calculation model is removed, because the E-field distribution is not influenced by the presence of the desk. The observation plane is the x-z plane at $y = 1$ and 0 dB indicates 300 V/m. Comparing (a) with (b), the electric field distribution is almost the same. However, in case of (c) and (d), the electric field does not propagate along the surface of the arm and it is radiated on the upper side of the arm. This result shows that the GND electrode of the transmitter is necessary to cause stronger electric field around the arm.

4. Conclusion

In this paper, investigations of the relationship between the received signal voltage of the receiver and the electrode structures of the transmitter and receiver using human body as a transmission channel have been presented. Also, in order to verify the validity of these calculation models for the FDTD, we compared the calculated received signal levels with the measured ones by using the biological tissue-equivalent phantom with the transmitter and the receiver. The result shows a good agreement of the calculated and measured received signal levels. In addition, a GND electrode of the transmitter is necessary to strengthen the electric field around the arm. However, the existence of a GND electrode for the receiver reduces the received signal level.

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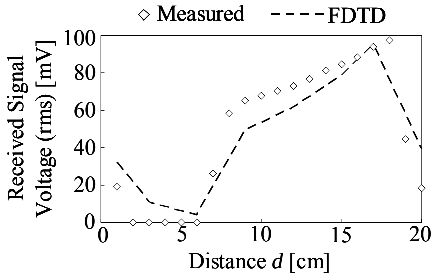
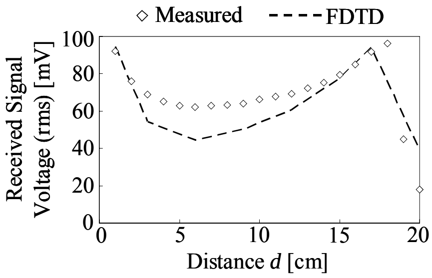
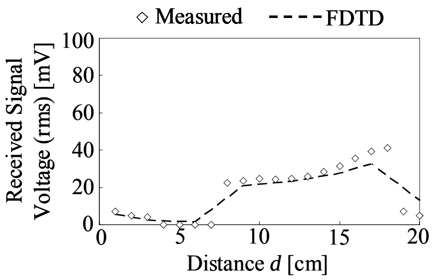


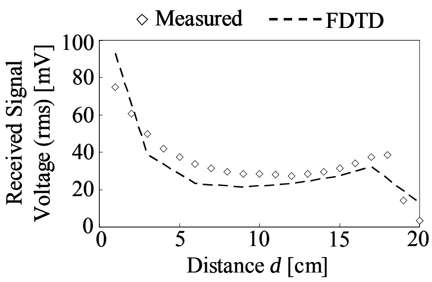
(a) TX with GND; RX with GND.



(b) TX with GND; RX without GND.

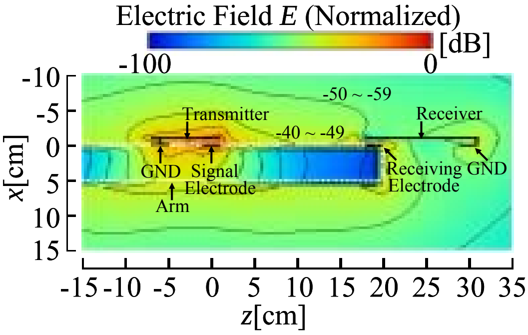


(c) TX without GND; RX with GND.

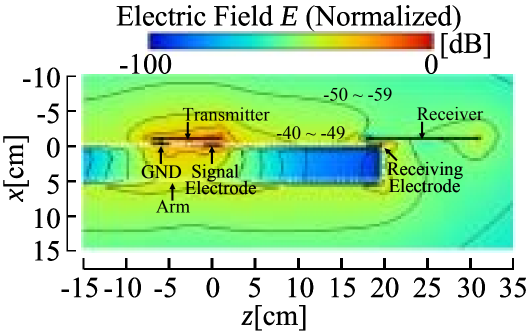


(d) TX without GND; RX without GND.

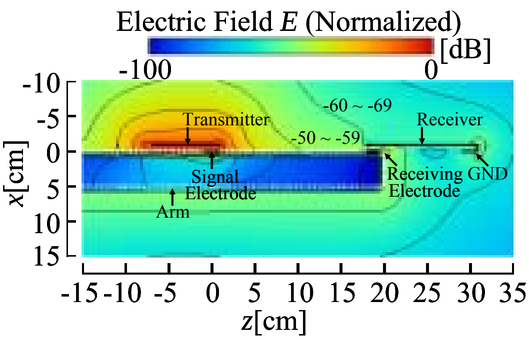
Fig. 5 Received signal voltage vs. distance *d*.



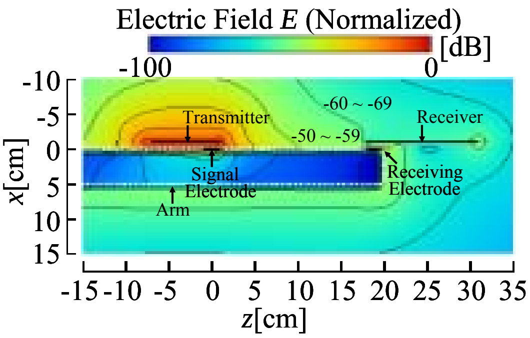
(a) TX with GND; RX with GND.



(b) TX with GND; RX without GND.



(c) TX without GND; RX with GND.



(d) TX without GND; RX without GND.

Fig. 6 E-field distributions in and around the arm (d=17 cm).