SIGNAL PROPAGATION OF WEARABLE COMPUTER USING HUMAN BODY AS TRANSMISSION CHANNEL

Katsuyuki FUJII*, Koichi ITO**, and Shigeru TAJIMA***
*Graduate School of Science & Technology, Chiba University
**Faculty of Engineering, Chiba University
1-33, Yayoi-cho, Inage-ku, Chiba-shi, 263-8522, Japan
E-mail fujii@ap.tu.chiba-u.ac.jp
***Sony Computer Science Laboratories, Inc.
Takanawa Muse Bldg. 3-14-13, Higashigotanda Shinagawa-ku, Tokyo, 141-0022, Japan

1. Introduction

Studies of wearable computing have been brought to public attention these days. It is thought that the environment of computing will be interaction between wearable computers and ubiquitous computers like Fig. 1 [1]. Fig. 2 shows the communication system which uses the human body as transmission channel [2]. When the user wearing the transmitter touches the ubiquitous computer, transmission channel is formed by using the human body. In this case, the ubiquitous computer recognizes the user's ID and can be personalized. The structure of the transmitter is shown in Fig. 3. The transmitter has two electrodes. One is the signal electrode to feed an excitation signal (3 V, 10 MHz sine wave), and the other is GND electrode which is connected to the ground level of the electrical circuit.

There has been no report that tried to clear transmission mechanisms using the human body as transmission channel. The difference of the transmission power caused by the electrode structure needs to be considered in detail. In this paper, we study the transmission property of the electrical signal inside the human body by use of the FDTD calculations under various conditions. We have compared two types of the electrodes to clarify the mechanism of transmission using the human body. The distributions of the electric field in and around the body have been calculated. The differences of the distributions of the electric field have been shown from the viewpoints of the impedance matching using the equivalent circuits, and primary transmission channel has been clarified.

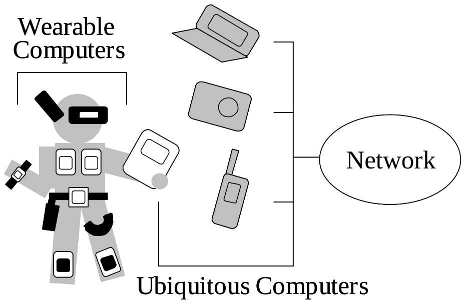


Fig. 1 Integration of wearable and ubiquitous computers.

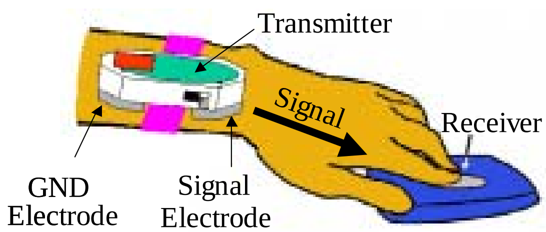


Fig. 2 Transmission system using the human body.

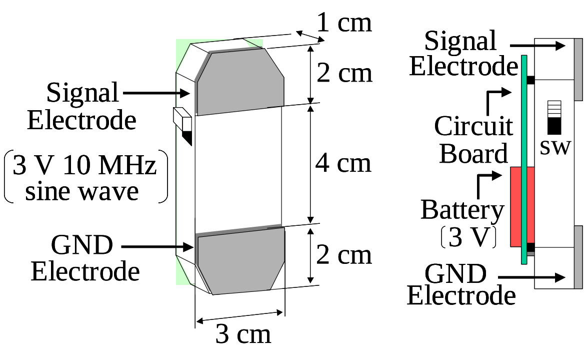


Fig. 3 Structure of the transmitter.

2. Calculation model of the transmitter attached to the arm

We have focused on the modeling of the transmitter for the FDTD calculations and there has been considerable validity in that result [3]. Figure 4 shows the calculation model of the transmitter to investigate the electric field around the transmitter. Two electrodes and circuit board are modeled as perfect conductor sheets. Continuous sine wave (3 V, 10 MHz) is fed to the signal electrode.

Figure 5 shows the calculation model of the arm with the transmitter. Figures 5 (a) and (b) show with GND electrode and without GND electrode models, respectively. The arm is modeled as a rectangular parallelepiped (5×5×45 cm^3) and the electrical parameters are equal to the muscle (relative permittivity ε_r = 81 and conductivity σ = 0.62 S/m). The size of the cells is $\Delta x = \Delta y = \Delta z$ = 1 cm. The absorbing boundary condition is assumed on the Liao, and the time step is 19.2 ps to satisfy the Courant stability condition.

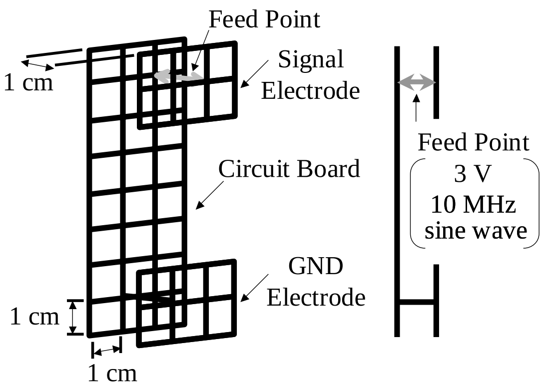
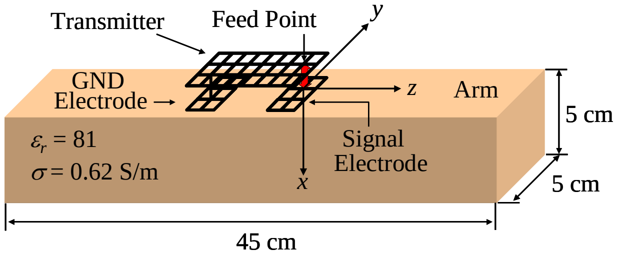
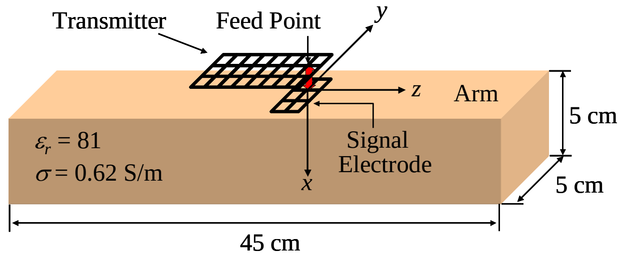


Fig. 4 FDTD calculation model.

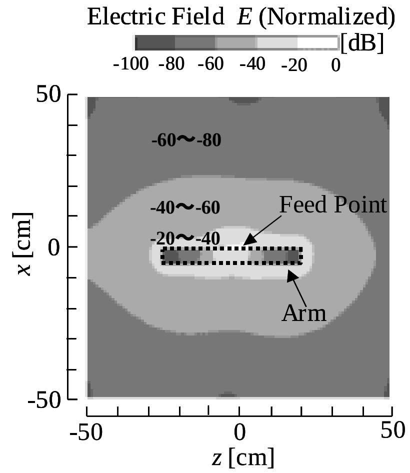


(a) With GND electrode.

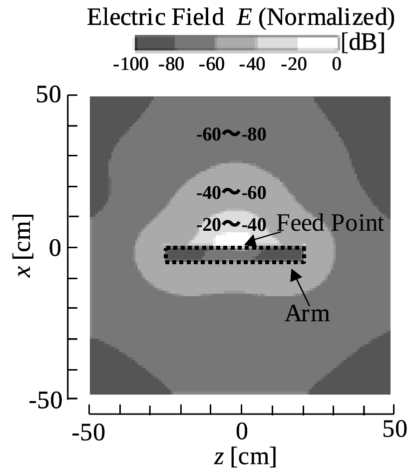


(b) Without GND electrode.

Fig. 5 Calculation models for the arm.



(a) With GND electrode.



(b) Without GND electrode.

Fig. 6 E-field distributions around the arm equivalent model.

Figure 6 shows the result of the electric field distributions around the arm. The observation plane is the *x-z* plane at *y* = 0 and 0 dB indicates 300 V/m. Figure 6(a) shows the electric field distributions along the surface of the arm (-20 ~ -40 dB) because the electric field penetrates inside the arm. However, in Fig. 6(b), level of the electric field on the surface of the arm seems low (almost -40 ~ -60 dB). And the electric field does not penetrate inside the arm when GND electrode does not exist. Therefore, GND electrode is necessary to make the electric field around the arm. Next, we examine this result using the equivalent circuit models of power transmission more closely.

3. Equivalent circuit models of the transmitter attached to the arm

In this section, we investigate the differences of the electric field distribution caused GND electrode using the equivalent circuit models [4]. Figure 7 shows the equivalent circuit models of the transmitter attached to the arm. Input power is expressed as the following equation

$$P_{in} = \frac{1}{2}\mathrm{Re}\left\{Z_{in}\cdot\frac{V_g}{Z_g+Z_{in}}\cdot\frac{V_g^*}{(Z_g+Z_{in})^*}\right\} = \frac{1}{2}\frac{|V_g|^2\cdot \mathrm{Re}(Z_{in})}{|Z_g+Z_{in}|^2} = P_{av}\,S \qquad (1)$$

where V_g, Z_g, Z_{in}, and P_{av} are the supply voltage, the output impedance, the input impedance, and the available power, respectively. If Z_g is equal to Z_{in}, then Fig. 7 represents a transmission line that is matched and $S = 1$. Therefore, P_{av} and S is expressed as the following equation.

$$P_{av} = \frac{|V_g|^2}{8\,\mathrm{Re}(Z_g)} \qquad (2)$$

$$S = \frac{4\,\mathrm{Re}(Z_g)\cdot\mathrm{Re}(Z_{in})}{|Z_g+Z_{in}|^2} \leqq 1 \qquad (3)$$

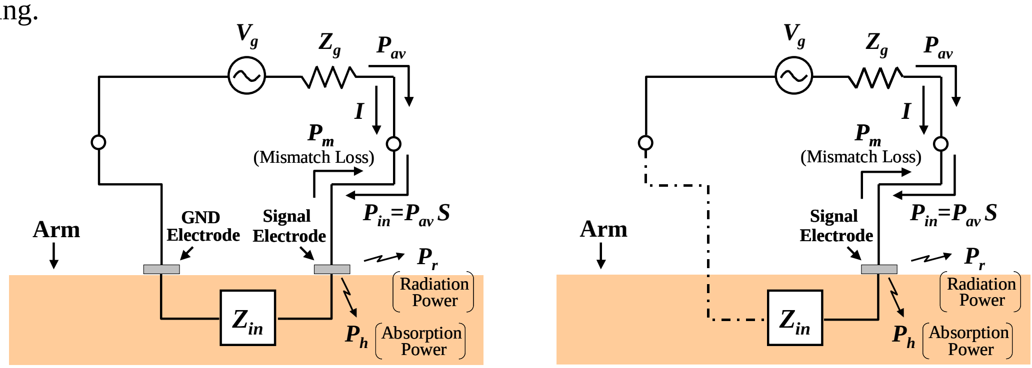
Under the assumption that the resistance of the electrode can be neglected, total power of the loss and the radiation efficiency based on the available power are expressed as follows

$$P_t = P_h + P_m \qquad (4)$$

$$\eta = \frac{P_r}{P_{av}} = \frac{P_{av} - P_t}{P_{av}} \qquad (5)$$

where P_h, P_m and P_r are the absorption power of the human body, the mismatch loss and the radiation power, respectively.

By using the FDTD calculation, the input impedance Z_{in} [Ω], the input power P_{in} [W] and the radiation power P_r [W] can be calculated. Figure 8 shows the partition of the available power P_{av} ($P_{av} = P_r + P_h + P_m$) under the assumption that the output impedance of the equivalent circuits are 50 Ω by substituting Z_{in}, P_{in}, P_r for eq. (1) - (5). From Fig. 8, the imaginary part of Z_{in} is low in the case of existing the GND electrode. Thus, most part of the available power P_{av} is fed to the signal electrode, and changes the absorption power of the human body P_h. On the other hand, in the case of without GND electrode, the input impedance Z_{in} has large amount of capacitance because not existence GND electrode causes stray capacitance between the human body and the transmitter. Thus, most part of the available power P_{av} changes the mismatch loss P_m. From these results, we find that existence GND electrode can be quite effective to transmit the signal because it contributes to the impedance matching.



(a) With GND electrode. (b) Without GND electrode.

Fig. 7 Equivalent circuit model.

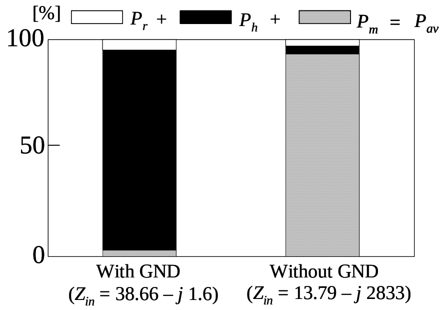


Fig. 8 Partition of the available power.

4. Signal transmission

The strength of the received signal depends on the electric potential of the electrode of the receiver when the signal is transmitted from the transmitter to the receiver. Thus, the electric field distributions from the signal electrode to the end of the arm need to be considered.

In this section, we investigate the electric field distributions along and inside the arm. Figure 9 shows the observation lines of the electric field from the feed point to the end of the arm along the *z* axis. The line A is at a distance 1 cm apart from the surface of the arm, the line B is the surface of the arm, the line C is inside the arm, the line D is the opposite side of the surface of the arm and the line E is 1 cm away from the opposite side of the surface of the arm.

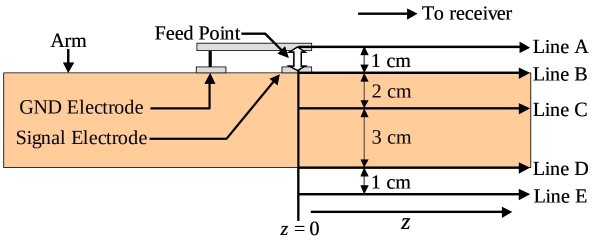


Fig. 9 Observation lines of the E-field.

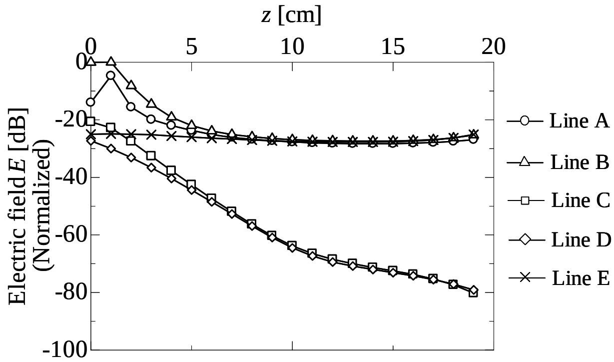


Fig. 10 E-field distributions along the arm.

Figure 10 shows the electric field distributions along and inside the arm. The level of each point is normalized by the maximum value. Figure 10 demonstrates that each observation line decreases as *z* is increased, however the region of $z \geq 10$ cm, the line A, B and E indicate almost the same value. Moreover, the value of the electric field does not decrease. On the other hand, the line C and D still decrease rapidly with the increase of *z* because the electric field propagates in the lossy medium. This result suggests that the electric field propagates along the surface of the arm and the primary transmission channel seems not to be inside the arm.

5. Conclusions

In order to clarify the transmission mechanisms of the transmission channel using the human body, first, the electric field distributions have been studied using the FDTD models, which are consisted of the arm and the transmitter. As a result, existing GND electrode can be quite effective to send the signal to the receiver because it causes the impedance matching between the circuit of the signal generator and the human body. Next, we have investigated the signal transmissions by making a comparison between the electric field distributions inside and around the arm. As a result, the primary transmission channel seems not to be inside the arm.

As a further study, we have to consider the transmission mechanisms with the arm, the transmitter and the signal receiver.

References

[1] M. Weiser, “The computer for the 21 century,” Scientific American, pp. 94 - 104, Sep. 1991.

[2] N. Matsushita, S. Tajima, Y. Ayatsuka, and J. Rekimoto, “Wearable key: device for personalizing nearby environment,” Proc. ISWC 2000, pp. 119-126, Oct. 2000.

[3] K. Fujii, K. Ito, and S. Tajima, “A study on the modeling of communication system using human body as transmission channel,” ITE Technical Report, Vol. 26, No. 20, pp. 13 - 18, Mar. 2002 (in Japanese).

[4] K. Ogawa, Y. Koyanagi, and K. Ito, “An analysis of the effective radiation efficiency of the normal mode helical antenna close to the human abdomen at 150 MHz and consideration of efficiency improvement,” IEICE, Vol. J 84 - B, No. 5 pp. 902 - 911, May 2001 (in Japanese).