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A Study on the Electric Field Distribution around Human Body with Wearable Devices Focused on the Earth Ground

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1. Introduction

In the near future, we will begin to adorn our bodies with wearable devices, and the ubiquitous computing society will dawn. However, currently very little method for these personal devices is available to exchange data directly. We want to exchange the data among the wearable devices without physical constraint like an external wire connection that may easily be tangled. As one of the solutions for networking these personal devices has been proposed as Personal Area Networks (PANs) which uses the human body as a transmission channel [1]. Many studies have been made on the development of such devices so far. However, most of the researches have been conducted by researchers who just want to utilize the fact that human body can be used as a transmission channel, and practically a little physical mechanism has been researched until recently.

Fig. 1 shows the communication system of the PANs using a 10 MHz carrier frequency which was made by Sony Computer Science Laboratory Inc. [2]. When a user wearing the transmitter touches the electrode of the receiver, a transmission channel is formed using the human body. This communication system uses the near field of the electromagnetic wave generated by the device which is eventually coupled to the human body by electrodes.

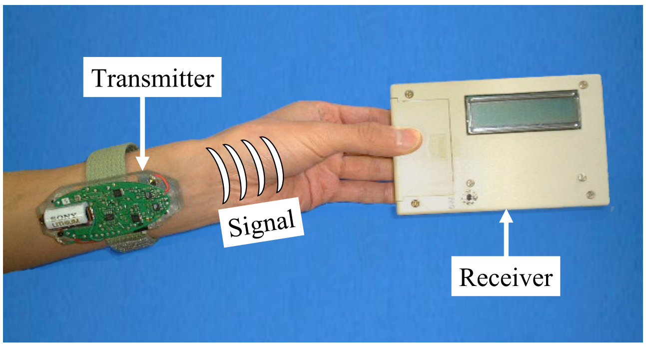

Fig. 1 Communication system using the human body as a transmission channel

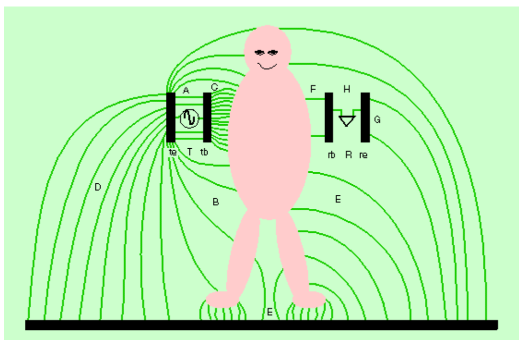

Fig. 2 Electric fields produced by PAN transmitter [1]

Fig. 2 shows the electric field model of a PAN transmitter T communicating with a PAN receiver R [1]. In this reference, electric field modelling is explained as follows. Electric fields exist between bodies at different potentials. A small portion of the electric field G reaches the receiver R. The transmitter T electrode closest to the body tb has a lower impedance to the body than the electrode facing toward the environment te. This enables the transmitter T to impose an oscillating

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potential on the body, relative to the earth ground, causing electric fields A, B, C, D, and E. Similarly the impedance asymmetry of the receiver electrodes (rb and re) to the body and environment allow the displacement current from electric fields F and G to be detected. Since the impedance between the receiver electrodes is nonzero, a small electric field H exists between them. The transmitter T capacitively couples to receiver R through the body (modeled as a perfect conductor). The earth ground provides the return signal. The circuit reveals that body capacitance to the environment E degrades PAN communication by grounding the potential that the transmitter T is trying to impose on the body.

Hence, we have a renewal of interest in electric field distribution around the human body, especially coupling between human body and earth ground. This paper describes the electric field distribution around human body focused on the earth ground to discuss the electric field modelling of the PAN, although, carrier frequency is completely different from reference [1] (330 kHz). We will propose the simple homogeneous whole body block model with wearable devices. For the basic analytical area, the radio anechoic chamber of the Chiba University (Japan) will be modelled. In the calculation, three calculation models will be analyzed as follows.

#1: Human body is standing on the earth ground in the radio anechoic chamber
#2: Human body is floating above the earth ground in the radio anechoic chamber
#3: Human body is floating in free space

2. Calculation model in consideration with the earth ground

In this section we calculate the electric field distribution around the human body standing on the earth ground by using the Finite Difference Time Domain (FDTD) method. For the calculation, simple whole human body block model is used. In our previous work, we have already clarified the validity not using realistic model but simple one [3]. This is because the electric field distributions between them are almost same. Fig. 3, 4, and 5 show the calculation models of the human body, transmitter, and receiver, respectively. The size of the human body model almost imitates the Japanese averaged size from the statistical data [4]. The electrical parameters are equal to the muscle (ε_r = 170.73, σ= 0.62 S/m) [5]. For the transmitter, we adopt single electrode structure to investigate the coupling to the earth ground similarly as in Fig 2. Detailed information of the modelling of the wearable devices is stated in [3]. For the calculation area, we modelled the radio anechoic chamber at Chiba University Japan. Fig. 6 shows its calculation model. Calculation space is surrounded by PEC wall, and floor is filled with concrete (ε_r = 3.8, σ= 6.67×10^{-6} S/m). A PEC sheet is spread on the floor to simulate the earth ground (size is 3 m×3 m). The human body with wearable devices is set at the center of the floor. Moreover, to investigate the influence of the earth ground, we propose other calculation models. The one is human body being floated 3cm above the PEC sheet. The physical meaning of this calculation model can be interpreted as wearing the shoes. The other one is the human body existing in free space that means no coupling from the surrounding (of course its calculation space is not surrounded by PEC wall but absorbing boundary condition). By comparing these calculation results, we can clarify how the earth ground affects the electric field distribution of the Body Area Network.

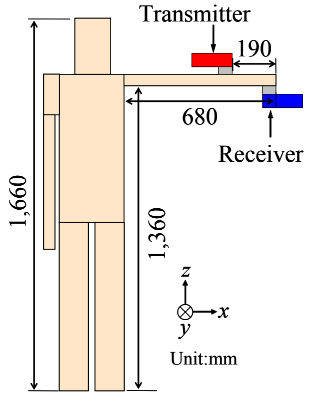


Fig. 3 Human body model [4]

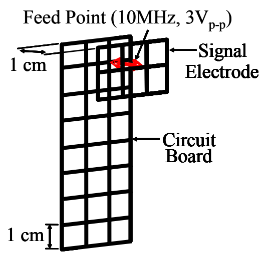


Fig.4 Transmitter [6]-[8]

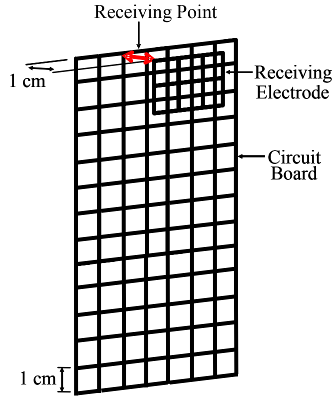


Fig.5 Receiver [6]-[8]

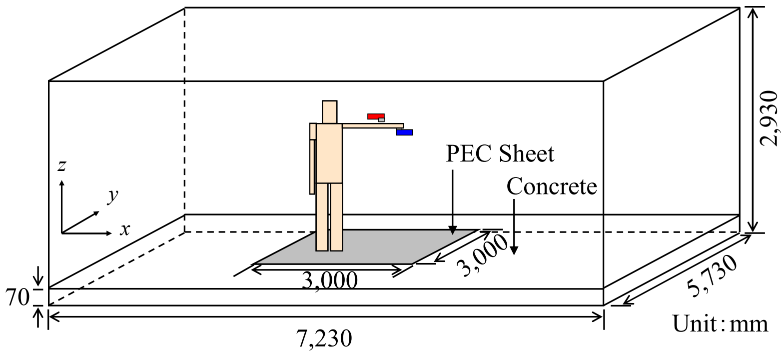
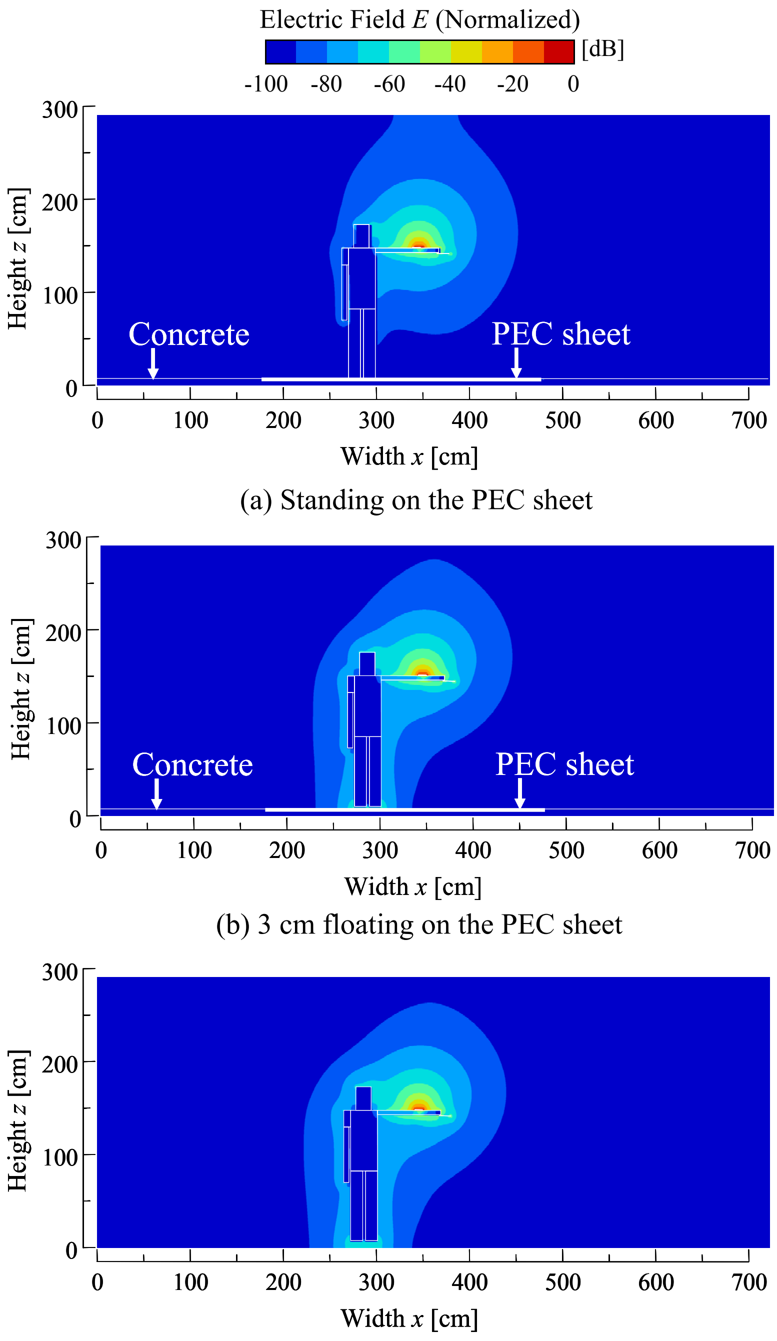


Fig. 6 Calculation model



(a) Standing on the PEC sheet

(b) 3 cm floating on the PEC sheet

(c) Floating in free space

Fig. 7 Electric field distribution around the human body

3. Results and discussions

Fig. 7 (a) - (c) shows the electric field distribution (root sum square of E_x, E_y, E_z) around the human body standing on the PEC sheet, 3cm floating on the PEC sheet, floating in free space, respectively. The observation plane includes the feeding point of the transmitter and 0 dB indicates the electric field at the feeding gap. From Fig. 7 (a), the electric field is not propagated but radiated into the air. Because of the single electrode structure of the transmitter, E field radiation-leakage into the air is observed of course, different from two electrode structure in our previous study [3]. In the case of the Fig. 7 (b), one of the notable features is that E field is propagated not only arm region but also around surface of whole body. The result of difference between Fig. 7 (a) and (b) is caused by contact with PEC sheet. Because human body is shunted to the earth ground in Fig. 7 (a), electric field is not distributed around the legs. In the case of the human body floating in free space, in Fig. 7 (c), E field distribution is almost same as Fig. 7 (b). It follows from what has been discussed thus far that E field distribution is affected only when the human body is connected to the earth ground directly. It can be concluded that the transmission characteristic of the wearable device is not influenced by the existence of the earth ground. However, direct contact to the earth ground by the bare foot weakens the E field around limited leg region.

4. Conclusions

In this paper, investigation of the transmission characteristics of Body Area Network using wearable devices focused on the earth ground has been carried out. The results lead us to the conclusion that uniform strength of the E field is distributed around surface of the whole body when the human body is slightly floating on the earth ground or in free space. However, once the human body is shunted to the earth ground, E field around the leg region is weakened.

Acknowledgments

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