A Study on Floor Ground Contribution in Semi-Passive Human Body Communication

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Abstract: Toward a battery-free wearable system, we have investigated a semi-passive human body communication wherein power and information are transmitted via the human body. In particular, we evaluated the effect of the position of the wearable device, the contact between the body and electrodes, and the contribution of the floor ground (GND) on the transmission between the HBC transceivers, using both subject experiment and numerical simulation. The results confirmed that, depending on the usage conditions, the floor GND deteriorates the transmission characteristics by increasing the electrical field that does not contribute to communication.

Keywords: human body communication, semi-passive, transmission characteristics, subject experiment, electromagnetic field simulation

Classification: Electromagnetic compatibility (EMC)

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1 Introduction

The exponential growth of electronics has led to information and communication devices that are smaller and lighter, and wearable devices, such as smartwatches, have increased in popularity. Human body communication (HBC) [1] using the human body as a transmission path for high-frequency signals has attracted increasing attention as a communication method to realize wireless body area networks connecting wearable and external devices [2]. In HBC, high-frequency signals are input into and output from the human body via electrodes for communication. Based on this communication principle, the electric field is distributed only in the vicinity of the human body, enabling both highly secure and low-power communications. Furthermore, as the transmission path is established through natural action such as touching the communication target, HBC can also be used as an intuitive human interface. Since wearable devices are used for daily bio-signal measurement and electronic payment, users need to wear and operate such devices all the time. When considering the battery capacity installed in a device, there is a trade-off between reducing the number of recharges and decreasing the device's size and weight. To improve this trade-off, a semi-passive HBC, in which both information and power are supplied from stationary devices, is desired.

While there have been studies on HBC among small devices, such as wearable and mobile devices [3, 4], HBC involving large-scale stationary devices has not yet been sufficiently studied [5]. In particular, regarding the signal transmission involving the stationary device, the device is expected to be connected to the floor GND via a commercial power supply. The electromagnetic environment of this system may be different from that involving only small devices powered by batteries [6]. Toward the semi-passive HBC system in this study, we focus on the contribution of the floor GND to the electromagnetic environment and evaluate signal transmission mechanisms, such as the transmission characteristics and electric field distribution, using both experiment with human subject electromagnetic field simulation.

2 Semi-passive HBC and experiment/simulation setup

For current automatic ticket gate systems that use contactless IC cards, the user is required to take the card from their bag or pocket and place it on the sensor. The utilization of HBC, in which the user can communicate by simply touching the sensor, promises to realize dramatic improvements in terms of the usability and operation of these gates. In this study, we propose the semi-passive HBC system shown in Fig. 1. In this system, the user wearing a battery-less wearable device touches the electrodes of the ticket gate, and the gate supplies power and information to the wearable device via their body. The signal transmission on the
The proposed HBC system is evaluated using the measurement system and electromagnetic field simulation model presented in the next subsections. The signal frequency was set to 10 MHz, in accordance with previous studies [3-6].

Fig. 1. Ticket gate consisting of semi-passive HBC.

2.1 Measurement system for subject experiments

Fig. 2(a) shows the measurement system for the proposed HBC. The transmitter (TX) side is assumed to be a stationary device (ticket gate), and the receiver (RX) side is assumed a wearable device (smartwatch or wristwatch). The dimensions of the chassis of the stationary device, assuming the current automatic ticket gate, were set to $460 \times 450 \times 880 \text{ mm}^3$. A $25 \times 25$-mm$^2$ TX electrode was placed on the central front surface of the chassis, corresponding to the IC card reader section. The TX electrode was connected to the signal generator (SG; Tektronix, AFG1062) via a coaxial cable, and the metal chassis of the stationary device was used as the GND for the TX circuit. Furthermore, the SG was powered by a commercial power supply or a battery to evaluate the effect of the floor GND on the signal transmission. In case that the SG was driven by a commercial power supply, the GND of the TX circuit was connected to the floor GND. When the SG was driven by the battery, the two were disconnected.

The wearable device was designed to be worn on the wrist, adopting an $8 \times 24$-mm$^2$ two-electrode structure [4]. The RX electrodes were connected to a spectrum analyzer (SA; Tektronix, RSA306B) via a coaxial cable and controlled it using a laptop. To emulate the electromagnetic environment of the actual wearable device, the SA and the laptop were both battery-powered. The human subjects were five Japanese adult men and women, and they changed the position of the wearable device (right/left wrist) and the contact condition of the TX electrode of the stationary device. However, human subjects always touched the TX electrode with their right hand. The participation of human subjects was approved by the Research Ethics Committee of the Tokyo University of Science. Fig. 2(b) shows measurement conditions (1)–(8) decided by the three parameters, which included: (i) contact between the hand and the TX electrode, (ii) mounting position of the RX electrode (wearable device), and (iii) condition of the floor GND. With regard to (iii), the impact of the floor GND was controlled by the driving conditions of the SG connected to the stationary device. When the SG was driven by the commercial power supply, the chassis of the stationary device was connected to the floor GND. When the SG was driven by the battery, the chassis of the stationary device was disconnected from the floor GND.
2.2 Numerical models for electromagnetic field simulation

Fig. 2(c) shows numerical models for electromagnetic field simulation corresponding to the subject experiment presented as condition (1) in Fig. 2(b). The dimensions of the human body model were determined regarding the average body shape of a Japanese adult male, and the model was composed of a combination of rectangles with muscle electrical properties [7]. The dimensions of stationary and wearable device models were set to the same values as used in the subject experiment. The TX port was placed between the electrode of the stationary device and the chassis, and the RX port was placed between the electrodes of the wearable device. The electrodes and the chassis of the stationary device were perfect conductors. The electromagnetic field simulator SIM4LIFE (ZMT Zurich MedTech AG, Switzerland) was used for the simulation based on the finite-difference time-domain (FDTD) method, and the signal frequency was set to 10 MHz.

(a) Measurement system for subject experiment.

(b) Measurement conditions.

(c) Models for electromagnetic field simulation.

Fig. 2. Experiment/simulation setup for semi-passive HBC.
3 Results and discussions

Fig. 3(a) shows the magnitude of the transmission characteristics between the stationary device (TX side) and the wearable device (RX side) \(|S_{21}|\) under each condition obtained from the subject experiment and numerical simulation. The measurement values are the mean values obtained from five subjects, and the error bars indicate the standard deviation. First, for the measurement values, a difference ranging from 45–63 dB in \(|S_{21}|\) occurred depending on the contact between the subject’s hand and the TX electrode of the stationary device. Accordingly, conductive contact between the body and electrodes is an important condition for signal transmission even in HBC involving the stationary device. This result indicates that the users can easily control the communication by their action. Furthermore, the situation in which the user did not contact the TX electrode, the \(|S_{21}|\) without floor GND (SG is driven by the battery) was 3–7 dB larger than that with the floor GND (SG is driven by the commercial power supply). This is because the connected floor GND increases the electric field not contributing to the communication that directly returns from the TX electrode to the chassis of the stationary device and the floor GND without going through the body and the RX electrodes. At the same time, under conditions in which the subject contacted the TX electrode, there was almost no difference in the \(|S_{21}|\) irrespective of the floor GND condition. This is because the conductive coupling between the TX and RX electrodes through the body becomes dominant, while the capacitive coupling via the floor GND can be negligible. In applications such as ticket gates, the stationary device will be driven by the commercial power supply and connected to the floor GND. In such case, the proposed system can realize a better communication interface because it reduces \(|S_{21}|\) during noncontact, when communication is not desired, without degrading \(|S_{21}|\) when communication is desirable.

We next compared the measured and simulated values of \(|S_{21}|\). The measured \(|S_{21}|\) values were 15–34 dB greater than the simulated values, except for under the conditions (1) and (2) in which the subjects wore the wearable device on their right wrist and touched the TX electrode. The main reason for this difference is thought to be because capacitive coupling occurred through the chassis of the measuring instruments and the coaxial cables, contributing to the signal transmission. On the other hand, under conditions (1) and (2), the direct coupling between the TX and RX electrodes, which were placed in proximity to each other, became dominant. Then, the influences of the measuring instruments and coaxial cables were relatively reduced in comparison with those under other conditions.

Additionally, the electric field distribution around the models was simulated to explain the contribution of the floor GND to the signal transmission. Fig. 3(b) shows the electric field distribution under the conditions (5) and (6) that the subjects worn the wearable device on their right wrist and did not touch the TX electrode of the stationary device. Whereas the floor GND has little impact on the electric field from the TX electrode to the RX electrodes, which is the main area contributing to signal transmission; it increases the electric field strength between the body and the chassis of the stationary device and the floor GND, which does not contribute to transmission. This change in the electric field decreases \(|S_{21}|\) in
conditions including the floor GND compared to those without floor GND. This result is considered an important finding, as it indicates that the floor GND, which was conventionally thought to contribute to the signal transmission of HBC, may degrade the transmission in the specific electromagnetic environment.

(a) Transmission characteristic $|S_{21}|$ in experiment and simulation.

(b) Electric field distributions around and inside the models.

Fig. 3. Experiment/simulation results.

4 Conclusions

In this study, the signal transmission of semi-passive HBC between wearable device and stationary device was evaluated using subject experiments and electromagnetic field simulation. We focused on the position of the wearable device, the contact with the electrode, and the contribution of the floor ground. The results indicated that electrical contact between the body and the electrode is essential for transmission. In the specific electromagnetic environment, the floor ground increased electric field that does not contribute to signal transmission and degraded the transmission characteristics. Moving forward, we continue to investigate semi-passive HBC against the device position and user’s posture.

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