Signal Analysis of Wearable Transmitter for Intra-body Communication

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ABSTRACT

We propose a signal channel model that involves using a wearable transmitter for an intra-body communication system. The impedance components regarding the wearable transmitter were added to our previous noise channel model to construct new model. The transmitting voltage through the human body was measured at the embedded electrodes by using a spectrum analyzer and compared with the circuit simulation. We found that the impedance components between the human body and the embedded electrodes agree with experimental results. However, the experimental results from between the wearable transmitter and human body differ from those of the circuit simulation. This means that the capacitance between the wearable transmitter and human body should be measured precisely.

Categories and Subject Descriptors

J.2 [**Computer Applications**]: PHYSICAL SCIENCES AND ENGINEERING– *Electronics, Engineering, Physics.*

General Terms

Measurement

Keywords

Intra-body communication, Wearable computer, Human body, Ubiquitous computing.

1. INTRODUCTION

Intra-body communication [1] has been studied to develop ubiquitous computing [2] services. In the communication system, the human body is used as a transmission line. Typical ubiquitous services using intra-body communication are security systems, medical care services, and ticket gates. A sports management and healthcare system using intra-body communication is shown in Fig. 1. A person's bio-information and personal data are transmitted to the doctor's computer just by the person standing on the floor or sitting on the chair. There are two types of transceivers. One is a wearable transceiver, which a person has in everyday life, and the other is a transceiver embedded in a living space such as a floor, door, or chair.

There are many services in communication between wearable and embedded transceivers [3], [4], so we studied such communication. There are two serious problems with intra-body communication systems. One is noise. An embedded transceiver is usually driven by an AC power line, and a large amount of environmental noise is produced through the line. We previously proposed a noise channel model that includes the impedance balance of the transmission line [5]. A two-layer electrode was used for reducing noise to improve the impedance balance of the transmission line.

The other problem is small induced voltage from the wearable transmitter [6]. Therefore, a signal channel model for the wearable transmitter should be investigated to obtain good communication performance. The impedance components regarding a wearable transmitter were added to our previous noise channel model to construct our proposed model. A circuit simulation model can be constructed by considering the impedance among the wearable transmitter, human body, embedded electrodes, and floor ground. We measured the transmitting voltage through the human body, and compared it with those of the circuit simulation. We found that the impedance components between the human body and embedded electrodes agree with the experimental results. However, the experimental results from between the wearable transmitter and human body differed from those from the circuit simulation. This suggests that the impedance components between the wearable transmitter and human body should be examined through electromagnetic field simulation.

First, we explain the wearable transmitter problem using the electric field model of intra-body communication. Next, we explain our signal channel model and the circuit simulation model with the wearable transmitter. Finally, we explain the experimental and the circuit simulation results.

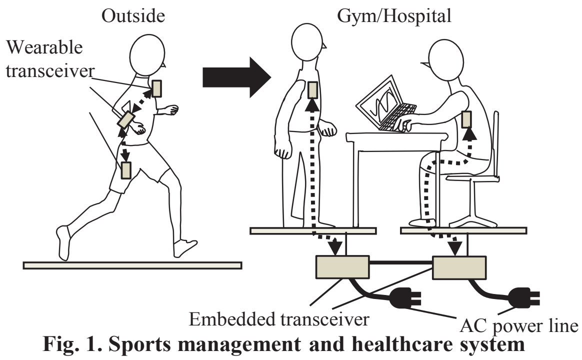

Fig. 1. Sports management and healthcare system using intra-body communication.

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2. WEARABLE TRANSMITTER PROBLEM

Figure 2 depicts a model of the electric near field induced by a wearable transmitter around a human body [1]. The electric field E_a induced by the signal electrode of the transmitter passes through the human body and electric field E_c escapes towards the earth ground (E-GND). A portion of E_a is canceled by electric field E_b generated from the ground electrode of the transmitter. Therefore, E_s is extremely small. This is a significant problem with wearable transmitters. It is necessary to precisely detect the electric near field E_s around the human body for obtaining good communication performance.

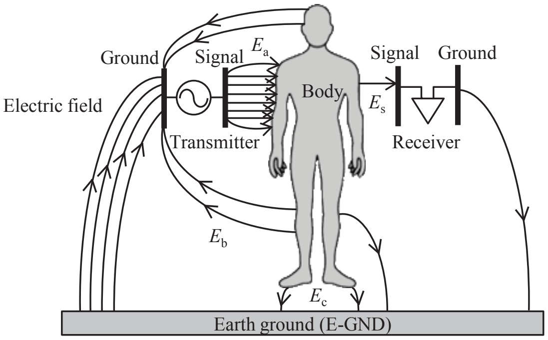

Fig. 2. Electric field model of intra-body communication.

3. SIGNAL CHANNEL MODEL

Electromagnetic field analysis [7]-[9] and channel model analysis [10]-[12] were reported. Our proposed channel model including the wearable transmitter is shown in Fig. 3. The impedance components related to the wearable transmitter (= this work) were added to our previous noise channel model [5]. The floor-ground (F-GND) and the power source ground (P-GND) are distinguished from E-GND.

The term Z_{TI} is the internal impedance of the wearable transmitter, Z_{TSG} is the impedance between the signal and ground electrode of the wearable transmitter, Z_{TSB} and Z_{TGB} are the impedances between the wearable transmitter and human body, Z_{TSES}, Z_{TSEG}, Z_{TGES}, and Z_{TGEG} are the impedances between the wearable transmitter and embedded electrodes, and Z_{TSF} and Z_{TGF} are the impedances between the wearable transmitter and F-GND.

The basic experimental setup for measuring the signal voltage is shown in Fig. 4. The distance between the signal electrode of the wearable transmitter and human body d_{TSB} is 5 mm, the distance between the signal electrode and the ground electrode of the wearable transmitter d_{TSG} is 25 mm, that between the human body and embedded signal electrode d_{BES} is 10 mm, that between the embedded signal electrode and embedded ground electrode d_{ESG} is 20 mm, and that between the embedded ground electrode and F-GND d_{EGF} is 100 mm.

The impedance components, except Z_{TI}, Z_L, Z_{CP}, Z_{PE}, and Z_{NI}, can be obtained from the capacitance [11]. The circuit simulation model is shown in Fig. 5. Common-mode noise voltage V_N (Fig. 3) is assumed to be zero volts because we discuss only the signal analysis of the wearable transmitter. The capacitance components of the wearable transmitter, C_{TSG} of 2.1 pF, C_{TSB} of 3.7 pF, C_{TGB} of 0.6 pF, C_{TSES} 20 fF, C_{TGES} of 20 fF, C_{TSEG} of 20 fF, and C_{TGEG} of 20 fF, are calculated from each electrode area and distance. The capacitances between the wearable transmitter electrodes and F-GND, C_{TSF} of 400 fF, and C_{TGF} of 400 fF, are calculated using our previous model. The C_{BES} of 31.5 pF, C_{BEG} of 10.5 pF, C_{SG} of 61 pF, C_{CSG} of 150 pF, C_{ESF} of 21 pF, and C_{EGF} of 23 pF regarding the embedded electrodes are measured using our previous model [5].

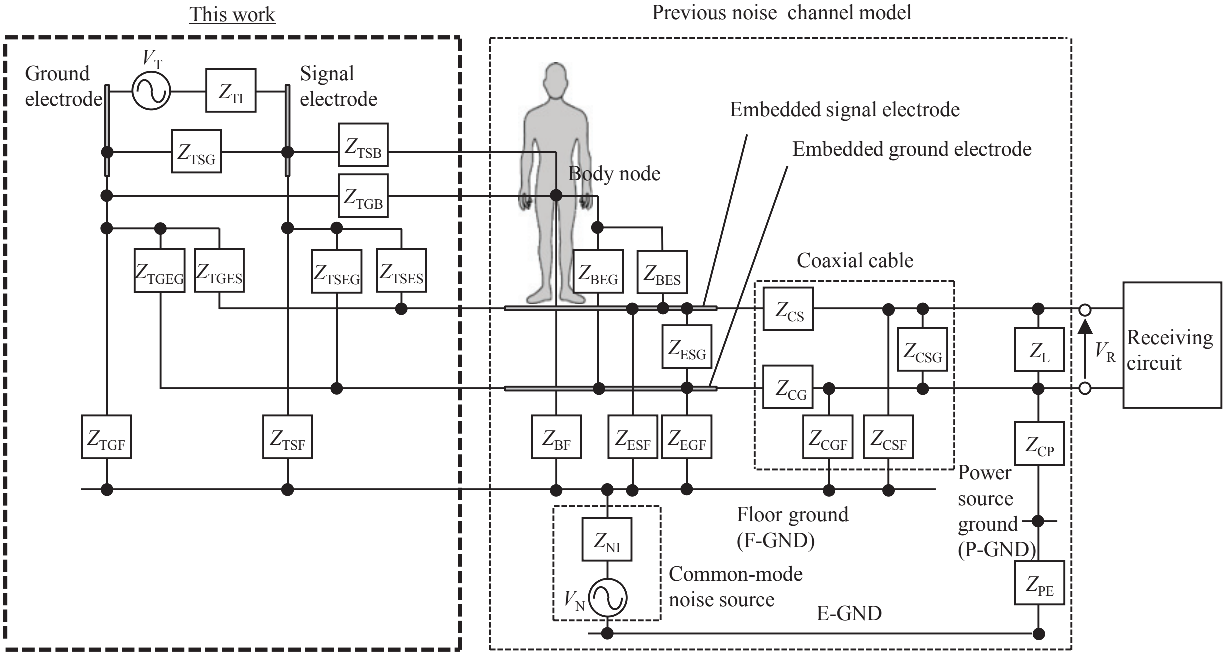

Fig. 3. Impedance regarding wearable transmitter with our previous noise channel model.

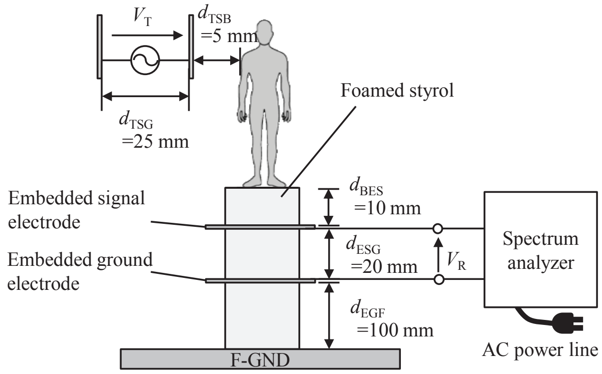

Fig. 4. Basic experimental setup for measurement of signal power.

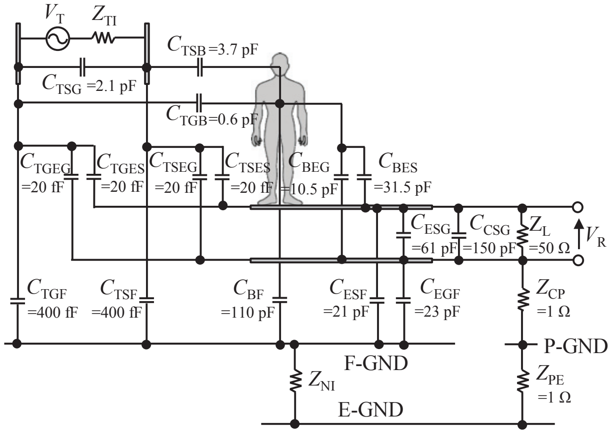

Fig. 5. Circuit simulation model.

4. EXPERIMENTAL RESULTS

We estimated the transmitting voltage of the wearable transmitter. The circuit and photograph of the wearable transmitter are shown in Fig. 6. The transmitter consists of a crystal oscillator (Xtal), buffer circuit, and battery. The size of the wearable transmitter is 74 mm x 49 mm x 25 mm, and the signal and ground electrode is 50 mm x 42 mm x 0.3 mm. The transmitter output voltage V_T, is 3 V. A photograph of the experimental setup for the wearable transmitter is shown in Fig. 7. The transmitter was placed on a foamed styrol support fastened to the person's waist with a belt. The distance between the wearable transmitter and the human body varied due to the position of the wearable transmitter. The received voltage V_R, was measured using the spectrum analyzer (ANRITSU MS2722C) driven by an AC power line. A photograph of the experimental setup for measurement V_R is shown in Fig. 8.

First, the V_R was measured by changing d_{BES} from 10 mm to 210 mm by changing the thickness of the foamed styrol. The experimental results are shown in Fig. 9. The circles signify the measured V_R to V_T ratio (= 20log (V_R / V_T)), and the solid line signifies the results of the circuit simulation under the initial circuit parameter shown in Fig. 5. The characteristics of the measured ratio are similar to those of the circuit simulation. In the circuit simulation, we calculated the capacitance change of C_{BES} and C_{BEG} by using our previous model by considering d_{BES} and d_{ESG}. We believe that the difference in the amplitude was caused by wrong estimation, i.e., C_{TSF} of 400 fF and C_{TGF} of 400 fF. The broken line signifies the results of the circuit simulation under the modified circuit parameter at C_{TSF} of 500 fF and C_{TGF} of 500 fF. We found that the simulation results under the modified circuit parameter were similar to the measured values.

Next, we measured V_R by changing d_{TSB} from 5 mm to 205 mm. The experimental results are shown in Fig. 10. The circles signify the measured V_R to V_T ratio, and the solid line signifies the results of the circuit simulation under the initial circuit parameter (Fig. 5). The characteristics of measured ratio differ from that of the circuit simulation. We could not measure C_{TSB} and C_{TGB} by using our previous method. In the circuit simulation, we assumed that C_{TSB} and C_{TGB} were proportional to d_{TSB}^{-1} and $(d_{TSB} + d_{TSG})^{-1}$, respectively. The experimental results show that the induced voltage to the human body is not proportional to d_{TSB}^{-1} and $(d_{TSB} + d_{TSG})^{-1}$. This means that the capacitance between the wearable transmitter and human body should be measured precisely. We believe that electromagnetic field simulation is needed for constructing a precise signal channel model with the wearable transmitter.

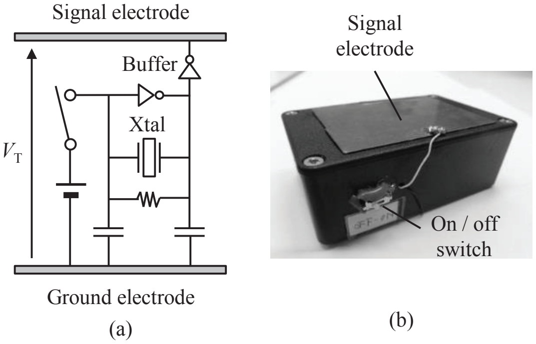

Fig. 6. (a) Circuit and (b) photograph of wearable transmitter.

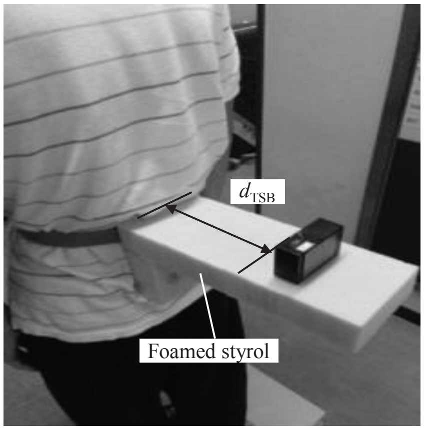

Fig. 7. Photograph of experimental setup for wearable transmitter.

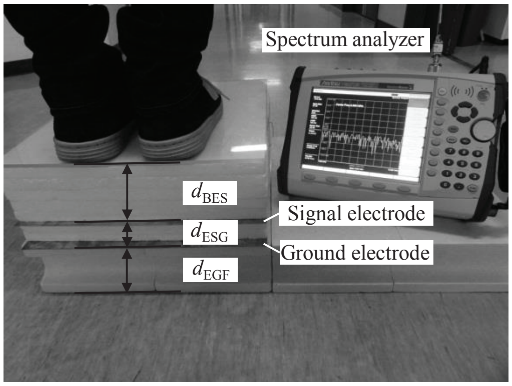

Fig. 8. Photograph of experimental setup for measurement of signal voltage.

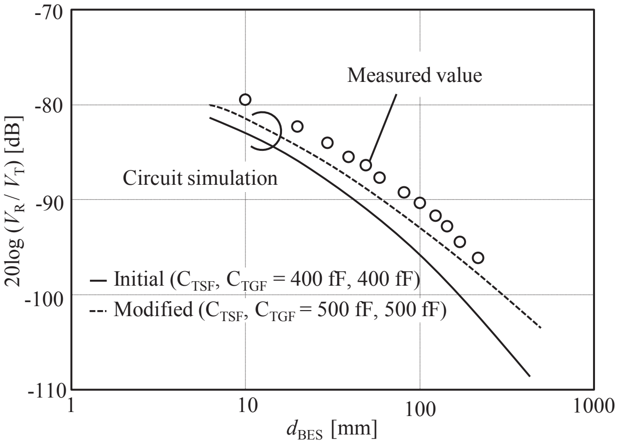

Fig. 9. d_{BES} dependence of V_R / V_T.

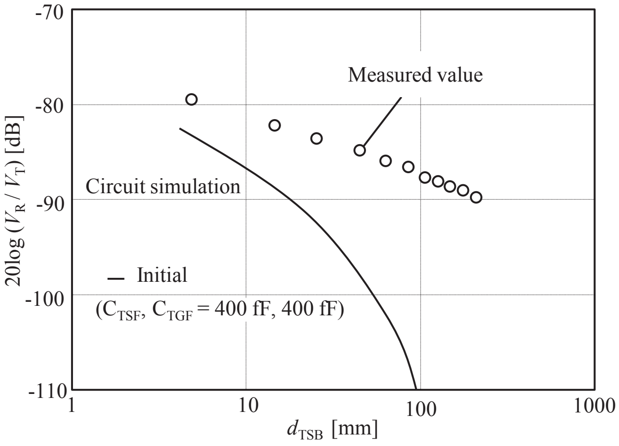

Fig. 10. d_{TSB} dependence of V_R / V_T.

5. SUMMARY

We proposed a signal channel model including a wearable transmitter for intra-body communication systems. The impedance components regarding the wearable transmitter were added to our previous noise channel model to construct this model. The experimental results from between the human body and embedded electrodes were similar to the circuit simulation results using a modified circuit parameter. We found that it is important to estimate the capacitance between the wearable transmitter and floor ground. The experimental results from between the wearable transmitter and human body differed from the circuit simulation results. This suggests that the induced voltage from the wearable transmitter should be analyzed using electromagnetic field simulation.

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