Radio Wave Propagation in an HBC Device Including a Transceiver

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ABSTRACT

In this paper, experiments have been carried out for a prototype human body communication system (HBC) using a music player. However, unstable communication states have occurred because of differences in the measurement environment and the posture of the human body. The radio wave propagation of the HBC is low when the transceiver is worn on the body. In addition, when the frequency used in the HBC system is equal to or less than 50 MHz, we must consider the binding of the transceiver due to near-field propagation. Therefore, it is necessary to consider the analysis of both space propagation and radio wave propagation on the surface of human body. In this study, we analyzed the radio wave propagation of the HBC system considering impedance matching of antenna design's parameter and the presence of the human body.

Categories and Subject Descriptors

Advanced propagation and channel model for BodyNets

General Terms

Measurement, Human Factors.

Keywords

HBC, human body communication, BAN.

1. INTRODUCTION

HBC is a system capable of transferring information through the human body instead of a cable [1]. The transmission methods for HBC are current systems, electric field systems, and elastic waves. The content of HBC involves a range of body-centric communication needs and requirements. These can be classified as on-body, in-body and off-body [2].

In HBC, the communication is performed in a variety of postures. Unfortunately, there are several requirements for realizing stable communication, including differences in electrode structure between each communication device and barriers in the implementation technology. Therefore, we believe that elucidating the propagation characteristics is important in HBC.

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We have carried out several experiments to evaluate prototype HBC devices using a music player. From the differences between the measurement environment and the posture of the human body, we find that stable communication is not always possible. For the purpose of this problem, and increasing the stability of HBC, a propagation analysis of HBC, including an antenna and a transceiver, has been carried out in this study.

Section 2 describes the experimental equipment and the evaluation of HBC. Section 3 presents the results of the simulation for examining the major destabilizing factors obtained from the evaluation experiments. Section 4 discusses the analysis considering both space and radio wave propagation on the surface of the human body. A summary of our work is given in Section 5.

2. HBC PROTOTYPE DEVICE

2.1 HBC Equipment

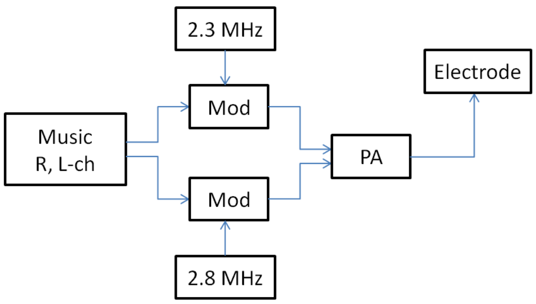
HBC prototype equipment using an electric field method was originally proposed in [3]. Here, the HBC prototype equipment has been developed to study the application of an electric field transmission method for HBC. Figure 1 shows the appearance of the prototype device, where a set of headphones (i.e. the receiver) is on the left and a transmitter is on the right. Table 1 lists the general specifications of the prototype device.

Figure 1. HBC prototype device.

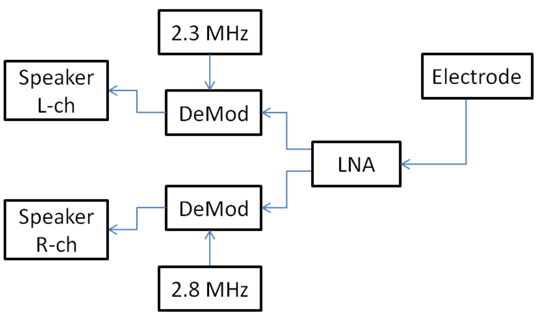
Table 1: General Specifications of Prototype Device

Frequency	Left channel 2.3 MHz Right channel 2.8 MHz
Dimension of Tx Electrode	6 × 2 cm
Dimension of Rx Electrode	23.5 × 2.8 cm
Input Voltage of the Electrode	12 V
Modulation Type	Frequency Modulation

Touch-based HBC schemes introduced in [9] exploit wideband signalling (WBS) for digital audio streaming over the human body. Meanwhile, our prototype system is realized using narrowband signalling. Figure 2 shows the block diagram of the prototype device. The process flow of the transmitter and the receiver is shown in Figures 2a and 2b, respectively. Two carriers of 2.3 MHz and 2.8 MHz are used to transmit music in stereo. An output signal from a music player (not shown in Fig. 1) is modulated and amplified at the transmitter and is applied to the electrodes. As a result, a person who is wearing the headphones can hear the music by touching the transmitter.



(a) Transmitter



(b) Receiver

Figure 2. Block diagram of prototype device.

2.2 Electrode

The electrode was placed in the headphones, so that it is in direct contact with the head. Transmitter was set up inside the housing as shown in Figure 3. In order to maximize the electric field in both electrodes, the ratio of the electrode and the ground areas on the printed circuit board loaded with demodulation and modulation boards are adjusted.

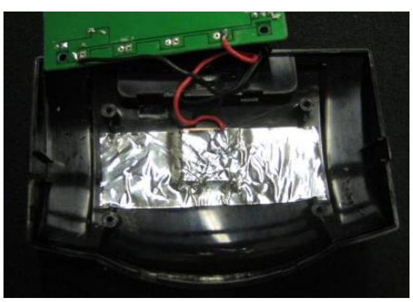


Figure 3. An electrode of a transmitter.

2.3 Evaluation experiment

Music can be heard only by touching the transmitter of the HBC prototype described in [3]. However, the results of the evaluation experiment indicate that sometimes the music cannot be heard even though the transmitter has been touched. Therefore, we assumed the phenomenon occurred because of the differences in human height and postures.

In the evaluation experiments, two postures for the human body were studied: the sitting and standing positions. This evaluation was carried out in a laboratory and an anechoic chamber. In the laboratory, some furniture and other objects were present in the surrounding.

When one hand is lowered and brought close to the chest while holding the transmitter and the music player, there were times when the communication is available and disable. In addition, there were times that communication was disrupted with the presence of an object, such as a desk, in the laboratory environment. In the anechoic chamber environment, communication was stable; however, in the laboratory, instability occurred probably because of the positional relationship between the furniture.

From this experiment, it can be concluded that a number of factors cause instability. The primary factor causing instability needs to be extracted precisely using simulation analysis, which enables elimination of the primary factor.

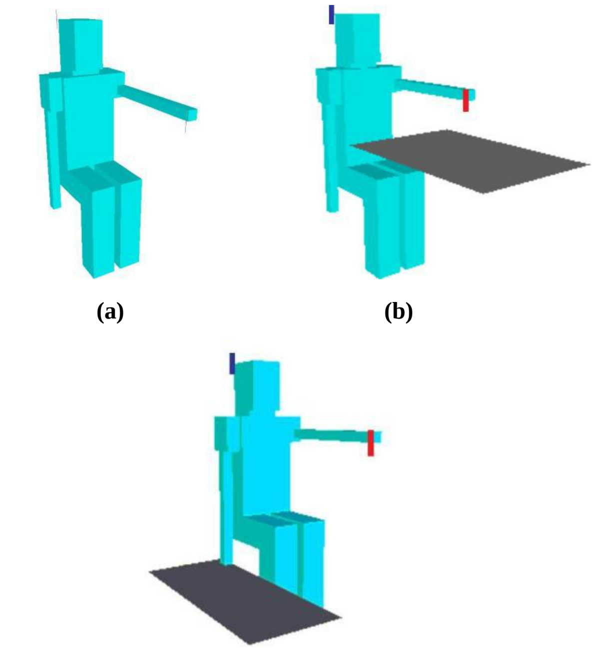
In the next section, the relationship between the position of the HBC system and the propagation in the presence of furniture is discussed to find the cause of the primary factor of the instability.

3. SIMULATION ANALYSIS

3.1 Simulation Model

The electromagnetic field was successfully analyzed via Finite-Different Time-Domain (FDTD) with the frequency set to 3 MHz. Figures 4 and 5 show the human body model in two different postures with a test section (2000 × 2000 × 2300 mm) and metal desk (800 × 430 mm). The human body models are created as described in [4]. For the purposes of this experiment, the permittivity of the human body model was set to 300 and the conductivity was set to 0.35. Dipole electrodes were used [5]. Analyses of the coupling between the electrode and the human body as well as that between the electrodes are being carried out。 The coupling between the electrodes and both sides of the human body surface are analyzed in the simulation by setting the electrodes on both the transmitter and the receiver.

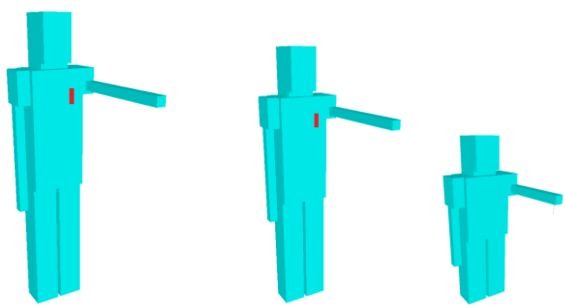
Figure 4 shows the case where the transmitter was located at the tip of the outstretched hand and the receivers were placed on the head. Figure 5 shows the case where the transmitter was installed on the chest and receivers were installed at the hand of the body model. The illustration in Figure 4 also shows the body model in a seated position under three different conditions: (a) body model with no metal desk, (b) body model with a metal desk and (c) body model and metal desk in contact. The illustrations in Figure 5 show: (a) greater than average human height (200 cm), (b) average human height (169 cm) and (c) child (100 cm) models in a standing position.



(a) (b)

(c)

Figure 4. Model of human body.



(a) (b) (c)

Figure 5. Model of human body.

3.2 Electric Field Distribution by Posture

Figure 6 shows the electric field distribution on the human body model with the posture shown in Figure 4a. For this part of the experiment, a comparison between the electric field distribution on the human body model in Figures 6 and 10 was made.

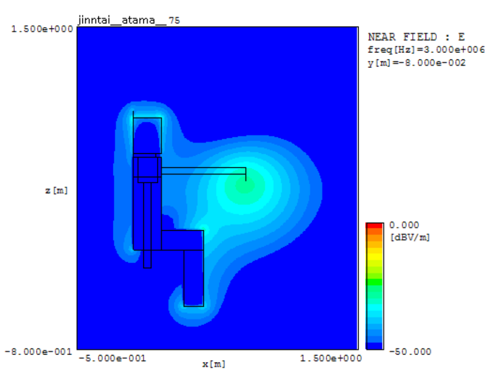


Figure 6: Electric field distribution (no metal) in the sitting position.

As can be seen in both figures, the human body models are in two different postures, and the electric field was distributed along both human body models. However, the electric field was not well distributed on the backside of the knee when the human body model was in a sitting position. Meanwhile, it is strong in front of the knee because of the short distance to the electrodes. On the other hand, when the human body model was in the standing position, the electric field was distributed around the human body model because a transmitter was installed on the chest of the model and the electric field generated was strong. Through this experiment, we can observe the difference in the strength of the electric field distribution on different postures.

3.3 Electric Field Distribution due to the Surrounding Environment

When the experiment was evaluated using the prototype device, communication was disrupted when a metal desk was present. Although the effect of the metal is described in [7], the details could not be analyzed. Here, we analyze the presence of the following conditions in the experiment.

Our analysis compares the presence of a metal desk in the following situations: (1) no metal desk present, (2) a metal desk present, and (3) a metal desk in contact with a human body. In situation 2, the human body was not in contact with the metal. In situation 3, the metal desk was grounded when the human body was contact with the metal desk.

In Figure 7, the electric field distribution for situation 2 is given, while Figure 8 shows the electric field distribution for situation 3. In addition, for this analysis, a transmitting electrode that mimics a transmitter has been installed in the left hand of the human body model and the receiving electrode that mimics a receiver has been installed on the right side of the head.

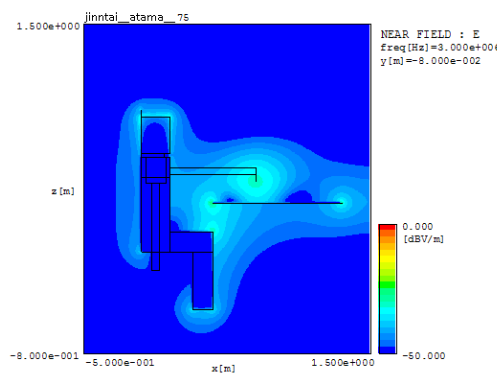


Figure 7: Electric field distribution (with metal desk) in the sitting position.

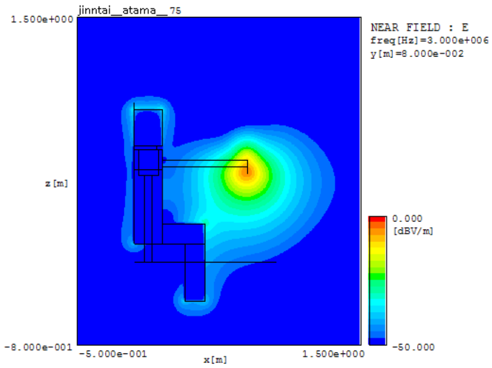


Figure 8: Electric field distribution (touching the metal) in the sitting position.

For this part of the analysis, we compare Figures 6, 7, and 8. Figures 6 and 7 are compared with or without a metal desk present. Figure 9 shows that the electric field distribution is disturbed by reflections from the desk. Table 2 lists the propagation losses for the three different situations of the metal desk. Although reflection is caused by the desk, no significant difference is seen in the propagation loss between the transmitter and the receiver.

For the next part, we compare Figures 6 and 8. It is clear that the electromagnetic wave distributed on the human body surface in Figure 8 has decreased overall, including the head of the model. The deterioration of the electromagnetic wave on the back of the model is particularly noticeable. It can be concluded from Table 2 that there is a propagation loss between the transmitter and the receiver of about 2 dB. This indicates that the density of electromagnetic waves around the human body has decreased because part of the electric field is coupled to ground through the metal.

Table 2: Propagation loss between the transmitter and the receiver

Frequency	No metal	With metal	Touching the metal
3 MHz	0 [dB]	0 [dB]	-2 [dB]

Therefore, it can be concluded that the instability in communication for the prototype device is influenced by the reflected waves with the desk present, as shown in Figure 7, and the decrease in the electromagnetic waves caused by metal contact, as shown in Figure 8.

3.4 Electric Field Distribution and Human Volume

Apart from the instability in communication for the prototype device, there are also individual differences in the human body. In this section, we discuss the body capacity rather than individual differences in the electric constant.

Figures 9, 10, and 11 show a human model with an average height (169 cm), above-average height (200 cm), and a child's height (100 cm). In addition, Table 3 summarizes the results obtained for the propagation loss of those three models.

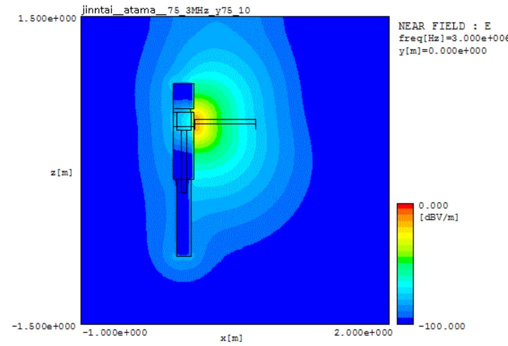


Figure 9: Electric field distribution of the average height model.

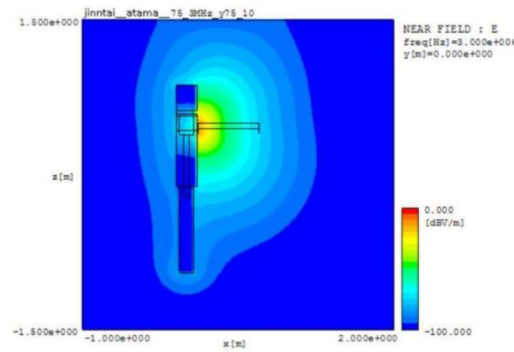


Figure 10: Electric field distribution of the above-average height model.

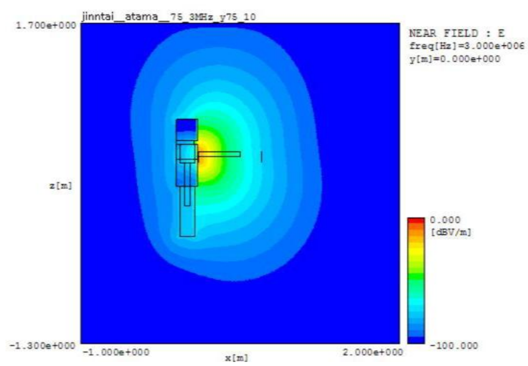


Figure 11: Electric field distribution of the child model.

Table 3: Height of human model (electric field intensity)

	Average	Above-Average	Child
Electric field intensity	-69.09 [dB]	-69.59 [dB]	-93.82 [dB]

Even though the electric fields are evenly distributed over the surface of the human body models in Figures 9–11, the lower body capacity of the child model yields a smaller total electric field. As can be seen in Table 3, the difference in the amount of propagation loss is approximately 0.5 dB when comparing the average and above-average body model, while the child model has a difference of 24.73 dB. From the results, we can conclude that the electric field floats on the surface of the human body

Furthermore, it varies on the basis of differences in body capacity, which is also considered one of the causes of instability.

4. Concept of Propagation of HBC

In HBC, a weak electromagnetic wave is distributed on the surface of the human body, which is dependent on the dielectric constant of the human body, frequency, and position of the transmitter and receiver. On the other hand, the human body can be equipped with communication devices, and coupling also occurs between the devices. The coupling between the equipment depends on propagation and electrostatic coupling, where propagation depends on the inverse cube of distance and the electrostatic coupling depends on the size of equipment. These two largely form the propagation of HBC. The results of these two effects have been explained in the analysis of the previous sections.

Although dependent on the posture of the human body, the electromagnetic wave distributed on the surface of the human body is relatively uniform. When the posture of the human body changes, the distance between the transmitter and the receiver changes. In this case, communication cannot be established. Therefore, for the propagation of HBC, it is necessary to know which propagation path is dominant.

Here, the electromagnetic wave around the human body and the electrostatic coupling are assumed as a human path and space path, respectively. Although it is a difficult task to separate each one, the simplest way to do the separation is as follows. Figure 12 shows the calculated results without the presence of the human body model and without changing the electrode arrangement shown in Figure 9. Table 4 lists the results for the comparison of the propagation loss based on this data.

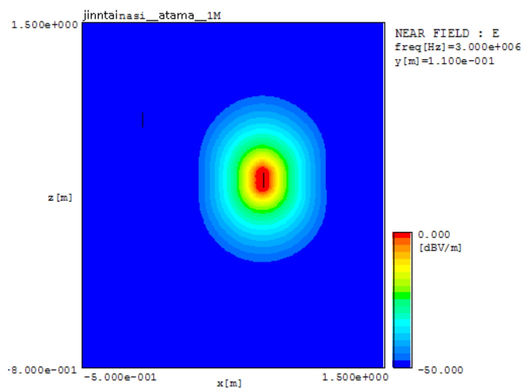


Figure 12: Electric field distribution when there is no human model.

Table 4: The presence or absence of human body model

	Presence of human body model	Absence of human body model
Propagation loss	-18.27 [dB]	-26.35 [dB]

From the analysis, we find that the loss at the antenna is large because a dipole antenna has been used. The difference in propagation loss between the presence and absence of the human body model is 8.08 dB. For example, if the output of a 1W transmitter is propagated through space and the surface of the human model, there is a difference of 10 dB in loss. However, there are cases where it can be ignored because a power of 10 dB is relatively small. In particular, when the transmitter is placed on the arm and the receiver is placed on the back, a direct path is not expected; thus, this case can be ignored.

5. Conclusion

There are situations where communication could not be established when using the HBC prototype device. Therefore, an electromagnetic field analysis has been conducted to explore possible causes of failure in communication. In this analysis, we found that the influence of posture and the surrounding environment resulted in a non-uniform distribution of electromagnetic waves around the human body. In addition, the presence of furniture in the surroundings resulted in weak signal strength because of the sensitivity of the receiver. The separation of the HBC propagation was also attempted.

Based on our results, we can conclude that it is necessary to adjust the receiver sensitivity depending on the conditions when designing an HBC device.

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