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A Study on Reception Electrodes for the Vital-Sign Monitor Using Near-Field Intra-Body Communication Enhanced by Spread Spectrum Technique

Takumi Kobayashi, *Student member, IEEE,* Yuichi Shimatani, and Masaki Kyoso, *Member, IEEE*

***Abstract*—As a novel vital sign monitor, we have developed wireless ECG monitoring system with Near-field intra-body communication (NF-IBC) technique. However, it was hard to ensure communication reliability because transmission channel is noisy and unstable. In order to solve the problem, we utilize spread spectrum (SS), which is known as robust communication technique even through poor transmission channel. In previous study, we have already developed an ECG monitor using NF-IBC enhanced by SS. In this paper, we evaluated on structure of the reception electrode for reliable communication. Based on the evaluations with bit error rate, we suggested the reception electrode structure which can keep the communication reliability. As the results we considered that we can expand the reception electrode up to 2.25m^2. Moreover, we proposed the structure of the reception electrodes that can keep the communication reliability. Finally we suggested how to use the SS NF-IBC vital-sign monitor in room that larger than 2.25m^2, and we had shown the practicability of the systems.**

I. Introduction

Recently, vital-sign monitors have been getting ubiquitous. However radio wave which is widely used for typical ubiquitous monitor has some problems such as interference to other medical devices and information leakage. As a solution using body area network, we proposed an application of near-field intra-body communication (NF-IBC) technique [1] to vital sign monitor. The concept of this technique is to use electric field instead of electromagnetic wave between the transmitter and the receiver as shown in Fig. 1. The problems like interference and leak can be suppressed because electric field is effective only in the limited area surrounding the body.

Fig. 2 shows wireless ECG monitoring system that we developed in previous study [2]. ECG signal was successfully transmitted by NF-IBC, however, communication reliability is not so high because transmission channel contains capacitive coupling and it is noisy and unstable. Higher transmission amplitude which may be the easiest way to improve these problems can not be applied to because of safety issue.

In order to solve the problems mentioned above, we proposed an application of spread spectrum (SS) technique to NF-IBC technique. SS system has two remarkable features; 1) robustness against interference, 2) low interference to other system. Those are derived from correlation demodulation and low power spectrum density [3]. Fig. 3 shows a structure of an SS transmitter and frequency spectra. The technique has two important operations that is "Spreading" in transmitter and "Despreading" in receiver as shown in Fig. 3. Those two are performed with "spread code" which has pseudo-random characteristics. Transmitted signal may not give interference to other systems because power spectrum density of SS is far lower than the signal by conventional narrow-band modulation. In the receiver, narrow-band modulated signal is retrieved through “Despreading” process. At the same time, additional noise component is scattered to wider frequency band because “Despreading” process is performed by correlation with the spread code. From the principle of SS modulation, it is effective on the noisy transmission path.

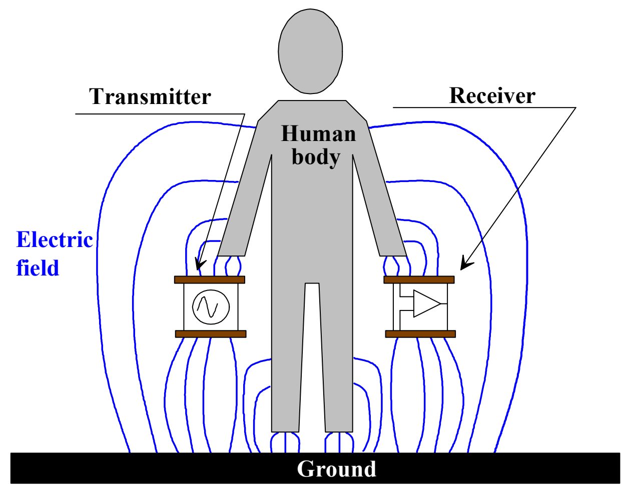

Figure 1. Principle of near-field intra-body communication.

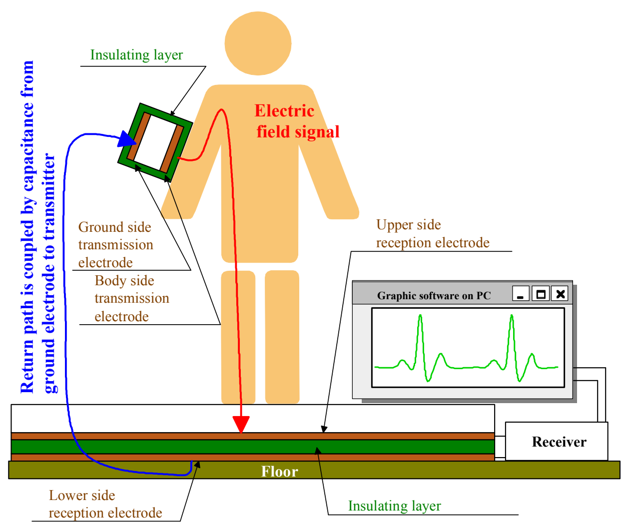

Figure 2. Proposing Vital-sign monitoring system using NF-IBC.

In previous study, we had developed the ECG monitoring

Takumi Kobayashi, is with the Yokohama National University, Kanagawa, Japan. (e-mail: kobayashi@kohnolab.dnj.ynu.ac.jp).
Yuichi Shimatani and Masaki Kyoso are with the Tokyo City University, Tokyo, Japan.

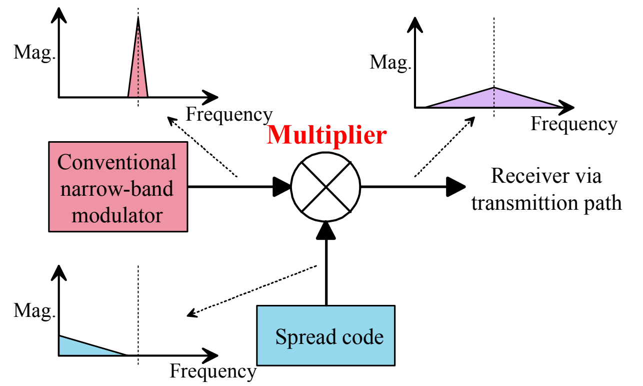

Figure 3. Simplified structure of a SS transmitter and frequency spectra.

system using NF-IBC with SS [4]. It has been shown that the system can be used for ubiquitous vital-sign monitor. The following study shows that a walking user can also use the SS NF-IBC system [5]. In this study, the user was walking on a treadmill which was placed over the reception electrodes. The system performance was found to depend greatly on the transmission path from the body to the reception electrodes. In order to use the NF-IBC system in general environment, we should consider about the reception electrode.

From above-mentioned background, we evaluated a relation between the reception electrode specifications and communication reliability in this paper. According to the evaluation, we finally proposed the reception electrode structure which can keep the communication reliability.

II. Experiment

A. Transmission Channel Model and Performance Estimation

In the NF-IBC, modulated signal propagates on the surface of the human body. The connections between the body and the electrodes can be modeled with capacitive coupling [1]. In this case, the surface of the body is treated as a conductor. Accordingly, a transmission path model is expressed by the equivalent circuit as indicated in Fig. 4. Parallel-plate capacitors form between the body surface and transmission / reception electrodes. The capacitance C is expressed by (1) where d is a distance, S is an area of the electrode, and ε is permittivity.

$$C = \frac{\varepsilon S}{d} \tag{1}$$

In the model Fig. 4, C_b, C_c, C_g, and C_h are fixed by geometry of the reception electrodes and the body. As shown in Fig. 2, the distance between the body side electrode or upper electrode (UE) and the body is far smaller than the distance between GND electrode or lower electrode (LE) and the body. Therefore in this model, we can omit the C_c and C_h because the capacitance of C_c and C_h are lower enough than C_b and C_g respectively.

In this model, C_d is very important because it works as the return path of the NF-IBC signal. This means that the total

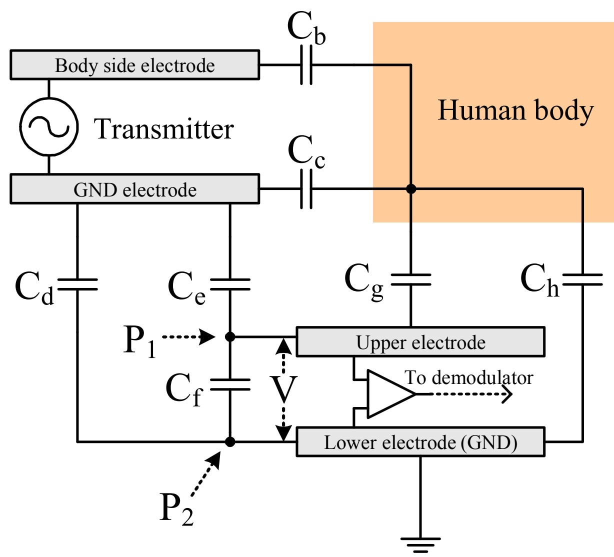

Figure 4. NF-IBC model.

communication reliability of NF-IBC is dominated by C_d. Its capacitive coupling is so weak because of long distance between the electrode and ground. A large C_d is desirable to achieve high communication reliability, however, it is hard to decrease the distance between transmitter and lower electrode because transmitter is put on the body of the user. It is also hard to expand the transmission electrode size because the size of transmitter greatly depends on transmission electrode size.

When a user is standing outside of the UE, geometric relations between UE or LE and the body are similar. In this condition, the amplitude of reception signal decreases because of $C_h \approx C_g$.

This estimation from model point of view indicates that the structure such as the size, and the layout of the electrodes should be evaluated. In this paper, we evaluated communication reliability in changing transmission path parameters; 1) distance between the transmitter and UE, 2) the size difference of UE and LE.

B. Evaluation Method

As a method to evaluate communication reliability, we measured bit error rate (BER). The BER was calculated with (2) where N is the number of total transmitted bits, E is the number of error bits which was received. The data that transmitted from transmitter were the static known data, and E was obtained by comparison between transmitted and received data. In all experiments, transmitter was put on upper arm of a static user as shown in Fig. 2, and N was 24kbits.

$$BER = \frac{E}{N} \times 100[\%] \tag{2}$$

All experiments were done by using a SS NF-IBC system which was developed in the previous study [4] and its specifications are listed in TABLE I. The measurements were carried out once for each condition.

TABLE I. SPECIFICATIONS OF THE SS-NF-IBC TRANSMITTER.

Power supply		AAA battery × 2
Size(W×D×H) [mm]		110 × 75 × 30
Electrode size (W×D) [mm]		90 × 55
Modulation method		DBPSK
SS carrier frequency [MHz]		7.3152
Data rate [bit/sec]		28800
Packet structure	**Start bit [bit]**	1
	Data bit [bit]	8
	Stop bit [bit]	1
	Parity	Odd, 1bit
for SS	**Spread code**	M-sequence
	Code period	127
Power consumption (Ave.) [mW]		29.1
Power consumption (Max.) [mW]		34.8

C. *Experiment on Electrode Size*

x_{UE} and x_{LE} are defined as the widths of UE and LE as shown in Fig. 5. The electrodes areas S_{UE} and S_{LE} are defined as (3) and (4) because the electrodes are squares. The difference of the widths is x_d and it is defined in (5).

$$S_{UE} = x_{UE}^{\ 2} \quad (3)$$

$$S_{LE} = x_{LE}^{\ 2} \quad (4)$$

$$x_d = x_{LE} - x_{UE} \quad (5)$$

In this experiment, we changed x_d and measured BER in each case. In order to change x_d, we changed x_{LE} without changing x_{UE}. The reason why we kept x_{UE} constant is that C_d in Fig. 4 is intended to be fixed. x_{UE} was set to 150cm and x_d was set to 0cm, 15cm, 30cm. In addition, all the experiments were done in two cases that a user was wearing shoes or bare feet.

D. *Experiment on User position on the reception electrode*

In this experiment, the position of the user was changed on UE. D_d defined as a distance from the center of UE in Fig. 5 was used for the evaluation. D_d was set to 0cm, 25cm, 50cm, 75cm and 100cm (Fig. 5). In these conditions, D_d=75cm and D_d=100cm means that the user stands on the edge of the UE and outside of the edge because x_{UE}=150cm. All the experiments were done in two footwear conditions, slippers or bare feet.

III. RESULTS

Fig. 6 and Fig. 7 show the BER performances in changing x_d. Fig. 8 and Fig. 9 show the change of the BER in case that we changed D_d. Fig. 6 and Fig. 8 were measured with barefoot user. Fig. 7 and Fig. 9 had measured in case that user was wearing slippers.

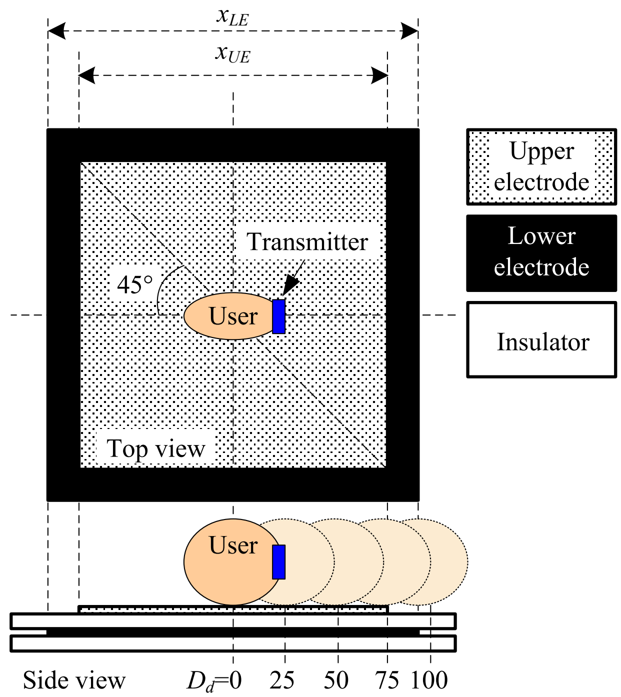

Figure 5. Reception electrodes and experimental conditions.

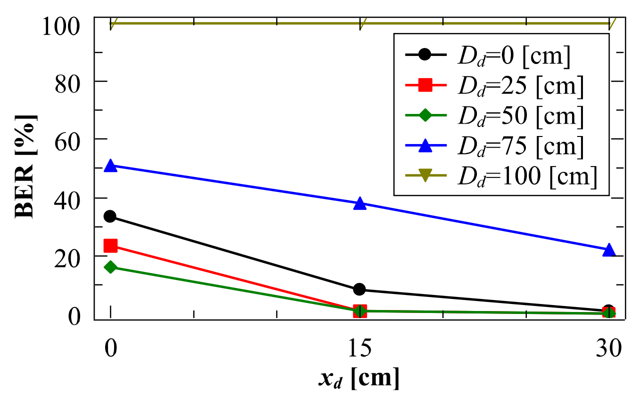

Figure 6. BER vs. x_d through the barefoot user.

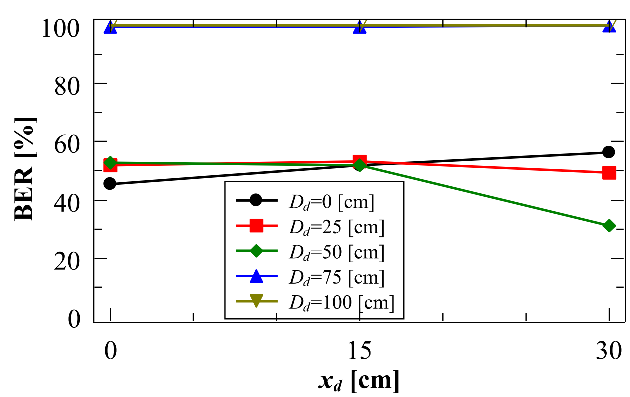

Figure 7. BER vs. x_d through the slippers.

IV. DISCUSSION

Fig. 6 and Fig. 7 show the decrease of BER that follow to the increase of x_d. It means that acceptable communication reliability can be obtained when LE has larger enough than

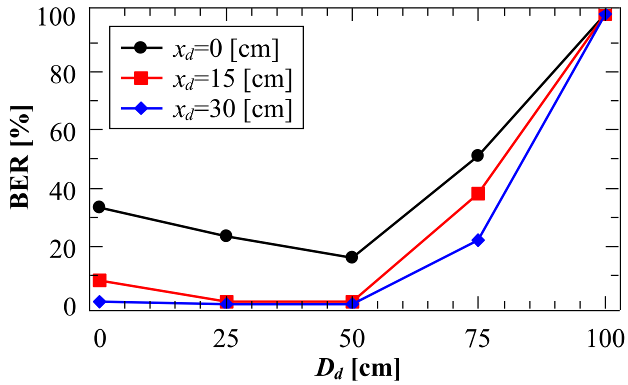

Figure 8. BER vs. D_d through the barefoot user.

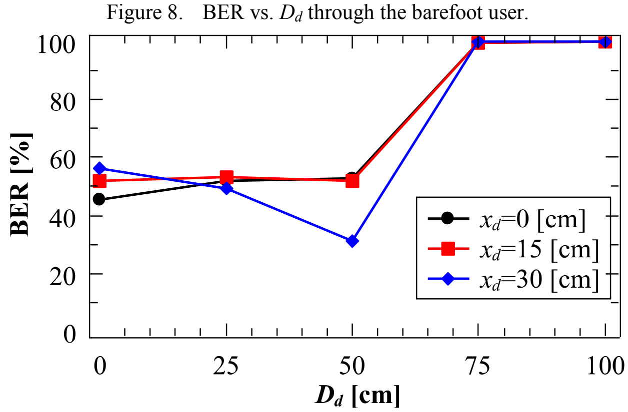

Figure 9. BER vs. D_d through the slippers.

UE. We considered that it came from the capacitive coupling strength at C_d in Fig. 4. The area of S_{LE} dominates the coupling strength at C_d. For the same reason, an increase of C_d follows to an increase of x_d, and C_g is kept constant because S_{UE} is constant. An increase of x_d produces good BER performance because the voltage V between P_1 and P_2 is caused from difference between C_d and C_g. Therefore, when x_d =0, BER deteriorates because coupling strength of C_d is weak.

Besides S_{LE}, C_d also depends on the distance D_d between transmitter and UE. Fig. 8 shows that BERwas lowest when D_d was 50cm regardless of x_d. The results for $D_d \geq$ 50cm mean that both foot of the user had to be put on the UE. If the user steps out of the UE, C_h becomes larger than C_g, and the most signal that transmitted through the body flows out to the ground. We considered that an increase of BER in case of smaller D_d caused by a decrease of C_d.

Based on these results, requirements on reception electrode for acceptable communication reliability can be summarized. In order to keep BER lower than 5%, x_d should be larger than 15cm and distance between the user and the edge of UE should be kept within 50cm, and the both foot of user should be placed on UE, the BER is kept in 5%. Accordingly, when x_{UE} is 50cm or 75cm, LE size x_{LE} is larger than x_{UE} by 15cm or more and both electrodes are square, communication reliability of SS NF IBC system is kept regardless of position of user on UE. In addition, if we can give the area larger than 30cm to x_d, we can expand x_{UE} up to 100cm.

In order to expand the communication area, we propose the structure of the reception electrode as shown in Fig. 10.

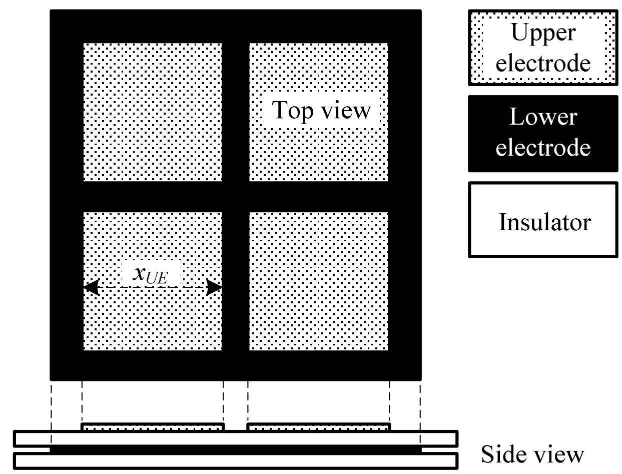

Figure 10. Structure of the electrodes to expand the communication area.

The communication reliability is ensured when both foot of the user are on any UE. It can be applied to any size, any shape of communication area by changing the number and layout of UE.

V. Conclusion

In this study, we evaluated about the reception electrode for improving the communication reliability. First of all, we had considered on the transmission model of the NF-IBC, and we anticipated that communication reliability depended on the structure of the reception electrodes and distance between the upper and the lower electrode. Next, we measured and evaluated the BER with a SS NF-IBC transmitter and receiver developed in the previous study [4,5] in changing structure of the reception electrode and location of user on the electrode. From the experimental results, we concluded that the diameter of the lower electrode should be larger than the upper electrode by 15cm or more and the distance between the user and lower electrode have to kept within 50cm in order to keep the communication reliability. Finally, we suggested a structure of reception electrode to expand communication area.

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