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Application of Near-Field Intra-Body Communication and Spread Spectrum Technique to Vital-Sign Monitor

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***Abstract*—As a novel vital sign monitor, we have developed wireless ECG monitoring system with Near-field intra-body communication technique. However, communication reliability is not so high because transmission channel is noisy and unstable. In order to improve the problem, we utilize spread spectrum (SS), which is known as robust communication technique even through poor transmission channel. First of all, we evaluated characteristics of human body to SS signal. The results show that SS can be used even through human body. Based on this result, we developed and tested near-field intra-body communication device enhanced by SS. The test result shows that SS can solve the problem mentioned above.**

I. Introduction

RECENTLY, vital-sign monitors have been getting ubiquitous, however, radio wave widely used for typical ubiquitous monitor has some problems such as interference to other medical devices and information leakage. As a solution for body area network, we proposed an application of near-field intra-body communication technique [1] to vital sign monitor. The concept of this technique is using electric field instead of electromagnetic wave between the transmitter and receiver as shown in Fig. 1 . The problems such 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 we developed in previous study[2]. ECG was successfully transmitted by near-field intra-body communication, however, communication reliability is not so high because transmission channel is noisy and unstable. Higher transmission amplitude which may be easiest way to improve this problems can not be applied because of safety issue. In order to solve the reliability problems, we proposed application of spread spectrum (SS) technique to near-field intra-body communication technique.

SS system has two remarkable features; 1) robustness against interference, 2) low interference to other system because of 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 as shown in Fig. 3 and "Despreading" in receiver. Those two are performed with "spread code" which has pseudo-random characteristic. Transmitted signal may not give interference to other systems because SS modulated signal has suppressed power spectrum in wide frequency band. Additional noise component is scattered to wider frequency band and received SS signal is retrieved to narrow band width with the same spread code as in the transmitter because "Despreading" process is performed by correlation with the spread code. From the principle of SS modulation, it is effective on the noisy and noise sensitive transmission path.

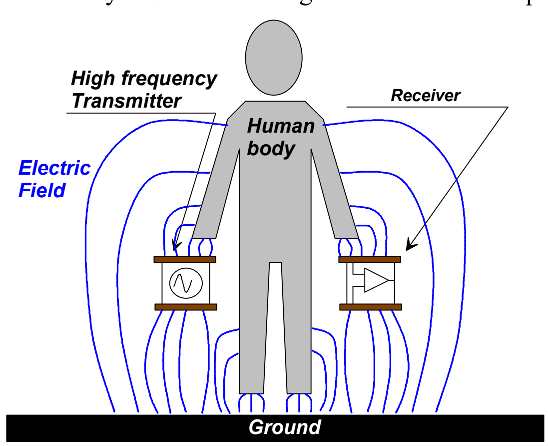

Figure 1. Principle of near-field intra-body communication

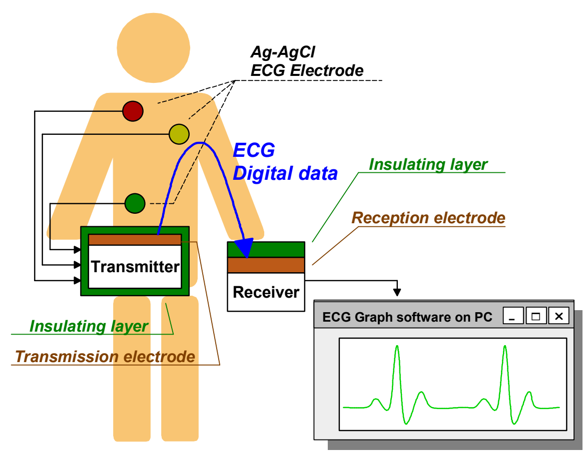

Figure 2. Wireless ECG monitor using near-field intra-body

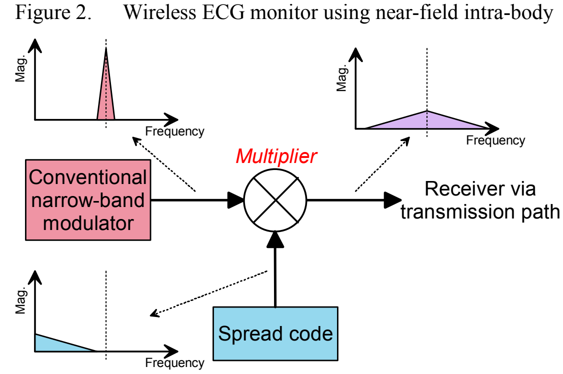

Figure 3. Simplified structure of a SS transmitter and frequency spectra

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From above-mentioned background, we proposed a vital-sign monitor by combined techniques with near-field intra-body communication and SS. First of all, we measured the characteristics of human body to SS signal to evaluate applicability of SS. As the next step, we completed and tested a communication system.

II. Transmission Channel Characteristics Through Human Body

A. Frequency response of human body

As mentioned before, SS signal occupies wide frequency band. Therefore, transfer characteristics of human body in wide frequency band is important to evaluate applicability of SS. Fig. 4 and TABLE I shows the measurement condition for human body channel characteristics. Attenuation through human body was measured by a gain-phase analyzer (Hewlett Packard: 4194A). A human subject was touched to transmission electrode with his palm, and stood on the reception electrode. Signal propagated human body was received at the electrode on the floor. The amplifier keeps gain of +40dB from DC to 70MHz so that measured result is not affected. In the experiment, all the circuits and equipments were separated and insulated from a ground to avoid capacitive coupling. We measured range of 100Hz-40MHz including the frequency range previously reported[4]. In addition, we also measured airborne propagation response. All the experimental condition except no human body was the same as the body propagation experiment.

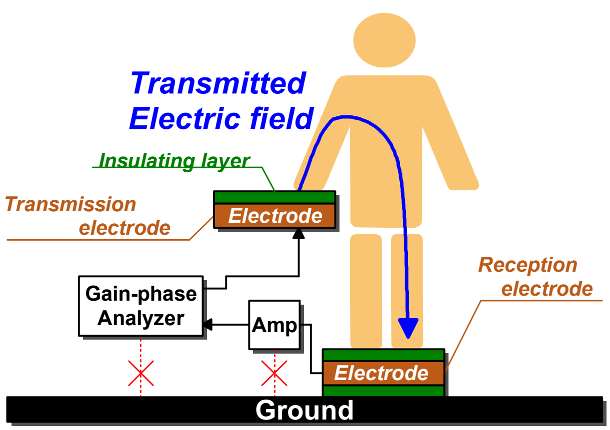

Figure 4. Experimental schematic

TABLE I. Electrode Specifications And Insulating Conditions

Parameter	Value	
	Transmission electrode	Reception electrode
Size [mm]	64.5 × 84.5	365 × 595
Conductive layer material	Copper	Copper
Top insulating layer thickness [mm]	1.5	20
Top insulating layer material	FR-3	Polyurethane
Distance from the ground [mm]	>1000	75
Bottom insulating layer material	-	Wood
Position of the electrodes	Palm	Sole
Distance between electrodes [mm]	>1000	

B. SS transmitter

A transmitter circuit was prepared to evaluate how frequency spectrum of SS signal was distorted through human body. The specification is shown in TABLE II . Length of spread code means how much degree the signal is spread in wider frequency band. The other parameters were decided from maximum sampling frequency for vital sign, propagation frequency response through human body, and so on. Especially, relationship between carrier frequency and chip rate of spread code is important. Differential detection[5] can be applied for SS despreading and BPSK demodulation at the same time if these ratio are set to a natural number. The ratio was set to two for this system. Fig. 5 shows structure of the transmitter. Transmitted data is ECG previously measured and stored. Spectrum spreading is done by multiplication between serial data sequence and pseudo-noise. One cycle of the spread code corresponds to a data bit in time domain. The signal modulated by binary phase-shift keying (BPSK) is applied to a transmission electrode.

C. Propagation of SS signal through the human body

In this experiment, we measured how SS signal was distorted through human body. The transmitter prepared was used as a SS signal generator. Frequency spectra at the transmitter output and amplifier output connected to receiving electrode were measured with spectrum analyzer (Tektronix: WCA230A). Measurement conditions were similar to the experiment for frequency response as shown in Fig. 4 and TABLE I .

III. Receiver Circuit and Communication Tests

A. SS receiver

Fig. 6 shows schematic of developed receiver. Differential detection technique[5] used for demodulation method is performed by multiplying delayed copy of the modulated signal by the original signal. If the ratio between carrier frequency and chip rate of spread code is a natural number,

TABLE II. Transmitter Specifications

Parameter	Value
Spread code	M-sequence
Length of spread code	127
Data rate [bit/sec]	28800
Chip rate of spread code [MHz]	3.6576
Carrier frequency of BPSK modulation [MHz]	7.3152

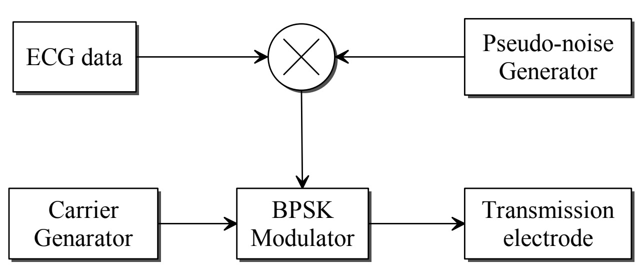

Figure 5. Structure of transmitter

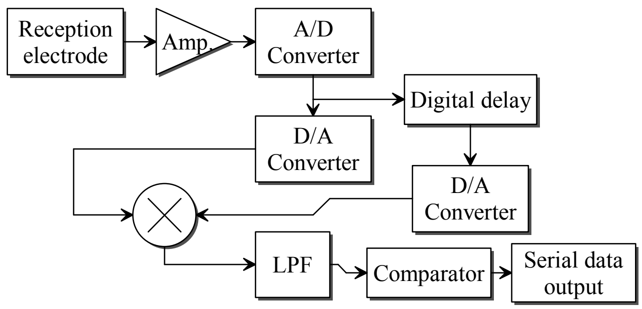

Figure 6. Structure of receiver

despreading and BPSK demodulation can be done at the same time. In this receiver, delay time is controlled by accurate clock because demodulation performance largely depends on an accuracy of delay time.

B. *Demodulation test and communication experiment*

Using developed transmitter and receiver, we measured the changes of signal spectrum through the process; spreading, BPSK modulation, human body propagation, despreading and BPSK demodulation. In this experiment, measurement conditions are similar as in Fig. 4 and TABLE I.

For the final evaluation of the system, ECG previously measured and stored was transmitted. Waveforms at ECG data output and receiver output were stored. Serial to parallel conversion was also applied to the digital data to retrieve sampled waveform.

IV. RESULTS AND DISCUSSION

A. *Human body characteristics*

Fig. 7 shows a frequency response. It shows that human body propagation has flat frequency response and lower attenuation than airborne one. Especially from 2MHz to 40MHz, magnitude variability was within 20dB.

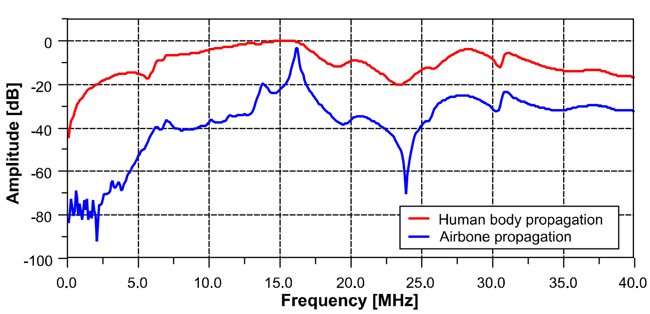

Figure 7. Frequency responses of human body and airbone propagation

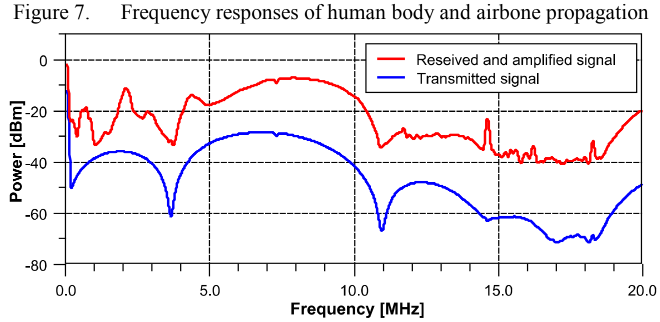

Figure 8. Frequency spectra of transmitted and received SS signal

Fig. 8 shows frequency spectrum of SS signal before and after propagation. Received signal which is drawn with red line in this figure was amplified by 40dB. The result shows that quality of received SS signal is enough to be correctly demodulated because spectrum of received SS signal keeps the shape on main lobe between 4MHz and 11MHz.

From those results, it was shown that wide bandwidth SS signal can pass through the human body in acceptable quality. It was also shown that the system parameters of the SS transmitter shown in TABLE II is appropriate for near-field intra-body communication.

B. *Transmission, reception and demodulation*

Fig. 9 shows frequency spectra at the notable points in the system. Comparison between (b) and (c) shows that distortion

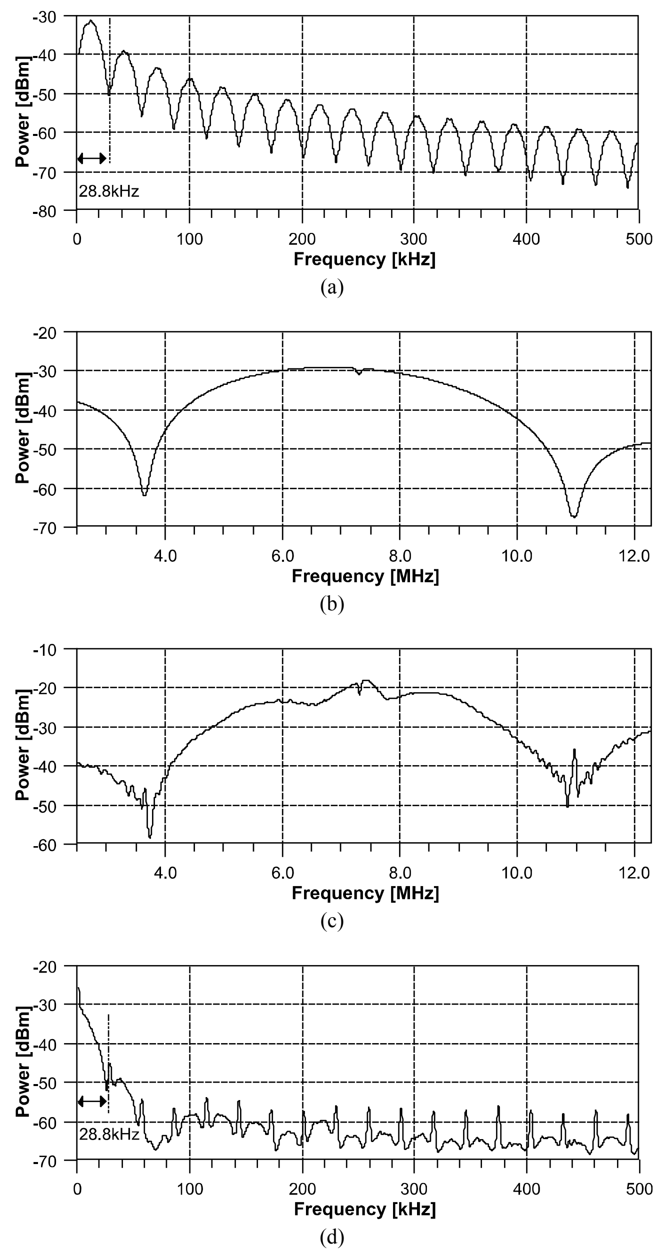

Figure 9. Signal spectra in SS system
(a):data sequence, (b):at the transmitter output, (c):at the amplifier output of the receiver and (d):final output

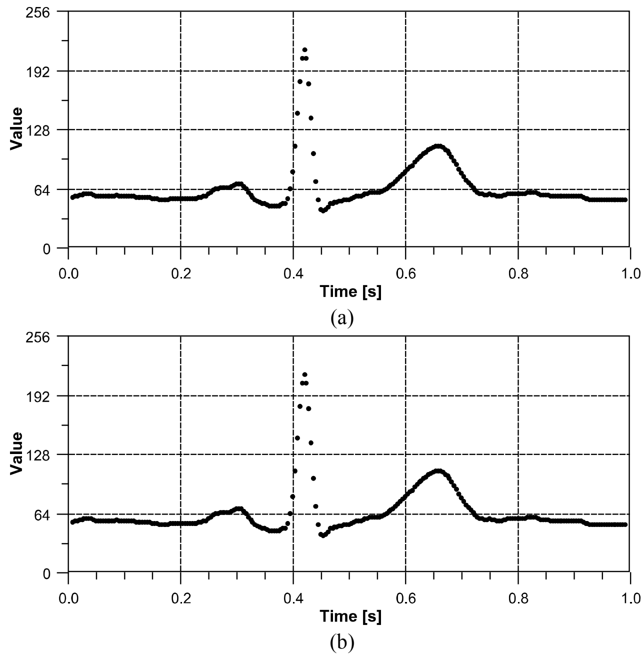

Figure 10. result of ECG data communication (a):original, (b):demodulator output

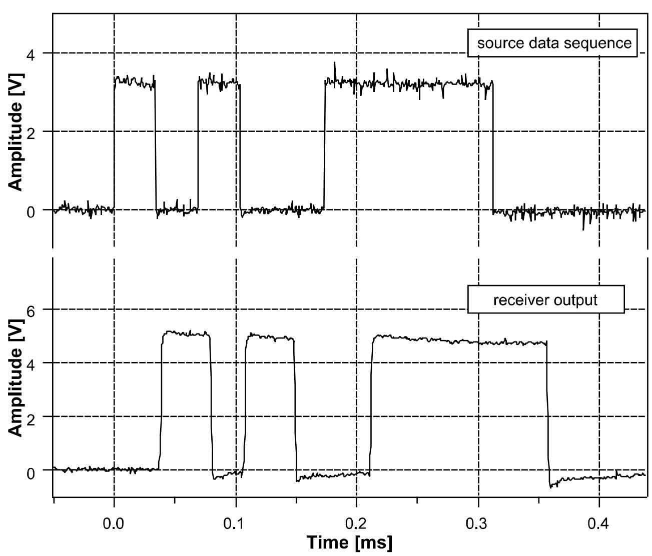

Figure 11. Signal delay between input and output

in frequency domain was low enough. Comparison (a) and (d) shows that original data spectrum was retrieved at the output of the receiver. (c) and (d) show that despreading and demodulation were successfully performed. From spectral point of view, SS modulation and demodulation were properly performed, and SS signal received little effect from human body frequency response.

C. Communication experiment

Fig. 10 shows original ECG data and receiver output. No bit error was detected even for long term communication experiment. This shows that communication reliability was remarkably improved from the previous system[2].

In this experiment, ECG data previously stored was used. For the next step, ECG amplifier and A/D converter block must be added to the receiver so as to be a vital sign monitor. It may be easily realized because data could be communicated in far higher data rate than required sampling rate for ECG measurement.

Fig. 11 shows how much delay occurred through whole process. These waveforms are captured at the same time. From these waveforms, it is shown that data sequence was retrieved perfectly and received signal has delay by 38.4us. This transfer delay in Fig. 11 is primarily came from demodulation process. Differential detection scheme is based on correlation between current signal and signal delayed by one bit. Therefore, transmitted data are demodulated by one bit delay in principle. However, the delay is small enough to keep real time communication as shown in Fig. 10.

V. CONCLUSION

In this paper, we proposed a combination of near-field intra-body communication and SS technique. For the first step, we measured human body frequency response. The result showed that flat frequency response could be acceptable for SS signal transmission. Based on these results, we developed SS communication circuit. As the result of communication experiment through human body, it was shown that communication reliability with SS technique was far higher than previous non-SS system because no bit error was detected in the experiment. From all these facts, it can be concluded that application of SS technique to near-field intra-body communication is effective for body area wireless communication.

For the next step, real-time ECG monitor should be developed. It is necessary for the system to sample and transmit ECG alternatively because transmitted signal affects ECG measurement. However, this technique will be easily implemented to the system because it was already used in the previous non-SS system[2].

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