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Invited Paper

Statistical Model of Intrabody Communication Channels

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Abstract. In the development of intrabody communication systems, it is important to understand the effects of the user's posture on the communication channels. In this study, we conduct a statistical modeling of the dynamic intrabody communication channels.

1. Introduction

In the development of intrabody communication systems [1], it is important to understand the effects of the user's posture on the communication channels. In this regard, Zedong et al. have measured the dynamic communication channels and made a statistical characterization in various environments [2]. However, the effects of the grounding conditions, which depend on applications, on the communication channels were not addressed in [2]. For this reason, we have measured the dynamic communication channels in several grounding conditions and have found that the variations in the channels are significant if both the transmitter (Tx) and the receiver (Rx) are not grounded [3]. In this study, we conduct further investigations based on statistical channel modeling [4].

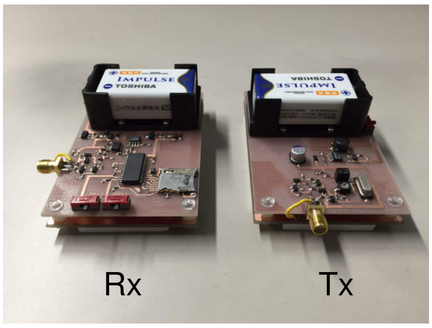
2. Measurement Instruments

To measure the dynamic signal transmission characteristics at arbitrary grounding conditions, we developed battery-powered Tx and Rx shown in Fig. 1(a) [3]. Both the Tx and the Rx consist of rectangular parallel-plate electrodes of 90 mm × 60 mm that are backed by FR-4 substrates of 1.6-mm thickness. The electrode that faces the human body is called the "hot" electrode, and that which faces space is called the "cold" electrode. The metallic faces of the hot and the cold electrodes are opposed each other and separated by a gap of 5 mm. The electrodes of the Tx are driven by a 10-MHz sinusoidal voltage source of 4.0 V with internal impedance of 50 Ω. On the other hand, the electrodes of the Rx are loaded by a receiving circuit of 5-kΩ input impedance. The received voltage was detected by a logarithmic detector and its envelope was sampled by a 10-bit analog-to-digital converter in a sampling interval of 50 ms. The sampled data are recorded on a microSD card. The measurable range is approximately from −90 dBV to −3 dBV. The details of the Tx and the Rx are described in [3].

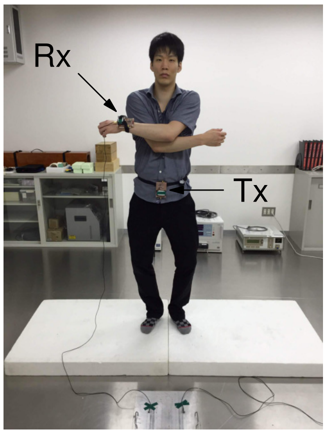
3. Measurement Conditions

Fig. 1(b) shows the measurement setup in a shielded room of 10 m × 5.5 m × 3 m. The experimental subject was a 24-year-old male student, who is 1.85 m in height and 75 kg in weight. The Tx and the Rx were mounted on his abdomen and left wrist, respectively. On an expanded polystyrene board with a thickness of 100 mm placed on the floor of the shielded room, the subject moved his body according to the radio calisthenics #1, which is broadcasted by the Japan Broadcasting Corporation (NHK). Because the pace of the movement is kept by the accompaniment, repeatable measurements are enabled. The received voltage of the Rx was recorded during the sequence of which time length is 180 s under the following four grounding conditions:

No GND: Both the Tx and the Rx are not grounded.
GND Tx: The cold electrode of the Tx is grounded.
GND Rx: The cold electrode of the Rx is grounded.
GND Tx & Rx: The cold electrodes of the Tx and the Rx are grounded.
The details are described in [3].



(a)



(b)

Fig. 1. (a) Measurement instruments and (b) measurement setup.

4. Channel Modeling Method

A probability density function (PDF) $f_{\mathrm{meas}}(x)$ as a function of the received voltage x in the decibel scale was obtained by post-processing the measured data. In this paper, a multiple normal distribution (MND) model is proposed to model the measured PDF. The MND model is defined as follows:

$$f_{\mathrm{meas}}(x) = \sum_{i=1}^{N} \frac{w_i}{\sqrt{2\pi}\sigma_i} \exp\left[-\frac{(x-\mu_i)^2}{2\sigma_i^2}\right], \tag{1}$$

where N is the number of normal distributions that constitute the MND model, and μ_i, σ_i, and w_i are the mean, the standard deviation, and the weight of the i-th normal distribution, respectively. The parameters μ_i, σ_i, and w_i were determined so as to minimize the integrated value of the squared residuals, i.e. they were obtained by solving an optimization problem described as

$$\begin{aligned} &\text{minimize} && \int_{-\infty}^{\infty} [f_{MND}(x) - f_{\mathrm{meas}}(x)]^2 dx \\ &\text{subject to} && \sigma_i > 0, \quad i = 1, \dots, N, \\ & && w_i > 0, \quad i = 1, \dots, N, \\ & && \sum_{i=1}^{N} w_i = 1. \end{aligned} \tag{2}$$

The solution of this problem was first searched globally by the genetic algorithm. Then, the better solution was searched locally by the Nelder–Mead method.

5. Results

Fig. 2 compares the measured PDF and the MND model in several grounding conditions, where $N = 4, 3, 2,$ and 1 in the conditions “No GND,” “GND Rx,” “GND Tx,” and “GND Tx & Rx,” respectively. In addition, the numerical values of the obtained parameters are summarized in TABLE I.

The PDF in the condition “No GND” has the most complex profile. However, it is reasonably approximated by the MND model of $N = 4$. The first and the second peaks corresponds to the first and the second normal distributions of $\mu_1 = -85.72$ dBV and $\mu_2 = -73.96$ dBV, respectively. In addition, the PDF between these peaks is very low. This fact means that the received voltage tends to lapse into extremely low levels with a probability of approximately 7% ($w_1 = 0.07227$) and is likely due to the shadowing by the body parts [3]. In the range approximately from -75 to -65 dBV, many distributed peaks constitute a broad profile and they are approximated by the third and the fourth normal distributions of $\mu_3 = -78.81$ dBV and $\mu_4 = -64.12$ dBV. This trend is observed only in this condition, and is likely because the direct return path formed between the Tx and the Rx is significant in this condition whereas another return path through the earth ground is dominant in the other conditions [3].

The PDF in the condition “GND Rx” is totally well approximated by the MND model of $N = 3$. However, the first peak approximately at -69 dBV is not well fitted, and this tendency was not resolved even if N is increased up to 4. This result suggests that there is room to improve the MND model for this case.

The PDFs in the conditions “GND Tx” and “GND Tx & Rx” are relatively simple. Therefore, they are sufficiently approximated by the MND models of $N = 2$ and $N = 1$, respectively. In addition, further improvements were not achieved even if N is increased.

The results described above suggest that the proposed MND model is useful to model the dynamic intrabody communication channels even if the PDF has a complex profile.

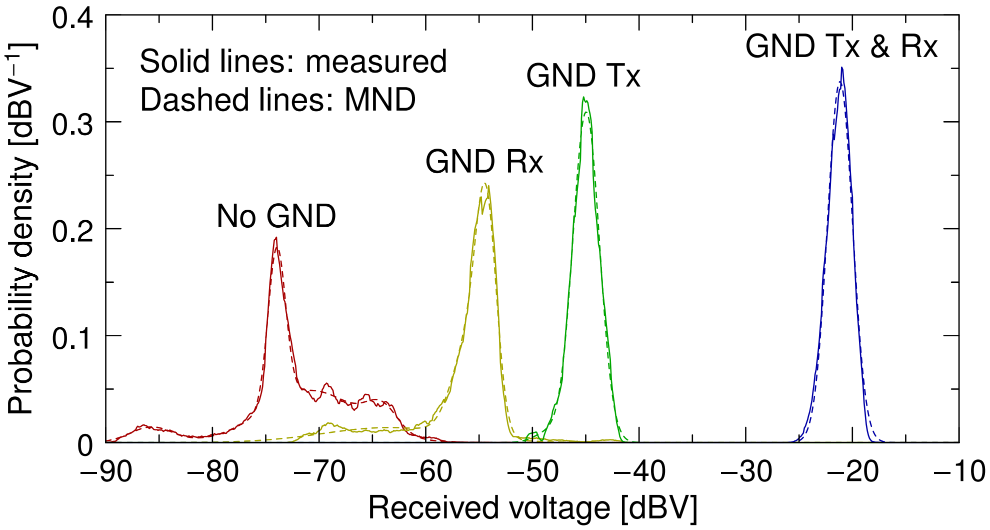


Fig. 2. Probability density function and MND model.

Table 1 Parameters for the MND model

Condition	i	μ_i [dBV]	σ_i [dBV]	w_i
No GND	1	−85.72	1.999	0.07227
	2	−73.96	0.8186	0.2974
	3	−70.81	4.482	0.5475
	4	−64.12	1.455	0.08290
GND Rx	1	−63.42	6.188	0.2174
	2	−56.02	1.531	0.3164
	3	−54.33	0.9748	0.4662
GND Tx	1	−48.46	1.297	0.03130
	2	−44.96	1.251	0.9687

GND Tx & Rx	1	–21.16	1.182	1.000

6. Conclusion

In this study, the dynamic intrabody communication channels were measured in several grounding conditions, and a MND model is proposed to model the measured PDF of the received voltage. The results suggest that the proposed MND model is useful to model the dynamic intrabody communication channels even if the PDF has a complex profile.

Acknowledgements

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