The Physical Layer Design of Intra-Body Communication: Model, Transmitter and Receiver

S. H. Pun, Y. M. Gao, P. U. Mak, M. I. Vai, and M. Du

ABSTRACT

The rapid growth of portable devices is changing the habit of people and improving the living quality of our daily life. The health care devices are emerging sector of portal devices. The increasing connections between devices on or in the body of the users have drawn much attention. Therefore, we proposes to use the Intra-Body Communication (IBC) to act as the network backbone for the health care devices.

In this article, we will report a model for IBC, which can calculate the distribution of the transmitting signal within a human limb. The result of the model will compare with an *in vivo* measurement in order to check the accuracy of the model. Then, the model will be used to estimate the distribution of the transmitting signal for the design of the transmitter and receiver for IBC.

INTRODUCTION

In recent years, the number of electronic devices carried by people has been increasing. These portable devices are small and powerful, nevertheless, they bring much benefit to general public. The rapid growth of the portable devices is also advantageous to patients and the elderly who require comprehensive care. Long term monitoring and continuous supervision of the physiological parameters of the patient become cost effective and popular. For example, a comprehensive health care system can possibly reduce the queuing time of the patients in the hospital and even can provide preliminary guidance during an emergency, etc.

In order to develop smaller and lighter devices, one of the ideas is to improve the connectivity between devices. Therefore, redundant parts of the devices can be reduced and information sharing between devices is encouraged. Currently, radio technology is a popular approach. Considering the in-body devices communication and electromagnetic interference, the radio technology may not give satisfactory result. Thus, we proposed to use the Intra-Body Communication (IBC) for the networking between devices on or in the body. In order to facilitate the design of the IBC transmitter and receiver, we introduce to use an analytical model for the IBC on a human limb. The design for the transmitter and receiver of the IBC is also given in this article.

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IBC AND ITS MODEL

IBC is a method of delivering an electrical signal through a human body. It uses the conducting properties of the human tissue to form a communicating channel. The working principle of the IBC is different from the radio technology and few electrical signal leaks outside the human body in low frequencies. The electromagnetic interference is reduced and the intrinsic security of the communication is improved.

In order to facilitate the design of the IBC transmitter and receiver, an analytical model for the Galvanic coupling type IBC on a human limb is introduced. This model is developed based on the assumptions that the human body is a volume conductors and the operating frequencies of the IBC is low [1][2].

$$V_s(r,\phi,z) = \sum_{m=1}^{\infty}\sum_{n=0}^{\infty}[E_{smn} I_n(\frac{m\pi r}{h}) cos(n\phi) + F_{smn} I_n(\frac{m\pi r}{h}) sin(n\phi) + G_{smn} K_n(\frac{m\pi r}{h}) cos(n\phi) + H_{smn} K_n(\frac{m\pi r}{h}) sin(n\phi)] sin(\frac{m\pi z}{h}) \quad (1)$$

where I_n is the modified Bessel function of the first kind of order n and K_n is the modified Bessel function of the second kind of order n.

In applying this model, we employed the parametric models of S. Gabriel et al.[3] to derive the electrical properties of the skin, fat, muscle and bone. Along with the dimension of the applied current at transmitter, the E_{smn}, F_{smn}, G_{smn}, and H_{smn} are calculated. Then, (1) can give the voltage distribution of the human limb by the transmitting signal.

In the beginning stage, an *in vivo* measurement was done to check the calculation of the model. The comparisons are shown in Figure 1. The model shows higher accuracy at low frequencies (less than 100kHz) and shorter distance between the transmitter and the receiver. For high frequency range, the difference between the calculations and the measurements is less than 20dB. Overall, the calculation generally underestimated the gain of the channel. In order to achieve a stable design, we still used the calculation for the design of the receiver.

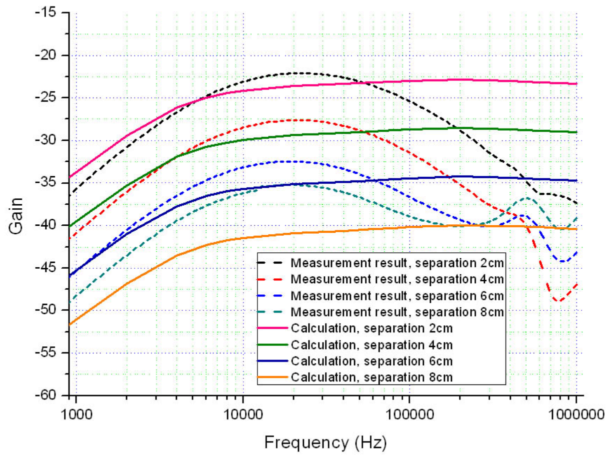

Fig. 1. Comparison between calculations and measurements

TRANSMITTER AND RECEIVER

The transmitter and the receiver of the IBC were designed with the aid of the model. In our system, we wanted to keep the electromagnetic radiation low and in the same time, the signal is sent at the low attenuation frequency range of the channel. From the proposed model and the measurements, the operating frequency of the IBC is better between 10kHz and 100kHz. Within this range, the loss of the channel is relatively small. In according to the model calculation, the attenuation of the signal is 40dB when the distance between the transmitter and receiver is 80mm. In reference to the safety guidelines for the electrical devices in contact with the human body, the applied current by the transmitter of the IBC should be equal or below 1mA [4]. In addition to the limitations of the applied current, the design of the transmitter must avoid potential hazard to the users. Therefore, we will use the stimulating electrodes to apply the differential signal to the human body. Stimulating electrode is used to avoid possibly depositing the metal ion into the human body when unbalanced electrical signal is applied [5]. Additionally, differential signal is less harmful and commonly used in medical stimulator[6]. Based on these considerations, the design of the transmitter can be found in Figure 2.

Currently, the receiver is located at 80mm away from the transmitter. From the calculation of the model, the expected voltage at the receiver is about 1.2mV when the applied current by the transmitter is 1mA (frequency: 10kHz - 100kHz). This signal level is comparable to the biopotential signal within the human body (e.g. The dynamic range of the electrocardiogram is 1-10mV [7]). In addition, since the transmitting signal is distributed in the human body, the signal exhibits a high source impedance for the receiver. This is a common phenomenon for all bioelectric signals. Therefore, we chose an instrumentation amplifier (AD620) as the front end of the receiver to detect the transmitting signal. It is worth mentioning that the gain of the front-end amplifier was less than 10 so that the instrumentation amplifier would not be saturated (e.g. the half-cell potential of the electrodes).The schematic design of the receiver can be found in Figure 3.

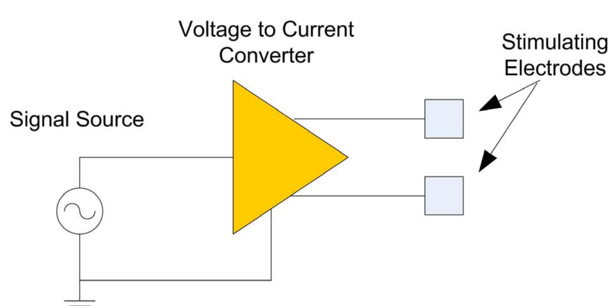

Fig. 2. Design of the IBC transmitter

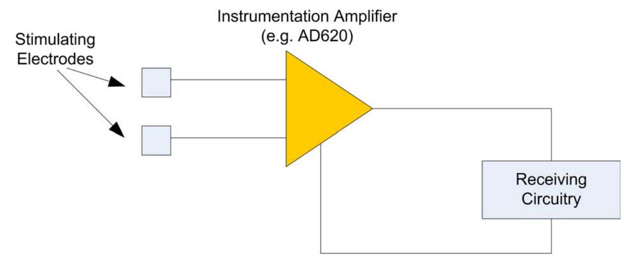

Fig. 3. Design of the IBC receiver

CONCLUSION

IBC is body centric communication method and is designed for connecting devices on or in the body. It can provide connectivity to the portable devices so that the abundant parts can be removed. In order to aid the design of the transmitter and the receiver of the IBC, an analytical model is reported. This model can provide the distribution of the transmitting signal within the human limb. The model simplified the complicated human tissues, so that the transmitter and receiver can be designed by the calculation of this model.

In the future, the model of the IBC will be extended to other parts of the human body. Therefore, a comprehensive analysis for the IBC can be achieved. In addition, prototypes with IBC network will be developed.

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