Preliminary Modeling for Intra-Body Communication*

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Abstract — **Intra-Body Communication (IBC) is an interesting and emerging communication methodology in recent years. Beneficial from conductive property of human body, IBC treats human body as transmission medium for sending/receiving electrical signal. As a result, interconnected cable and electromagnetic interference can be greatly reduced for devices communicated within human body. These advantages are significant for home health care system, which abundant of interconnected cables are needed. Furthermore, IBC technology also provides an alternative solution to communicate with implanted devices.**

Currently, pioneer researchers have proposed two general methods for realization of IBC, namely: "Capacitive coupling technique" and "Galvanic coupling/Waveguide type technique". Among the methodologies, the Galvanic technique requires neither return path nor common reference. This feature enables the technology attractive for networking biomedical devices on human body and draws much attention from recent studies. Thus, in this work, a preliminary 3D model of electromagnetic (EM) technique is developed in order to provide insight for electric signal distribution within human body. The development of a mathematical model also facilitates future researches in the aspect of communication theory of IBC, such as: optimizing carrier frequency, identifying channel characteristics, developing suitable modulation/demodulation technique, and etc.

In this paper, a mathematical model, which employs a homogeneous cylinder in analogous to a human limb, is obtained by solving the Laplace Equation analytically. The proposed model is simple and preliminary, yet it encourages further development of better model in the next phase and lays a foundation for future research and development of Intra-Body Communication.

Keywords — **Intra-Body Communication, Body Area Network, Galvanic coupling type/Waveguide type technique.**

I. Introduction

Home health care system and long term physiologic parameters monitoring system are important for chronic disease patients and elderly. They could provide patient and paramedic instant health information and generate alert while emergence. As a result, the research and development of these systems are attracting much attention from researchers. Currently, one of the main research directions is to develop versatile, intelligent, accurate, and convenient system, because it can elevate the performance for the users.

Intra-Body Communication (IBC) is a new communication technique, which employs human body as transmission medium for electrical signal. This is a special type of communication methodology and treats human tissue as a "cable" for electrical signals transmission. The merits of this technique are successful removal of connection cable, reduction of possible electromagnetic radiation, and less probably to be interference by external noise. These features are attracting much interest in the aspect of Body Area Network (BAN); especially, IBC works and relies on the human body. It also can improve home health care system and long term monitoring system, as abundant cables create problems for this kind of system. Thus, these features and advantages motivate the development and advance the research of IBC.

In this article, the authors attempt to present a mathematical model for IBC. In this model, a human limb is generalized as a 5-cm radius homogeneous cylinder with 30-cm long. After applying the quasi-static conditions, the governing equation has been reduced to Laplace Equation and a mathematical model for IBC can be obtained. The proposed model is simple and preliminary, yet it encourages further development of better model in the next phase and lays a foundation for future research and development of IBC.

II. Background

IBC was first introduced by T.G. Zimmerman in 1995[1]. They employed the electrostatic coupling technique to demonstrate the feasibility of the idea and built the first prototype system. The design consisted of a transmitter and a receiver, which had electrodes attached to the human body as depicted in Figure 1. The electric field of the transmitter is induced by the electrodes, coupled to the human body and flowed towards the ground, and then the electrodes of the receiver detected the electric field flowing through the human body with respect to the ground. Normally, only a few potion of electric field flowed to other parts of the body

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and detected by the receiver eventually. Thus, the sensitivity of the receiver should be high enough in order to have better and reliable performance.

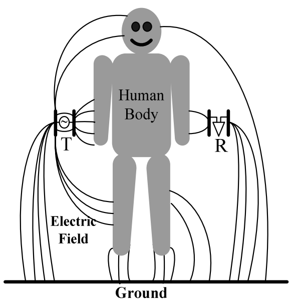

Figure 1 Electrostatic coupling technique

Since the development of the prototype IBC system by Zimmerman, several interesting applications, such as: heart rate and oxygen saturation sensors[2], sensors[3, 4], modeling[5, 6] and various communication techniques: On/Off Keying(OOK)[5], Differential Binary Phase Shift Keying (BPSK), Frequency Shift Keying (FSK)[2, 7, 8] etc. have been employed for improving the performance and stability of IBC.

The Galvanic coupling/Waveguide type technique[9-13] is an alternative configuration for implementation of IBC. As shown in Figure 2, electrodes of the transmitter are attached to one end of the human body while electrodes of the receiver are attached to another end. When electrical signals are applied to the electrodes of the transmitter, the signal will propagate along the human body in analogue to electromagnetic wave propagate along a waveguide. The electrodes of the receiver, which attached on the other end of the body, detect and convert the information from the transmitter. Unlike the electrostatic coupling technique, the electrical signal propagated via ionic fluid and thus, less dependent on the surrounding environment. Since the technique is relative new, the research of galvanic coupling technology mainly focused on application – especially biomedical application. Although the achieved data rate of Galvanic coupling type technique is low, independent of the earth ground and current propagation within human tissue are more attractive than the electrostatic coupling technique. Based on these reasons, the research direction of the authors is focused on the Galvanic coupling type IBC.

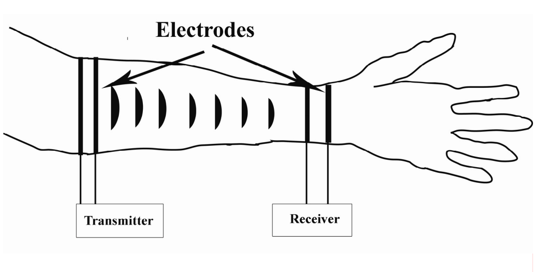

Figure 2 Waveguide type technique

III. MATHEMTICAL MODEL

Since the first report of IBC appeared in 1995, Galvanic coupling technique received much attention from researchers and engineers. During the period, various prototypes and experiments have been built and conducted. Other than demonstrated the feasibility of the method and developed application for IBC, one of the main research goals is to investigate the electrical properties of IBC. Currently, various researchers will employ different carrier frequency, coupling amplitude, encoding scheme, electrode location, and etc. The reasons behind of this phenomenon would be quite complicated; however, lack of good understanding of IBC propagation mechanism may be an explanation. Based on this observation, the authors attempt to develop a model in order to give insight about the electrical and communication properties of Galvanic coupling type IBC.

As the initial attempt of modeling IBC, a human limb is selected and ring-type electrodes are attached to either bands (at $z=z_1$ & z_2) as shown in Figure 2. The irregular geometry of human limb is difficult to be described by mathematics, so, a h=30-cm long homogeneous cylindrical muscle with a=5-cm in radius would be studied instead (as depicted in Figure 3). Then, applying the Maxwell Equations for the simplified problem to study the mechanism of IBC and find out the mathematical model for the problem.

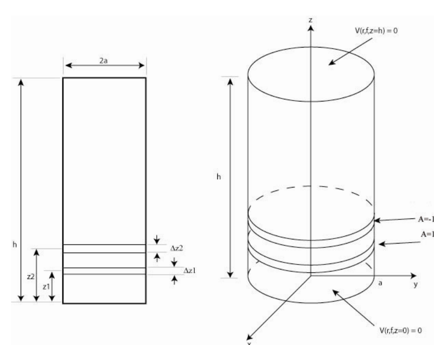

Figure 3 Simplified model with ring electrodes

Additionally, as the material of the IBC problem is biological tissue and is operating at low frequency[9-11], the quasi-static approximation may be used. The quasi-static approximation states that "if the dimension of the studied problem is less than 1 meter and satisfies Eq. (1), the capacitive effect can be neglected" [14, 15].

$$\frac{\omega\epsilon_0\epsilon_r}{\sigma} \ll 1 \tag{1}$$

In Eq. (1), ε_r and σ represent the relative permittivity and conductivity of the tissue and ω denotes the operating angular frequency. In Table 1, the quasi-static approximation with muscle's electrical characteristics[16] is listed.

Table 1 Quasi-static condition

	10kHz	100kHz
Conductivity σ	3.4e-1	3.9e-1
Relative Permittivity ε_r	3.0e4	8.0e3
$\frac{\omega\epsilon_0\epsilon_r}{\sigma}$	≈0.049	≈0.114

From Table 1, for the operating frequency less than 100kHz, the quasi-static could be applied and according to the prior research, the operation frequency of waveguide type technique is typically less than 100kHz[9, 11]. Thus, the governing equation becomes Laplace Equation and, the formulation of the IBC problem can be written as:

$$\nabla^2 V = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial V}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2 V}{\partial \phi^2} + \frac{\partial^2 V}{\partial z^2} = 0 \tag{2}$$

with general side-excited case:

$$\begin{aligned} &V(r,\phi,z=0) = 0 \\ &V(r,\phi,z=h) = 0 \\ &\frac{\partial V}{\partial r}(r=a,\phi,z) = \frac{J(z)}{\sigma} \end{aligned} \tag{3}$$

where the ring type injected current signal is defined as:

$$J(z) = \begin{cases} J_1 = 1mA/m^2 & z1 - \frac{\Delta z1}{2} \le z \le z1 + \frac{\Delta z1}{2} \\ J_2 = -1mA/m^2 & z2 - \frac{\Delta z2}{2} \le z \le z2 + \frac{\Delta z2}{2} \\ 0 & elsewhere \end{cases} \tag{4}$$

By solving the above formulation, an analytical solution for voltage distribution within the cylinder can be obtained.

$$V(r,\phi,z) = \sum_{m'=1}^{\infty} A_{m'} I_0\left(\frac{m'\pi}{h}r\right) sin\left(\frac{m'\pi}{h}z\right) \tag{5}$$

where

$$A_{m'} = \frac{2}{\left[I_0\left(\frac{m'\pi}{h}r\right)\right]'_{r=a} h} \int_0^h J(z) sin\left(\frac{m'\pi z}{h}\right) \mathrm{d}z \tag{6}$$

and, I_0 represents the modified Bessel function of the first kind of order 0.

With Eq. (5) and Eq. (6), the potential on the surface and within the human limb could be found spatially. From Figure 4, the plot of electrical signal inside the human limb is shown (X-Z sectional view at y=0 of the voltage distribution). Due to the electrode configuration employed in this case, the expected or calculated voltage induced by the electrodes is symmetry with respect to z-axis and the voltage on the same level of z-axis at the surface of the human limb is equal. This suggests that the electrodes of the receiver should not be placed on the same level of z-axis for this parallel ring type electrode case.

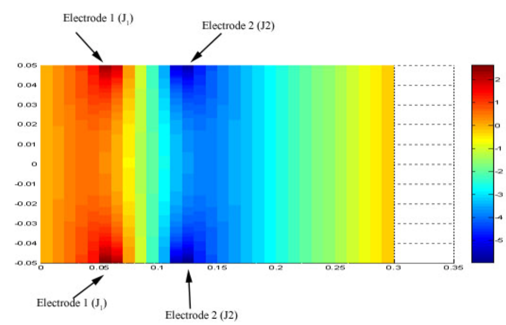

Figure 4 X-Z sectional view (at y=0) of the voltage distribution of the cylinder

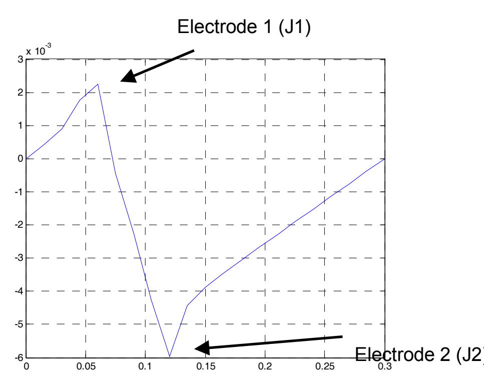

Figure 5 Voltage distribution on the surface of human limb along z-axis

On the other hand, from Figure 5, if electrodes are placed in the direction of z-axis, the voltage difference between electrodes of the receiver will be high (e.g. if the electrodes of receiver located at z=0.2cm and z=0.25cm, the voltage difference would be around 1mV). Thus, according to the mathematical model derived by this paper, the electrodes of the received of IBC would be better placing across z-axis.

IV. SUMMARY

Intra-Body Communication (IBC) is an interesting and emerging communication methodology in these years. Beneficial from conductive property of human body, IBC treats human body as transmission medium for sending electrical signal.

In this paper, a mathematical model, which employs a homogeneous cylinder in analogous to a human limb, is obtained by solving the IBC problem analytically. Through applying the quasi-static approximation, the Maxwell Equation can be simplified to Laplace Equation and the obtained an analytical solution for the voltage distribution can be obtained in certain symmetrical cases. The obtained model reveals the propagation mechanism of the ring type electrodes in human limb and suggests the insight of the configuration of the electrodes placement of the receiver.

The proposed model is simple and preliminary, yet it provides a foundation for analysis and future development of IBC. The obtained model encourages further development of better model in the next phase and lays a foundation for future research and development of Intra-Body Communication.

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