Signal Transmission by Galvanic Coupling Through Human Body

D.G.Agarwal[1], Kashmira D.Chaudhari[2]

Assistant professor, Dept. of ECE SSGB College of Engineering & Technology, Bhusawal, Maharashtra, India[1]

PG Student [CE], Dept. of ECE SSGB College of Engineering & Technology, Bhusawal, Maharashtra, India[2]

ABSTRACT

The paper presents a new concept of communication method called as Intra-body communication for the purpose of security. In this concept, our human body will be used as a medium of transmission of data. The use of this technology eliminates the complexity of existing technologies that involves cables, wire connection for transmitting data. The proposed model provides a secure and efficient communication system that consists of wearable devices for authentication and also useful for transmitting the data to the master device in real time. Galvanic coupling is a method for injecting an electrical communication signal into the body. Galvanic coupling provides a more power efficient and more secure means of communication. These advantages make galvanic coupling useful for many applications, especially in the medical field. This report discusses these applications, how galvanic coupling works, its advantages over other communication techniques, and electrical properties of the body that affect galvanic coupling.

KEYWORDS: *Galvanic coupling; Intra body; Communication; Secured data transmission*

I.INTRODUCTION

Intra-body communication (IBC) is a technology using the conductive properties of the human body to transmit signals, thus providing a novel communication method among wearable sensors in body sensor networks. Compared with current short-distance wireless technologies, such as Bluetooth and ZigBee, IBC technology has the advantages of high reliability, high speed, low consumption, and security. In order to transfer data in a secured manner, we can use this Intrabody communication process in which data in one's controller can be transferred to other person controller connected with a Red Tacton device by making physical contact between them. This method overcomes the complexity of wired and wireless communication. The intra body communication uses the human body as a conducting medium, providing the security and is a noncomplex method. This paper investigates on signal propagation within the Human Being by means of Intra Body Communications without radiofrequency waves but, instead, with lower (if not deeply lower) frequency waves.

Body transmission systems based on capacitive and galvanic coupling. Capacitive coupling for data transmission between transmitter and receiver units requires one signal path which is established through the human body while the return path has to be connected by earth ground. Galvanic coupling follows the approach of coupling alternating current into the human body. The two electrodes of the coupler and the two electrodes of the detector are coupled to the human body. Therefore, ground is not required for reference as in the method of capacitive coupling.

In this paper, we investigate the modeling of galvanic coupling intra-body communication via human body using the transfer function method. Firstly, we propose a circuit model of the galvanic coupling IBC via human body. Secondly, the modelling process of the contacting parts between two individuals is discussed in detail. Furthermore, the corresponding mathematical model of the whole IBC system is developed. Finally, the validity of the developed model is verified by measurements. The characteristics of the galvanic coupling IBC via human body are compared and discussed with that of the IBC via a single body channel. Our results indicate that the proposed method will lay a foundation for the theoretical analysis and application of the IBC via human body.

II.CIRCUIT MODEL

In the galvanic coupling intra-body communication via human body, as shown in Figure 1, when two individuals (subject A and B); the IBC transmitter attached to subject A detects a triggering signal, prompting it to output digital data through a pair of differential electrodes. The data signal transmits through subject A, the contacting part of the two hands on metal pad, and subject B. Finally, it is detected by the IBC receiver attached to subject B. Therefore, the galvanic coupling intra-body communication between subject A and B can be achieved by touching two hands on metal pad of the transmitter and receiver.

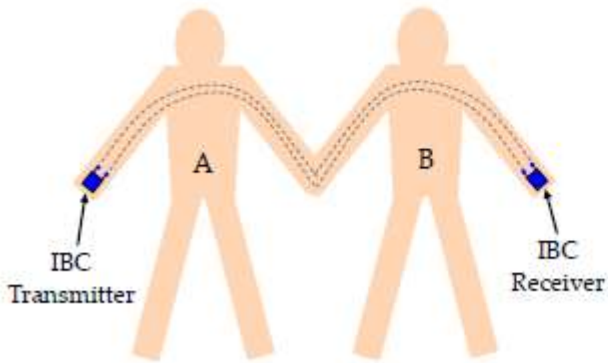


Figure 1. The Galvanic coupling intra body communication between subject A and B via Human Body

The circuit model of the galvanic coupling IBC via human body is developed by a four-terminal circuit model with discrete complex impedances, as shown in Figure 2, which includes the IBC transmitting terminal model, the model of the human body, and the IBC receiving terminal model. In the IBC transmitting terminal model, as shown in Figure 2, Vi represents a voltage source, Ro is the internal resistance of the IBC transmitter, and Zc represents the coupling impedances between the transmitting electrodes and the skin of subject A.

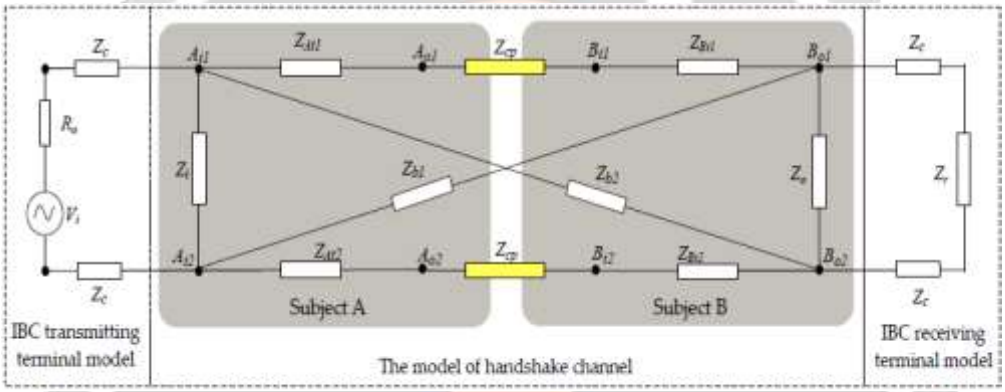


Figure 2. The circuit model of the galvanic coupling intra-body communication via Human Body.

The model of the transferring of data through human body includes the circuit models of subject A, the contacting parts corresponding to the touching hands to metal pad, and subject B, respectively. In the circuit models of subject A and B, Zi and Zo are the input impedance and output impedance of the whole channel, respectively. Zb1 and Zb2 are the cross impedances of the whole channel. On the other hand, ZAt1, ZAt2 represent the transverse impedances of subject A, while the transverse impedances of subject B are represented as ZBt1 and ZBt2. Meanwhile, Zcp represents the contact impedances corresponding to the contacting parts caused by touching hands to metal pad, which are very important for the whole circuit model. In the model of the handshake channel, the body impedances except for contact impedances are approximately equivalent to parallel circuits of resistance and capacitance, where parameters are up to Cole-Cole equation. In the IBC receiving terminal model, Zc represents the coupling impedances between the receiving electrodes and the skin of subject B, and Zr represents the input impedance of the receiver in the IBC receiving terminal model.

III.MATHEMATICAL MODEL

Based on the proposed circuit model, a mathematical model of a galvanic coupling IBC can be obtained. The equivalent circuit of the proposed circuit model can be developed using the method of equivalent transformation.

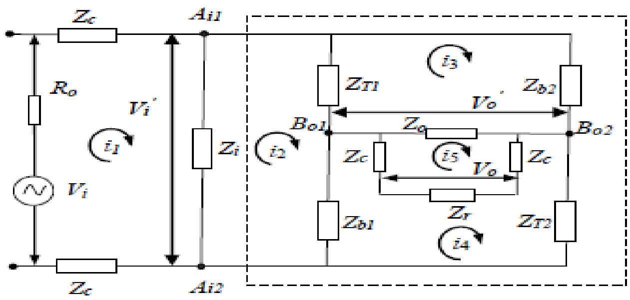


Figure 3. The equivalent circuit of the galvanic coupling IBC

According to Figure 2, the series impedance Zt1, Zcp, and Zt1' can be equivalent to ZT1 shown in Figure 3, which is the sum of Zt1, Zcp, and Zt1'; while the series impedance Zt1, Zcp and Zt1' can be equivalent to ZT1 shown in Figure 3. Therefore, the following equation can be achieved.

$$\begin{cases} Z_{T1} = Z_{At1} + Z_{cp} + Z_{Bt1} \\ Z_{T2} = Z_{At2} + Z_{cp} + Z_{Bt2} \end{cases}$$

The transfer function can be expressed by five linear equations, which can be calculated by a matrix form.

$$\begin{bmatrix} V_i \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 2Z_c + Z_i + R_0 & -Z_i & 0 & 0 & 0 \\ -Z_i & Z_i + Z_{T1} + Z_{b1} & -Z_{T1} & -Z_{b1} & 0 \\ 0 & -Z_{T1} & Z_{T1} + Z_{b2} + Z_o & 0 & -Z_o \\ 0 & -Z_{b1} & 0 & Z_{T2} + Z_{b2} + 2Z_c + Z_r & -2Z_c - Z_r \\ 0 & 0 & -Z_o & -2Z_c - Z_r & Z_o + Z_r + 2Z_c \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \\ i_5 \end{bmatrix}$$

The matrix multiplication form is:

V = ZI

Where **V** is a column vector, in which the elements represent independent voltage source in each mesh, **Z** is a 5 _ 5 impedance matrix, and **I** is a column vector holding mesh currents. Thus, the values of **I** can be obtained by multiplying the voltage vector by the inverse matrix of **Z**, and

$$\mathbf{I} = \mathbf{Z}^{-1}\mathbf{V}$$

Therefore, the value of output voltage Vo can be calculated as:

$$\mathbf{Vo} = \mathbf{(I_4 - I_5)\ Zr}$$

On the basis of Equations, the transfer function H can be obtained,

$$H = \frac{|V_o|}{V_i}$$

Therefore, the whole transfer function can be expressed,

$$\begin{cases} H = \frac{H_h Z_r Z_i Z_h}{(Z_r+2Z_c)[(Z_i Z_h+(2Z_c+R_0)(Z_i+Z_h))]} \\ Z_h = \frac{Z_{T1}(Z_{T2}Z_o'+Z_{b2}Z_o')}{(Z_{T1}+Z_{b2}+Z_o'-kZ_o')(Z_o'-Z_{T2}H_h)} \\ H_h = \frac{(k-1)Z_o'}{Z_{b2}+kZ_{T2}} \\ k = \frac{Z_{b1}Z_{T1}+Z_{b1}Z_o'+Z_{b1}Z_{b2}+Z_o'Z_{T1}}{Z_{b1}Z_{T1}+Z_{b1}Z_o'+Z_{T2}Z_{T1}+Z_o'Z_{T1}} \\ Z_{T1} = Z_{At1} + Z_{Bt1} + Z_{cp} \\ Z_{T2} = Z_{At2} + Z_{Bt2} + Z_{cp} \\ Z_o' = Z_o / / (2Z_c + Z_r) \end{cases}$$

Above shows the whole transfer function of galvanic coupling intra-body communication via human body, which includes the transmitter, subject A, the contacting parts, subject B, and the receiver, and can simulate the whole signal transmission for this kind of IBC. H represents the whole transfer function; Zh represents the total impedance of dotted portion shown in Figure 3; Hh represents the transfer function of the circuit between Vi' and Vo'; k is the ratio of i4 to i3; ZT1 is an equivalent series impedance formed by Zt1, Zcp, Zt1'; ZT2 is an equivalent series impedance formed by

Zt2, Zcp, Zt2'; and Zo' is the impedance corresponding to the Vi' between nodes Bo1 and Bo2. Finally, the attenuation of the signal transmission in the galvanic coupling IBC channel can be determined by

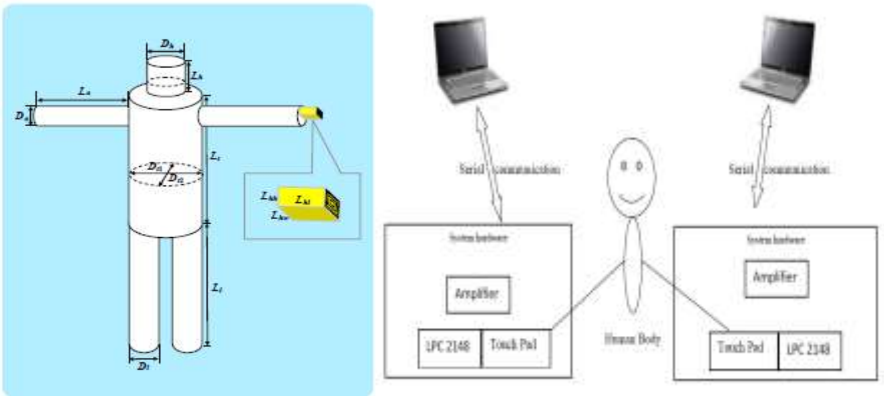
$$\mathbf{G = 20 \log_{10} H + K}$$

Where K is the correction factor used for correcting the inherent error between the measurements and the simulations. Generally, K is influenced by the modelling method, the parameter determination method and the measurement precision.

IV. MEASUREMENTS AND ANALYSIS

- **Measurement Setup:**

An in vivo measurement setup was built to verify the feasibility of the developed mathematical model. Meanwhile, the amplitude-frequency characteristics of the galvanic coupling IBC were carried out. In our experiments, two males were chosen as the subjects, the definitions of the geometry parameters are shown in Figure 4a. The measurement setup was composed of a signal generator (Tektronix AFG3101, *R*0 = 50 Ω), a digital oscilloscope (Tektronix MSO3012, *Zr* = 1 MΩ), the galvanic coupling electrodes and two high-power lithium power batteries, as shown in Figure 4b. In our measurements, the galvanic coupling electrodes included two pairs of circular copper electrodes with



(a) **(b)**

Figure 4. Parameter definitions and measurement setup. (**a**) Definitions of the geometry parameters; (**b**) The measurement setup

Considering the geometry of the arm, both the transmitter electrode and the receiver electrode were attached to the arms at a distance of 6 cm. Moreover, 10 in vivo measurements were conducted within 10 days to eliminate the influence of time, with the average attenuations being considered to be the measured values in our experiment. In addition, the signal generator output sinusoidal signals had an amplitude of 5 V (peak-to-peak value), which is below the safety thresholds and avoids resulting in adverse heating effects. The frequency range of 100 kHz–6 MHz was selected, for which the lower boundary is well above the spectrum of biological signals of the human body. Meanwhile, according to, the lumped circuit model is generally valid only when Lc < ʎ, where Lc is the circuit characteristic length, and ʎ is the circuit operating wavelength. For IBC, due to the fact that two subjects are involved in the signal transmission channel, the dimensions (the circuit's characteristic length) of the IBC via handshake channel is about double that of the IBC via single body channel, which indicates that the operated frequency should be cut in half. Therefore, the upper limit frequency should be set at approximate half of the upper limit frequency (10 MHz) of the IBC via single body channel. As a result, the signal electromagnetic field transmitting within two human bodies can be regarded as a near-field region, which can be modelled using a static circuit model. Finally, the upper limit frequency was set at 6 MHz in our experiments. Additionally, the influence corresponding to the operated frequency between the measurement instruments and the cables was ignored.

- **Signal Transmission of the Different Distances:**

The in vivo measurements along the arms and hands of the two subjects who were shaking hands were carried out. As shown in Figure 5, the transmitting electrodes were placed on the positions of *A*1, *A*2 and *A*3 of subject A, while the receiving electrodes were placed on *B*1, *B*2, and *B*3 of subject B, resulting in signal transmission distances of 30 cm (*A*1–*B*1), 40 cm (*A*2–*B*2) and 50 cm (*A*3–*B*3), respectively. Additionally, according to our measurement experiments, the tiny gap between the two hands had a small influence on the signal attenuation of the IBC. In our subsequent experiments, in order to unify the experimental conditions, the two hands of the two subjects contacted tightly in the processes of shaking hands, and the influence of the tiny gap between the two hands was ignored.

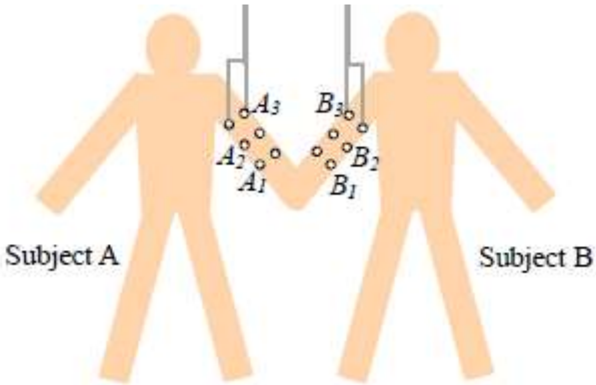


Figure 5. The in vivo measurements of the different signal transmission distances.

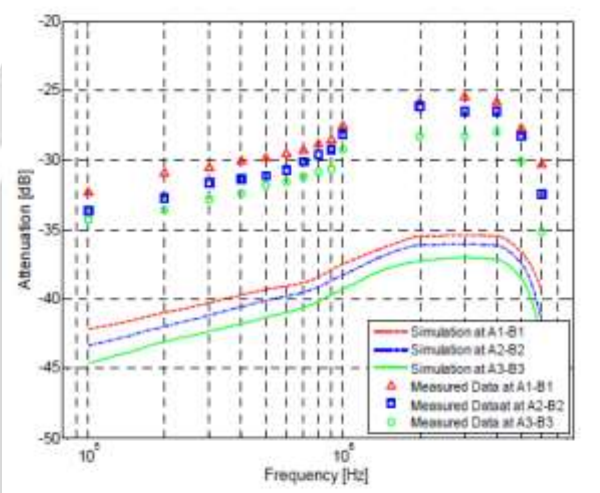


Figure 6. Simulation results and the measurement results of the different signal transmission distances without the correct factor.

V.CONCLUSION

We believe this idea will prove to be a new, innovative. We firmly believe that the implementation of the project will be smooth as it is expected to be in accordance with the detail study of our project that we have achieve till this stage. The various modules and their detailed design studied above will help define our project's implementation and provide strong base for developing the various modules practically. Overall, galvanic coupling is a very effective method for intra-body communication. It is secure because the signal is contained completely in the body. It is more power efficient than wireless RF communication and is more reliable than capacitive coupling. Also, its lack of wires makes its comfortable and hassle free for the patient. Galvanic coupling has many potential applications and could revolutionize the medical field.

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