

Modeling and Simulation of Galvanic Coupling Intrabody Communication

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Abstract- Intra-Body communication (IBC) is an innovative approach outlined in the IEEE 802.15.6 Wireless Body Area Network (WBAN) standard. This data communication method uses the human body as a communication medium. The basic principle of IBC is that a small electric field is induced onto the human body in order to propagate a signal between devices. IBC system assures transmissions between sensors that are both safe and accurate and therefore could be utilized in establishing a communication network for monitoring and transmitting crucial data to a health centre such as a hospital or a clinic over established external network. In galvanic coupling, a signal transfer is established between the coupler and detector units by coupling signal currents galvanically into the human body.

Index Terms- Body Impedance, Galvanic Coupling, IBC.

I. INTRODUCTION

The concept of IBC was first proposed by IBM in 1996. In the IBC technology, the human body serves as a communication channel. The basic principle of IBC is that a small electric field is induced onto the human body in order to propagate a signal between devices. IBC system assures transmissions between sensors that are both safe and accurate and therefore could be utilized in establishing a communication network for monitoring and transmitting crucial data to a health center such as a hospital or a clinic over established external network. IBC is a short-range communication solution between devices in which the human body is used as the signal transmission medium, is one of proposed technologies to achieve the goal of WBAN. IBC network offer superior characteristics compared to WBAN in terms of power consumption and electromagnetic noise problems. IBC has many advantages over traditional RF approaches. Because the communication mechanism is based on near-field coupling, transmission is not interfered by electromagnetic waves in free space and signal cannot be intercepted easily, while the signal is restricted to the human body. Since the body channel has lower attenuation than the air medium, the power consumption is lower than other wireless technologies, such as Bluetooth and Zigbee. IBC realizes a short-range “wireless” communication method with less electromagnetic interference and less susceptible to

external interference in comparison with existing electromagnetic wave based communication technique. Like on-body IBC, the implant IBC provides benefits to many applications like biomedical monitoring systems and other related application fields [1].

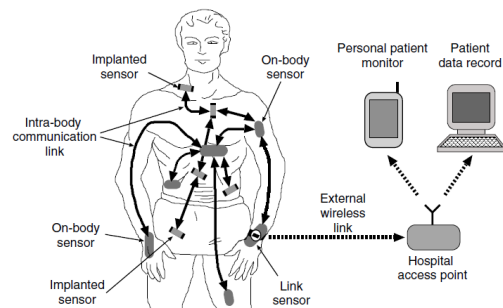


Fig. 1 Health monitoring IBC network

Compared with other implantable device communication methods, implant IBC has the advantages of low transmission power, compact size, etc. The IBC range is confined to the close proximity of the human body, so the receiver unit is always located at the short distance from the transmitter unit (maximum possible distance is the subject’s height)[2].

Galvanic Coupling- In this coupling, both electrodes of transmitter and receiver side are attached to the human body. Galvanic coupling is achieved by coupling alternating current into the human body. It is controlled by an ac current flow and the body is considered as a transmission line (waveguide). The signal is applied differentially over the two coupler electrodes. A primary current flow between the coupler electrodes is established and a small secondary current propagates further into the conductive body parts. The induced current results in an alternating potential difference between the detector electrodes. In this case, ionic fluid within the human body, rather than electromagnetic waves in free space, is the carrier of the information. As a result, the signal transmission quality is not influenced by the individual’s surroundings. The idea of galvanic coupling is depend on the signal transfer that is established between transmitter and receiver unit by coupling signal currents galvanically into the human body [3].

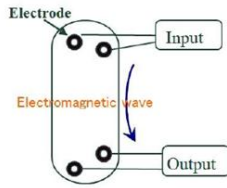


Fig. 2 Galvanic Coupling

Body Impedance- It measures the resistance of body tissues to the flow of small and harmless electrical signal. Bioelectrical Impedance Analysis (BIA) is method to measure the impedance of the body. BIA is a non-invasive and convenient method of body composition analysis. Impedance is a combination of resistance ie. opposition to the flow of alternating current through intra- and extra- cellular ionic solutions and reactance X_c ie. the capacitive element of cell membranes and tissue interfaces. The impedance of cellular tissue can be modeled as a resistor (representing extracellular path) in parallel with a resistor and capacitor in series (representing intracellular path). This results in a shift in impedance versus frequency used in the measurement. The impedance evaluation can be done using either two or four electrodes. A small current on the order of 0-1 μA is passed between the electrodes and the voltage is measured between the same or between the other electrodes. Body can be modeled as a cylindrical body.

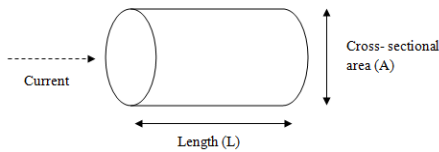


Fig. 3 Cylindrical Model of Human Body

For the purpose of impedance analysis, human body can be considered to be made of cylindrical tubes. Each tube represents body part [4].



Fig. 4 Human Body as cylindrical tubes

For body impedance testing, devices used are tetrapolar which consists of four electrodes. 500 μA of current can be applied at a single frequency of more than 50 kHz. With tetrapolar configuration, two electrodes

inject the current while the other two electrodes sense the emerging current.

Electrode Types- The intended application requires flat and self-adhesive electrodes with a low contact resistance.

- i. Neuroline 715
 - Skin friendly solid-gel electrodes that allow to reposition the electrode several times without losing the adhesive power.
 - High quality silver/silver chloride sensor gives an optimum signal quality.
 - Transparent sensor area allows precise sensor placement over the target area.
 - No risk of cross-contamination.
 - Touch-proof safety connector DIN 42 802.
- ii. Swaromed REF 1008
 - Pre-gelled electrodes having silver/silver chloride sensor.
 - Used for short-term monitoring, in operating theatre and for emergency use (eg. ECG).
 - Time of application: Can stay on skin for up to 2 days.
- iii. Blue Sensor BR
 - Single use
 - Skin friendly solid-gel that provides optimal signal quality in a wide range of applications and allow the electrode to be repositioned if necessary.
 - Due to cloth backing material, the skin is able to breathe so that the electrode remains comfortable to wear over long periods [5].



Fig. 5 (a) Swaromed REF 1008, (b) Neuroline 715, (c) Blue Sensor BR

II. GALVANIC COUPLING

Galvanic coupling pursue the approach of coupling alternating current into the human body. The signal is applied differentially over two coupler electrodes and received differentially by two detector electrodes. The coupler creates a modulated electrical field, which is observed by the detector. Therefore, a signal transfer is established between the coupler and detector units by coupling signal currents galvanically into the human

body. The induced current has a peak amplitude of 1 mA, and the alternating signal frequency remains in the frequency range from 10 kHz to 1 MHz. The effect on body signals located below 10 kHz shall be expunged, while the hindrance of signal loss above 1 MHz would be increasing.

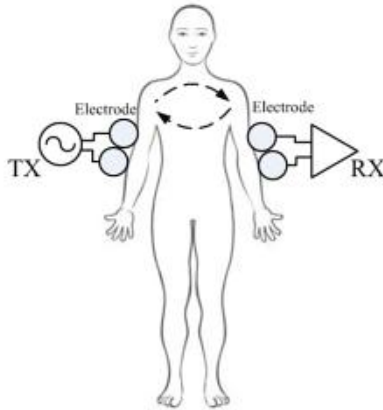


Fig. 6 Galvanic Coupling IBC

III. TRANSFER FUNCTION

A. Circuit model of human body

First step to achieve galvanic coupling IBC is to establish circuit model of the human body.

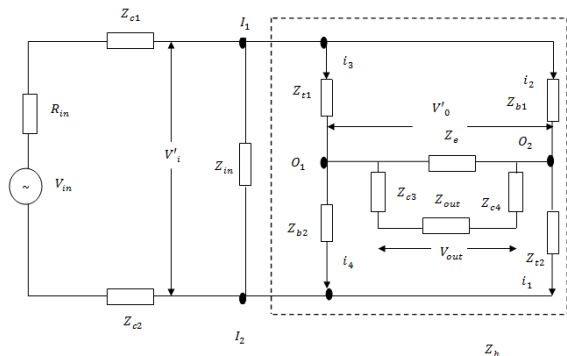


Fig. 7 Four-Terminal Circuit Model

In this, transfer function method can be used which is based on circuit model and can be used to illustrate the mathematical relation among the signal transmission paths within the human body, transmitter, electrodes, receiver, etc.

In Fig. 7, Z_{c1} , Z_{c2} are the coupling impedances between the transmitting electrodes and the skin whereas Z_{c3} , Z_{c4} are the coupling impedances between the receiving electrodes and the skin. Z_{in} is the input impedance of human body. Transverse impedances of the transmission path are Z_{t1} and Z_{t2} . Z_{b1} and Z_{b2} are cross impedances of the transmission path in the human body. R_{in} is the input resistance and V_{in} is the input voltage of the transmitter whereas V_{out} is the output voltage of the receiver. Z_e is the output impedance of the human body and Z_{out} is the output impedance of the receiver.

Based on the above circuit model, transfer function can be calculated.

Impedance between O_1 and O_2 can be represented as Z'_e :

$$Z'_e = \frac{Z_e (2 Z_c + Z_{out})}{Z_e + 2 Z_c + Z_{out}} \tag{1}$$

Transfer function between I_1 and I_2 can be calculated as:

$$H_h = \frac{V'_0}{V'_i} = \frac{(i_1 - i_2) Z'_e}{i_2 Z_{b1} + i_1 Z_{t2}} \tag{2}$$

Transfer function of human body can be expressed as:

$$H'_h = H_h \frac{V'_i}{V_i} = \frac{Z_h Z_i H_h}{Z_h Z_i + (2 Z_c + R_0)(Z_i + Z_h)} \tag{3}$$

Whole transfer function of Galvanic Coupling IBC (H_G) can be expressed as:

$$H_G = \frac{V_0}{V_i} = \frac{Z_h Z_i H_h}{Z_h Z_i + (2 Z_c + R_0)(Z_i + Z_h)} \frac{Z_o}{Z_o + 2 Z_c} \tag{4}$$

Attenuation of the signal transmission in the Galvanic Coupling IBC can be determined as:

$$A = 20 \log_{10} H_G \tag{5}$$

IV. RESULTS

In this paper, the Galvanic coupling method of IBC is implemented using MATLAB software. Attenuation of signal transmission with different signal frequencies and channel lengths is calculated and simulated.

- Impedances at different signal frequencies.

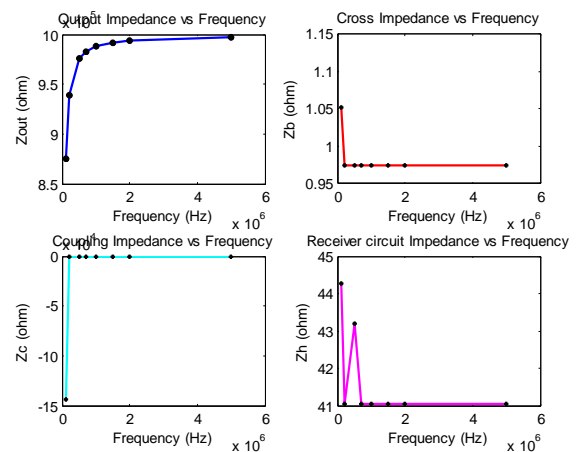


Fig. 8 Impedances at different signal frequencies

Output impedance increases with increase in signal frequencies.

- Attenuation of different electrodes at different channel lengths.

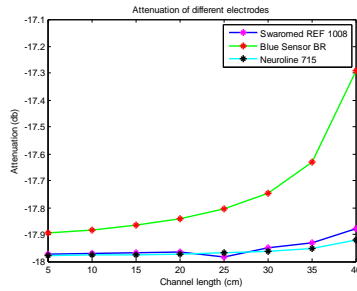


Fig. 9 Attenuation of different electrodes

- Attenuation of different electrodes at different signal frequencies.

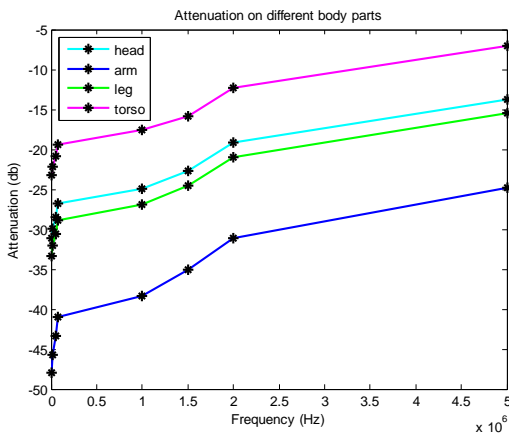


Fig. 10 Attenuation on different body parts at different signal frequency

V. CONCLUSION

IBC is a new Human Area Networking technology that uses the surface of human body as a safe, high speed network transmission path. It is different from RF standards like Bluetooth and Zigbee in which electromagnetic energy gets radiated in the environment causes more power consumption. In galvanic coupling IBC, a pair of transmitter and receiver electrodes is attached to the body whereas in capacitive coupling IBC, only signal electrodes of the transmitter and receiver are attached to the body and both the ground electrodes float. Ground is taken as a

reference in capacitive coupling IBC but ground is not required in galvanic coupling IBC. Results show that the Galvanic Coupling IBC is a suitable method to transmit data for short distances and in the frequency range of 10 kHz to 1 MHz.

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