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Study of Modeling Techniques in IntraBody Communication

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Abstract

Intra-body communication (IBC) is a new, "wireless" communication technology that enables electronic devices on the body to exchange information. It uses the dielectric properties of human tissues so that human body can be used as the communication channel for data exchange. Transmitting data directly through the human tissue/skin can be more efficient than the present wireless transmission technologies (Bluetooth, Wi-Fi), since it consumes less energy as it is not susceptible to electromagnetic interference. The rapid increase in healthcare demand has led to enormous developments in health monitoring technologies, using body area networks (BAN). BAN technology visualizes a network of sustained operating sensors, which measure critical physical and physiological parameters e.g., mobility, heart rate, and glucose levels. Wireless connectivity in BAN technology has gained success as it grants portability and flexibility to the user. While radio frequency (RF) wireless technology has been successfully deployed in most BAN implementations, they consume a lot of battery power as they are susceptible to electromagnetic interference and have security issues. Intrabody communication (IBC) is an alternative wireless communication technology which uses the human body as the signal propagation medium. IBC has characteristics that could naturally address the issues with RF for BAN technology. This survey examines the on-going research in this area and highlights IBC core fundamentals, current mathematical models of the human body. IBC has exciting prospects for making BAN technologies more practical in the future.

Keywords: Dielectric, Bluetooth, Wi-Fi, BAN, IBC

I. Introduction

In present day scenario there are many wireless technology which aid in transmission of data to a remote sensing system, to name a few Bluetooth, ZigBee, etc… T. G. Zimmerman introduced transmission of signals using human body as the transmission medium for personal area networks (PAN) which was defined as Intra body Communication (IBC)[1].IBC was first shown as a advantageous technology in [1] using near field communication compared to far field communication. Personal Area Networks [PAN] builds communication between devices placed on the surface of body or implanted in the body [1].PAN was based on ISO 7498 network standard. It consisted of seven layers out of which PAN was concerned with first physical layer-evaluating the electrical properties of the transmission channel, secondly the data link layer- providing a reliable connection oriented information link and thirdly the network layer which connects PAN devices to their applications.

In literature, generally there are two approaches for realization of IBC, namely: Capacitive coupling/AC coupling technique and Galvanic coupling/Waveguide type technique as shown in fig 2 a and b respectively. 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

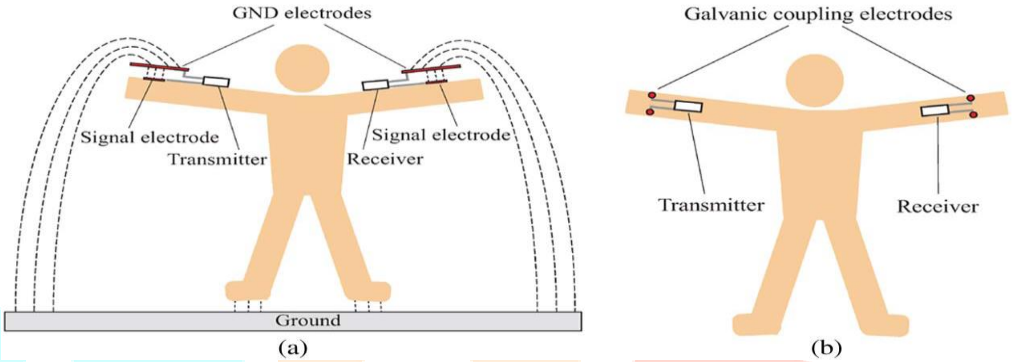


Fig. 1. Types of Intra-body communication.

Coutersy: [4]

In the electrostatic coupling IBC, the return path is formed by the electrical coupling between the transmitting electrodes and the receiving electrodes through the external ground, while signal transmits between the transmitter and the receiver by making a current loop[5]. In galvanic coupling IBC, the electrical signal is considered as electromagnetic waves [4], and electromagnetic signal transmits from a pair of transmitting electrodes to a pair of receiving electrodes within the human body directly.

IBC has many advantages over other wireless technology like Bluetooth, ZigBee, etc. which can be listed as 1) Higher data rate can be achieved as signal transmits within the human body and negligible radiation leaks out to avoid the interference of environment electromagnetic noise [14]. 2) Signal transmission based on human body needs comparatively low energy consumption [2] 3) network access can be achieved by the motions of the human body [3], i.e. Communication can be easily started or stopped by the touching, position change like sitting and standing of the human body. It is believed that IBC technology will offer significant advantages in Personal Area Network (PAN) [1], biomedical monitoring and interaction between the humans and their environments [4]. For instance, IBC technology can be used to build a biomedical monitoring network or also termed as Body Area Network (BAN) consisting of on-body sensors and implanted sensors, as shown in Fig. 2, in which biomedical data collected from the different parts of the human body transmit within the human body, and eventually arrive at the cell phone or hospital through a link sensor attached on the wrist. Therefore, the patients and their doctors can achieve the biomedical data of the human body almost anytime and anywhere.

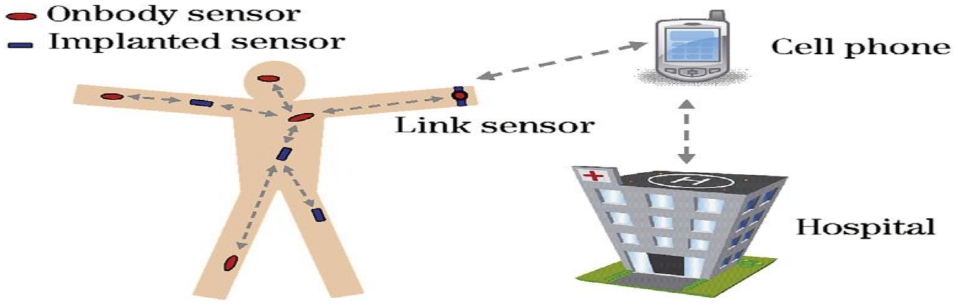


Fig. 2. Biomedical monitoring based on IBC technology.

II. Modeling and simulation techniques

Considering safety of human, simulation is implemented for investigating IBC. Hence two methods have been implemented to model human body for IBC. Firstly the transfer function method [4] and the Finite element method [6] [7].

Modeling of IBC based on transfer function method:

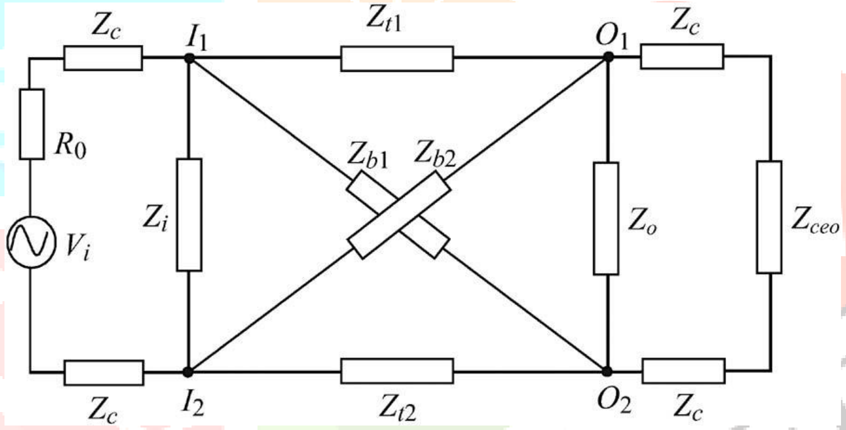


Fig3. Four-terminal circuit model of the galvanic coupling IBC

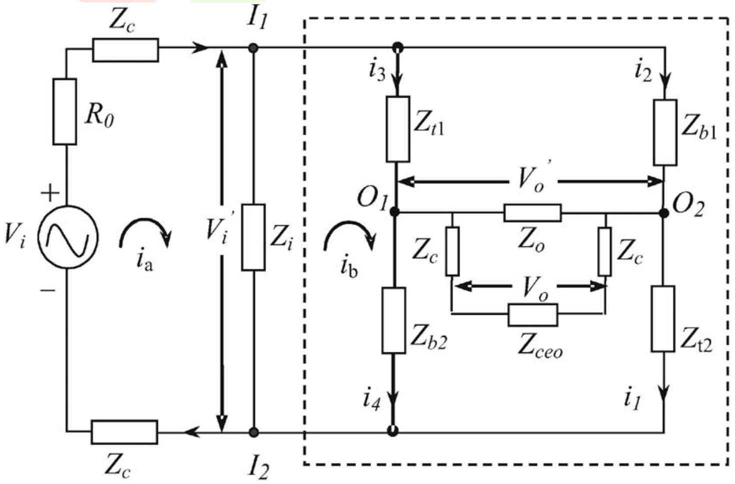


Fig. 4. Equivalent circuit of the galvanic coupling IBC

Coutersy: [4]

The signal transmission path of the galvanic coupling IBC was described by the four-terminal circuit model[4] as shown in Fig. 3 in which all the impedances of the connecting wires were ignored. In Fig. 3, Zc represents the coupling impedance between the transmitting electrode and the skin, while the two transmitting electrodes are attached to the human skin at I1 and I2, respectively. Additionally, the impedance of Zi, which represents the impedance between I1 and I2, is treated as the input impedance of the human body. On the other hand, Zt1 and Zt2 are the transverse impedances of the transmission path, while Zb1 and Zb2 are the cross impedances of the transmission path in the human body. Similarly, the output impedance of the human body is represented as Zo, while the coupling impedance between the receiving electrode and the skin is also represented as Zc. It should be noted that the internal impedances of the IBC devices also influence the signal transmission characteristic of the galvanic coupling IBC. Since sensors influence the data rate for transmission output resistor of transmitter R_o and input impedence of receiver Z_{CEO} was considered.

An equivalent circuit was derived for the above four terminal circuit as shown in Fig. 4 and a transfer function was derived as

$$H_A = \frac{Zi\,Zh}{ZiZh+(2Zc+Ro)(Zi+Zh)} \cdot \frac{Zceo}{Zceo+2Zc}\,Hh$$

Where $H_h = \frac{Vo}{Vi}$

Attenuation of the signal transmission path was formulated as

$$A = 20\log_{10} H_A + K$$

Where K is the correction factor used for correcting the inherent error between the actual measurements and the simulations.

Modeling and simulation of IBC based on finite element method:

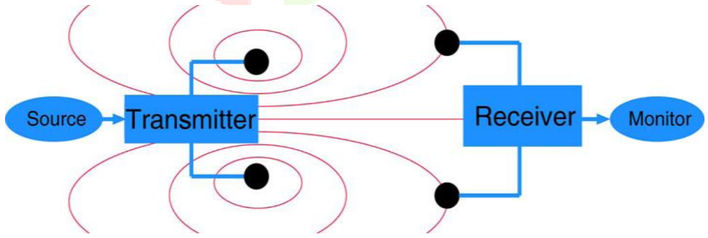


Fig 5 The human body used as a transmission medium for signal transmission

Coutersy: [6]

In Galvanic coupling, signal transfer is established between the transmitter and receiver by coupling signal currents galvanically into the human body. The transmitter establishes a modulated electric field which is then detected by the receiver as shown in fig. 5. The injected current establishes a certain potential distribution in human body, which can be described by finite element models [6].A very low current of 1mA of maximum amplitude between 10kHz and 1MHz has the ability of energy efficient data communication when compared to other wireless technologies.

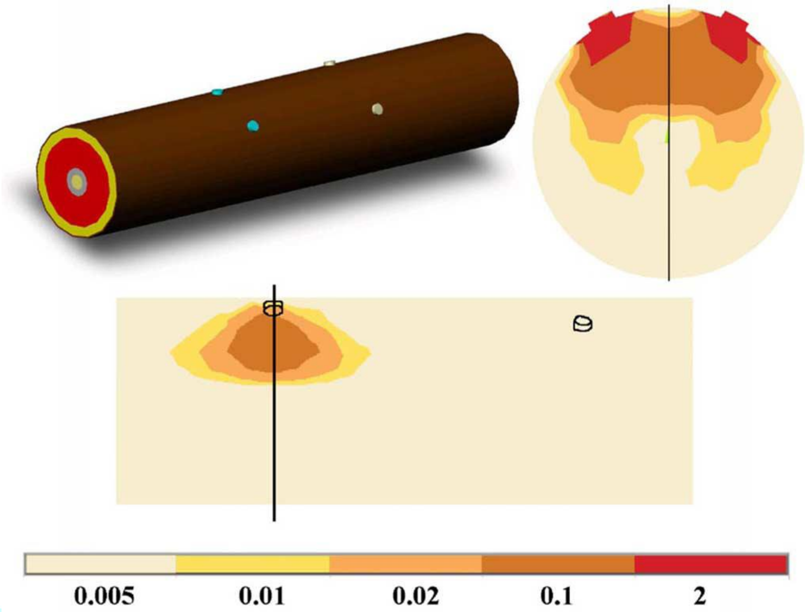


Fig 6 : Top left picture shows the arm model consisting of multiple layers with the transmitter and the receiver electrodes. The other two pictures show the current distribution in an axial and a longitudinal cut that is present during data transmission. The black lines indicate the position of the cut.

Courtesy: [6]

Due to the low frequencies signal transmission through the body , signal is attenuated. Attenuation is dependent on the dielectric properties of tissue[12]. Hence attenuation was investigated using FE models[6]. A 3-D FE model was developed[8] as shown in Fig 6. The capacitive effects were also considered which are due to the dielectric properties (permittivity) in skin, fat and muscle tissue.

Attenuation factor is dependent on three factors [6]:

1. Di-electric properties of skin.
2. Distance between transmitter and receiver.
3. Joints between transmitter and receiver.

Attenuation factor was formulated as:

$$\text{Attenuation}=20.\log_{10}\left(\frac{U Receiver}{U\ Transmitter}\right)$$

The influence of the conductivity of human tissues and its effect on the attenuation of the signal were focused [6], without considering the signal dispersion characteristics in IBC. Distributed-parameter circuit[12] was developed to study the transverse admittance of the skin which affected the propagation characteristics of the signal. To deduce the transverse admittance dielectric properties of skin were studied [12]. The dielectric properties of a biological tissue include its permittivity and conductivity, which is dependent on frequency. Skin mainly presents two dispersive regions [9], the first region includes the low frequency region, up to 1 MHz, where the total skin impedance is practically determined by the impedance of the SC [10], which is composed of keratinized cells that do not contain cytoplasm and whose electrical behavior is similar to a dielectric material. In this first dispersive region, conductivity is determined by the electrical current paths through sweat glands. The frequency response of the conductance G and susceptance B of the skin up to 1 MHz was reported in [11] and, in particular, it was found that the SC represented only 10% of the total skin impedance around 100 kHz. The second dispersive region ranges approximately from 1MHz to 1 GHz: in this band, the skin impedance is determined by the deeper layers. Therefore, the dielectric properties of the skin in this region are given by the membrane of the living inner cells. Thus, permittivity is influenced by the lipid bilayer , and conductivity by the ionic channels that cross it.

Relative permittivity was expressed as:

$$\varepsilon^{*}r\ (\omega)=\varepsilon_{\infty}+\frac{\sigma s}{j\omega\varepsilon 0}+\sum_{k=1}^{2}\frac{\Delta\varepsilon k}{1+j\omega\tau k}$$

Complex conductivity was expressed as:

$$\sigma^{*}(\omega)=\sigma^{1(}\omega)+j\sigma^{11}(\omega)=j\omega\varepsilon_{0}\varepsilon r^{*}\,(\omega)$$

$\varepsilon\infty$ is the permittivity at infinite frequency, ε_0 is the permittivity of vacuum, $\Delta\varepsilon k$ and τk are, respectively, the strengths and the relaxation times of the Debye dispersion model; σ_s is the electric conductivity at dc and ω is the angular frequency. A reduced circuital structure for simplicity was represented for the skin admittance Y : a parallel two-component circuit with one conductance G and one susceptance B (i.e.,Y = G + jB).

III. Implementation

Various experimentation were conducted[6] to study the attenuation of signal due to the properties of skin. According to [6] study were done to know the dependency of distance and tissue properties on simulation which includes influence of distance between transmitter and receiver , influence of size of the electrode , influence of joints , Sensitivity to Changes in resistivity of Selected tissues. These factors were experimented on upper and lower arm and later extended to thorax and chest. It was also noted that there was no signal degradation when the human body was subjected to motion (i.e activity on treadmill).

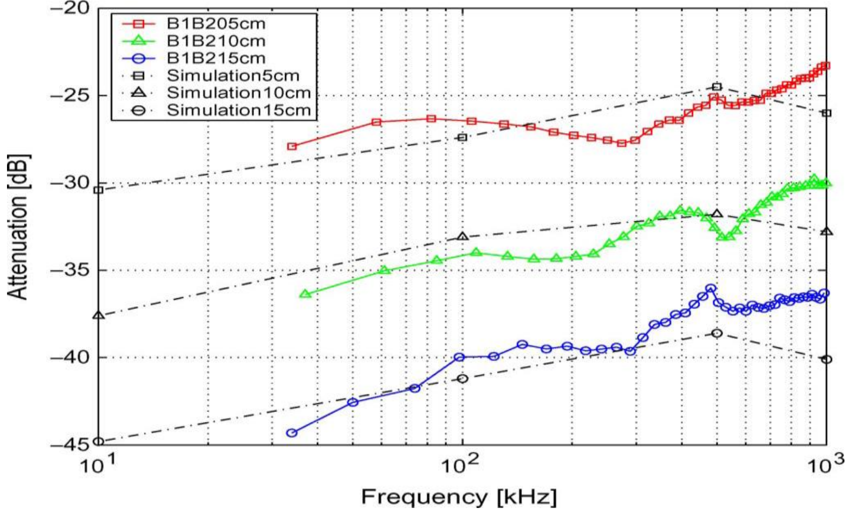
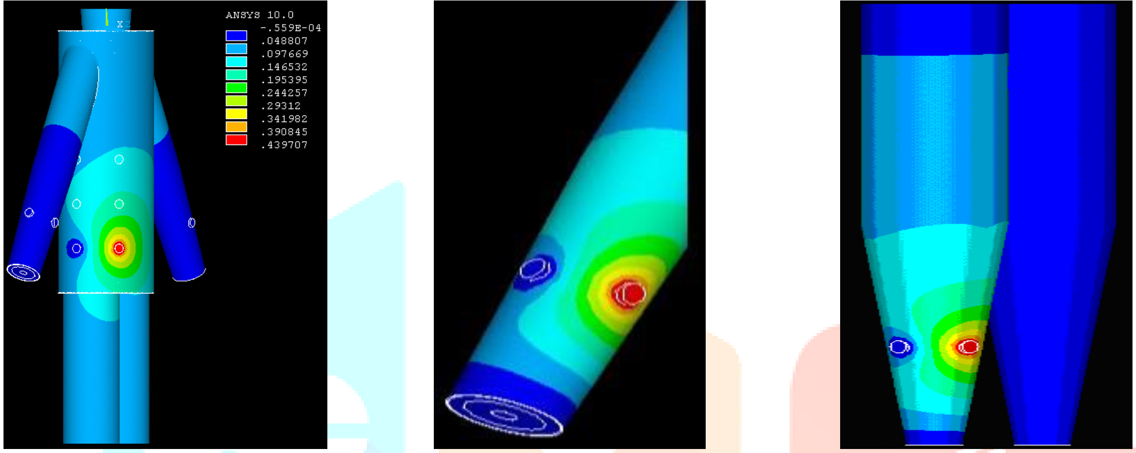


Fig 7. Attenuation studies of dependency of distance between transmitter and receiver on upper arm (measurements and simulations)

Courtesy: [6]

In [15] study was conducted to improvise the performance in galvanic coupling. A system was developed to study the characteristics of human body as a channel in frequency domain. Depending on these characteristics, to improvise bit error rate [BER] pulse shaping and channel equalization were introduced. These were validated both by simulation and experimentation. Experiment was conducted for both QPSK and 16QAM at symbol rate of 50Kbps and 80 Kbps. It was concluded that applying equalizer for 16QAM was more effective compared to that of QPSK.

In [14] simulation was conducted to study the potential distribution of signal transmission from various parts of the body like from arm, torso, leg



(a) (b) (c)

Fig 8. Potential distribution of signal transmission from a) Torso b) Arm c) leg

Courtesy: [14]

The simulated results were investigated with in vivo experiments where it was shown that simulation results agree with experiment results within the 10 kHz–5 MHz frequency range. As the frequency range is increased between 10 kHz to 200 kHz both the simulation and the measurement results gradually decrease for arm. In case of torso as the frequency is increased from 10 kHz to 500 k Hz , the simulation and the measurement results gradually decrease. It was concluded that 1) higher potential distribution was focused at the transmitting electrode which gradually diminishes towards the receiver. 2) Lower potential was detected at muscle and higher potential at skin and fat layer. 3) Within the frequency range 10 kHz- 100 kHz both simulation results and measurement result agree. 4) Distance influences attenuation from 100 kHz – 5 M Hz range.

IV. Conclusion

In the present review, research in intrabody communication (IBC) was surveyed. IBC is a new short-range non-RF wireless communication technique specified by the IEEE 802.15.6 using the human body as a transmission medium. We reviewed the current IBC coupling methods, various IBC models, and latest transceiver designs. As it stands, the IBC technique potentially offers a more power efficient and naturally secure short-range communication method for body sensor networks, compared to wireless RF. Though ratified in a standard, there are still remaining challenges such as the effect of user motion on transmission quality, increasing data rates for low frequency carriers and effect of long-term use on health which requires further advances before this technology matures.

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