Body Mass Index (BMI) Effect on Galvanic Coupling Intra-Body Communication

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***Abstract*—Intra-body communication (IBC) is a wireless communication system where human body is used as a signal transmission medium. Main advantage of IBC compared to other wireless communication is capable of low power consumption. There are two coupling methods in IBC, which are capacitive and galvanic coupling. The characteristic of human body play an important role in IBC because the transmitted signal is propagates through the body tissue. Therefore, this paper investigates the effect of different dielectric properties of body tissues to the quality of IBC signal transmission by focusing at body fat. Galvanic coupling method was used. 12 subjects were volunteered in this study and the value of subject's body fat was differentiates by body mass index (BMI). The frequency was focused on 21 MHz, 50 MHz and 80 MHz. The signal quality at 21 MHz and 80 MHz shows the degradation as the increasing of body fat. The signal attenuation is increasing as body fat increased because in human body, the bone and fat has higher resistance than nerves and muscle. However, at frequency 50 MHz, the increasing of human BMI does not increase the attenuation where the attenuations are at peak value.**

***Index Terms*—Body Mass Index; Intra-Body Communication; Signal Transmission Medium.**

I. INTRODUCTION

The advancement of technology in electronics and engineering has made the development of biomedical sensor smaller from time to time that can be attaching to human body and also can be implanted inside the human body. The data from this sensor then need to be sent to server for analyzing. By using the wireless interfacing, the data can be sent and analyzed easier without the patient go and stay at the hospital. Thus, it more cost efficient than using the wired connection [1].These communication systems are known as Wireless Body Area Network (WBAN). The physical layer of WBAN system consists of radio frequency (RF) and non-RF propagation techniques which is Intra-body communication (IBC).

The devices that could continuously monitor health vital sign such as glucose level using miniature sensor already applied using the RF propagation technique for wireless data transmission. However, wireless RF propagation has major drawback for miniature portable monitoring devices where it consumed high power. IBC also known as Human Body Communication (HBC) utilized human body as a medium for electrical signal transmission. The wireless communication system method that using human body as a transmission medium was first proposed by Zimmerman in 1995 [2]. IBC has an advantage over the RF due to its very low power consumption and data rate more than 100 kb/s [3].

Human body is main part in transferring data from transmitter to receiver of the IBC. Therefore, the study of body tissue characteristic is essential for the implementation of IBC system. The electrical characteristic of body is different for different people depend on the dielectric properties such as relative permittivity (ε_r) and conductivity (σ). The body state and temperature surrounding also can lead to the changing of body tissue dielectric properties. Hence, the investigation in effect of body tissue dielectric properties must be conducted.

II. DIELECTRIC PROPERTIES OF BODY TISSUE

Propagation of IBC signals through human body tissue. Body tissue consists of skin, fat, muscle, cortical bone, and bone marrow layer. Each layer of body tissue has different electrical resistance. Two major electrical properties of body tissue are relative permittivity (ε_r) and conductivity (σ). The dielectric properties for the different tissues at corresponding frequencies that was measured by Gabriel *et al.* shown in Figure 1 and 2 [4]. High frequencies tend to make the signal pass more easily through human tissue where conductivity is higher as seen in Figure 2.

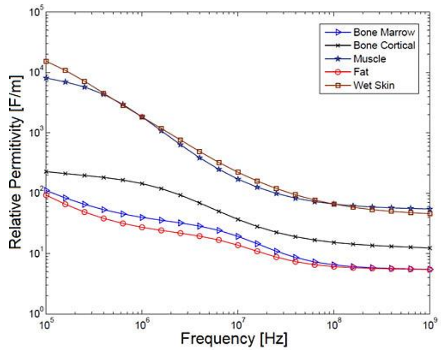

Figure 1: Relative permittivity of human body tissue [4].

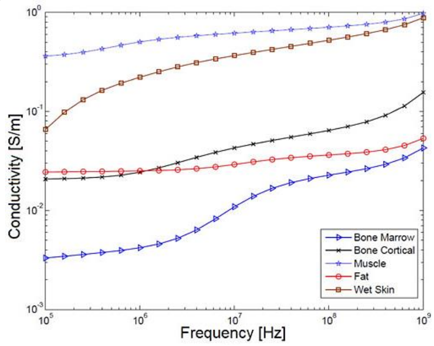

Figure 2: Conductivity of human body tissue [4].

III. Methodology

A. Intra-Body Communication Coupling Method

There are two basic coupling methods in intra-body communication, which are capacitive and galvanic coupling. In capacitive coupling, transceiver signal electrode is attached to human body and the ground electrode is floating, while both of the transceiver electrodes for the galvanic coupling are attached to the human body.

This paper focused on galvanic coupling method. In galvanic method, body tissue is the dominant pathway for signal transmission. Therefore, the quality of signal transmission is influenced by dielectric properties of human tissue [5]. An empirical comparison from previous studies also said that galvanic method have superior data transmitting and have more than 10% better immunity to distortion compared with capacitive method [6]. An electrical signal is applied at the transmitter electrodes and propagated through the body. The majority of applied current will flow between two of transmitter electrode and the remaining current will propagate through the human body to the receiver electrodes. This small secondary current also will contribute to the potential difference that detected by receiver [7]. Figure 3 below show the current flow path in galvanic coupling.

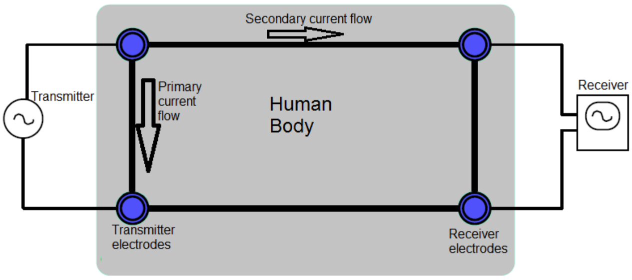

Figure 3: Current flow in galvanic coupling [5].

The dielectric properties of body tissue such as relative permittivity (ε_r) and conductivity (σ) controlled the amount of current signal that receive by the receiver. This tissue dielectric properties is different depend on many factor such as skin type, surrounding temperature and frequency of signal.

B. Measurement Setup

In order to study the body fat effect on the transmission of intra-body communication signal, 6 male subjects and 6 female subjects with different height and weight were volunteered. For each gender, 3 subjects that have Body Mass Index (BMI) below 25 and above 25 were choosing. The differences body fat of these subjects was differentiate based on their BMI. The BMI for each subjects are shown in Table 1 below:

Table 1
Body Mass Index (BMI) for the subjects

Male Subject	BMI	Female Subject	BMI
Subject 1	16.7	Subject 7	19.9
Subject 2	19.9	Subject 8	20.8
Subject 3	20.7	Subject 9	21.9
Subject 4	28.5	Subject 10	29.1
Subject 5	31.3	Subject 11	39.6
Subject 6	32.9	Subject 12	42.0

A portable vector network analyzer (miniVNA Pro) from Mini Radio Solutions was used to generate the signal at the transmitter and to measure the signal received by the receiver. A pair of differential amplifiers or balance-unbalanced (balun) transformer (FTB-1-1+) was connected to the transmitter (TX) and receiver (RX) port at the mini VNA to decouple both transmitter and receiver from miniVNA and provide realistic signal path. A pair of transmitter and receiver electrodes was attached to the subject's right waist and above subject's right ankle respectively and then connected to the baluns. Self-adhesive Ag/AgCl EMG dual Electrodes from Noraxon were used. The measurement was setup as in Figure 4.

In all measurement, transmitter and receiver electrode distance was fixed to 80 cm for all subjects to minimize the attenuation from distance effect. The distance is calculated from centers of transceiver electrodes. The wire attached to the human body was wrapped using bandage to minimize the wire movement effect. The signal attenuation was measure for all subjects in static condition.

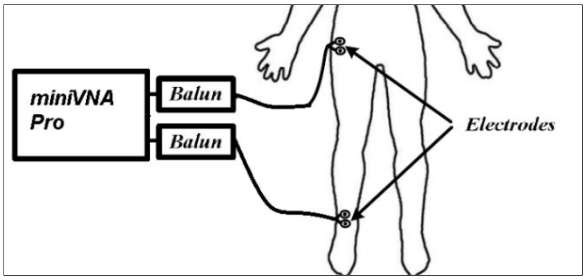

Figure 4: Measurement setup for the galvanic coupling IBC

Figure 5: Subject in static condition and wire wrapped using bandage

The frequency for measurement signal was sweep from 200 kHz to 200 MHz. From these range frequency, the comparison for the attenuation effect from body fat was focused on 21 MHz , 50 MHz and 80 MHz. 21 MHz frequency is the centered frequency for the intra-body communication that was standardize in IEEE 802.15.6 standard [8]. IEEE 802.15.6 is a standard for WBAN that was ratified in 2012.

C. Protocol

Twelve subjects in this study was completed the approval from the Universiti Teknologi MARA Research Ethics Committee before volunteered. All the volunteered subjects were aged from 25 to 30 years old.

For further safety, a very low input power was generate from miniVNA transmitter port of just 0dBm (=1.0mW). This generating current is 20 times lower than the maximum allowed contact current that was outlined by International Commission on Non-ionizing Radiation Protection (ICNIRP), [9].

IV. RESULT AND DISCUSSION

First of all, the investigation for each gender for the frequency range from 200 kHz to 200 MHz was investigated. Figure 6 and 7 below shows the signal attenuation for the male and female subjects below 200MHz. For both gender, it shows that the signal attenuation for different people is different. However, the pattern of signal attenuation versus frequency is similar where the attenuation is decreasing as frequency increasing.

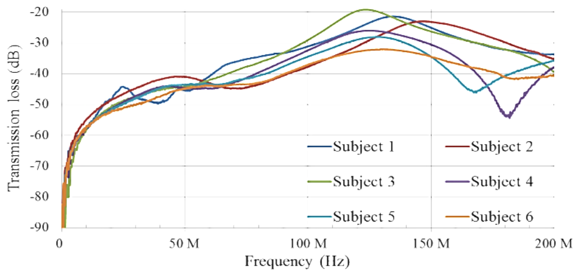

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Figure 6: Signal attenuation for male subjects

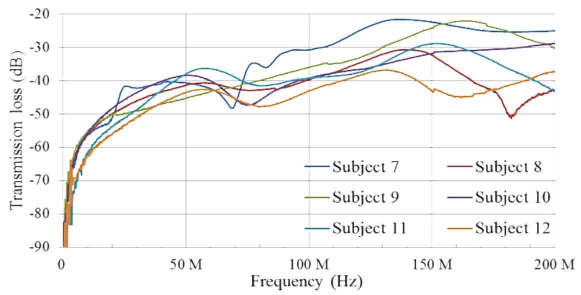

Figure 7: Signal attenuation for female subjects

The resistance of female body tissue is bit difference with men. Women that have equal BMI with men have more fat because men tend to have more muscle than women. From previous research, Gabriel *et al.*'s [4] showed that the conductivity of muscle tissue is good compared to other tissue layer.

The signal attenuation is said to be at peak between the frequencies 40 till 60 MHz and the minimum losses at this frequency range was measured. The minimum losses of all subjects are range from -38dB to -45dB at the frequency 50 MHz. The signal attenuation for this frequency range is shown in Figure 8 below:

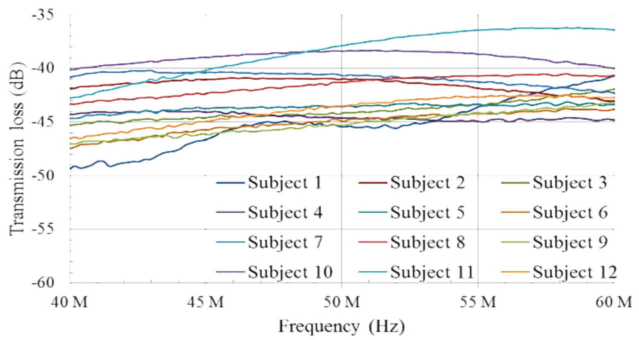

Figure 8: signal attenuation for all the subjects

The signal attenuation at the IBC centered frequency, 21 MHz also measured for the different BMI. From the previous study by Seyedi *et al.*'s [10], the operating frequency 70 MHz to 90 MHz was suggested due to good attenuation for the existing of limb joint. The attenuation for the frequency 21MHz, 50 MHz and 80 MHz was compared and tabulated in table 2 below:

Table 2
Signal attenuation at the investigating frequency

BMI (kg/m^2)	Subject	Transmission loss at 21 MHz (dB)	Transmission loss at 50 MHz (dB)	Transmission loss at 80 MHz (dB)
16.7	Subject 1	- 47	- 45	- 34
19.5	Subject 2	- 48	- 41	- 43
20.0	Subject 7	- 49	- 40	- 35
20.7	Subject 3	- 50	- 44	- 36
20.8	Subject 8	- 50	- 45	- 40
21.9	Subject 9	- 49	- 41	- 43
28.5	Subject 4	- 51	- 45	- 40
29.1	Subject 10	- 48	- 38	- 46
31.3	Subject 5	- 51	- 44	- 41
32.9	Subject 6	- 52	- 45	- 43
39.6	Subject 11	- 53	- 38	- 41
42.0	Subject 12	- 55	- 43	- 48

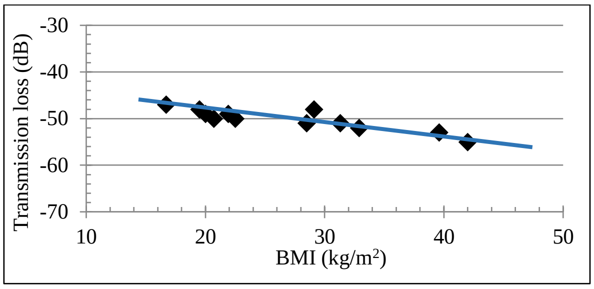

Figure 9: Attenuation at 21 MHz

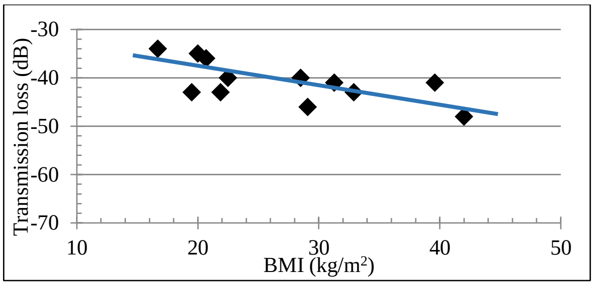

Figure 10: Attenuation at 80 MHz

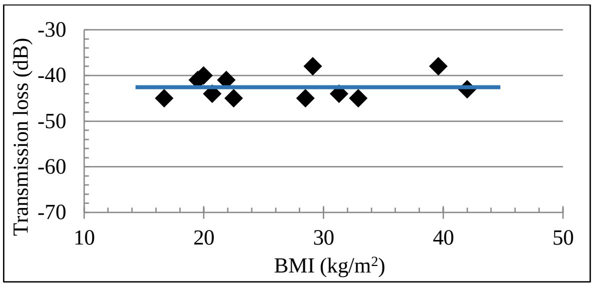

Figure 11: Attenuation at 50 MHz

From the data tabulated in table 2, the graph for each frequency was constructed. For the frequency signal at 21 MHz, it clearly shows that the BMI have clear effect on the signal attenuation of galvanic IBC. The higher BMI will effect to the increasing of signal attenuation. This is due to the increasing of fat resistance. Previous studies on an attempt to model the human body as a transmission medium stated that the resistivity differences of bone and skin does not affect the attenuation, however the resistivity difference of muscle and body fat will affect the attenuation [11]. Decreasing fat resistance leads to lower attenuation and decreasing muscle resistance leads to higher attenuation [11]. Muscle tissue has good conductivity compared with other body tissue.

The attenuation for the frequency ranging from 70 to 90 MHz also proves the same theory. However, at the minimum attenuation, which is 50 MHz, the attenuation does not affected by the increasing or decreasing body fat. This is the frequency where the attenuation is at peak before the attenuation start increasing before it decrease again at frequency 60 to 70 MHz.

V. CONCLUSION

Intra-body communication offers an alternative solution for the low power portable healthcare-monitoring device. At the frequency 21MHz and 80MHz shows that the increasing resistance of body fat will cause the attenuation to increase. It concludes that the increasing of fat resistance will lead to degradation of signal transmitted whereas the increasing of muscle resistance does not degrade the signal because it has good conductivity. However, due to the frequency of signal that also effecting the signal attenuation, the minimum of attenuation is not increased based on the increasing of body fat.

The attenuation between male and female also different because differences of tissue resistivity. Male and female that have same BMI not necessarily have same muscle and fat. Male body characteristic tend to have more muscle than female body, thus give better conductivity for the signal.

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