Binary Frequency-Shift Keying (BFSK) Transceiver Design for Galvanic Intra-Body Communications

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Abstract- **The development of health monitoring technologies has been increasing due to the increasing demand in the healthcare system. In order to continuously monitor critical patient health vital sign such as heart rate and glucose level, communication between the miniature sensor on the human body already successfully deployed using radio frequency (RF) technology, however it's consumed high power. Intra-body communication (IBC) technology is an excellent alternative as it provides flexibility, portability and consumed less power. IBC system used the human body to transfer the transmission data. In this paper, new IBC transceiver based on Binary Frequency Shift Keying (BFSK) was designed. IBC transmitter modulated binary input data to specific frequency before transmitting through the human body. Then IBC receiver demodulated the receiving signal into binary to be processed. The design was implemented using the FPGA board. The galvanic Coupling IBC method was chosen, and the result shows that the receiving data at the receiver is precisely the same as transmitting data.**

Index Terms—**radio frequency (RF), intra-body communication (IBC), IBC transceiver, galvanic coupling**

I. INTRODUCTION

RECENT development in electronic technology and tremendous demand for a better quality of life have led to the push of advancement of the Internet of Things (IoT) at every front possible. Nowadays, monitoring vital human signs (e.g. heartbeat, blood pulse pressure, and glucose level) is performed through miniature sensors, which are lightweight and intelligent devices, capable of measuring physical and physiological data, necessary processing and data transmission. Sensor motes are attached on or implanted in the body and develop short distance networks around the body, named healthcare sensor networks (HSNs).

This manuscript is submitted on 25th July 2019 and accepted on 1st November 2019. This work was financially supported by Research Grant Scheme (RAGS) [File No: 600-RMI/RAGS 5/3 (195/2014)]. [1]Electronic Architecture and Applications (EArA), Faculty of Electrical Engineering Universiti Teknologi MARA, 40450 Shah Alam, Selangor. [2]Discipline of Cardiology, Medical Specialist Center, Faculty of Medical, Universiti Teknologi MARA, Sungai Buloh. Email: izaidi_wanibrahim@yahoo.com.

Currently, healthcare applications focus on wireless HSNs to increase the quality of treatment as well as to decrease healthcare costs by introducing the freedom of portability. These devices, such as portable ECG process the data and send the medical information to recording stations through radio frequency (RF) transmissions using standard protocols such as Bluetooth, Zigbee, or ANT.

The advancement of technology in engineering has enabled the biomedical sensor to be wearable or implanted within the human body for HSNs purpose. The biomedical sensor that functioning to monitor vital human sign can be communicated using a wireless body area network (WBAN), which is a communication protocol that was ratified in 2012. This WBAN protocol, IEEE 802.15.16 outlined three physical layers (PHY), as shown in Fig. 1 which are Narrowband (NB), Ultrawideband (UWB) and Intra-body Communication (IBC) [1]. Narrowband (NB) and Ultrawideband (UWB) operation frequency are based on RF frequency range while Intra-body Communication (IBC) is non-RF. A wireless system based on the RF frequency using Bluetooth, Zigbee already successfully developed, but it consumed vast power [2]. The main advantage of IBC is that it consumed less power compared with Bluetooth and Zigbee.

IBC is a method where the communication uses the human body as a transmission medium. The data from the transmitter is sent to the receiver using the human body with below 1.0 mW of power transmission. The concept of using the human body as a transmission medium was introduced in 1995 by Zimmerman [3].

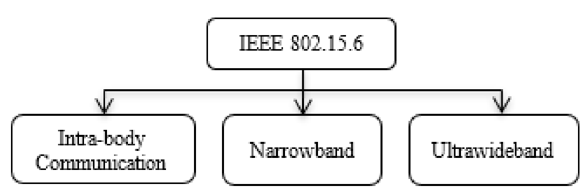


Fig.1. Physical Layers of IEEE 802.15.6 standard

II. EMPIRICAL MEASUREMENT

Researchers around the world have conducted several types of research regarding IBC technology. Nonetheless, up to date, there is still no IBC related device on the market. Which make our propose pre-commercialization prototype very attractive and we are very enthusiastic to accelerate the commercialisation processes. Nevertheless, the gap in the theoretical understanding of the electric signal mechanism through the human body and the channel model of a human body has led to non-systematic and trial and error analysis that results in abstruse data and non-concrete evidence. By consequence, an agreement on how to accomplish standard intra-body communication measurement is facing an obstacle.

Most research done in IBC is focused on electrical properties of the human body, modelling method of body tissues and hardware design of the IBC system. In order to design the IBC transceiver, the understanding of the communication channel is essential. Therefore, the effect of human body movement as a communication channel was investigated before we can conclude what the most reliable transceiver to be designed is. First, was to characterise the intra-body communication signal using in vivo experiment of human movement. We compare two IBC coupling method to analyse the performance when human locomotion was introduced. The coupling methods were capacitive coupling (Electric field) method and galvanic coupling (Waveguide). The data collections were based different age, weight, height, gender and speed of movement of the test subject. Different types of electrodes were also compared. The analysis was based on gait analysis. The second stage based on the result of the first stage, we design a suitable transceiver with the optimum performance for IBC. The techniques that were concluded in the first stage were modulation techniques, operating frequency of the transmitter, the gain of the amplifiers, balun type to eliminate the grounding effects, and electrode type. [4].

A. Preliminary Experiment

Since understanding the channel characteristics plays a crucial role in an ideal IBC transceiver design, the study of signal attenuation was significant. To characterise the human movement effect on IBC signal, we use a portable Vector Network Analyzer (VNA) to collect the data and using 2-port scattering parameters (s-parameters) to evaluate the signals. The VNA is calibrated to induce AC current to the human body below 1 mA (20 times lower than the allowed contact current according to International Commission on Non-ionizing Radiation Protection (ICNIRP)). The source power from the VNA will be fixed to a very lower input power of just 0 dBm (=1.0mW) for further safety (this is well below the possible health effect based on the study of World Health Organization (WHO). The data collecting was tabulated into difference situation, using a treadmill for movement evaluation. All data collection was done at Cardiovascular and Thoracic Centre (CTC), Faculty of Medicine, Sungai Buloh with the supervision of a qualified cardiologist. The IBC data collection setup is shown in Fig. 2 From the experiment, several novel findings and conclusions were made. The significant result is presented in Fig. 3, Fig. 4 and Fig. 5.

Fig. 2. Data collection of test subject using Quinton Q-Stress 4.0 Treadmill

Fig. 3, compares the effect of knee joint existing in IBC communication channel [5]. Here we conclude, the signal loss is higher at the knee joint. One significant finding we found that during movement, the insertion loss is varied even if the transmission distance is maintained. Thus, we want to study what contributes to the loss.

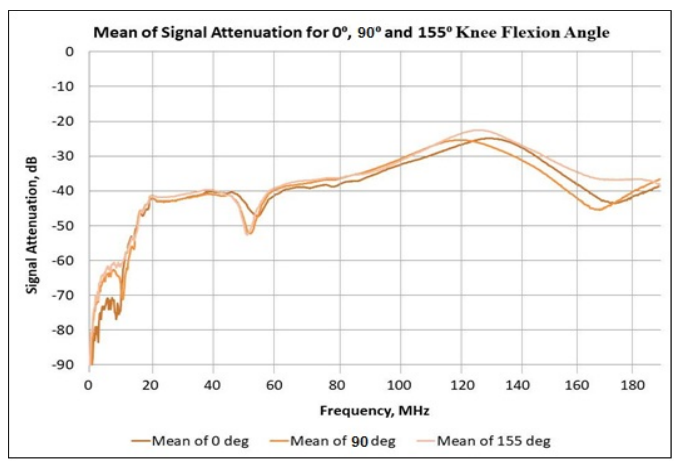


Fig. 3. Mean of signal attenuation for 0°, 45° and 155° knee flexion angle [5]

Fig 4, we systematically study the transmission loss in one gait cycle [6]. Here we found that bend on human limb contributes to higher transmission loss. When the limb bend reduced, the insertion loss increased. We also found that the loss varies in the same control conditions. As a result, we want to study at what operating frequency contributes to minimal variation loss. This frequency would be suggested to be implemented in the transceiver design.

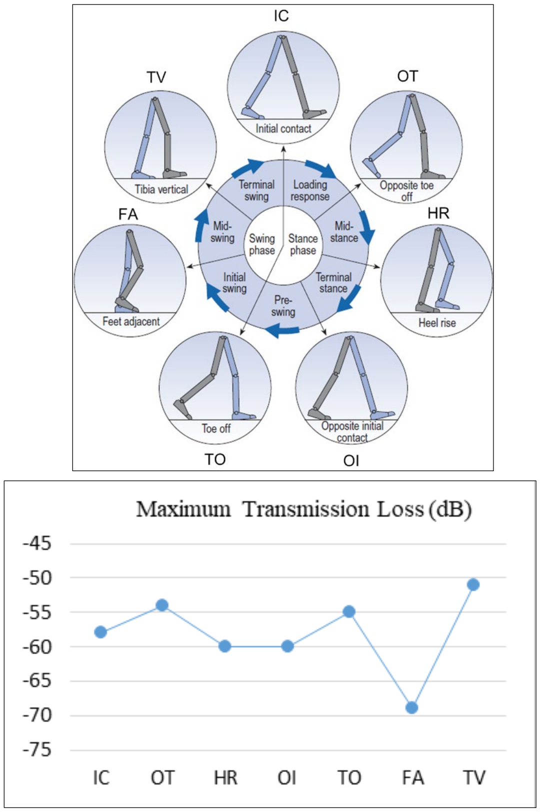


Fig. 4. Study the effect of human movement on galvanic intra-body communication during a single gait cycle [6]

Fig. 5, we test several operating frequencies with respect to different test subject body mass index (BMI) [7]. What we conclude in this experiment is that at 50MHz, there is variation loss, but it is at minimal compared to other frequency within its range.

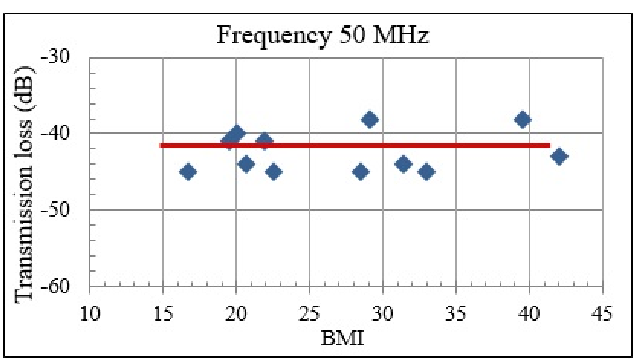


Fig. 5. Body Mass Index (BMI) effect on galvanic coupling intra-body communication [7]

B. *IBC Coupling Method*

In Intra-Body Communication system, two basic coupling methods can be used to transmit signal from transmitter to receiver, which are galvanic and capacitive coupling. Both coupling types need two pairs of transmitter and receiver electrodes. In galvanic coupling method, both electrodes at transmitter and receiver are attached to human skin while in capacitive coupling method, the only signal electrode at transmitter and receiver side are attached to human skin, and the ground electrode is left floating. Fig. 6 shows the measurement setup for the galvanic coupling method. Fig. 7 shows the measurement setup for the capacitive coupling method.

In this paper, the galvanic coupling method was used due to its superior data transmitting and has more than 10% better immunity than capacitive coupling [8, 9]. Compared with capacitive coupling, the dominant signal transmission pathway for galvanic coupling is the human body while the environment is dominant for capacitive [10].

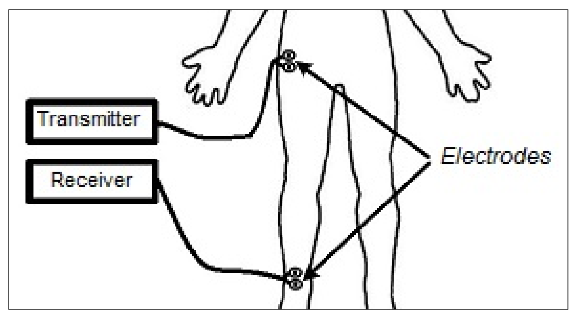


Fig. 6. Galvanic coupling IBC setup

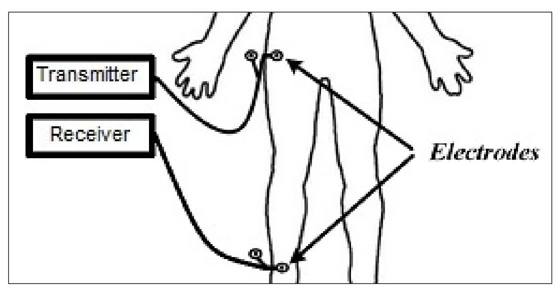


Fig. 7. Capacitive coupling IBC setup

III. IBC Transceiver Architecture

The communication performance of HBC systems was investigated by using simulations and experiments, and many prototypes have been developed to achieve different communication performance. Various transmission parameters (carrier frequency, modulation scheme, and transmission power) were adopted to achieve different data rates. Table 1. summarise the comparison of the currently reported IBC transceiver in the literature. IBC started in 1995, where narrowband modulation on-off keying (OOK) and wideband signalling direct sequence spread spectrum (DSSS) were examined in [3]. The prototype achieved a data rate of 9.6 kbps by using FSK modulation with a carrier frequency of 10.7 MHz [11]. The comparison of modulation schemes FSK and BPSK was conducted by Wegmueller et al. [12]. According to Ruiz et al. [13], the minimum transmission power of 17.8 dBm was the peak to transmit through the body. It was found that, with an input current of 2 mA, BPSK and FSK obtained a rate of 64 kbps. Both BPSK and QPSK achieved data suitable modulation schemes among PSK, FSK, and QAM [14] in galvanic coupling HBC. Based on the comparison measurements, BPSK was selected as the optimal modulation method among BPSK, QPSK, MSK, and 16QAM [15]. The SOC prototype from Lin et al. [16] obtained a data rate of 2 Mbps by using OOK with transmission power 4 dBm. By using the differential probe, which always contains a differential amplifier with several dB gains, satisfactory receiving performance was obtained [17]. Later, a 65 nm CMOS process HBC transceiver [18] for both entertainment and healthcare were implemented by this research group; for the latter case, a data rate of 100 kbps. Recently, a wideband signalling HBC transceiver with high data rate between 1 Mb/s to 40 Mb/s was developed by Chung et al. [19]. With all the progress in IBC transceiver design, there is still lacking designing miniaturised IBC transceiver that characterise the dynamic body behaviour.

In this paper, the IBC BFSK transceiver was designed using the FPGA Altera board. Binary Frequency Shift Keying (BFSK) modulation method was used. In this method, binary input data were modulated to produce a signal at frequency 19MHz and 25MHz. This modulated analog signal was propagated through the human body and finally demodulated back by receiver module.

Fig. 8 depicts the block diagram of the IBC BFSK transmitter design. The presented transmitter consists of clock divider, parallel in serial out (PISO), frequency generator and analog multiplexer (MUX). The 8-bit binary input data is set using the switch on the FPGA Altera board. PISO serialises this parallel data. The clock divider generated the required frequency needed by PISO. Two different frequencies which are 19MHz and 25MHz were generated by frequency generator that supplied into analog MUX. Analog MUX was used to select which frequency to be transmitted into the human body based on selected input from PISO output.

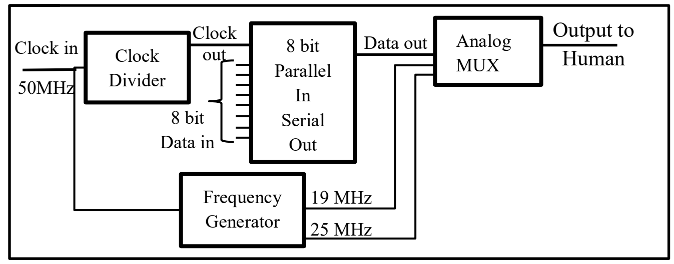


Fig. 8. Block Diagram BFSK Transmitter

Fig. 9 depicts the block diagram of the IBC BFSK receiver design. The receiver consists of low noise amplifier (LNA), clock divider, comparator, and decision module. Firstly, the small receiving signal from the attached electrode at human body is amplified by LNA. The comparator is used to compare the receiving analog signal into digital data. The clock frequency used by the comparator is 50MHz, which is clock provided by the FPGA board. Finally, the decision module will convert the data into an output signal ‘0’ or ‘1’. Fig. 10 shows the LNA circuit that was used in the IBC receiver design. At frequency 25 MHz, the LNA amplify the amplitude up to 30dB.

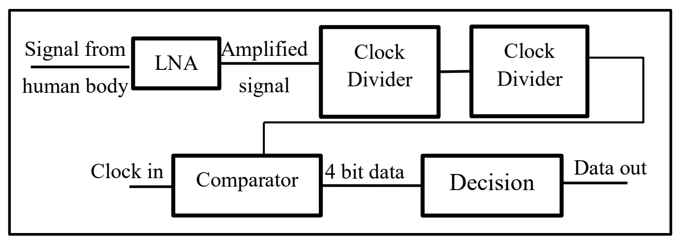


Fig. 9. Block Diagram of BFSK Receiver

Fig. 10. LNA circuit

IV. RESULT

A. *Measurement setup*

In order to implement the human body as a transmission medium, the IBC transmitter and receiver circuit were built on FPGA Altera DE2 board. This FPGA Altera board provides 50 MHz clock frequency. The transmitter output signal was connected to the human body using self-adhesive Ag/AgCl EMG dual Electrodes from Noraxon as an input signal. The transmitter and receiver electrodes were attached on the human body at the right wrist and ankle, respectively. Low Noise

Amplifier (LNA) circuit was used to amplify the output signal from the human body before it demodulates using receiver module that was built on the FPGA board. Fig. 11 below shows the measurement setup for the measurement.

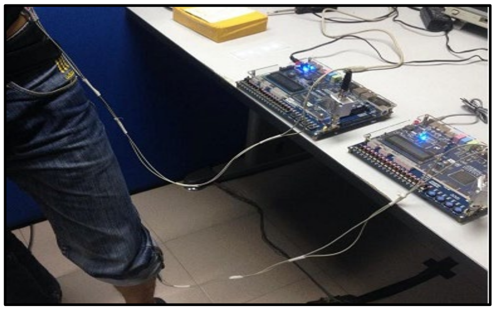
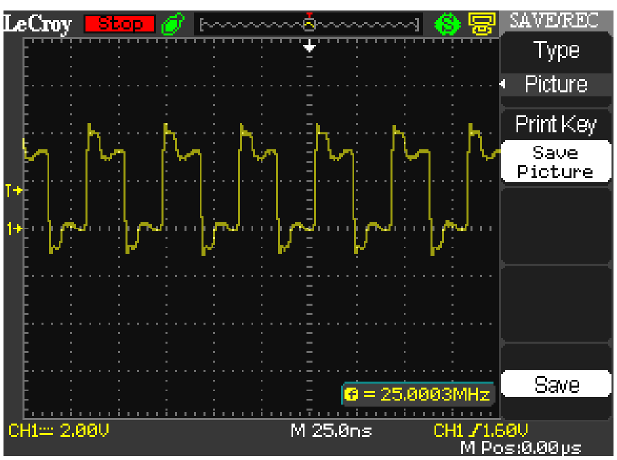


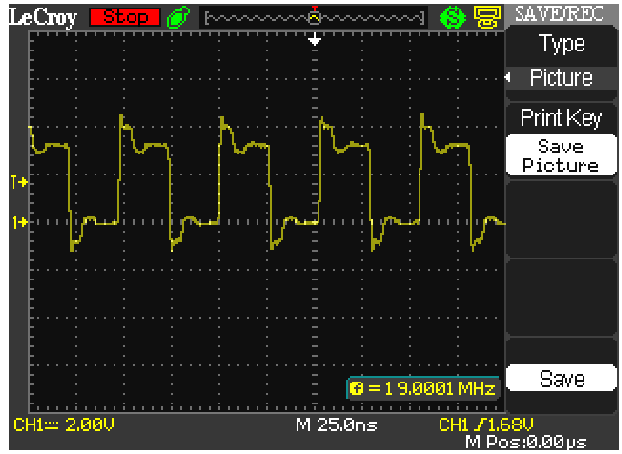
Fig. 11. IBC Transceiver measurement setup

B. Experimental Result

The sinusoidal wave signal was modulated by the transmitter module based on digital data input. Fig. 12 demonstrates the modulated signal from the transmitter for input data set to 1 and 0, respectively. The modulated signal was monitored using the oscilloscope. The result display that when transmitter input was set to '1' and '0', the modulated signal is transmitted at frequency 25 MHz and 19 MHz respectively.



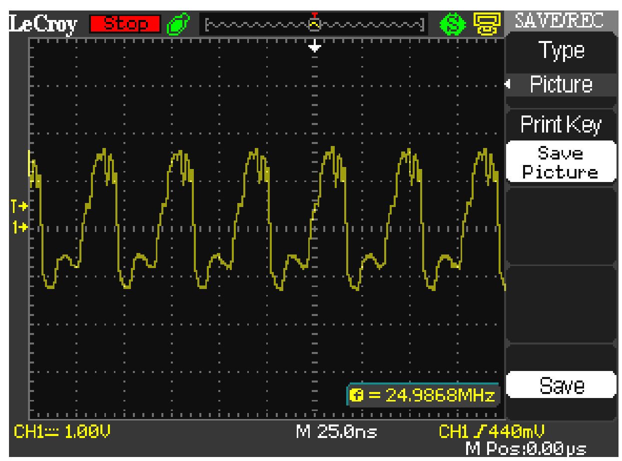
(a)



(b)

Fig. 12. Output of IBC Transmitter: (a) input set to 1, (b) input set to 0

After the signal propagated through the human body, there was some attenuation to the signal. Therefore, the LNA were used to amplify the received signal and then was demodulated by IBC receiver module. Fig. 13 shows the receiving signal before demodulated by the transceiver module. The receiving signal shows that the signal was a drop-in amplitude, however, maintain its frequency. Therefore, amplified signal was later demodulated using the IBC receiver module into digital '1' or '0'.



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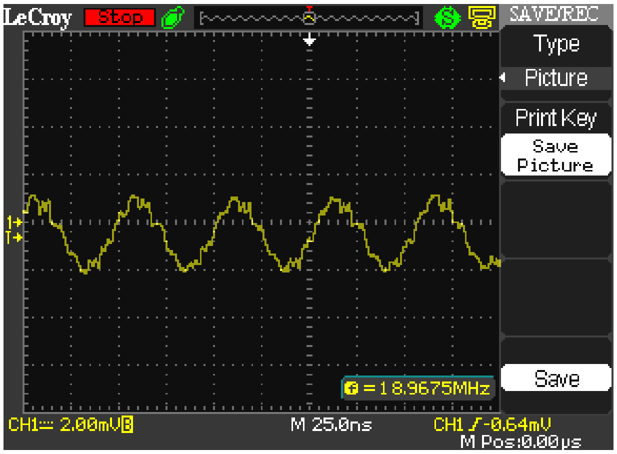

(b)

Fig. 13. Receiving signal from human body: (a) input 1, (b) input 0

Fig. 14 below demonstrated the demodulated output from IBC receiver when 8-bit input at the transmitter was set to 10101111.

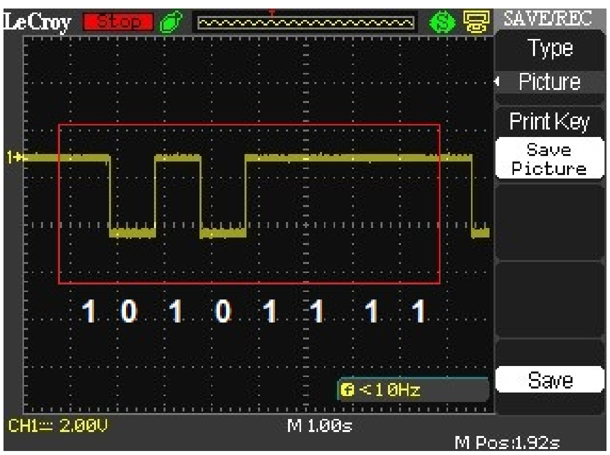

Fig. 14. IBC Transceiver measurement setup

V. Discussion and Conclusion

Intra-body communication is a convincing technology capable of solving the high-power consumption of the portable healthcare-monitoring device. From the original IBC transceiver concept introduced by Zimmerman in 1995 that using on-off keying (OOK) modulation method [3], IBC has developed more than two decades. By using the binary frequency shift keying (BFSK) technique and frequency used is 19 MHz and 25 MHz, the design denotes that it is possible to implement the human body for transmission medium of the signal. Although there is some attenuation to the signal due to human body structure and atmosphere, the receiving signal still can be processed by the receiver module to get the transmitting data. The receiving signal from the human body shows a drop in amplitude yet maintain its frequency. Thus make it able to demodulate by receiver module.

Acknowledgement

Most appreciation to the Universiti Teknologi MARA (UiTM) that provide the academic research training and Ministry of education for supporting this research through Research Grant Scheme (RAGS) [File No: 600-RMI/RAGS 5/3 (195/2014)].

Reference

[1] M. Seyedi, B. Kibret, D. T. H. Lai, and M. Faulkner, “A survey on intrabody communications for body area network applications,” *IEEE Trans. Biomed. Eng.*, vol. 60, no. 8, pp. 2067–2079, 2013.

[2] S. Adibi, “Link technologies and BlackBerry mobile Health (mHealth) solutions: A review,” *IEEE Transactions on Information Technology in Biomedicine*, vol. 16, no. 4. pp. 586–597, 2012.

[3] T. G. Zimmerman, S. A. Benton, and T. G. Zimmerman, “Personal Area Networks (PAN): Near-Field Intra-Body Communication,” 1995.

[4] M. Seyedi, D. T. H. Lai, and M. Faulkner, "Limb joint effects on signal transmission in capacitive coupled intra-body communication systems," in *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2012.

[5] I. W. Ibrahim, M. M. M. Aruwa, A. H. A. Razak, A. Ahmad, and R. N. Khir. "Investigation of Knee Flexion Angle Influences on Intra-Body Communication’s (IBC) Signal Attenuation." *Indonesian Journal of Electrical Engineering and Computer Science* 9, no. 2:424-430, 2018.

[6] I.W. Ibrahim, A. H. A. Razak, A. Ahmad, and M. K. M. Salleh. "Effect of Human Movement on Galvanic Intra-Body Communication during Single Gait Cycle." *In IOP Conference Series: Materials Science and Engineering,* vol. 99, no. 1, p. 012027. IOP Publishing, 2015.

[7] I. W. Ibrahim, A. H. A. Razak, A. Ahmad, M. K. M. Salleh, and R. N. Khir. "Body Mass Index (BMI) Effect on Galvanic Coupling Intra-Body Communication." *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)* 10, no. 1-6: 177-180, 2018.

[8] A. H. A. Razak, A. Zayegh, R. K. Begg, M. Seyedi, and D. T. H. Lai, “BFSK Modulation to Compare Intra-body Communication Methods for Foot Plantar Pressure Measurement,” in *2013 7th IEEE GCC Conference and Exhibition (GCC)*, 2013.

[9] T. C. W. Schenk, N. S. Mazloum, L. Tan, and P. Rutten, “Experimental characterization of the body-coupled communications channel,” *ISWCS’08 - Proc. 2008 IEEE Int. Symp. Wirel. Commun. Syst.*, pp. 234–239, 2008.

[10] A. H. A. Razak "Performance Comparison between Intra-Body and Radio Frequency Wireless Communication for Foot Plantar Pressure Measurement, Modelling," *AMSE Journals 2014 Series: Modelling C,* Vol. 75, Issue 1, pp. 45-64, 2014.

[11] K. Hachisuka, T. Takeda, Y. Terauchi, K. Sasaki, H. Hosaka, and K. Itao, “Intra-body data transmission for the personal area network,” *Microsystem Technologies,* vol. 11, no. 8-10, pp. 1020–1027, 2005.

[12] M. Wegmueller, N. Felber, W. Fichtner et al., “Measurement System for the Characterization of the Human Body as a Communication Channel at Low Frequency,” *Proceedings of the 2005 IEEE*

Engineering in Medicine and Biology 27th Annual Conference, pp. 3502–3505, Shanghai, China, 2005.

[13] J. A. Ruiz and S. Shimamoto, "Experimental evaluation of body channel response and digital modulation schemes for intrabody communications," *Proceedings of the IEEE International Conference on Communications (ICC '06),* vol. 1, pp. 349–354, IEEE, Istanbul, Turkey, June 2006.

[14] M. S.Wegmueller,W. Fichtner, M. Oberle, andN.Kuster, "BPSK & QPSK Modulated Data Communication for Biomedical Monitoring SensorNetwork," *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society,* pp. 2071–2074, New York, NY, USA, August 2006.

[15] L. Zhang, J. Huang, and L. Wang, "Experimental study on the optimum modulation schemes for human body channel communication," *Bulletin of Advanced Technology Research,* vol. 4, no. 9, pp. 29–33, 2010.

[16] Y.-T. Lin, Y.-S. Lin, C.-H. Chen, H.-C. Chen, Y.-C. Yang, and S.-S. Lu, "A 0.5-V biomedical system-on-a-chip for intrabody communication system," *IEEE Transactions on Industrial Electronics,* vol. 58, no. 2, pp. 690–699, 2011.

[17] J.W. Li, X.M. Chen, S.H. Punet al., "Bit error rate estimation for galvanic-type intra-body communication using experimental eye-diagramand jitter characteristics," *Proceedings of the 2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC 2013,* pp. 5195–5198, jpn, July 2013.

[18] H. Cho, H. Kim, M. Kim, J. Jang, and H. Yoo, "79pJ/b 80Mb/s full-duplex transceiver and 42.5jiW 100kb/s super-regenerative transceiver for body channel communication," *Proceedings of the 2015 IEEE MTT-S 2015 International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO),* pp. 14-15, Taipei, Taiwan, September 2015.

[19] C. Chung, C. Lin, and J. Yang, "Time-domain characteristics of body channel communication (BCC) and BCC transceiver design," *Proceedings of the 2016 International Symposium on VLSI Design, Automation and Test (VLSI-DAT),* pp. 1–4, Hsinchu, Taiwan, April 2016.