Investigation on Error Performance for Galvanic-type Intra-body Communication with Experiment*

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***Abstract*—Intra-body Communication (IBC), which utilizes the human body act as communication channel, offers a novel technology for information exchange in Biomedical Engineering (BME) field. Galvanic-type IBC has been a promising choice for IBC because of its advantages like lesser interference to the nearby environment and lower frequency operation. Bit Error Rate (BER) is a standard figure of merit to indicate the error performance of communication channel. For low frequency and low transmit rate in galvanic-type IBC, the traditional method of BER measurement is time-consuming. Furthermore, to measure through the human body for such a long time is neither practical nor feasible without physiological changes. In order to evaluate the error performance of galvanic-type IBC, this paper presents an alternate approach to investigate BER values of the channel and verifies its behaviors with human lower arm experiment. After comparing the experimental results and theoretical calculation based on ideal Additive White Gaussian Noise (AWGN) channel, it is found that their traces have similar agreement. Besides, the experimental phenomenon indicates the assumptions that channel noise of galvanic-type IBC has AWGN characteristic are reasonable and applicable in some regions.**

Keywords—Intra-body Communication; Error Performance; Bit Error Rate; Eye-diagram; Jitter

I. Introduction

Intra-body Communication (IBC) is a novel technology employs the electrical conducting property of body tissues for information exchange in Biomedical Engineering (BME) field. After intensive research and development, it has own characteristics such as low attenuation, low transmission power (<1 mW), low frequency (<1 MHz) and enough data rate for transmitting biological signal with high security [1]. Nowadays, capacitive-type IBC and galvanic-type IBC are two main coupling-types of IBC. Galvanic-type IBC is the relatively new one and it has becoming an advanced method for IBC because of its advantages like lesser interference to the nearby environment and lower frequency operation, while capacitive-type IBC is highly dependent on the nearby environment. Therefore, to explore more characteristics of galvanic-type IBC is worth and essential for improving the IBC technology.

Bit Error Rate (BER) is a standard figure of merit has been widely used to indicate and evaluate the error performance of communication channel. It denotes the number of errors divided by the total number of transmitted data bits, as expressed below [2]:

$$BER = Number\ of\ Errors\ /\ Total\ Number\ of\ Data\ Bits$$

The traditional method of BER measurement usually compares the input and output to get the number of errors by designing specified prototype applying Field Programmable Gate Array (FPGA) or using specialized equipment like BER tester. For low frequency and low transmit rate in galvanic-type IBC, assuming the evaluated BER value is 10^{-10} and the transmit rate is 10 kbps, through calculation, it is found that the measurement process is order of 12 days. More importantly, to measure through the human body for such a long time is neither practical nor feasible without physiological changes. Consequently, seeking an alternate approach to investigate the error performance in term of BER is crucial to study the characteristics of galvanic-type IBC.

Jitter is one of the important factors in communication system and it can help to determine the error of transmitted data stream, so the error performance is influenced by jitter. Additionally, eye-diagram offers the effect of jitter. Thus, to combine the two principles together, the investigation on error performance of galvanic-type IBC using eye-diagram and jitter has been proposed. In the meanwhile, the behaviors of communication channel can also be studied.

To lay the foundation for investigating error performance of galvanic-type IBC, the fundamental theories between eye-diagram, jitter and BER in communication system are reviewed in Section II. Section III concentrates on the galvanic-type IBC experiments based on human lower arm with the modulations of Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM). Integer method and decimal method are designed and applied for experimental data processing in this paper. Then the experimental results and comparison with Additive White Gaussian Noise (AWGN) channel are presented in Section IV. Discussions about the

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experimental phenomenon and performance of the proposed method are also in this section. Section V makes conclusions of the study at last.

II. FUNDAMENTAL THEORIES

Jitter is a time-domain phenomenon reflecting any errors deviate from the ideal timing, so it also known as timing jitter [3]. This phenomenon can lead to undesired deviation of the edge transitions to be either earlier or later compare with the ideal. In other word, jitter only happens on the rising and falling crossing, as depicted in Fig. 1.

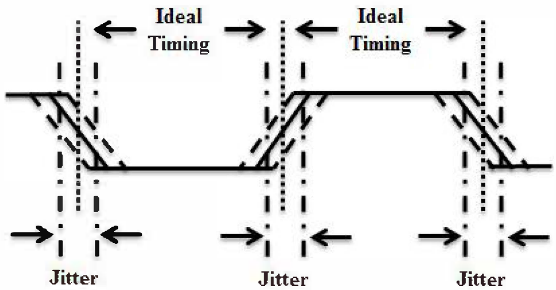

Fig. 1. Definition of Jitter

Eye-diagram is a visual display that provides valuable evaluation and offers insight into the effect of channel noise sources [4]. Technically, it is composed of all possible data sequences and superimposes them into one Unit Interval (UI) range. As shown in Fig. 2, eye-diagram contains plentiful information, which is helpful to interpret the communication channel.

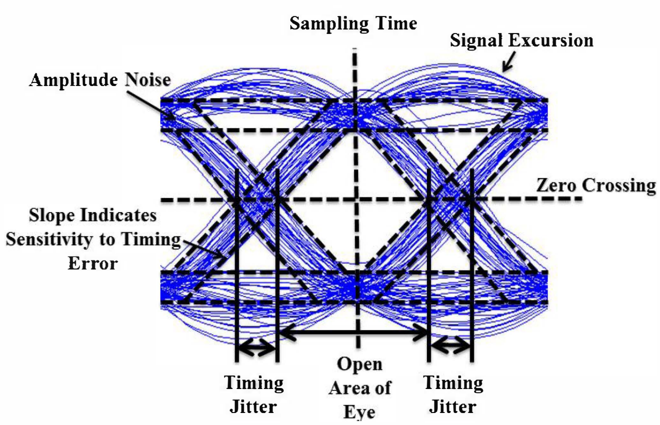

Fig. 2. Interpretation of Eye-diagram

The traces of transmitted data are superimposed in the eye-diagram with times of rising and falling. Because jitter only exists on the two edge transitions, so how jitter displaces the edge transitions can be found from eye-diagram. Additionally, jitter is one of the factors affects the error. Thus, BER depends closely on jitter and it can be obtained from jitter. Fig. 3 illustrates the mathematical relationship between jitter and BER in communcation channel. From Fig. 3, it is found that a bit error happens when the relative timing relationship between jitter and sampling time t_s is out of the expected range. In left edge transition, for jitter PDF $f_{left}(t)$, any edge transitions on the right side of sampling time t_s can make a bit error. So the BER curve in this interval $F_{left}(t)$ is the integral of all the jitters larger than the sampling time t_s in $f_{left}(t)$, as drawn in the black part of Fig. 3. Similar situation happens in right edge transition. In short, the resulting BER curve is made up with both left and right edge transitions [5]:

$$\begin{aligned} BER &= F_{left}(t) + F_{right}(t) \\ &= P_{tr}\int_{ts}^{\infty} f_{left}(\Delta t)\, d\Delta t + P_{tr}\int_{-\infty}^{ts} f_{right}(\Delta t)\, d\Delta t \end{aligned} \tag{1}$$

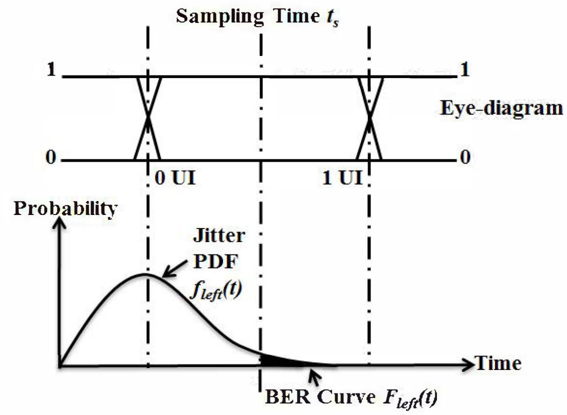

Fig. 3. Mathematical Relationship between Jitter and BER

P_{tr} in (1) means the probability of edge transition and the BER curve can be figured out using (1). In the resulting curve, when t_s equals to 0.5 UI, the sampling time is the best and its corresponding BER value is the best case. This value can be used for BER evaluation and study the error performance for measured channel.

III. GALVANIC-TYPE IBC EXPERIMENT

In order to investigate the error performance of galvanic-type IBC, an experiment based on its principle has been designed and implemented in this section.

To consider galvanic-type IBC, the transmitter converts the transmitted data into a flow of ionic current within the body tissue and the receiver recovers the original signal by detecting the ionic current flow [6]. According to this principle, a healthy adult male is recruited and his lower arm acts as the communication channel. A signal generator (Agilent, N5182A MXG Signal Generator) is used as the transmitter. The modulations of QPSK and 16QAM with 500 kHz carrier frequency have been selected. Phase shift keying is a widely used modulation for low rate application and it has advantage of moderate error performance. Moreover, QPSK seems to be an efficient modulation to improve power efficiency and bandwidth efficiency for galvanic-type IBC [7]. Besides, quadrature amplitude modulation appears to increase the transmission efficiency by utilizing both amplitude and phase variations. As a result, the performances of QPSK and 16QAM for galvanic-type IBC have been investigated in the experiment. On the other sides, a signal analyzer (Agilent, N9020A MXA Signal Analyzer) is used as the receiver to detect and record the transmitted data. Both the received data and information of eye-diagram can be demodulated and generated by its associated 89600 Vector Signal Analysis (VSA) software. Two pairs of physiotherapy electrodes (Shanghai Litu Medical Appliances Co., Ltd, Lt 01, 4 cm*4 cm) are employed to connect the transmitter to lower arm and the receiver to lower arm simultaneously. The separation distance from one pairs of transmitter electrodes to other pairs of receiver electrodes is settled 6 cm in the experiment.

In QPSK experiment, the range of symbol rate is from 10 ksps to 100 ksps, step 10 ksps. The setting powers are 0 dBm and -5 dBm. In 16QAM experiment, the range of symbol rate is from 10 ksps to 50 ksps, step 5 ksps. The setting power is -5 dBm. All the transmitted data are digital modulation electrical signal with random pattern. As usual, the experiment has been performed carefully to take care of the common ground problem by using a differential probe (Agilent, 1141A). The overview of human lower arm experiment is shown in Fig. 4.

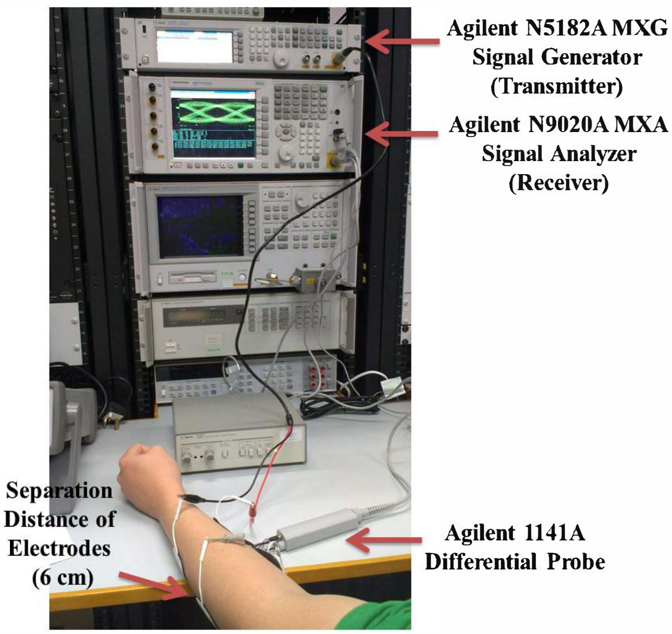

Fig. 4. Overview of Human Lower Arm Experiment

Using the acquired traces and information of eye-diagram, the time intervals of transmitted data should be found. However, the zero point has not been recorded due to the limitation of measurement. The zero point decides a whole time intervals, hence, integer method and decimal method have been designed for experimental data processing.

Integer method means to get the time intervals of transmitted data only consider the integer part of recorded points. In this approach, the recorded point which near to the zero point is used to be the start or the end of its corresponding time intervals so that the time intervals can be approximately calculated from the start point to the end point.

Although the points near to the zero point are used, some deviations still exist due to they have distance to the actual zero point. Therefore, decimal method, which adds an estimated decimal part of the recorded points, has been applied. Its principle is using the triangle to remedy these deviations, as depicted in Fig. 5.

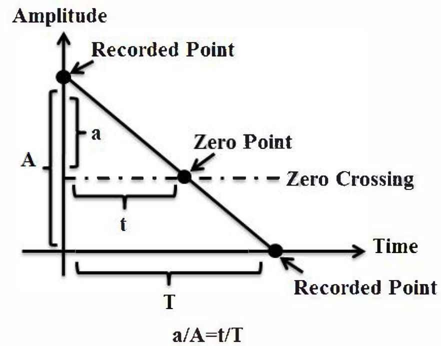

Fig. 5. Principle of Decimal Method

In Fig. 5, a is the distance between recorded point and zero crossing and A is the distance between two adjacent recorded points in amplitude. These values can be obtained from the experimental data. On the other side, t is the distance between recorded point and the zero point and T is the distance between two adjacent recorded points in time-domain and its value equals to one UI. Hence, t is the values for estimating the decimal part of time intervals and it is calculated using the relationship shown in Fig. 5.

After obtaining the time intervals of actual data, comparison with UI can be done so that their deviations, which equal to timing jitter, are obtained. With the results of jitters, the corresponding histograms and their statistical parameters, *e.g.* mean (μ), standard deviation (σ), and variance (σ^2) can be calculated. Fig. 6 shows the samples of statistical jitters histograms. The left one is using integer method, while the right one is using decimal method for the same set of data.

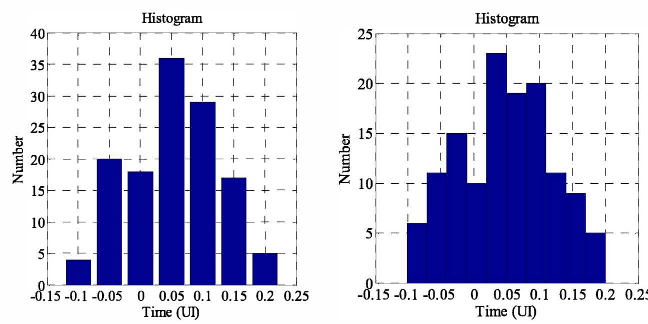

Fig. 6. Samples of Statistical Jitters Histograms

To generate jitter PDF for further calculation, the statistical parameters are substituted into the formulation of Gaussian distribution. Hence, the jitter PDF on left edge transition $f_{left}(t)$ and right edge transition $f_{right}(t)$ can be written as:

$$f_{left}(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(t-\mu)^2}{2\sigma^2}} \quad (2)$$

$$f_{right}(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(t-UI-\mu)^2}{2\sigma^2}} \quad (3)$$

With (2) and (3), the integral calculation based on (1) can be performed. Moreover, the integral results with t_s equals to 0.5 UI can be used for investigating the channel performance of human lower arm.

IV. RESULTS AND DISCUSSION

Additive White Gaussian Noise (AWGN) is a noise model widely used in communication analysis to simulate the effect of random noise process. In ideal AWGN channel, for modulations of QPSK and 16QAM, the theoretical calculation of BER can be done through Signal to Noise Ratio (SNR) using the following (4) and (5), where Q(x) is the Gaussian Q-function [8]:

$$BER_{QPSK} = Q\left(\sqrt{2E_b/N_o}\right) \tag{4}$$

$$BER_{16QAM} = Q\left(\sqrt{0.8E_b/N_o}\right) \tag{5}$$

AWGN produces a simple mathematical model for gaining insight into the behaviors of communication channel and the SNR values of each measured eye-diagram in the experiment are recorded. Furthermore, it is assumed that galvanic-type IBC has AWGN characteristics and the BER of different modulations can use that of ideal AWGN channel [9]. As a result, the comparison between experimental BER results and ideal AWGN channel is meaningful for studying the error performance. Fig. 7 presents the comparison results with QPSK and 16QAM.

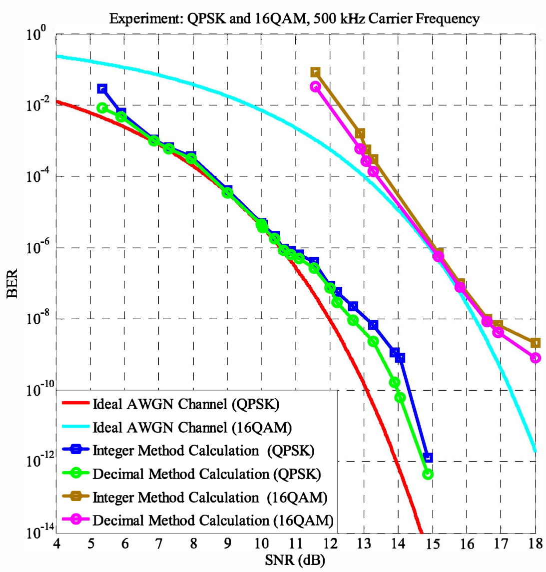

Fig. 7. Performance of BER versus SNR in Experimental Results and Ideal AWGN Channel with QPSK and 16QAM

From Fig. 7, it is obvious that the experimental results have similar trend as the theoretical calculation based on ideal AWGN channel. To consider the two methods of experimental data processing, it is found that decimal method achieves closer results to ideal AWGN channel than integer method. However, the integer part of experimental data in two methods is the same, it leads to decimal method has limited improvement and the difference of two methods seems insignificant.

Except some deviations occur at both ends of SNR regions, when SNR is between 7 dB to 11 dB with QPSK and 13 dB to 16 dB with 16QAM, the BER is closed to the ideal AWGN channel. Furthermore, the limited measurement of recorded points and the imperfection of distribution shape in some cases may cause these deviations. Consequently, to find the more suited and proper jitter distribution can get the more accurate and applicable BER results.

V. CONCLUSION

In this paper, the error performance of galvanic-type IBC has been investigated. From the final results, it is found that the traces of experimental BER and ideal AWGN channel have similar agreement. To analyze the experimental phenomenon, it appears that the noise of galvanic-type IBC channel in some regions can be assumed as AWGN. Additionally, the human lower arm experiment verifies the relationships between eye-diagram, jitter and BER, which are suited for galvanic-type IBC channel. According to the results of error performance, it also indicates the technology of galvanic-type IBC has potential for information exchange in biomedical engineering field. For future work, to explore more about the jitter distribution can increase more understanding of characteristics in galvanic-type IBC.

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REFERENCES

[1] Z. Lucev, I. Krois and M. Cifrek, "Intrabody Communication in Biotelemetry," Wearable and Autonomous Biomedical Devices and System for Smart Environment, vol. 75, pp. 354-368, 2010.

[2] G. Breed, "Bit Error Rate: Fundamental Concepts and Measurement Issues," High Frequency Electronics, vol. 2, pp. 46-48, 2003.

[3] M. Shimanouchi, "An Approach to Consistent Jitter Modeling for Various Jitter Aspects and Measurement Methods," IEEE International Test Conference, pp. 848-857, 2001.

[4] G. Breed, "Analyzing Signals Using the Eye Diagram," High Frequency Electronics, vol. 4, pp. 50-53, 2005.

[5] M. P. Li, "Jitter, Noise, and Signal Integrity at High-Speed", Prentice Hall, 2007.

[6] X. M. Chen, P. U. Mak, S. H. Pun, Y. M. Gao, C. T. Lam, M. I. Vai and M. Du, "Study of Channel Characteristics for Galvanic-Type Intra-Body Communication Based on a Transfer Function from a Quasi-Static Field Model," Sensors, vol. 12, pp. 16433-16450, 2012.

[7] Y. M. Gao, X. X. Li, Z. Lucev, S. H. Pun, P. U. Mak, I. Krois, M. Cifrek and M. I. Vai, "Channel Modeling and Simulation for Galvanic Coupling Intra-body Communication," IFMBE Proceedings, vol. 43, pp. 655-658, 2014.

[8] J. G. Proakis, "Digital Communications, 4th edition," McGraw-Hill, 2001.

[9] X. M. Chen, S. H. Pun, Y. M. Gao, P. U. Mak, M. I. Vai, M. Du, "Study on Transfer Function of Intra-Body Communication Based on Quasi-static Electric Field Modeling", IEEE-EMBS International Conference on Biomedical and Health Informatics, pp. 388-391, 2012.