Phase Characterization of 1-200 MHz RF Signal Coupling with Human Body

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***Abstract*-To continuously monitor health information using wireless sensors placed on a person is a promising application. Human body communication (HBC) is proposed as a low power, security and light-weight communication technology that could be applied in aforementioned applications. In this work, the characterization of HBC propagation delay and phase deviation were investigated for the first time. *In-situ* experiments were performed in our lab in the frequency bands:1MHz-200MHz. Four HBC propagation channels, i.e., from left arm to right arm, from left arm to right leg, from right leg to left leg and from left arm to left leg were investigated. Group delay was measured from 13 volunteers, and then the propagation delay and phase deviation were estimated by statistical analysis. The propagation delay values are almost equal for four communication channels in each sub-band:1-100MHz and 100-200MHz. It is concluded that propagation delay is independent with propagation channel. However, from 1MHz to 100MHz the delay is generally longer than that in the frequency band 100-200MHz. i.e., in channel 1, the mean delay is 17.06 ns in frequency band 1-100MHz, while the mean delay is 15.23 ns in frequency band 100-200MHz. Lognormal model is found to be the best fitting distribution for the normalized phase deviation according the maximum likelihood estimation (MLE) and Akaike information criterion (AIC).**

***Keywords*-human body communication (HBC), propagation delay, phase deviation, statistical analysis**

I. INTRODUCTION

The increasing use of real-time healthcare monitoring without constraining the activities of the user demands new designs of portable and wearable biomedical sensors, as well as convenient communication technology for transmitting distributed information from sensors to base in further processing[1]. Majority of body area network (BAN) researches attempted to apply existing wireless communication technologies, such as ultra wideband techniques [2] [3],Bluetooth , Zigbee [4], and other industrial scientific medical (ISM) band-based communication protocols. Recently, a novel near field communication technology-human body communication (HBC) which uses the human body as propagation medium, shows its great potential for BAN applications[5]. Until now, many researches have shown that HBC has several advantages over wireless body area network (WBAN) schemes[6, 7]. The attenuation of body channel is much lower than that of the air channel because most of the signal from the transmitter is confined to the body. Little interference also is an advantage over human body, due to its near-field-coupling operation.

Human body communication channel modeling is important to the understanding of the communication mechanism and to the transceiver and system design. Many studies have been made on the development of the HBC, they were mainly focused on the following issues:

- Electromagnetic field distributions around human body and equivalent circuit models [8-10].
- HBC propagation path gain, fade duration and fade depth with different HBC system design elements, such as: the different electrodes size, the different frequency bands, the channel is dynamic or not[11, 12].

However, the detailed phase characterization of HBC is not well understood. Phase distortion has a great influence for digital communication which would cause inter symbol interference (ISI) and increase bit error ratio (BER). In this work, we have investigated the phase characterization of 1-200 MHz RF signal coupling with human body.

The paper is organized in four sections. Experimental setup is introduced in Section II. Section III describes the results of propagation delay, normalized phase deviation and its fitting distribution. Finally, section IV draws the conclusions.

II. EXPERIMENTAL SETUP

A. Group Delay

Group delay is a measure of the time delay of the amplitude envelopes of a signal through a device under test (DUT), and is a function of frequency for each component. Group delay could be calculated by differentiating the DUT's phase response versus frequency, which is also a useful measure of phase distortion.

The function for group delay T_g is:

$$T_g = -\frac{1}{2\pi}\frac{d\phi(f)}{df} \tag{1}$$

Where $\phi(f)$ is the phase response, f is the frequency of signal. Group delay variation means that signals consisting of multiple frequency components will suffer distortion because these components are not delayed by the same amount of time. In this experiment, the propagation delay is calculated by averaging group delay value at each measured point while

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phase distortion is indicated by the phase deviation from average delay[13].

B. *Experimental Configuration*

In HBC, the frequency band is suggested to be below 100MHz. When the carrier frequency is above 100MHz, human body acts as an antenna and the communication is no longer limited to the human body [14]. In order to better understand the HBC phase characteristics, the frequency band 1-200MHz is set in this paper, and in the following analysis, the frequency band 1-200MHz is divided into two sub bands:1-100MHz and 100-200MHz.

The Agilent E5061A Vector Network Analyzer (VNA) was adopted to measure the group delay. Just as Fig. 1(a) shows, the volunteer stood in front of the VNA and were tied with a pair of electrodes by bandages. Fig. 1(b) shows the different electrode positions placed on the body and the measurement channels. The four HBC propagation channels are from left arm to right arm, from left arm to right leg, from right leg to left leg and from left arm to left leg respectively. Fig. 1(c) illustrates a 4cm×4cm copper electrode which is used to couple the signal to the body.

There were 13 volunteers (8 male and 5 female) selected, they were requested to keep standing still in whole experiment. The body weight of the volunteers varied from 40 to 70 kg, and the body height varied from 150 to 175 cm with the average age being 24 years old.

III. RESULTS

A. *The Results of Propagation Delay*

Fig. 2 shows the mean value of propagation delay and its standard deviation of two measured frequency bands: 1-100MHz and 100-200MHz, Table I illustrates the detailed value.

From 1-100 MHz, the delay values of four channels are basically equal. For example, in four measured channels, channel 2 has the maximum propagation delay 18.37 ns and channel 4 has the minimum propagation delay 16.86 ns. The delay values of channel 1 and channel 3 are 17.06 ns and 17.74 ns respectively. The maximum value of propagation delay is only larger 1.56 ns than the minimum one in four channels.

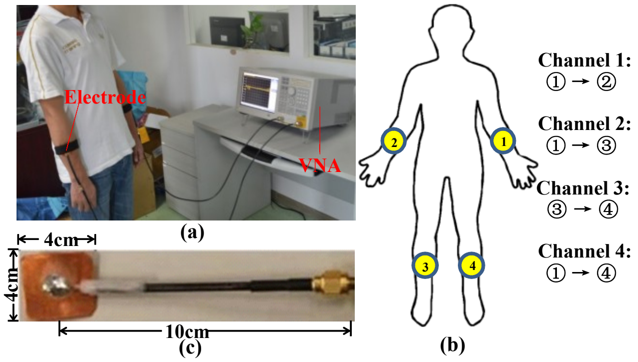

Figure 1. (a) Experimental scenario setup; (b)Measurement configuration, channel 1:left arm to right arm ;channel 2:left arm to left leg; channel 3:left leg to right leg ; channel 4：left arm to right leg;(c) TX and RX signal electrode.

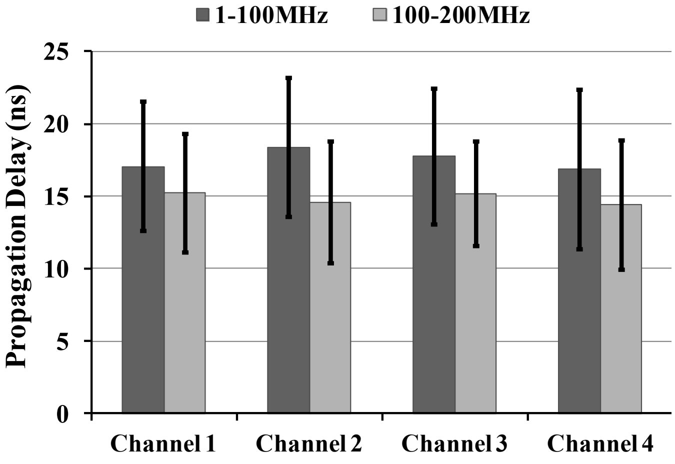

Figure 2. The propagation delay value in the frequency bands: 1-100MHz and 100-200MHz against channel for all subjects. The error bar represents the standard deviation from the mean

TABLE Ⅰ

MEAN DELAY AND STANDARD DEVIATION AT EACH CHANNEL

	Mean(ns)		**Standard Deviation(ns)**	
	1-100MHz	**100-200MHz**	**1-100MHz**	**100-200MHz**
Channel 1	17.06	15.23	4.47	4.09
Channel 2	18.37	14.56	4.79	4.19
Channel 3	17.74	15.14	4.71	3.61
Channel 4	16.86	14.39	5.51	4.45

From 100-200 MHz, the delay values are almost equal. For instance, channel 1 has 15.23 ns propagation delay and channel 3 has 15.14 ns group delay. Channel 2 has 14.56 ns delay value and channel 4 has 14.39 ns propagation delay. It was obvious observed that maximum delay value is larger 0.84 ns than the minimum of four channels in frequency band 100-200MHz.

Based on the analysis above, the delay values are almost equal in the frequency band 100-200MHz in different propagation channels. In frequency band 1-100MHz, the propagation delays in four channels are also equal. It could be concluded that the propagation delay is independent on propagation channel. However, as the Fig. 2 shows, the signal propagation delay values in the frequency band 1-100MHz are greater than these in the frequency band 100-200MHz.

B. *The Result of Phase Distortion*

Linear phase delay is represented by a flat group delay response. The deviation of constant group delay indicates phase distortion of the measured channel at each frequency point. Phase distortion has a great influence for digital communication which would cause inter symbol interference (ISI) and increase bit error ratio (BER). The result of phase distortion provides reference for transceiver designs.

Fig. 3 depicts the normalized distortion of phase against frequency from 1 MHz to 200MHz. It is illustrated that the phase deviation value is lower and varies slightly in the frequency band 100-200MHZ. The lowest value of normalized phase deviation is 2.53 ns at 150 MHz frequency and the largest value is 7.69 ns at 130MHz frequency in the frequency band 100- 200MHz. In the contrary, from 1 MHz to 100MHz, the phase deviation varies largely between 3.41 ns to 12.99 ns.

C. The Probability Density Function of Phase Distortion

To model the phase deviation accurately ,three well-known distribution models for normalized phase deviation of four channel such as：Lognormal, Gamma, Weibull distributions are adopted to find the besting fitting distribution. We have obtained distribution parameters by using the maximum likelihood estimation (MLE) first, then calculate AIC value according Akaike information criterion (AIC) [15].

The AIC is defined as follow:

$$AIC = 2k - 2\ln(L) \tag{2}$$

Where k is the number of parameters in the statistical model, and L is the maximized value of the likelihood function for the estimated model.

Table II summarizes the best fitting distribution functions and the estimated parameters by AIC and MLE, respectively. It is observed that Lognormal is the preferred model which has the minimum AIC value. Fig. 4 indicates the probability density function (PDF) of normalized phase deviation and fitting model. All parameters were calculated on a 95% confidence interval (CI).

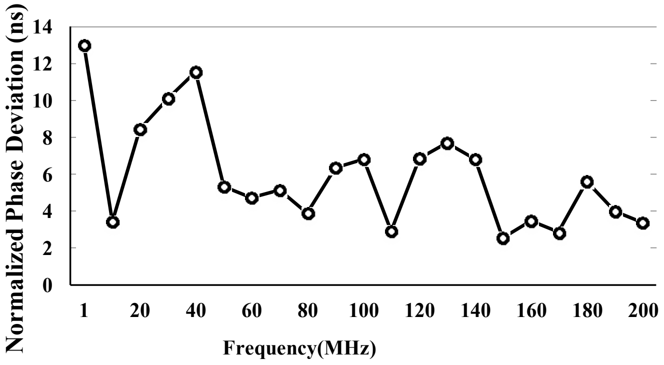

Figure 3. Normalized distortion of phase against frequency

TABLE Ⅱ

STATISTIC PARAMETER AND CANDIDATED MODEL

Model	Log likelihood	AIC
Lognormal	-712.559	1429.118
Gamma	-720.262	1444.524
Weibull	-711.421	1468.788

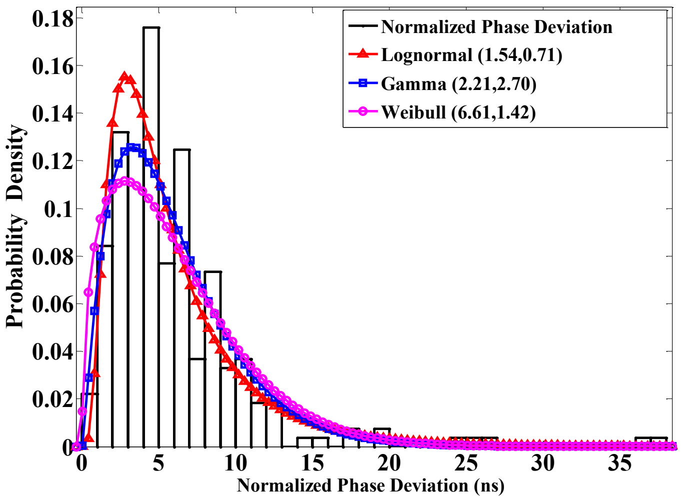

Figure 4. Empirical PDF of the normalized phase deviation for four channels and the fitting model

IV. CONCLUSION

In this paper, the phase characteristic of 1-200MHz RF signal coupling with human body is characterized *in situ*. We acquired group delay in the frequency band 1-200MHz with 13 subjects. The statistical results show that the phase characteristic is quiet different between two measured frequency bands: 1-100MHz and 100-200MHz.

From the general statistics view and considering the possible accidental error, the propagation delay is equal approximately in each frequency sub-band 1-200MHz and 100-200MHz. It could be concluded that the propagation delay is independent on propagation channel in that two sub-bands. However, the signal propagation delay in the frequency band 1-100MHz is generally longer than these in the frequency band 100-200MHz.We infer that the delay difference between two sub-bands may be caused by the different transmission mechanism:

1) Between1-100MHz, most signal is coupled with body and human body is treated as a special kind of transmission medium
2) Between 100-200MHz, the signal mainly couple with the air around body. The human body acts as an antenna and the communication is no longer limited to the human body.

Furthermore, we have given the profile of normalized phase deviation against frequency. The profile implies that the frequency band 100-200MHz has more optimal phase-frequency characteristic because the lower normalized phase deviation in this band. By using the MLE and AIC criterion, Lognormal distribution is found to be the best fitting distribution for the phase deviation.

ACKNOWLEDGMENT

The research supported by National Natural Science Foundation of China (Grant Nos.60932001 and 61072031), Guangdong Innovation Research Team Fund for Low-cost Healthcare Technologies, the National Basic Research (973) Program of China (2010CB732606) ,the “One-hundred Talent” and the “Low-cost Healthcare” Programs of the Chinese Academy of Sciences.

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