A 1 Mb/s – 40 Mb/s Human Body Channel Communication Transceiver

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Abstract – **A high data rate, low-power, and large random jitter tolerance wideband signaling (WBS) transceiver for human body channel communication (BCC) is presented in this paper. Firstly, an investigation of human body channel characteristics from 1MHz to 80MHz is discussed. Then in the transmitter part, the proposed WBS transceiver uses a NRZI encoding scheme to transmit data. At the receiver part, a blind 7X oversampling clock and data recovery (CDR) circuit with the vote mechanism can effectively recover the data which distorted by the frequency drift and random noise from body antenna effects. The proposed WBS transceiver is implemented in a standard performance 90nm CMOS process, and the core area is 0.04 mm^2. The supported data rate of the proposed WBS transceiver ranges from 1Mb/s to 40Mb/s. The power consumption is 1.94mW at 40Mb/s, and the bit energy is 0.0485 nJ/b.**

I. INTRODUCTION

In recent years, the wearable devices or personal healthcare devices for biomedical applications to build up the body area network (BAN) become more and more popular. The personal healthcare devices are grown rapidly due to the aging of population. Traditionally, electronic medical devices such as ECG, EMG, thermometers, and sphygmomanometers are quite large and require wire line connection. Therefore, IEEE 802.15 Task Group 6 established a wireless body area network (WBAN) standard [1] around the human body which uses existing industrial scientific medial (ISM) bands. There are two types for BAN realization. First type, such as radio frequency transmission, electromagnetic wave transmission, and near field electrostatic coupling, they transmit data through wires or air [2],[3]. However, these methods have a relatively low data rate and relatively high power consumption (>10nJ/b). In addition, they are susceptible to the interferences in nearby environment and easily affected by body shadowing effects [4]. Consequently, body channel communication was first proposed in [5].

Human body communication (HBC) uses the human body skin as a transmission medium. As compared to wireless transmission methods, HBC is more stable and has less power attenuation. Furthermore, it is almost insensitive to the motion of the human body in accordance to [6]. The IEEE 802.15.6-compliant wireless BAN transceiver is proposed in [7]. As stated in the standard, the HBC transmitter uses the frequency selective digital transmission (FSDT) modulation and the frequency shift code (FSC) where the data is centered spread at 21MHz with 5.25MHz bandwidth in the frequency domain. The transmitter power must be less than -80dB at 2MHz and -75dB at 400MHz ISM band as compared to the power at 21MHz [7].

In order to transmit data via human body channel, many papers had researched for the characteristics of the human body channel [8]-[10], and then, HBC transceivers with different modulation are designed. In [8], it reveals that body channel in low frequency (< 4MHz) acts as a high pass filter in spite of the transmission distance. With the frequency increases over 10MHz, the frequency response of the body channel is distinctly affected by the transmission distance between TX and RX.

In [11], a transceiver which adopts the direct sequence spread spectrum (DSSS) technique and 3-level pulse-position modulation (3-Level PPM) can achieve a 10Mbps data rate. An OOK modulation is used in [12] to achieve a 2Mbps data rate. A relatively high data rate HBC transceiver [10], [13] which uses double FSK modulation can reach up to 10Mbps. In [9], the wideband signaling without any modulation is adopted to transmit data with a 2Mbps data rate. A dual-band transceiver which can communicate with implanted sensors inside the human body is presented in [14] with the max 5Mbps data rate.

The body antenna effects cause interferences in body channel communication, as discussed in [3],[10],[15],[16]. In consideration of body antenna effect, the human body not only emits the electromagnetic wave to cause electromagnetic interference (EMI) in nearby circuits, but also absorbs radio signals in the environment to decrease the signal-to-interference (SIR) ratio. Both of them lead to an extreme damage in the received signal in RX. The possible interference sources in body resonance frequency range (40 – 400MHz) are discussed in [4]. The measurement environment which has desktops and a lot of equipment will also cause interference [6],[16].

From above discussions, for one wants to design a body channel communication transceiver should concern about (1) constructing a body channel model, (2) solving the interferences from nearby electronic products, (3) amplifying the attenuated signals in different distance between TX and RX, and providing tolerance to random jitter in the CDR circuit, and (4) designing a transceiver with low energy per bit for multimedia or healthcare applications.

The rest of this paper is organized as follows. Section II investigates the signal power attenuation and human body channel characteristics in different transmission distance. Section III describes the proposed WBS transceiver. Section IV shows the experimental results. Finally the conclusion is given in Section V.

II. BODY CHANNEL CHARACTERISTICS

A. Measurement Setup

To measure the HBC characteristics, the ground plane must be considered with special attention [8]. While the return path is established by air-coupling across the body channel transceiver, the grounded instruments, such as the signal generator at TX, do not present in a real situation. Thus, a battery-powered signal generator is used. In addition, the circular single electrode with 1.5 cm diameter in TX and RX is used during the measurement.

The power attenuation at 10cm and 40cm are measured, and the measured frequency ranges from 1MHz to 80MHz. The subject is 172 cm in height and 75kg in weight. HBC characteristics are measured while the subject is sitting. The transmit electrode is

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attached on the human skin, and is connected to the signal generator. Moreover, the receiver electrode is also attached on the human skin, and is connected to an oscilloscope.

B. Measurement Results

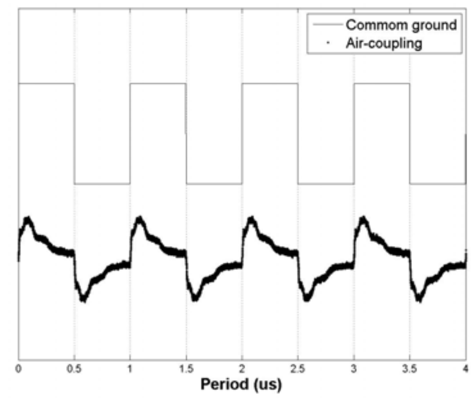

FIGURE 1. MEASURED WAVEFORM WITH/WITHOUT THE RETURN PATH.

The human body channel characteristics are investigated in time domain and frequency domain. The relationship of the power attenuation at different frequencies is presented in the frequency domain. Fig. 1 shows the measured waveform in RX with the transmitter (i.e. signal generator) is battery-powered or plugging into the power outlet. The transmit frequency is at 1MHz. The upper received waveform with common ground looks like the original transmitted square waveform. However, when the return path is formed by air-coupling across the body channel transceiver, the measured waveform becomes quite different from the transmitted square waveform.

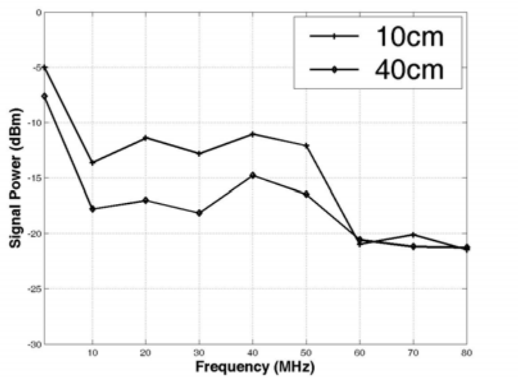

FIGURE 2. MEASURED SIGNAL POWER AT 10/40CM.

Fig. 2 shows the measured signal power in the RX electrode at 10cm and 40cm in frequency domain. The transmitted signal by the signal generator has a 1.0 Vpp. Two curves at 10cm/40cm distance have similar properties such as tendency and nonlinearity. It is worth mentioning that the signal power suddenly decreases close to -15dBm at 10MHz and decreases to -20dBm at 60MHz. Fig. 2 also shows that below 5MHz, the received signal power for 10cm/40cm is higher than -10dBm.

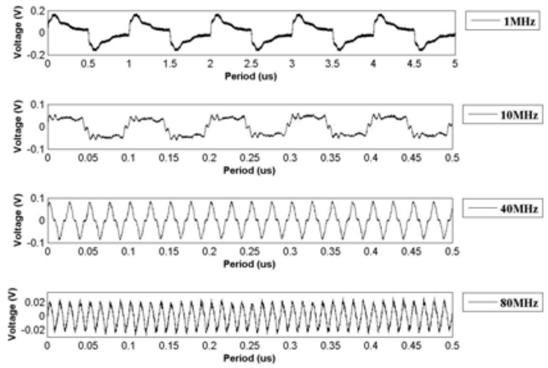

FIGURE 3. RECEIVED WAVEFORM AT DIFFERENT FREQUENCIES IN 10CM.

Fig. 3 shows the time domain waveform at different frequencies in 10cm. The transmitted signal by the signal generator is also 1.0 Vpp square waveform. However, the received waveform looks like a triangle waveform especially when frequencies are over 40MHz.

III. THE PROPOSED WBS TRANSCEIVER

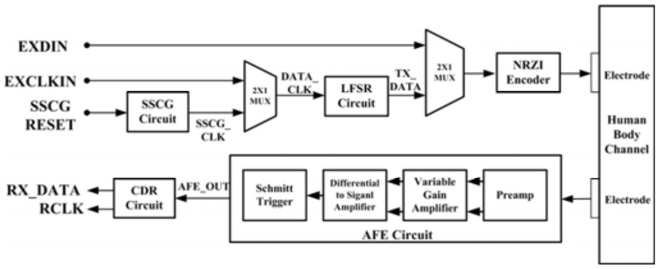

FIGURE 4. THE PROPOSED WBS TRANSCEIVER.

Fig. 4 shows the architecture of the proposed wideband signaling transceiver for body channel communication. The transmitter is composed of a spread spectrum clock generator (SSCG), a linear feedback shift register (LFSR) circuit, and a non-return to zero inverted (NRZI) encoder. The 2-to-1 multiplexers are used to select the external clock input or the external data input. The WBS receiver is composed of an analog frontend (AFE) circuit and an all-digital CDR circuit. The SSCG circuit at the transmitter part is used to reduce the electromagnetic emission with a low hardware cost. The maximum continuous identical digits (CID) are 5 bits in the NRZI encoder after bit stuffing.

In the transmitter part, the SSCG circuit generates the spread spectrum clock signal (SSCG_CLK) to trigger the LFSR circuit for random pattern generation. Subsequently, the TX_DATA is encoded by the NRZI encoder and transmit to the HBC with a driving buffer. In the receiver part, the AFE circuit amplifies the received WBS signals and converts WBS signals back to the original NRZI digital waveforms. Finally, the CDR circuit recovers the data clock (RCLK) and data (RX_DATA) from the output of the AFE circuit (AFE_OUT). The attenuation of the received signal is dependent on the transmission distance between electrodes. In the AFE circuit, we use a variable amplifier (VGA) that provides 5-bit control code, EN0 to EN4, to amplify the wideband pulse signal. The maximum gain of the AFE circuit is 38dB.

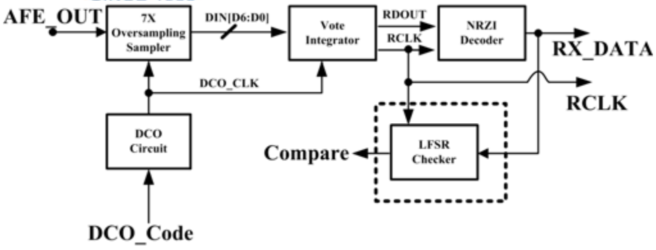

FIGURE 5. THE PROPOSED 7X OVERSAMPLING CDR CIRCUIT.

Fig. 5 shows the architecture in the proposed 7x blind oversampling CDR circuit. The CDR circuit is composed of a digital controlled oscillator (DCO), a 7X oversampling sampler, a vote integrator, a NRZI decoder, and a LFSR checker. The LFSR checker is for error free measurement. It generates random pattern sequences which is exact the same as the LFSR circuit in the transmitter. Therefore, this WBS transceiver can detect whether there are bit errors in the recovered data (RX_DATA) or not. The DCO generates a 280MHz signal to the sampler. The 7X oversampling sampler samples seven data points in one symbol period and outputs the DIN[D6:D0] signals, as shown in Fig. 6. Subsequently, the DIN[D6:D0] signals are sent to the vote integrator. In the vote integrator, it creates an integration window, as indicated in Fig. 6. The voltage integrator counts the number of "1" inside the integration window, and the maximum value of the integrator output is 49=(7×7). As shown in Fig. 7, when the value of the integrator has a rise transition over the threshold line, the RDOUT signal is set to "1". When the value of the integrator has a fall transition through the threshold line, the RDOUT signal is set to "0". The threshold value is set to the half of the maximum value of the integrator output.

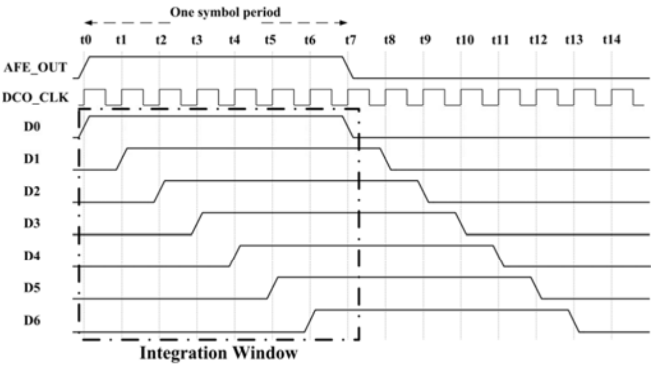

FIGURE 6. INTEGRATION WINDOW OF THE VOTE INTEGRATOR

It takes three clock cycles to calculate the RDOUT signal and the RCLK signal. Whenever there has a rise or fall transition over the threshold line, the data clock position (RCLK_UP and RCLK_DN) is updated by the value of Cnt signal. For example, as shown in Fig. 8, at the first rise transition of the integrator value, the value of Cnt signal is 5. Then, the RCLK_UP and RCLK_DN are updated as 1=((5+3) mod 7) and 3=((5+5) mod 7), respectively. Similarly, at the first fall transition of the integrator value, the value of Cnt signal is 6, and then, the RCLK_UP and RCLK_DN are updated as 2 and 4, respectively. Finally, when the Cnt value is equal to the RCLK_UP value, the data clock (RCLK) is set to "1", and when the Cnt value is equal to the RCLK_DN value, the RCLK signal is set to "0".

The proposed vote integrator can tolerate large frequency drift or random jitter in the AFE_out signal, and therefore, the maximum frequency drift can be up to 24,000 ppm with 2.5ns peak-to-peak jitter at 40Mbps.The NRZI decoder receives the RDOUT signal and the RCLK signal and outputs RX_DATA signal.

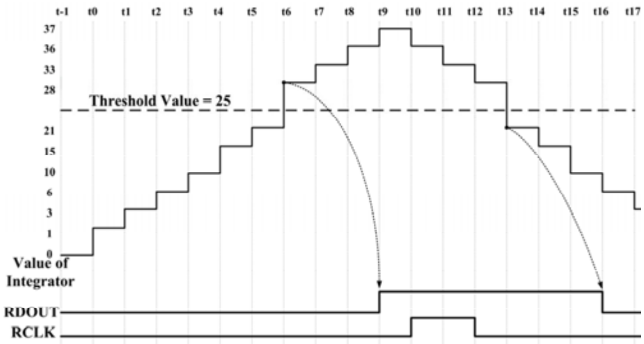

FIGURE 7. CLOCK AND DATA RECOVERY FROM THE VALUE OF THE INTEGRATOR.

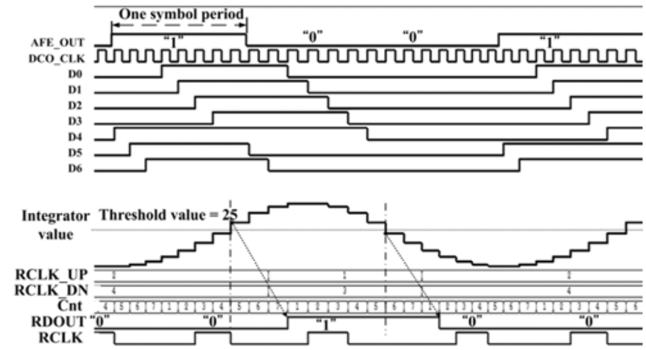

FIGURE 8. SIMULATION WAVEFORM OF THE CDR CIRCUIT.

IV. EXPERIMENTAL RESULTS

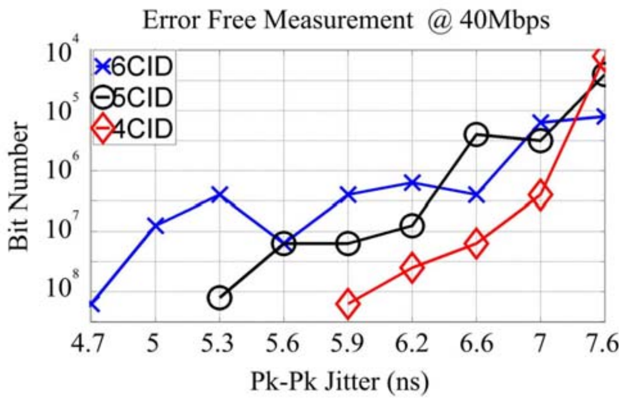

FIGURE 9. ERROR FREE SIMULATION RESULTS

Fig. 9 shows the error-free CDR simulation results at different CID (continuous identified digit) at 40Mbps. As shown in Fig. 9, with a smaller CID, more redundant bits are added in bit stuffing. However, the random jitter tolerance can be improved with a smaller CID. Fig. 10 shows the error-free CDR simulation results with different frequency drift at 5 CID. We define the frequency drift that is the average frequency difference between the clock frequencies generated by the SSCG circuit at the ideal 40MHz clock. The performance of the CDR circuit has a BER < 10^{-8} within the range from -48000 ppm to 42800 ppm at 40Mbps. The test chip is implemented in a standard performance 90nm CMOS process with standard cells and a 1.0V power supply. In addition, the chip core size is $0.04mm^2$, and the power consumption is 1.94mW including the AFE circuit.

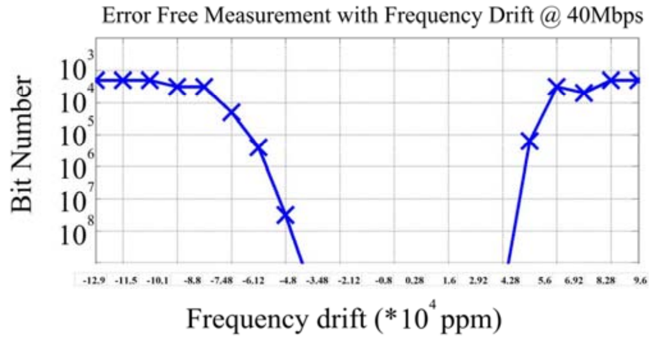

FIGURE 10. ERROR FREE CDR SIMULATION WITH DIFFERENT FREQUENCY DRIFT @5CID

TABLE I. PERFORMANCE COMPARISON

Performance	Proposed	JSSC'09[3]	JSSC'07[9]	JSSC'12[10]	TIE'11[12]	ISCAS'12[17]
Process	90nm	0.18μm	0.25μm	0.18μm	0.18μm	0.13μm
Max Data rate(Mbps)	40	10	2	10	2	0.2
Modulation	WBS	AFH FSK	WBS	Double FSK	OOK	FSK
Supply(V)	1	1	1	1	0.5	0.7
Power Consumption (mW)	1.94@40Mbps	4.6	0.2	2.4	4.535	0.39
Area (mm^2)	0.04(w/o AFE)	2.3	0.85	2.5 x 5	0.121	2
Sensitivity	-36dBm	-65dBm	-6dBm	-66dBm	$<10^{-3}$	-55.2dBm
BER @Max Data rate	$<10^{-8}$	10^{-5} @10Mbps	1.1×10^{-7}	10^{-5} @10Mbps	$<10^{-3}$	N/A
Energy/bit (nJ/b)	0.0485	0.37	2.5	0.24	2.27	0.195

V. CONCLUSION

In this paper, we proposed a low power, low hardware cost, high speed, and large jitter tolerance WBS transceiver for the human body communication. As compared to conventional designs, our HBC transceiver provides the SSCG to achieve the EMI reduction in the transmitter. In addition, the NRZI encoder generates the data with enormous data transitions and let the CDR circuit in the receiver can correctly recover data. The proposed WBS receiver uses the 7X oversampling CDR architecture which adopts the vote mechanism to reduce the effect of jitter accumulation and the AFE duty-cycle distortion.

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