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A Low Power Wearable Transceiver for Human Body Communication

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***Abstract*—This paper reports a low power transceiver designed for wearable medical healthcare system. Based on a novel energy-efficient wideband wireless communication scheme that uses human body as a transmission medium, the transceiver can achieve a maximum 15 Mbps data rate with total receiver sensitivity of -30 dBm. The chip measures only 0.56 mm^2 and was fabricated in the SMIC 0.18um 1P6M RF CMOS process. The RX consumes 5mW and TX dissipates 1mW with delivering power up to 10uW, which is suitable for the body area network short range application. Real-time medical information collecting through the human body is fully simulated. Architecture of the chip together with the detail characterizes from its wireless analog front-end are presented.**

I. INTRODUCTION

The advent of wearable computing technology has spearheaded the transition towards an ubiquitous heath monitoring environment [1-3]. In recent years, the advances of wireless communication technologies have enhance the access and exchange of information in each device node of wearable computing system. One emerging area is human body communication (HBC) for medical, sensing, wearable computing and other portable wireless networking applications [4]. Studies on body-channel-communication have been proposed and some preliminary progress has been achieved [4-6].

Human body communication, the new method to connect medical devices worn around human body, uses human body as an information transmission medium and was firstly introduced by Zimmerman in his master thesis [4]. Since its operation is confined to human body near-field coupling, the HBC can achieve efficiency in per bit energy consumption at nJ/bit level, which is better than most conventional communication methods such as UWB and Bluetooth. Recently, some groups have developed human body communication systems using current and voltage signals transferred via human body [7-9]. However, due to the data transmission rate and reliability issues, the human body communication technology is still primitive.

There are some typical representative communication methods for wearable medical healthcare, Bluetooth [10-11], Zigbee, Wi-Fi and an Ultra Wideband (UWB) standard [12]. Compared to such traditional methods, the HBC solution can fulfill the stringent requirement of high data rate and low power in the body area network application.

This paper presents a novel low power IC that is implemented by using standard 0.18 um CMOS process for a human body communication wireless interface transceiver. This transceiver operates from a power supply of 1.8 V, while only consuming 5 mW in receive (RX) mode and 1 mW in transmit (TX) mode. The design block diagram of presented HBC system is depicted in Fig. 1, which exploits wideband communication scheme to acquire ultra-low energy consumption with high data transmission rate. The proposed transceiver architecture used for HBC retains data transmission rate up to 15 Mbps and the core chip area is 0.56 mm^2. This work shows the potential of achieving the high performance required by wireless transceiver analog front-end for wearable medical system.

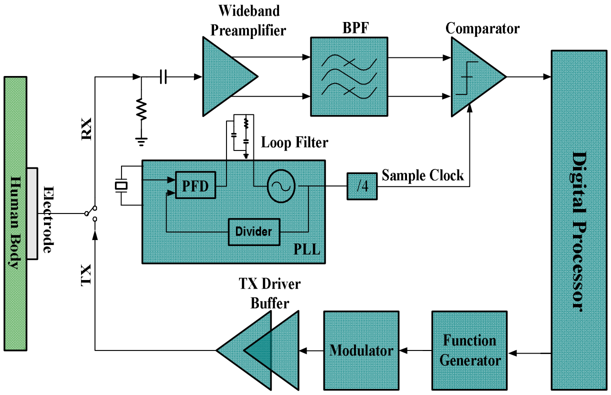

Figure1. Block diagram of the presented transceiver analog front-end

II. ARCITECTURE DESCRIPTION

The block diagram Fig.1 illustrates blocks of the transceiver: a wideband preamplifier, a band pass filter, a comparator, a PLL and a transmitter buffer. For longer battery life, the transmitter must directly send the digital binary data to the human body without any digital/analog modulation. Also considering the power consumption, after the small voltage pulse signal received by the high sensitivity preamplifier, a second order biquard band pass filter removes unwanted interference injected to the receiver. The combination of high sensitivity preamplifier and variable gain band pass filter brings the input signal (HBC data) to a level sufficiently high to overcome offset and noise of the 1-bit analog-to-digital comparator. A 1-bit solution has been used since the carrier

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frequency of sampled signal is basically HBC signal band (HBC signal detected by the preamplifier is as low as -27 dBm, which was detailed in formal study [8]). The comparator samples the analog signal f_0 with a $4f_0$ clock, and then the 1-bit data stream is processed by the baseband with Manchester decode, which recovers the binary data over the body channel. To realize the variable signal bandwidth, we adopt a PLL with digital divider to provide sample frequency for the 1bit comparator.

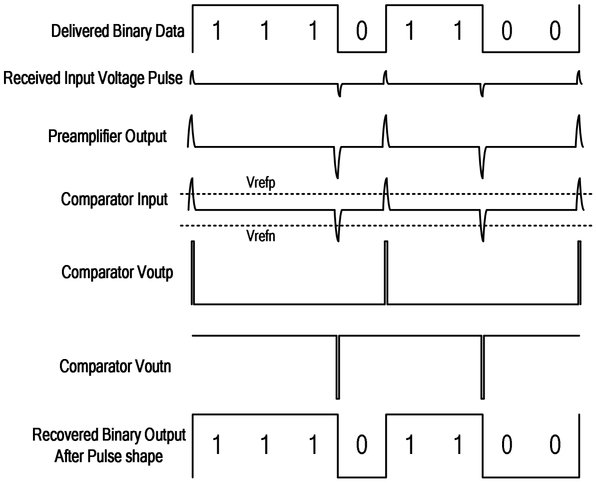


Figure 2.Timing diagrams of the receiver waveforms

Fig. 2 shows the timing diagrams for the binary data signal transferred over the human body and subsequently amplified and recovered by the presented receiver.

III. BUILDING BLOCK

A. Low Powe Preamplifier

For the human body communication, the body behaves as a band pass filter, whose pass band width depends on the distance between the transceiver and receiver electrodes. With a fixed distance of 15cm, the pass bandwidth is 10K-100MHz with single electrode [6]. If binary data is directly applied to the skins, the signal of the channel shows narrow small pulse with no DC offset.

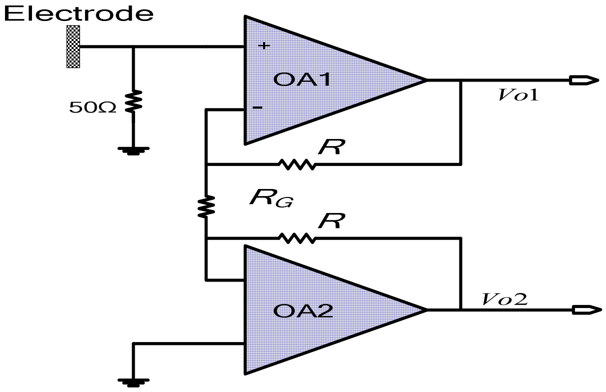


Figure 3. Preamplifier circuits

Fig. 3 shows the preamplifier structure. Operational amplifier OA1 and OA2 were combined to give a differential output and a good common mode rejection ratio (CMRR). Resistors R and R_G set the system gain as

$$A_V = \frac{2R+R_G}{R_G} = 1 + 2\frac{R}{R_G} \tag{1}$$

Here R=30k, R_G=2k were set to achieve a voltage gain of 31V/V. OA1 and OA2 share the same structure and features. In order to realize a good match with the transmission line model of the human body channel, a 50 ohm resistor was added to the input. A unit gain bandwidth of 200MHz was attained by using the feedforward technique.

The opamp (Fig. 4) used in the preamplifier uses a two-stage topology in order to keep sufficiently high gain even with a resistive load.

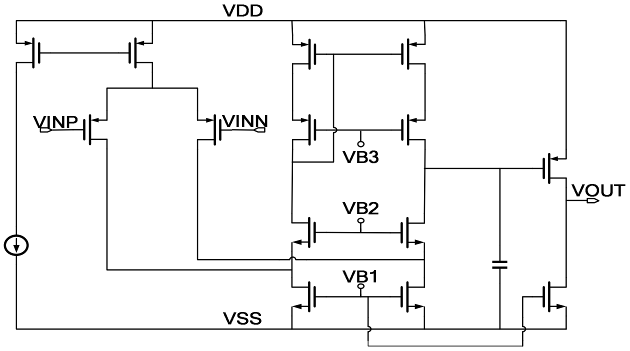
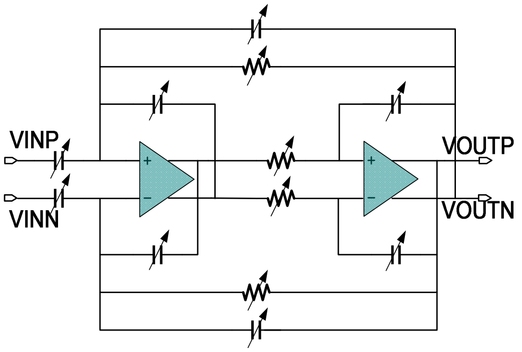


Figure 4. Schematic of folded cascade operational amplifier used in the proposed preamplifier

B. Band pass filter

The band pass filter, shown in Fig. 5, can easily remove unwanted signal. The circuit provides ant-aliasing function before the comparator. Filter bandwidth selection was controlled by the tunable integrator capacitor matrix. Additional gain adjustment was done by adding more control range to the input resistor bank. The central frequency of the filter and the gain were adjusted by 4-bit digital code capacitor and resistor banks.



Figu

Figure 5.Band pass filter topology

C. Comparator and PLL

Traditionally, a multi-bit ADC is needed to deal with signals from filter. Thanks for the wideband preamplifier and novel HBC schemes, a wide dynamic input range S/H comparator can be used to eliminate power consumption instead of ADC. The S/H comparator, which is very similar to flash ADC, avoids the necessity of a variable gain amplifier, or gain switching stage of preamplifier. Instead, as shown in Fig. 6, the comparator's sampling and amplifying stages were employed to expand signal resolution. This enables the comparator to sense the signal level of much less than 1 mV without introducing any troublesome self-oscillation. The S/H comparator digitizes the analog signal to 1-bit digital data. In order to appreciate the noise rejection capability, a PLL utilizing a wide frequency range ring VCO to generate the clock for the S/H comparator is integrated. The PLL operates from 0.5 to 150MHz at 1.8 V power supply. Since the output frequency is the VCO frequency divided by four, a PLL output with 50% duty cycle is guaranteed.

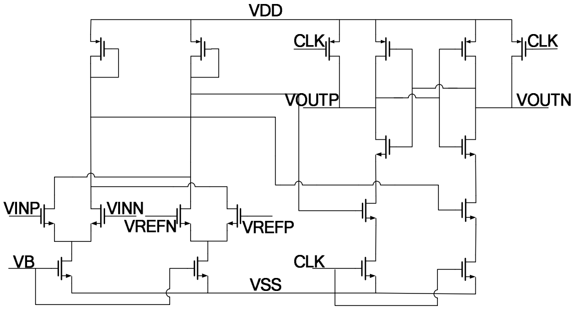


Figure 6. Circuit schematic of the comparator

D. Transmitter and baseband

To achieve high data rate, an inverter-type driver amplifier is utilized. For power saving consideration and body radiation safety, which is defined in FCC regulations [13], the output power of the transmitter is limited to 10 μW to minimize interference with others. Two-stage driver amplifier is adopted for large signal processing and low signal distortion.

Before transmission of the data, we use the Manchester coding encoder in the baseband to encode the data received from the digital processor, in order to generate a signal whose data rate is dependent on the carrier frequency. The data will be encoding in Manchester (a modulating bit "0" is coded "10 ", a modulating bit "1" is coded "01 ") and each bit is transmitted in a fixed clock period. This not only doubles the data rate of the modulated signal but also doubles the bandwidth requirement compared to non return zero (NRZ) coding schemes. Manchester data was chosen for the Bio-channel messages transmission because this coding method has characteristics which yield simplified hardware implementation and thus reduce the power consumption. Moreover, Manchester code ensures frequent line voltage transitions, directly proportional to the clock rate. The DC component of the encoded signal carries no information, allowing the signal to be conveyed by human body which usually does not convey a DC component via electromagnetic field around body. As a result, such method makes clock recovery relatively easy from wide band communication scheme point of view.

IV. RESULT

The layout floor plan of the transceiver is shown in Fig. 7, and the die size is 0.56 mm^2.

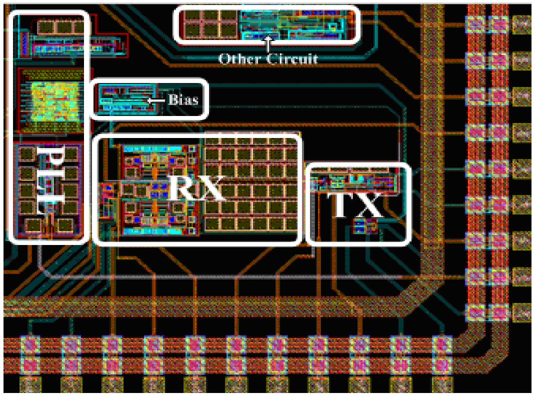


Figure7. Layout floor plan of the transceiver

Fig. 8 shows the open-loop AC gain and phase margin of the opamp used in the wide band preamplifier. It is clear that the opamp has an open-loop AC gain of 80dB while the unity-gain bandwidth reaches 280MHz with an approximate 55 degree phase margin.

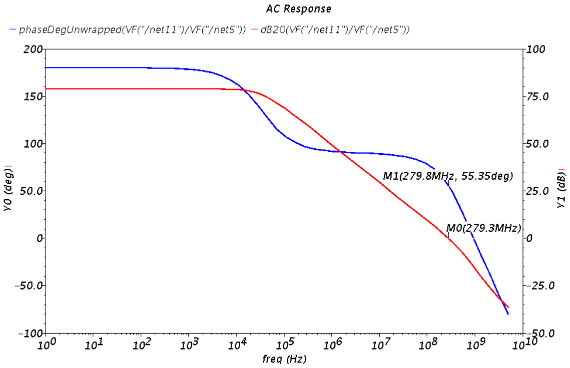


Figure 8. Open-Loop Gain Frequency Response of opamp used in preamplifier

Simulation of the HBC band pass filter, as shown in Fig. 9, demonstrates a ripple of less than 0.4 dB.

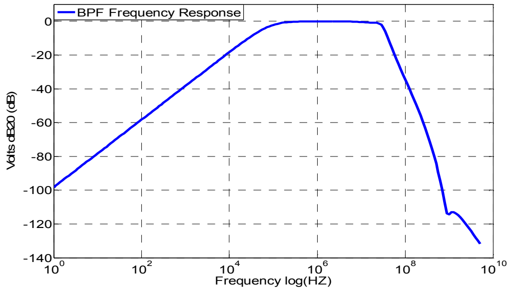


Figure 9. Frequency response of the proposed BPF

The proposed comparator has been simulated by Cadence Spectre®, as depicted in Fig. 10. When the sample clock signal goes down, the differential input signal is compared with the threshold voltage, which is adjusted according to the system requirement. The comparator compares the 230mV$_{pp\text{-}dif}$ differential input with a common-mode voltage of 1V with the threshold voltage at the falling edges of the 1MHz sampling clock.

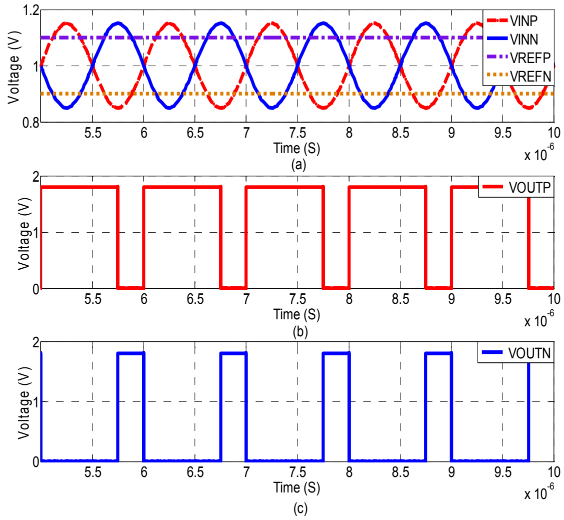


Figure 10. Transient waveforms of the inputs (a) and differential outputs (b) (c) of the dynamic comparator

Table 1 summarizes the specifications of the proposed HBC transceiver and the comparison with a reported chip realization [1]. Our presented chip has higher data rate, higher integration level and lower power consumption per bit.

TABLE I

COMPARISON WITH OTHER HUMAN BODY COMMUNICATION TRANCEIVERS

	Zimmerman' 95 Ref. [4]	***Shinagawa '04 ref.[5]***	***This Work (simulated)***
Carrier frequency	330 KHz	0-10MHz	1-20MHz
Modulation	OOK	NA	NA
Data Rate	2.4 kbps	10 Mbps	15Mbps
Power consumption	400 mW	650 mW	5 mW
Energy/bit	170μJ/b	65 nJ/b	0.33 nJ/b
Supply Voltage	9 V	5 V	1.8 V
Communication Scheme	Narrow band	Electoopic Conversion	Wide band
Range	2m	1.5m	2m

V. CONCLUSION AND FUTURE WORK

A wireless HBC transceiver was implemented in a 0.18um CMOS process with six metals consuming no more than 5mW from a 1.8-V supply. The total sensitivity as a single-chip is -30dBm (f_0=10MHz). With careful design, the transceiver can reach a high RF performance with reasonably low power consumption. The proposed system operated at the 1-15MHz band and it utilizes wideband schemes for uplink and downlink to achieve lower power consumption and reduce circuit implementation complexity. This frequency band is chosen primarily because signal propagation characteristic in a human body below 10 MHz is better than other available frequency bands. Since its operation is confined to human body network, it can acquire high data rate up to 15Mbps and 1-2 m nominal communication range without off chip antenna, which could be very large at lower carrier frequency. The variable bandwidth of the filter and receiver is supported due to the utilizations of low power synthesizers and variable bandwidth band pass filter.

The feasibility of a fully integrated 0.56 mm^2 CMOS HBC transceiver with RF performance suitable for short range wearable medical healthcare applications has been reported. The next step is the single-chip integration of the wireless biosensor together with a digital baseband processor.

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