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POWER LINE COMMUNICATION TRANSCEIVER CIRCUIT ON CONDUCTIVE FABRIC FOR WEARABLE COMPUTING

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Abstract

This paper describes the Power Line Communication on the wear using conductive fabric for wearable computing. Both the powering and the communication signals are on the pair of the conductive fabrics, and the communication is carried out by small-swing signal on DC line with inductive and capacitive coupling with the power source. The preliminary communication module was developed and the communication on the conductive wear was confirmed. Next, we also designed the components of transceiver LSI, transmitter buffer and comparator, using 0.18um standard CMOS technology for single-chip integration of transceiver LSI. The measurement results indicated the proper performance for transceiver LSI implementation.

1. Introduction

Nowadays, the wearable computing, the computing paradigm of using attached computers on human's body, attracts attention on numerous applications for human-assist systems, such as health condition monitoring or user's behavior support [1-4].

There are two important and intrinsic problems in wearable computing. One is the "cabling problem". Power supply method to the computers and the devices distributed on the user's body, and the other is the communication method among

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devices with keeping the user free from complicated cables. Some researches are reported to solve this cabling problem by embedding the cable in the cloth [5]. However, this method prevents the user to re-arrange the positions of the devices, which often occurs on practical usages. The other approaches for this problem are to employ wireless communication [6], which keeps the user free from cabling problem. However, the wireless communication method has the problem of electromagnetic radiation exerts on the human body or the interference with other systems, and further, the battery maintenance problem for all the devices exists, which is critical in practical applications; "battery problem." Although the human body communication [7-8] is also a solution for the cable problems, the "battery problem" still exists.

This paper describes the network system, "TextileNet" that solves the both problems of "cabling" and "battery" problems by using the pair of conductive fabrics in the wear as the two-dimensional "wire" on the user's body. The pair of the conductive fabric is located on the both sides of the wear, surface side and back side, forms the pair of the electric conductors for the devices on the wear. All the devices are physically and electrically connected to the pair of the conductive fabric. This system has the following features:

- Each device does not have the battery.
- Each device can be arranged on the cloth freely.
- Signal and power are superimposed on the cloth.

2. Conductive Cloth

Figure 1(b) shows the developed experimental wear (jacket) used for TextileNet system. The surface and back of this jacket is made of conductive fabrics, which is the commercial product for electromagnetic radiation shield cloth as shown in Figure 1(a). The non-conductive fabric is placed between both sides as an electric insulator. The surface resistance of this fabric is approximately $0.5\Omega/\text{sq}$. Tailoring of this fabric is also as easy as the conventional clothes and it is possible to wash it.

The electrical characteristic of the wear of conductive fabrics can be modeled as a low pass filter that is composed of the surface resistance and the capacitor between the pair of clothes [9]. The surface resistance and the capacitance depend on the operation condition; with sweat, bended and so on, and they decide the cut-off frequency as the transmission line. The lowest cut-off frequency in worst cases was measured between both sleeves of the cloth; the resistance of 50Ω and the capacitance of 4.8nF [9].

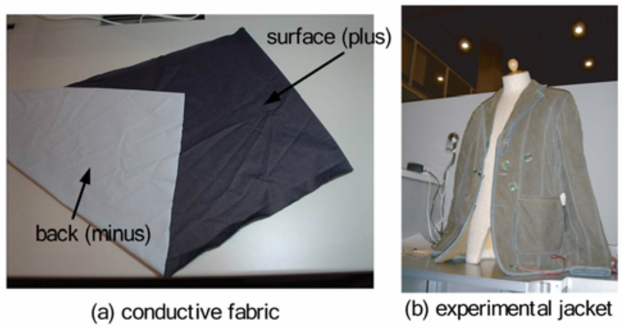

Figure 1. Conductive and the developed wear (jacket) using conductive fabric.

3. TextileNet

TextileNet system is composed of one power supply module and the communication modules, and all the modules are connected to the pair of conductive fabric as shown in Figure 2. Power supply module supplies power on the conductive wear. The communication modules are supplied power through the conductive fabric and the communication among the communication modules is performed by using the small-swing signal on the conductive fabrics.

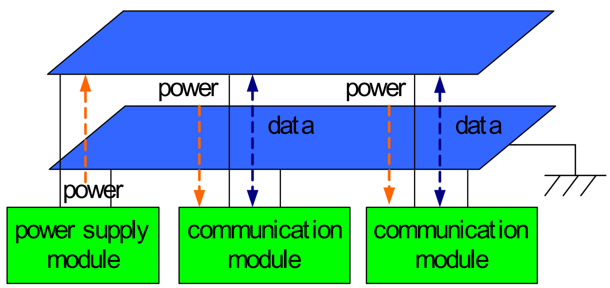

Figure 2. Configuration of TextileNet.

Table 1 shows the target specifications of developed TextileNet system. The higher supply voltage for power supply module reduces the current flow, and thus the voltage drop on the conductive fabric from the power supply module to the communication module, while the supply voltage must be kept as low as to keep the safety operation for the user. The supply voltage is set as 15V to satisfy both requirements. The communication speed will be restricted by the cut-off frequency of the conducive wear, and is set as 250kbps.

Table 1. Specification of TextileNet

Supply voltage of power supply module	15[V]
Communication speed	250[kbps]
Carrier frequency	250[kHz]

Figure 3 shows the circuit configuration of TextileNet. The communication modules are required the power supplied as well as transmitting and receiving communication signals through the conductive fabric. The communication module is composed of three parts. The power is supplied with inductive coupling with the conductive fabric in order to cut the signal swing. The transmission and receive parts are connected to the conductive fabrics with the capacitive fabric to separate small-swing signals from the power supply voltage.

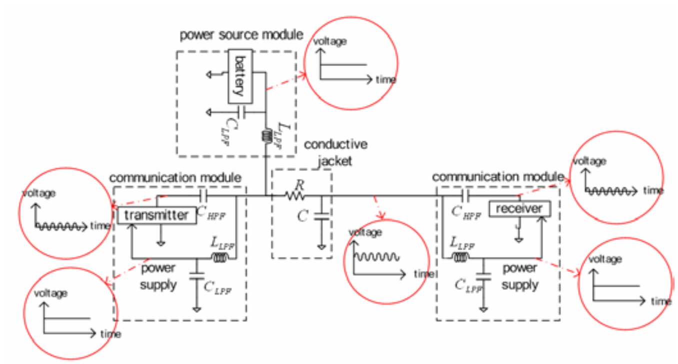

Figure 3. Circuit configuration of TextileNet.

The number of the modules is restricted by the voltage drop on the conductive fabric from the power supply voltage to the communication modules to keep enough voltage for the operation of the communication modules.

4. Design of Communication Module

The communication module was designed based on the specifications in Table 1. The communication module consists of the DC-to-DC converter for power supply, a digital-to-analog converter (DAC) with discrete ladder configuration and buffer of LMH6639 for transmitter, an analog-to-digital converter (ADC) of ADC9283 for receiver, and digital controller to modulation/demodulation of BPSK signal. A switching regulator of MAX1837 is used for DC-to-DC converter to generate power supply voltage of 3.3V. Sampling rate of analog-digital converter is set as 2MHz, x8 over sampling against the carrier frequency of 250kHz. The digital controller is implemented by using the FPGA of Xilinx XC3S200. The effective number of bits used for operation of DAC and ADC are 4bit and 8bit, respectively.

We carried out the bit error rate (BER) measurements for the developed preliminary TextileNet system. The BER against the parameter of signal swing voltage and the inductance of the coupling inductor was measured. The pseudorandom PN9 bit sequence of 8Mbits from signal generator was modulated in BPSK and transmitted to the conductive fabric. The signal through the conductive fabrics was received at receiver side, and the demodulated. BER was defined the bit error ratio between transmitted and the received signals. The power supply module and two communication modules are located and connected to the conductive wear as shown in Figure 4. The supply module is located at the waist surroundings because of a little motion artifacts. The communication modules are located at both sleeves, to implement the worst-case cut-off frequency of conductive fabrics.

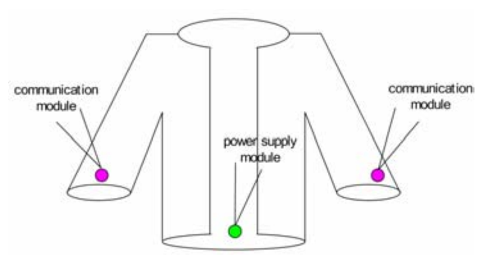

Figure 4. Locations of the modules.

Figure 5 shows the measured BER against the signal swing voltage, with coupling inductance of 1.65[mH]. The BER degradation is expected to due to switching noise generated from switching regulator.

Figure 6 shows the measured BER against the inductance of the coupling inductor in the power supply module, L_{LPF} for voltage swings of 400mV, 550mV and 700mV. The BER can be kept low enough for the larger inductance of 1[mH]. The reduced inductance of the coupling inductor causes the reduced signal swing voltage, which result in the increased BER.

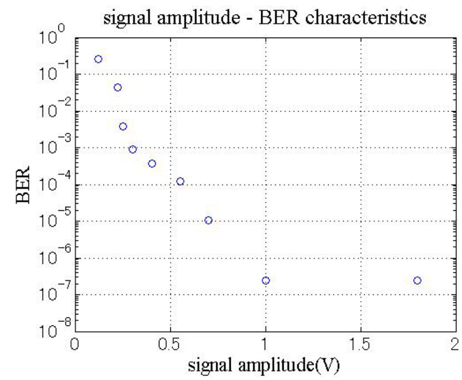

Figure 5. BER against the signal swing voltage.

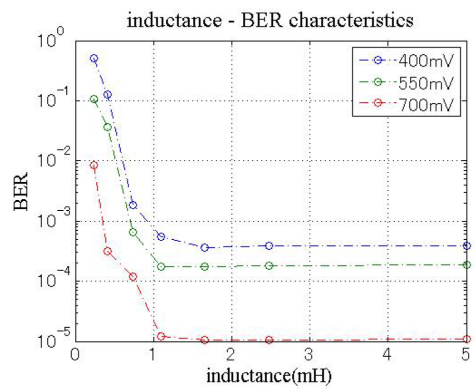

Figure 6. BER against the coupling inductance.

The number of bits for DAC and ADC are also evaluated, and the results show that the minimum required number of bits for DAC and ADC are 1bit and 1bit, respectively. This result indicates that the comparator can be used as ADC.

5. LSI Implementation of the Communication Module

The component circuit of the communication module was designed with 0.18um standard CMOS technology for implementation of single-chip TextileNet transceiver. In this paper, we describe the design of the transmission buffer and the comparator for the receiver, which are the key component circuits for single-chip transceiver. The specifications of the transmitter buffer and the comparator are shown in Table 2 and Table 3, respectively, that are determined from the experimental results with preliminary TextileNet system.

Figure 7 shows the designed circuit of the transmitter buffer. The basic configuration of the transmitter buffer is an operational amplifier, with the high current drive capability for large capacitive loads (~5nF) of the conductive fabrics, with the optimized, MOSFET size at the output stage.

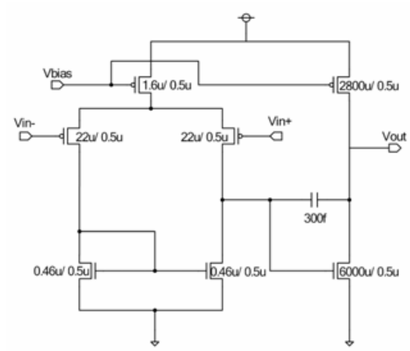

Figure 7. Designed transmitter buffer.

Figure 8 shows the designed comparator. Double-tail latch-type configuration [10] is employed to achieve the short setup+hold time and the low sense voltage.

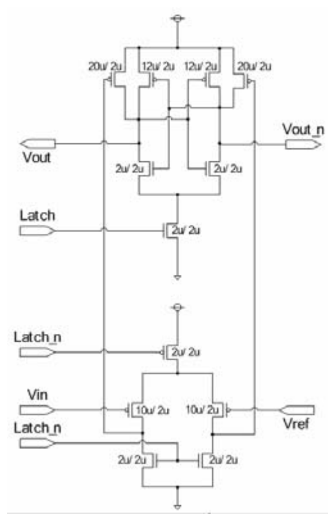

Figure 8. Designed comparator.

Figure 9 shows the microphotograph of the fabricated chip. The die size is 2.5[mm] square. This LSI chip has been fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC), the University of Tokyo in collaboration with Rohm Corporation and Toppan Printing Corporation.

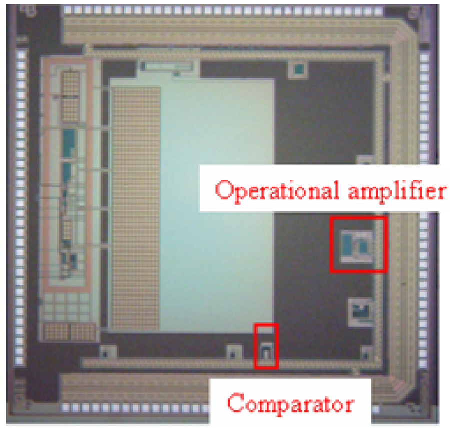

Figure 9. Microphotograph of the fabricated chip.

6. Evaluation Result

The circuits in the fabricated LSI chip were evaluated.

Figure 10 shows the AC characteristics of the open-loop gain of the transmitter buffer. Also, the other measured characteristics are summarized in Table 2. The target specifications for the transmitter buffer have been achieved.

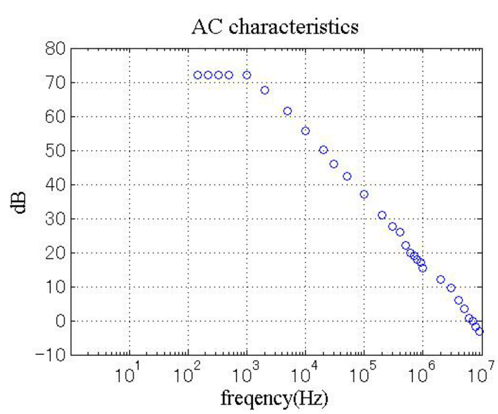

Figure 10. Measured AC characteristics of the transmitter buffer.

Table 2. Target and measured specifications of the transmitter buffer

	Target	Measurement
Vdd	1.8V	1.8V
Open loop gain	-	72dB
Unity gain frequency	-	7MHz
Phase margin	60°	90°
Gain @250kHz	0dB	29dB
Slew rate standing up	2V/us	3.6V/us
Slew rate fall	2V/us	6V/us

The "delay" in the comparator has been defined as the time from rising edge at 50% of latch signal to falling edge at 50% of output voltage, Vout as shown in Figure 11. Figure 12 shows the measurement delay of the comparator against the difference of the input voltages, Vin and Vref. The delay of under 250[ns], which required for the sampling rate of 2MHz, can be achieved for the voltage difference of 10[mV]. The measured results are summarized in Table 3, which has achieved the requirements for implementing the receiver.

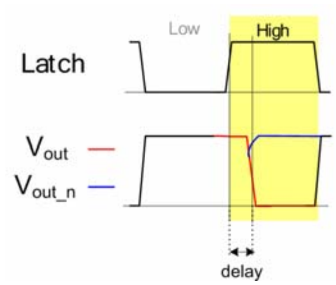

Figure 11. Definition of the comparator delay (for the case of larger Vref than Vin).

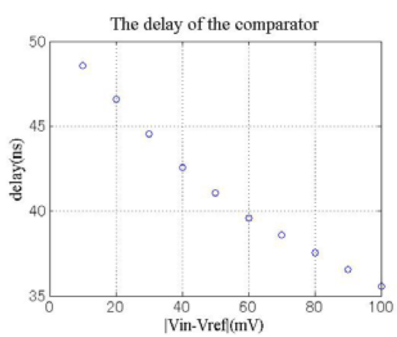

Figure 12. Measured delay of the comparator against the input voltage difference.

Table 3. Target and measured specifications of the comparator

	Target	Measurement
Supply voltage	1.8V	1.8V
Sampling frequency	2MHz	10MHz
Minimum sense voltage	10mV	7mV

7. Conclusion

In this paper, we proposed the network system for wearable computing, TextileNet, that solves both the powering and cabling problems by using the conductive fabrics for the wear. The preliminary TextileNet system was developed to specify the system parameters. We also described the design and the measurement results of the key circuit components of the TextileNet transceiver, the transmitter buffer and the comparator, in CMOS LSI implementation. Since other circuit components for TextileNet transceiver can be implemented by using the conventional technologies, the single chip TextileNet transceiver is expected to be realized, which will be reported in our future works.

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