Intra-body Communication Modem on FPGA with AHB-Lite Bus Interface

Sang Don Kim and Seung Eun Lee*
Department of Electronic Engineering, Seoul National University of Science and Technology,
172 Gongreung-2-dong, Nowon-gu, Seoul-si, Korea

Abstract

The intra-body communication can be used to establish a secure communication channel, providing the simplicity and the security. Although the communication distance is limited within a body-area, it is useful on the construction of personal area network. In this paper, we introduce our prototype intra-body communication modem implemented on an FPGA, along with ARM Cortex M0 processor. Experimental results demonstrate the feasibility of our intra-body communication modem for establishing a secure network.

Key Words: Intra-body Communication, PAN (Personal Area Network), FPGA, System-on-Chip, Wearable Devices, AMBA

1. Introduction

The human body is conductive because it includes water and electrolytes. The ECG is an example of intra-body conductivity, a process in which electrical signals are conducted along the body. Therefore, external electrical signals can be transmitted through the human body, thus establishing a communication channel. The weaker biological signals can be ignored or filtered. Intra-body communication is emerging as an effective communication method that possesses the security and simplicity of wireless communication. It is well known that intra-body communication is not dangerous because the amount of electric current passing through the human body is very small.

In this paper, we introduce our prototype intra-body communication modem. First, we perform experiment to decide a range of frequencies that can pass through the human body, and describe how to implement a communication module using digital hardware. The intra-body communication modem supports the AMBA AHB-Lite bus, interfacing with an ARM Cortex-M0 processor. The experimental results demonstrate the feasibility of our intra-body communication modem for establishing a secure network.

The rest of this paper is organized as follows. We briefly introduce related works. Section 3 describes the body channel characterization and implementation details of the intra-body communication modem. Section 4 shows our experimental results, demonstrating the feasibility of our proposal. Finally, we conclude in section 5 by proposing the usage model of our system.

2. Related Works

The human body has an electrical conductivity because it includes water and electrolytes. The ECG (a.k.a. EKG) is an example of intra body conductivity. ECG is generated by the heart and can be measured outside of the human body. Furthermore, external electrical signal can be transmitted through the human body. T. G. Zimmermann introduced the intra body communication. He transferred a business card data via a handshake. This intra body communication module is attached in shoes, and it supports 9600 bps of baud rate [1]. In [2], Bae et al. proposed body-channel communication using the surface of the human body. It consists of transmitter and receiver, where the human body surface is used for com-
munication channel supporting 100 kHz to 100 MHz with 50% duty cycle sine wave. In [3], Park et al. proposed frequency selective baseband transmission for intra body communication and demonstrated their system by transmitting the movie and music stream. However, unmodulated digital signal is hardly transmitted through the human body because it has the impedance and biometric noise. In order to transfer the signal acceptably, a signal modulation is required. The studies on human body characteristic and proper modulation scheme are conducted [4,5]. Zhang et al. implemented the FSK-based system and transferred the data through the human body from transmitter to receiver using the LabVIEW [6]. We had presented our prototype intra body communication system, which uses the human body as a conducting wire and establishes a 9600 bps of communication channel [7]. This is an extension of [7]. Compared with the paper, new materials in this paper includes: experimental results for body channel characterization, detailed description of the modem architecture, implementation with the prototype along with ARM Cortex M0 processor.

3. Intra-body Communication

The human body has a restricted frequency bandwidth in which it can transmit a signal, although the exact response is different for each individual. There are related studies that model the human body as an electrical element. However, these models cannot accurately represent the body. Therefore, we use an experimental frequency decision method to determine a suitable bandwidth for intra-body communication. Figure 1 shows the experimental environment. The function generator produces square waves over a wide range of frequencies. The measured signal through the human body is attenuated and has a constant time. The attenuated signal should be in the effective region, satisfying the threshold voltage of the digital level. This experiment was repeated for each individual to decide on a representative usable frequency bandwidth. Figure 2 illustrates the waveform recorded by the oscilloscope and the peak-to-peak voltage of the attenuated signals. The voltage swing is smaller at higher frequencies. On the basis of this result, signals under 2.5
MHz can be used for signal modulation (see Figure 3). The signals to be transmitted must be modulated properly at the transmitter side for effective communication. A received signal from the human body is demodulated and data is reconstructed at the receiver module. The modulation such as ASK (amplitude shift keying), PSK (phase shift keying), or FSK (frequency shift keying) can be applied to the data. ASK is unsuitable for intra-body communication because the distorted amplitude modulated signal is not consistent in amplitude. PSK uses more complex hardware than FSK and may result in errors when the transmitted signal is distorted. On the other hand, the frequencies used in FSK are almost constant (although the signals were distorted); thus, we adopt FSK modulation in our intra-body connector.

The human body can be treated as a single wire and can therefore be used for serial communication. The data must be modulated at the chosen frequency by a modulator. The proposed modulator includes a counter, completing FSK modulation (see Figure 4). This modulator generates pre-defined frequencies on the basis of serialized data. Next, the modulated signal is transmitted through the human body. The demodulator on the receiver side checks the frequency and reconstructs the serial data. The frequency measuring operation requires 2 cycles. The signal period is measured during the first cycle using the internal counter. The serial data are reconstructed during the second cycle on the basis of the period. The serialized data are received using serial communication methods.

The proposed system is implemented on an FPGA (EP3C25Q240, Altera). An ARM Cortex-M0 processor is used to control all subsystems using the AMBA bus interface (see Figure 5). The AHB-Lite bus is controlled by the Cortex-M0; it has a 4 GB address range. In the transmitter module, the intra-body communication modem receives parallel data and serializes that data. The numerical counter and clock generator complete the FSK modulation for intra-body communication. Once the modulated signal has been transmitted through the body, the demodulator in the receiver module checks the frequency of the received signal and reconstructs the data. To improve the accuracy of communication, we include parity checking in the system.

The intra body communication module consists of an AHB interface unit, a SerDes (serializer and deserializer), and a MODEM (modulator and demodulator). The AHB interface is an on-chip communication fabric used for interfacing with embedded microcontrollers. The integrated ARM processor controls the intra body communication module via the AHB interface. The SerDes consists of a serializer and a deserializer. The serializer uses a FIFO to improve system performance, and it converts the data to serial form. The serialized data is modulated to the transmission signal used for intra body communication. The MODEM performs the signal modulation us-

![Figure 3. Conductivity ratio for different subjects.](image)

![Figure 4. Block diagram of intra-body communication modem.](image)

![Figure 5. Block diagram of intra-body communication system.](image)
ing the data: the serial data is modulated with predefined frequencies so as to use the human body as its conduction wire. The MODEM also demodulates any received signal with predefined frequencies at the signal receiver. Demodulated data is transmitted to the processor through the deserializer in the SerDes and the AHB interface unit.

4. Experimental Results

Figure 6 illustrates the experimental environment used to verify our method of intra-body communication. To verify the whole system, the intra-body communication module requires a serialization protocol. We selected the RS-232C protocol for serial communication. The data contain a start bit and a stop bit. The bytes of data are transmitted through the human body at a speed of 115200 bps. The electric signals, which are modulated at the transmitter, are forwarded to the receiver through the human body. The restored data can be checked to ensure that it is identical to the transmitted data. Finally, the transmitter transmitted an audio data through human body and the receiver played the received audio data on the speaker, successfully. The amount of electric current passing through human body varied $2.6 \times 10^{-9}$ A to $11.3 \times 10^{-9}$ A (7.81 $\mu$A in average). The experimental results demonstrate the feasibility of our proposal to the secure communication channel for wearable devices.

5. Conclusions

In this paper, we introduced a intra-body communication system that uses FSK modulation. A suitable frequency bandwidth for conduction along the human body was selected by experiment. Our results showed that digital data were successfully transmitted to the receiver through the human body. Experimental results demonstrated the feasibility of our proposal, namely, that intra-body communication provides secure and simple wireless communication for PAN. Intra-body communication is simpler and more secure than conventional wired and wireless communication.

In applications such as financial services, where higher security is required, conventional wireless communication is at risk of wiretapping. However, intra-body communication can reduce this risk, in addition to being able to prevent other possible attacks. Safety can be further improved by applying an encryption method. We expect that intra-body communication will be applied in various fields because of its simplicity and safety.

References


*Manuscript Received: May 3, 2014
Accepted: Sep. 12, 2015*