Health Monitoring System Based on Intra-Body Communication

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Abstract. This paper presents a model of a Body Area Network (BAN) health monitoring system based on Intra-Body Communication (IBC). A health monitoring system is a system that monitors the health signal of the human such as heartbeats, heart rates, and respiratory rates. It is a comprehensive monitoring system that beneficial to the human healthcare. IBC was originally proposed by T.G. Zimmerman[1]. The concept of IBC is to utilize the human body as a medium for transmission. The signals will pass through the human body using induced electric near field which is exists at around 21 MHz frequency and reduce the power consumption for a longer battery lifetime.

1. Introduction
This project presents a model of a Body Area Network (BAN) health monitoring system based on Intra-Body Communication (IBC). A health monitoring system is a system that monitors the health signal of the human such as heartbeats, heart rates, and respiratory rates. It is a comprehensive monitoring system that beneficial to the human healthcare. IBC was originally proposed by T.G. Zimmerman[1]. The concept of IBC is to utilize the human body as a medium for transmission. The signals will pass through the human body using induced electric near field which is exists at around 21 MHz frequency and reduce the power consumption for a longer battery lifetime.
the human body. One of the main advantages of using IBC is that electromagnetic noise and interference have a little influence on the transmissions of the signal because the signals do not leak through the skin of the human body [2].

The main objective of the project is to design IBC modules that can operate at the 21 MHz. The first objective is to design the IBC’s transmitter and receiver modules using the of – the – shelf components. Next objectives are to model and implement the digital parts of the transmitter and receiver modules on the Altera’s FPGA board.

IBC is suitable solution for MBANs in a mobile health care system because of the low power requirement of the IBC itself [3]. IBC has the characteristics of high transmission quality with high data rates, easy network access and no communication bandwidth problem which has made the IBC are better compared to the near field electromagnetic waves [4]. It is also suitable for the mobile terminals and the other terminals embedded in environments.

The main problem of IBC is to use a lower frequency such as 21 MHz in order to transmit the signal through the human body and display it in a proper waveform. It is because the frequency of 21 MHz is the centre of the operating frequency band of IBC with scalable data rates of 164 – 1312.5 kB/s according to the IEEE 802.15.6 standard of Wireless Body Area Network (WBAN) [5]. The challenge of this project is to design a hardware setup, which are the transmitter and the receiver of IBC that can satisfy the IEEE 802.15.6 standard of WBAN.

![Image](image_url)

**Figure 1.** Example of Measurement setup for IBC [6].

IBC is categorized in a wireless communication field. However, IBC has several benefits over traditional wireless schemes. Some of the advantages are as follows: First, the use of cables is no longer needed. Second, the transmission of the signal area easily to conduct at will since the transmission of the signal can be formed only when the human body is touching the terminal. Third, the electromagnetic noise and interference have a little influence on the transmissions of the signal because the signal does not leak through the skin of the human body. Fourth, the human body can use the communication channel exclusively, which make the large-throughput data communication is highly possible [7].

The health monitoring system consists of two main modules which are the transmitter module and the receiver module. The sensor will detect the health signal such heart beats, respiratory rates or heart sound. After that, the signal will be transmitted via the transmitter and the balun. The human body will become the transmission medium of the signal as the signal will be travelled from the balun of transmitter to the balun of receiver. The external device such as oscilloscope will be displaying the signal that has been received from the receiver.

It is anticipated that the success of this project will help in the advancement of wireless biomedical and wireless sensor network market which encompasses every layer of the society.

The benefit will include in wearable system, health-coming monitoring devices and even sport performance analysis just to name a few. Therefore, it is reasonable to pursue designing such device due to its potential contribution to the community.
2. Design and Methodology
There are 3 different designs sections that need to be focused concurrently in this IBC project. The first section is to design the whole system using off the shelf components. The second and third sections will focus on designing the digital block in the transmitter and receiver modules using the FPGA Altera board. It also includes interfacing with the FPGA on-board modules and the discrete components. The design task for each section has been equally divided and simultaneously executed among the team.

2.1. Off-the-shelf component transmitter and receiver module
The main idea of this project is design a transmitter and receiver module for intra-body communication. In each module consists of some sub-modules such as analog-digital converter (ADC), parallel load 8-bit shift register, memory, BFSK modulator, and BFSK demodulator. All sub-modules are combined and implemented in this project to perform intra-body communication.

2.1.1. Analog-digital converter (ADC). The input signal read from the human body is in analog waveform. The ADC function is to convert the analog signal into digital signal. The input signal read at human body by the sensor is in analog signal. In order to make it digital signal ADC is used convert the signal. The output ADC reading can be calculated using this formula [8]:

\[
\frac{\text{Resolution of the ADC}}{\text{System Voltage}} = \frac{\text{ADC reading}}{\text{Analog Voltage Measured}}
\]

2.1.2. Parallel load 8-bit shift register. The output ADC produced 8 bit simultaneously which mean all 8 bit are data transmitted. 74LS165 IC used to shifted out all 8 bit parallel data into series which is compatible to the BFSK modulator.

2.1.3. Memory. The data shifted from the shift register stored inside memory so that the data not lose for every clock cycle.

2.1.4. BFSK modulator. The data from memory is sent to BFSK modulator. The data is manipulated base on its setting which is high input it produce 23.9MHz and low input it produce 21.3MHz.

![Block diagram transmitter module using off-the-shelf component.](image)

2.1.5. BFSK demodulator. The data produced by modulator been demodulated using BFSK demodulator. Before that the signal been amplified because the output signal from modulator is small and in order BFSK demodulator to recognize the data transmitted.
2.2. Digital Block of the Transmitter Module
The FPGA Altera board has been used for development of digital block in the transmitter modules of the IBC. The Quartus II software has been used to design the digital block for the transmitter modules. The Verilog HDL language has been implemented in order to develop the digital block in the transmitter modules of the IBC. The main block modules have a several separated component modules that operates a specific task for the transmission purpose.

The component modules that had been used to develop the transmitter modules are sensor, Phase Lock Loop (PLL), analog to digital converter (ADC), modulator, amplifier and patches. The sensor is used to sense or detect the pulse of the human body. The function of the PLL module is to lock the clock frequency to the specific value. The function of the ADC module is to convert the analog signal from the output sensor to a digital signal that can be read by the modulator. The function of modulator module is to modulate the frequency of the signal from the ADC. The modulation method that has been implemented in order to modulate the signal is BFSK modulation method. The function of the amplifier inside the transmitter modules is to amplify the power of the signal. The patches for the transmitter will be acted as the antenna to transmit the signal. The result of the transmission can be observed using the Oscilloscope.

Figure 4. Block diagram of transmitter modules of a health monitoring system based on IBC.

2.3. Digital Block of the Receiver Module
There are several components modules that will be used to design the receiver modules like the binary frequency shift keying (BFSK) demodulator, amplifier and patches or balun. The function of BFSK demodulator is to demodulate the receiving signal from the patches into the data result such as the data of the human heart beats. The receiving signal is a signal that was transmitted through the human body via the transmitter modules of the IBC. The function of the amplifier inside the receiver modules is to amplify the power of the signal. The patches or balun for receiver will be acted as the antenna to receive the signal that was transmitted via transmitter module.

The demodulation method that has been implemented in order to demodulate the signal is BFSK demodulation method. Figure 5 shows the block diagram of receiver modules of health monitoring system based on IBC. There are several combination modules that have been used to develop the
receiver modules such as clock divider, Selector, Multiplexer and Series Input Parallel Output (SIPO) as shown in Figure 6.

**Figure 5.** Block diagram of receiver modules of a health monitoring system based on IBC.

**Figure 6.** Block module of BFSK demodulation for receiver module inside Quartus II software.

**Figure 7.** Combination blocks inside the BFSK demodulation for receiver module inside Quartus II software.
Figure 7 shows the combination block inside the BFSK demodulation for receiver module. Clock divider module used to lock the clock frequency to the specific value which is 12 MHz and 8 MHz for this design. Then, the selector module function as a selector input for multiplexer module. Multiplexer module will create a combination of two value of frequency from the clock divider such as high bit is 12 MHz and low bit is 8 MHz in-term of digital waveform. SIPO was used to demodulate the combination of two signals from multiplexer and change it into the 8 bits binary number. The 8 bits binary number will determine that the receiver module either successful read the input data at the transmitter module or not successful read the input data that was transmitted through human body. The result of the receiver can be observed using the Oscilloscope.

3. Result and Discussion

3.1. Off-the-shelf component transmitter module
The design had been tested and simulated in the Proteus software to perform the design behaviour of each module before proceed to design using off-the-shelf component.
3.1.1. **Analog-digital converter (ADC) module.** ADC module used to convert the analog signal from input sensor into digital signal.

3.1.2. **Parallel load 8-bit shift register module.** 74LS165 IC is used in to convert the 8-bit parallel data into series output data. This performed provide a proper data reading for the modulator input. Figure 9 shows 74LS165 circuit diagram. Figure 10 shows the result simulation of the shift register module. The first, second, and third waveform is produced by the function generator to provide clock for the shift register to perform the load and shift data. The fourth waveform is the output data shifted from parallel input into series output.

![Figure 10](image1.png)

Figure 10. Result simulation of the shift register module.

3.1.3. **Binary frequency shift keying modulator (BFSK) module.** BFSK modulator is used to manipulate the input signal either high or low into two different frequencies. From the simulation the signal produced by the BFSK is 23.9MHz for high input signal and 21.3MHz for low input signal.

![Figure 11](image2.png)  
Figure 11. 23.9MHz frequency produced at high input signal.

![Figure 12](image3.png)

Figure 12. 21.3MHz frequency produced at low input signal.

3.2. **Digital Block of the Transmitter Module**

A simple BFSK modulation module block has been design inside the Quartus II software. The design had been tested at the FGPA Altera DE2 board. The waveform can be observed using the oscilloscope. The BFSK modulation method is using two different values of frequencies in order to modulate the signals. In this project, the frequencies that were applied to the modulation method are 21 MHz and 24 MHz. The PISO module has been simulated using the VWF simulation in order to test the behavior of the PISO. The frequencies that had been produced from the module block are in the range of 21 MHz until 24 MHz.

Both of the frequency had been successfully locked into the specific value, which mean that the PLL module had successfully developed. The waveform that has been produced from the BFSK module block is not in the fully square wave waveform. Due to the limitation of the components of the DE2 board itself that is not harmonic enough.
Figure 16: Simulation result for PISO block using VWF simulation method.

Figure 16. First frequency that have been locked at 21 MHz. Figure 17. Second frequency that have been locked at 24 MHz.

3.3. Digital Block of the Receiver Module

The design had been tested on the FGPA Altera DE2 board. The waveform can be observed using the oscilloscope. The BFSK demodulation method is using two different values of frequencies in order to demodulate the received signals. In this project, the frequencies that were applied to the demodulation method are 12 MHz and 8 MHz. The selector module and SIPO module has been simulated using the University Program VWF in Quartus II software in order to test the behaviour of both modules. The selector module and SIPO module also had been simulated in ModelSim Altera software to identify timing violation using testbench for both modules. The frequencies that had been produced from the clock divider block are in the range of 12 MHz and 8 MHz. Both of the frequency had been successfully locked into the specific value, which mean that the clock divider had successfully developed. The waveforms that have been produced from the BFSK demodulation block are not in the fully square wave waveform due to the limitation of the components of DE2 board itself that is not harmonics to generate a proper square wave for output waveform.

Figure 18 shows the simulation result for selection or selector block using University Program VWF simulation method inside Quartus II software. The result shows that the output of selector is toggle between 1 and 0 based on which first input either D0 or D1 are high. If D0 is high, the output of selector will high but if D1 is high, the output selector will low. This scenario will toggle the output of the selector. Figure 19 shows the simulation for selection or selector block from testbench using ModelSim software to identify the time violation of the selector block. The similarity result from both simulation shows that the selector block has been designed successfully.
Figure 18. Simulation result for selector block using University Program VWF simulation method.

Figure 19. Simulation result for testbench of selector block using ModelSim software.

Figure 20 shows the simulation result for Serial In – Parallel Out (SIPO) block using University Program VWF simulation method inside Quartus II software. Result shows that the output of SIPO block has generated 4-bits output from the 1-bit input. The 4-bits output are based on current input when the clock of the SIPO is high. The 4-bits output can be declare as successful generated when the output get the same input after the input has entered 4 times from one input port. Figure 19 shows the simulation result for testbench of SIPO block using ModelSim software to identify the time violation of SIPO block. The result of the simulation is not same from University Program VWF because the time hold in testbench is not same with the University Program VWF and this effected to generate the 4-bits output properly.

The output signal from receiver module are shown in figure 22 for high frequency is 12 MHz and figure 23 for low frequency is 8MHz has successful generated.

Figure 20. Simulation result for SIPO block using University Program VWF simulation method.

Figure 21. Simulation result for SIPO block using ModelSim software.

Figure 22. first frequency for high bits that have been locked at 12 MHz.

Figure 23. second frequency for low bits that have been locked at 8 MHz.
4. Conclusion

In conclusion, the low power of health monitoring system had been designed, developed and implemented based on IBC method. The IBC has a characteristic of low power consumption and low communication frequency without enlarging antenna size compare to RF technology. The signals do not leak through the skin of the human body thus the electromagnetic noise and interference has little influence on the transmissions of the signal. For the future recommendation work, the health monitoring system can be improved by enabling it to monitor the human health more efficiently and display the result to the external device such as oscilloscope or mobile phones.

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