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UWB-WBAN Sensor Node Design

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***Abstract*—In this paper, we discuss the hardware development of a UWB sensor node for wireless body area networks. A few unique UWB pulse generation techniques have been discussed. The sensor node transmits multiple pulses per bit to increase the average power of the transmitted signal in order to improve the bit-error rate (BER) performance. The multiple-pulse per bit technique is also used as the coding scheme to identify the individual sensor nodes when more than one sensor forms a network. The sensors nodes are able to transmit body signals up to 2 m with a BER lower than 10^{-5}.**

I. Introduction

Ultra Wideband (UWB) presents some unique benefits when compared to the narrow band systems: (i) low-power transmitter design, (ii) low radio frequency (RF) and electromagnetic interference (EMI) effects in medical environment, (iii) small size antenna, and (IV) high data rate. Especially the UWB has efficiently been used for simultaneous monitoring of many continuous physiological signals such as EEG, ECG and EMG [1] and detecting neural signals for brain-computer interfaces because of its high data rate capability [2], and electronic pills for video and image processing [3]. Unlike the narrow band technologies, a UWB can support scalable data rates in a single node. For example it can easily be designed to transmit from 10 bps to 10 Mbps without introducing much complexity in the hardware.

II. UWB-WBAN System

In recent years, there has been vast interest in using ultra wideband wireless technology for Wireless Body Area Network (WBAN) applications. WBAN is a collection of wireless sensors placed around or in a human body that are used to exchange important information from a human body to remote stations. Fig. 1 depicts an application of WBAN in healthcare. The gateway-called body control unit (BCU) is used to connect sensors to remote locations (i.e. hospitals).

In a WBAN system, very stringent requirements have been placed on the sensor node. The sensor nodes should be small, consume extremely low power and reliable. Therefore, it is very important to minimize the power consumption of a sensor node. For the current WBAN efforts in the literature, the commercially available narrowband wireless platforms such as Crossbow's Mica nodes and Texas Instrument' CC1010 and CC2400 platforms are used for the design of WBAN sensor nodes. These nodes have been based on Bluetooth or ZigBee wireless modules. Unlike narrowband WBAN nodes, the UWB hardware platforms are not available in the commercial domain. In this paper, we will present the development of a complete impulse radio (IR-UWB) based sensor node for WBAN applications.

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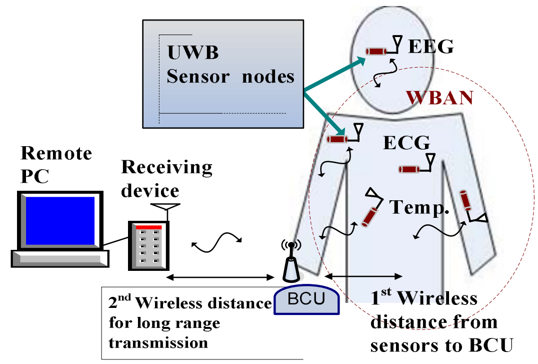

Figure 1: A WBAN system for physiological signal monitoring.

III. UWB Sensor node

Although a UWB transmitter is reputed to be low power, UWB receivers are however designed to sense the regulated low-level transmitted signals. They are thus designed to be complex and consume high power. Operating at a high carrier frequency also contributes to the high power consumption. The design of a UWB wireless chip has been difficult for chip designers due to the difficulties in the demodulation of narrow pulses. Generally a UWB receiver circuit has demonstrated power consumption higher than that of narrow band systems.

One way to eliminate the high power consumption of a UWB receiver is to use a transmitter-only method for low-power networks like WBAN. The sensor node includes only a transmitter to send data from a body to an external device for monitoring and recording. To identify the individual users, each sensor attached on the body is assigned a unique number of pulses per data bit [4].

Each UWB sensor node is attached to or implanted in the body for the targeted WBAN application. Meanwhile the BCU contains an off-the-shelf UWB receiver system which is placed at a location 0.5-2 meters away to detect the transmitted medical signal, as shown in Fig. 1. Fig. 2 shows the block diagram of the proposed UWB sensor node.

A. UWB Pulse Generators

There are mainly two methods of generating a UWB pulse in the literature; transmission line method and CMOS-based methods. A UWB monocycle pulse can be generated by passing a square wave through a step recovery diode (SRD) and a pair of shorted circuit transmission line [5]. This method is not suitable for low power WBAN applications because the size of the transmitter using transmission line is much larger than that of a CMOS UWB transmitter. An alternative method of implementing UWB pulse generator is using CMOS integrated circuit (IC) technology. CMOS-based UWB transmitters are more energy efficient and have much smaller form factors, which is more suited for WBAN applications [6]. CMOS based solutions generate very small pulses through a delay unit using logic gates [7].

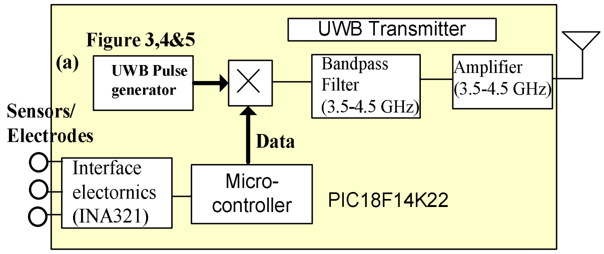

Figure 2: Block diagram of a UWB-WBAN sensor node.

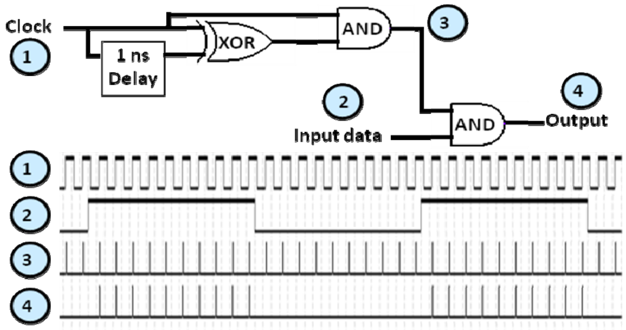

Figure 3: Digitally controlled UWB pulse generation.

Fig. 3 shows a design of UWB pulses through simple logic gates. Additional gates such as XOR, AND, etc can be used to generate PPM and OOK type of modulated UWB signals.

The waveform (3) in Fig. 3 is the 1 ns UWB pulse generated through a delay unit using a clock signal. A UWB signal is generated at the positive edge of each clock pulse using the delay-XOR unit together with an AND gate. The clock signal is taken from the Crystal inside the micro-controller. Fig. 3 is one of the efficient pulse generation techniques implemented in our WBAN sensor nodes. The output signal (4) is generated simply by multiplying (3) by the data signal (2) using the AND gate. In this design, the UWB pulse rate is controlled by the clock frequency, which allows multiple UWB pulses to be sent in a single data bit.

Two other unique pulse generation techniques used in our sensor nodes are given in Fig. 4. The narrow pulse train in Fig. 4-(a)) is generated using a variable clock and a buffer with 8 ns propagation delay. The clock width is variable, and thus a narrow pulse can be generated by adjusting the clock width to ensure that it is slightly more than 8ns. The variable oscillator is configured to generate a clock signal of 60 MHz, which corresponds to a half duty cycle period of 8.33ns. In an ideal case, an UWB pulse less than 500 ps can be generated, but due to finite rise/fall time, a UWB pulse of between 1 to 2 ns was achieved in practice. Although the pulse repetitive frequency (PRF) is fixed for Fig. 4-(a), the pulse width can be adjusted by tuning the clock frequency. Again the advantage of using the clock is that it helps to make the pulse width adjustable, which is used to optimize the spectrum shapes.

The pulse generator in Fig. 4-(b) uses a positive emitter coupled logic (PECL) D-flip flop, which has a rise time of 130 ps and a propagation delay of 400 ps. The transistor–transistor logic (TTL) signals from the micro-controller and oscillator clock are converted to PECL logic using SY10ELT22LZG and the output is fed a D-flip flop (MC10EP31). The narrow UWB pulses are generated by connecting the output of the D-flip flop to the asynchronous reset pin [8]. One pulse is generated at every rising edge of the clock signal. For this design, the pulse width is fixed, but the PRF is variable and determined by the clock frequency. The propagation delay from the reset pin to output is 400 ps, which defines the UWB pulse width.

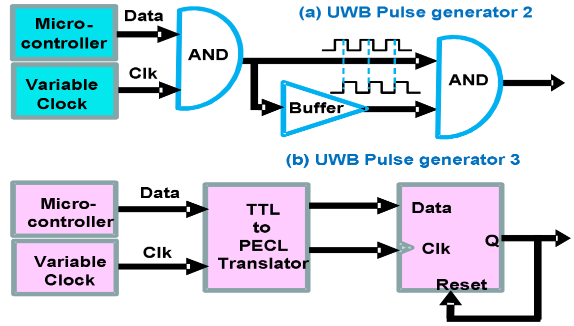

Figure 4: UWB pulse generation using off-shelf IC devices, (a) gate based narrow pulse generation; (b) flip-flop based narrow pulse generation.

Another pulse generation technique employed by our sensor nodes is depicted in Fig. 5. The pulse generator is able to generate pulse width ranging from 300psec to 4nsec by adjusting the *VDDB1* and *VDDB2*. The main components used for the pulse generator are Linear technology LT6905 programmable oscillator that generates an variable output frequency from 17 MHz to 170 MHz, Fairchild semiconductor NC7WZ126 ultra high speed buffer and Fairchild semiconductor NC7SZ86 ultra high speed XOR gate. The working principle of this pulse generation is based on adjusting the propagation delay of a buffer unit. Both buffers are selected exactly same. Therefore, the only factor that would affect the propagation delay is to modify the supply voltage-VDD. A narrow pulse is formed by changing the propagation delay on one of the buffers to allow a slightly delayed version of the input clock pulse to appear at one of the input port of the XOR gate. Apart from adjustable pulse width, the PRF and pulse amplitude can also be varied to meet the different operating requirements. PRF is varied by changing the oscillator output, while adjustment of amplitude is performed by changing the VDDC.

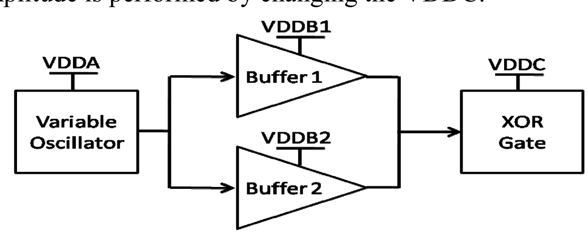

Fig. 5. A variable supply voltage technique for narrow pulse generation.

The key advantages of these pulse generators mentioned herein are the ability to vary the pulse width, PRF, and pulse amplitude. This allows optimizing the transmitter operation in various environments. It is important to note that the ability to change the PRF in our sensor nodes enables the system to vary the number of UWB pulses per data bit.

A. *Wearable UWB Sensor Node*

The sensor node block diagram for wireless body area network applications is depicted in Fig. 2. The square narrow pulses from the pulse generator are multiplied using logic gates to form a modulated UWB signal. For an OOK modulation, the multiplier is a simple AND gate as explained in Fig. 3. The generated UWB square pulses are then passed through a 1 GHz wideband band pass filter (BPF) centered at 4 GHz to ensure the UWB spectrum mask requirements are met (See Fig.2). A wideband antenna designed for 3 to 5 GHz with an antenna gain of 2dBi is used for wireless transmission.

The physiological signal from the electrodes is supplied to the transmitter through the front-end circuit- interface electronics and then processed by the microcontroller-PIC18F14K22 [9]. The microcontroller performs the analog to digital conversion, determines the transmission format and the modulation scheme, and sets the data rate. It is mentioned earlier that the UWB pulse rate is independent of the data rate and arranged by the pulse generator via the clock frequency. This clock can be taken from the microcontroller' reference clock. The generated UWB pulses are multiplied with the binary data bits created by the micro-controller.

The role of the interface electronics is to provide low noise amplification for physiological signals such as ECG and EEG. A typical ECG/EEG signal has amplitude of less than 500μV with frequency less than 100 Hz. The two components used in this front-end circuit are the instrumental amplifier (INA321) and an active low pass filter (LTC6081) [10]. The input signals are amplified by 60dB, with a cutoff frequency at 100 Hz.

Fig. 6 shows the photo of the UWB sensor node designed for a UWB-WBAN system. The sensor nodes are assembled on a four layers printed circuit board with dimensions of 27 mm (L) x 25 mm (W) x 15 mm (H) with the battery attached, which is sufficiently compact for use in a WBAN application. The transmitter is able to produce narrow pulse ranging from 0.5 ns to 2 ns, with a variable pulse repetitive frequency of between 17 MHz to 170 MHz. After passing through the filter, the UWB pulse is amplified using a wideband low noise amplifier (LNA) to meet the -41.3 dBm transmission power level. This amplifier has been included to guarantee that the amplitude of the UWB pulses is sufficient enough for the distance targeted by a WBAN application.

IV. Experimental Results

The UWB sensor nodes designed are powered from a 3.7V battery. The analog, digital and pulse generation circuits all operate with a supply of 3.3V while the RF components use a 3V supply. National semiconductor-LP5996 linear regulator is selected to provide the power supplies to the entire circuit. The receiver circuitry is assembled using off-the-shelves modules. Block diagram of the receiver circuit is shown in Fig. 7 [12]. The signal entering the receiver passes through a 3 to 5 GHz BPF to eliminate the unwanted interfering signals.

The filtered signal is amplified by 48 dB using three wideband LNAs before down converting to a baseband signal using a mixer and a 4 GHz VCO.

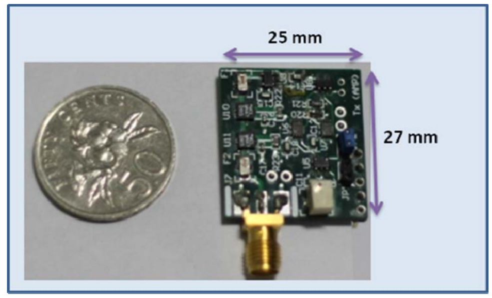

Figure 6: UWB sensor node

The baseband signal is passed through a low pass filter with 100 MHz bandwidth before going through the analog amplification stage. After the analog amplifier, the transmitted UWB pulses are recovered. The recovered UWB pulse is the digitalized using a high speed ADC and processed by the FPGA before transferring the data to the laptop using serial cable. The role of the FPGA is to process the received multiple UWB pulses and determine whether it is bit "1" or bit "0" before sending to the laptop and set the appropriate baud rate for data transfer to the laptop. After FPGA processing, the data is transfer to the laptop based on the baseband data rate. The BER (bit-error rate) is computed in the laptop using Matlab based on a known pseudorandom data sequence that the transmitter is sending. Since the UWB pulse rate is selected to be much higher than the actual data rate (multiple pulses per bit), it increases the processing gain and hence eases the synchronizing process.

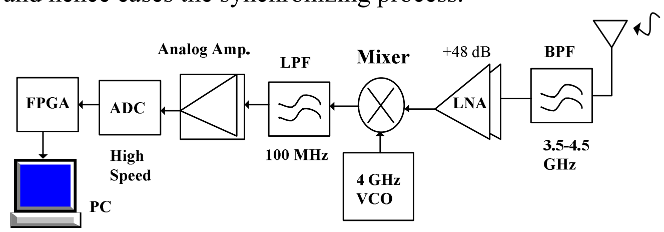

Figure 7: UWB receiver block diagram

In the experiment to calculate the BER, a UWB pulse rate of 25 MHz is used. The UWB pulse width was 2 ns. BER is obtained based on the multiple UWB pulses per data bit. The UWB nodes are designed to perform a gating operation, which allows the transmitter to transmit at a maximum peak power of -24.4 dBm based on a 3 MHz resolution bandwidth on the spectrum analyzer. The peak power measured is -24.4 dBm for maximum and -48 dBm for average (lower than the regulated -41.3 dBm level). Fig. 8 and Fig. 9 show time plots of a transmitted and a recovered UWB pulse after passing through the receiver front-end in Fig. 7.

Table 1 shows the detailed specifications of the existing wireless sensor platforms used for WBAN applications. Wireless sensor node technologies based on narrow bands especially 2.4 GHz ISM have been used in medical monitoring widely. The presented sensor node is superior to the existing narrowband ones in terms of power consumption, size and the high data rate capability. The UWB-BAN nodes eliminate the use of power hungry UWB receiver by accommodating different UWB pulse rate and asynchronous package transmission pattern to provide a multi-access communication [4].

TABLE 1 COMPARISON OF THE EXISTING NARROWBAND SENSOR NODES WITH THE UWB-BAN NODE

Model	Company	Frequency	Data Rate	Trans. Power (dBm)	Physical Dimension	Power Consumption	
						Tx	Rx
Mica2 (MPR400)	Crossbow	868/916 MHz	38.4 kbps	-24 to +5	58 x 32 x 7 mm	27 mA @ 3.3v	10 mA @3.3v
MicAz	Crossbow	2400 MHz to 2483.5 MHz (IEEE 802.15.4)	250 kbps	-24 to 0	58 x 32 x 7 mm	17.4 mA@3.3v	19.7mA @3.3v
Mica2DOT	Crossbow	868/916 and 433 MHz	38.4 kbps	-20 to +10	25x6 mm^2	25 mA@ 3.3v	8 mA @ 3.3v
Tmote Sky node	Moteiv	2.4 GHz (IEEE 802.15.4)	250 kbps	25 to 0	66x32.6x7 mm	19.5 mA@3v	21. 8 mA @3 v
T-node	SOWNet	868, 433, 915, or 315 MHz	52.2 kbps	-20 to -5	Diameter of 23 mm	25 mA@3 v	13 mA@3 v
MICS Node [11]	U. Newcastle	402-405 MHz	76 kbps	-16	30X75mm	27mA@3.3V	8mA@3.3v
UWB-BAN Node (Our design)	U. Newcastle	3.5-4.5 GHz	Up to 10 Mbps	-41	25X27mm	15 mA@3 V	0 (no receiver)

The UWB sensor node has been evaluated for an on-body application using the practical BER performance [12]. The sensor was placed on the different areas of the human body to represent physiological parameters such as ECG (chest), EEG (head) etc. Meanwhile the receiver (the control device) has also been replaced at different locations to configure and study the performance of the sensor node around the human body. The sensor node demonstrates a BER performance lower than 10^{-5} for the worst case scenario.

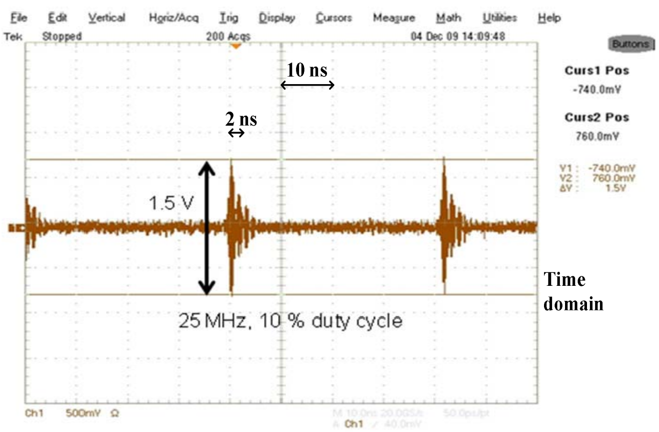

Figure 8: Generated UWB pulses at the UWB-WBAN node.

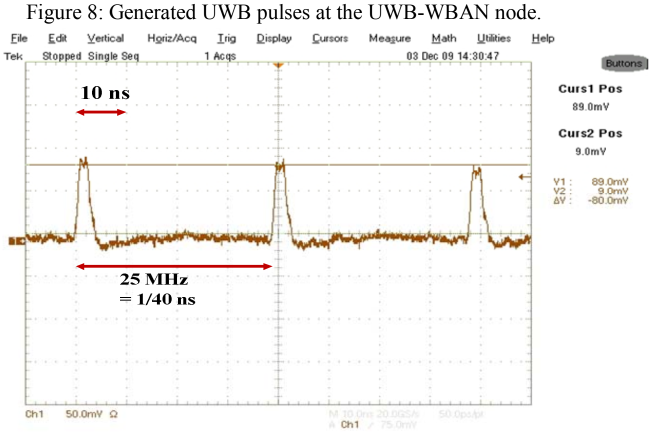

Figure 9: An example of recovered UWB pulse at the reciver.

V. CONCLUSION

This paper addresses and discusses implementation of a UWB based sensor node for WBAN systems. One big advantage of UWB wireless technology is its high data rate ranging from 850 kbps to 20 Mbps which can be used for simultaneous monitoring of many continuous physiological signals such as ECC, EEG and EMG. In addition, UWB wireless technology does not present an EMI risk to other narrow band systems and medical equipments in healthcare as its transmitter power is quite low and the frequencies used are at very high frequencies (>3.5 GHz). The biggest drawback for the use of the UWB technology is that the UWB chips are not available commercially to apply in a telemedicine system at the moment. Therefore designers will need to develop their own transmitters and receivers to develop sensor nodes. This paper described techniques for generation of such sensor node boards for WBAN.

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