VHDL IMPLEMENTATION OF NEURAL RECORDING SYSTEM WITH UWB TELEMETRY

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***Abstract*— Wireless transmission plays a key role in the field of clinical neuroscience to transmit the neural signals to the outside world. The major challenges associated with the neural recording system are:- the system should be capable of recording a larger number of channels, transmit the signal through a wireless media, consume a minimal amount of power and utilize as little chip area as possible. To meet these challenges, it is proposed to design a low power neural recording system which is highly energy efficient using UWB for the transmission of neural signals. The proposed system consists of a neural recording block, a UWB transceiver, a digital controller and a digital processor that controls the operation of the VLSI circuits and data communication between them. The neural recording block contains a probe array which collects the neural signal from the extracellular region of the brain. The digital controller contains a multiplexer and the SPI block that are used to control the ADC output in the neural recording block. Digital processor is controlled by digital controller in order to select the particular channel. The digital processor can be implemented based on sequentially turn-on-method and sorting method to reduce the power consumption and data bandwidth for wireless communication. The Ultra wide band Telemetry is used to achieve a high data rate with low power consumption. Thus the proposed system serves as the hardware platform to record and transmit the data in a wireless medium.**

***Index Terms*— Neural Recording, Digital Processor, Digital Controller, UWB Transceiver.**

I. INTRODUCTION

The neural recording systems are extensively used in clinical neuroscience to learn the behavior of animals. The multi-channel neural recording system has sample applications such as upper and lower limb prostheses and bowel movement control for spinal cord injury patients. To support these applications, a neural recording system must meet some of the demanding requirements imposed by the environment.

First, it should be able to record a large number of channels simultaneously. Second the system must be capable of transmitting large amount of data to a receiver which is located outside the body. However, usage of wires is not preferable in neural recording applications as the wires restrict the movement and behavior of animals or humans. Third power consumption and chip area should be optimized.

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II. RELATED WORK

Several neural recording systems were reported to support simultaneous multichannel recording [1],[2]. In the field of clinical neuro-engineering, the effects of cardiac arrest on the brain is essential to monitor electroencephalographic(EEG) activity for treatment [3].The significant amount of work is focused on designing systems which can record neural activity in awake behaving subjects [4],[5]. A work on neural recording system for 32 input channels has been carried out with an average power consumption of 483 nW [6]. A low power digital signal processing system has been developed to extract the neural signals with an efficient use of transmission bandwidth [7]. However, assigning enough data rate becomes difficult for the neural recording systems containing a larger number of channels [8]. Therefore, it is quite obvious that there is an immediate need for higher-bandwidth data transmission for neural recording telemetry systems. The FCC assigned the spectrum from 3.1 GHz to 10.6 GHz for unlicensed use of ultra wideband devices to support high data rates [9]. A quantitative evaluation of different spike detection has been carried out to minimize power using synthesized spikes [10]. The IR-UWB uses simple short pulse for transmitting data and thus makes transmitter design very simple and power efficient [11]. Challenging of spike sorting due to several factors is reported in [12].

The focus of this work is to reduce the memory usage, power consumption, and to remove the cables (wires) thereby allowing free movement of the patient or the test subject. The existing system consumes more power and more data rate as the channel increases. Hence, it is proposed to realize a system which requires less power and less memory for wireless transmission in neural recording system. The proposed system supports two different modes of operation to reduce the power consumption and memory usage.

III.PROPOSED METHOD

The proposed work aims to develop low power neural recording system with UWB telemetry in two modes: Sequentially turn-on-method and sorted method in digital processor.

1) Sequentially turn-on-method: In this method at any instant a channel is selected in sequential manner and remaining channels are turned-off.

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The selected channel data is stored in RAM and transferred via UWB for wireless transmission.

2) Sorting method: In this method a selected channel is connected to the sorted process and sends it to UWB for wireless transmission. In sorted process instead of sending the raw data, spikes are detected based on the threshold from the electrodes and transmitted. Hence this method will reduce the data bandwidth requirement for wireless transmission.

1. Neural Recording System in Sequentially Turn-on-Method with UWB Telemetry

The block diagram of the proposed system is shown in Figure 1. The Neural Recording block contains probe array to collect the EEG signals from the extracellular region of the brain. In this block, the EEG signal is amplified and converted into digital data using ADC. DSP block is programmed in two modes of operation: sequentially turn-on-method and sorted method. UWB is used for low/high data rate wireless communication as it has the widest bandwidth and low emission power density.

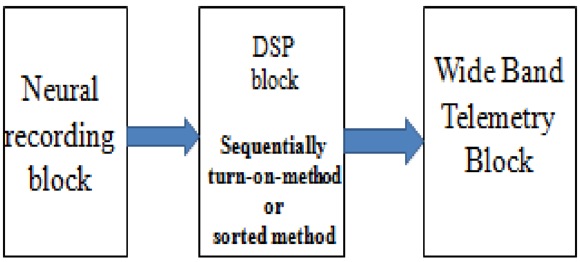

***Figure 1**. Block Diagram of the Proposed System*

1.1 Sequentially turn-on-method

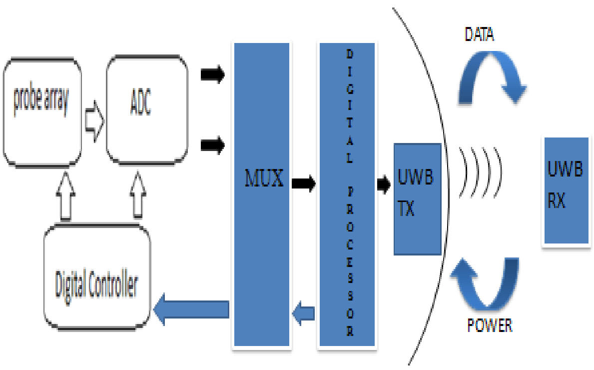

***Figure 2**. Block Diagram of the Sequentially Turn-On-Method*

The block diagram of sequentially turn-on-method is shown in Figure 2. The proposed system consists of EEG signal blocks, multiplexer, UWB transceiver, digital processor and a digital controller which controls the operation of the VLSI circuits and data communication between them. Digital controller contains multiplexer and SPI block which are used to control the ADC output.

1.2 Sequentially Turn-On-Method for Selection of a Channel

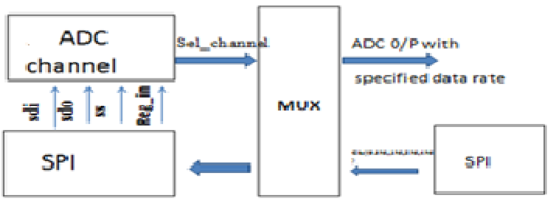

***Figure 3**. Block Diagram for Selection of a channel*

The block diagram of selection of a channel is shown in Figure 3. The data rate of ADC output is fixed and the data rate that the proposed work works at is 0.5M, 1M, 2M and 4M. The data rate can be configured by SPI. The recorded EEG signal is amplified and converted into digital using ADC. To accommodate the requirements of various different applications, the specifications, such as the selected channels, the gains and bandwidths of amplifiers and the mode of ADC should be programmed by digital controller through SPI. The channels which are not being used will be disabled to reduce the power consumption. The proposed work is implemented with 10 channels and increased to 20 channels.

1.3 Wideband Telemetry Unit for Multi-Channel Neural Recording Systems

A wideband telemetry unit is realized as proposed in [11].

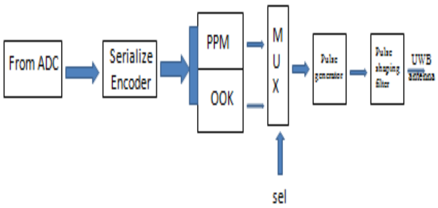

***Figure 4**. Block Diagram of Wideband Telemetry system*

The block diagram of Wideband Telemetry system is shown in Figure 4. There are two common transmitter categories used for UWB devices.

The first category is Multi-carrier UWB which contains pulse generator and an up-converter that uses a mixer and a local oscillator (LO) to transfer the baseband signal into the UWB band. But this transmitter is not used in the proposed method because it requires complex design and consumes high power. The transmitter in the second category called Impulse Radio UWB (IR-UWB) consists of pulse generator and pulse shaping circuit where the pulse directly falls in the UWB band. The IR-UWB uses simple short pulses for transmitting data so that it makes the transmitter design very simple, little area, less power and it can also provide enough data bandwidth. The selected ADC output through sequentially turn-on-method as in Figure 3 is passed to UWB block.

1.4 Working of Impulse Radio UWB (IR-UWB)

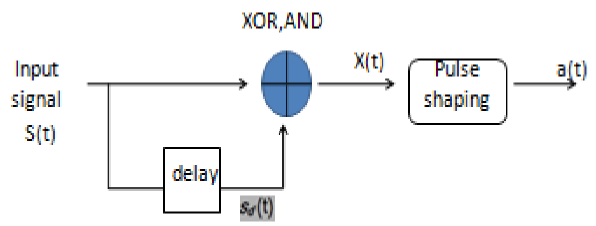

Figure 5. *IR-UWB Pulse Generation*

The block diagram of IR-UWB Pulse Generation as in [11] is shown in Figure 5. The first stage of the UWB transmitter is an encoder as in Figure 4. The encoder is used to convert the baseband data into different formats (e.g. NRZ, Manchester). It can also be used to enable the receiver to recover clocks directly from the encoded data as well as to distinguish the data from different channels. The transmitter can be configured in two different pulse modulation schemes: On-Off-Keying (OOK) and Pulse-Position Modulation(PPM).OOK signal is generated by passing the NRZ and Manchester NRZ signal through an AND gate. Pulse gets transmitted when the signal is '1' else no pulse is transmitted. The PPM UWB signal is generated by using the Manchester NRZ signal and the OOK UWB signal. First Manchester NRZ is passed through the pulse generation and the resulted pulses are added to the OOK UWB then PPM UWB is obtained.PPM uses a delay to distinguish the pulse representing the binary one from the binary zero pulse.

After configuring the transmitter to a modulation scheme, the encoded data is the input for the narrow pulse generator unit. In IR-UWB pulse generator circuit, a pulse width is controlled by the voltage Vc. Generated pulses are passed through the pulse shaping filter to fit them into the FCC emission mask and to eliminate the transmission of unnecessary frequencies.

2. Neural Recording System in Sorted Method with UWB Telemetry

Spike sorting is the process of classifying individual spikes into groups such that the spikes within a group represent the signals from the same neuron. Due to varying physical properties of individual neurons as well as their different location for recording electrodes, the spike associated with different neurons will have different properties. When a single electrode records spikes from multiple neurons, their differences in spike characteristics can be used to sort the spikes into appropriate categories.

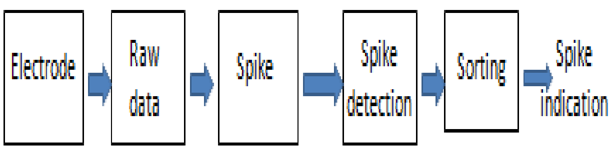

Figure 6.*Block Diagram of Sorted Method*

The block diagram of the sorted method is shown in Figure 6. The main aim of this method is to minimize the power consumption. The neural data is sorted and detected in order to reduce the data bandwidth and for reliable wireless communication. It transmits only the spike indication and avoids sending the raw signal. So this method requires much lower communication bandwidth and also requires less power. The spike sorted is detected based on the hard decision algorithm as in [12].

2.1 Working of spike sorting method

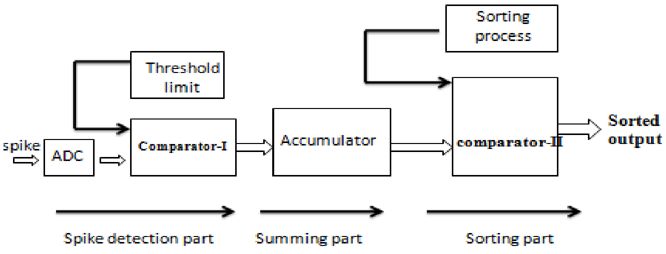

Figure 7. *Internal Architecture of Sorted Method*

The block diagram of Internal Architecture of Sorted Method is shown in Figure 6. The architecture of the spike sorting method that processes the signal from a selected channel is shown in Figure 7. The Spike Detector detects the presence of spikes in the input and determines their starting point to initiate the operation of the Spike Sorter. Both spike detection and sorting must be adaptable, due to unstable recording conditions. Therefore, raw data is periodically transmitted to the host computer. At all other times, the spike signal is processed by the Spike Detector and Spike Sorter. The output produces the spike notification message.

The input (raw data) is compared to the threshold value for the detection of spikes with corresponding two time limits. The comparator compares the detected spike for particular two time limits and stores in an accumulator for sorted process. These two sums represent the number of signal points within the respective time intervals that are above the separation line. In the second stage, these sums are compared with the sorting threshold values. If the two comparisons agree with the predefined values, it provides a spike notification message or sorted output. The sorting performance may be improved by considering more than two decision intervals. So due to the detection and sorting process this method will reduce the data bandwidth, power consumption and thus feasible for wireless communication.

IV.EXPERIMENTAL RESULTS

The Neural Recording System with UWB has been implemented using Modelsim 6.2cversion software and Xilinx software.

Electroencephalography (EEG) is a method used in measuring the electrical activity of the brain. The brain generates rhythmical potentials which originate in the individual neurons of the brain. These potentials get summated as millions of cell discharge synchronously and appear as a surface waveform, the recording of which is known as the electroencephalogram. Figure 8 shows a set of EEG signals with ADC output. Using Matlab software, a set of EEG signals are collected. These signals are sampled and quantized. The sampled data is collected through sine-package for VHDL Implementation. For every rising of the clock the corresponding sampled data is called and it's converted into 8-bit digital data using VHDL.

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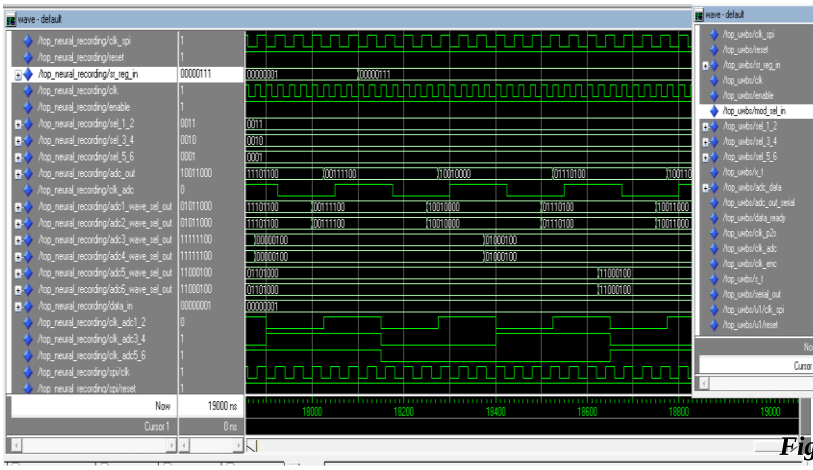

Figure 8.Simulation Result for the Selection of a Channel with Specified Clock Rate Based on Sequential Turn-On Method

Figure 8 shows the selection of channel1 with selection signal 00000001. Thus channel 1 is selected with specified rate configured by SPI in Digital controller through digital processor. Figure 8 also shows the selection of another channel with selection signal 00000111 through digital processor in sequential manner.

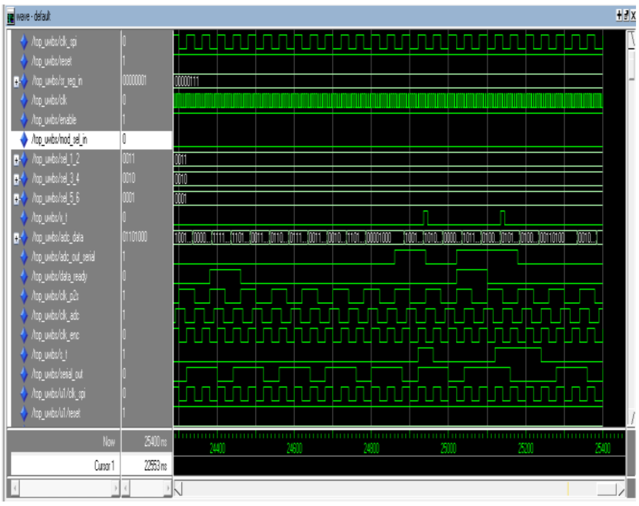

Figure 9(a). *Simulation Result for Pulse Generation of OOK UWB Signal*

OOK signal is generated by passing the NRZ and Manchester NRZ signal through an AND gate. Pulse gets transmitted when the signal is '1' else no pulse is transmitted as shown in Figure 9(a).

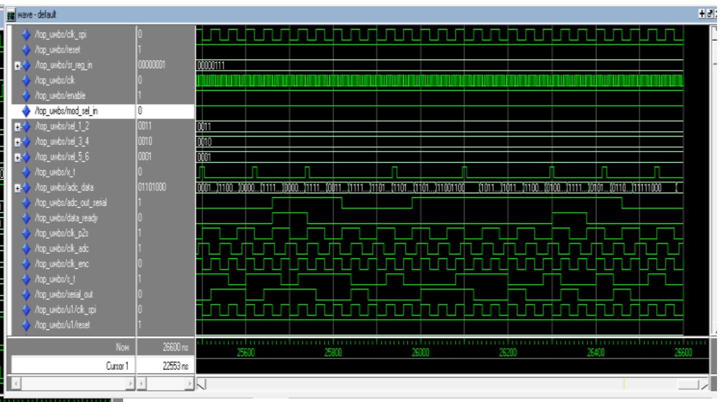

Figure 9(b). *Simulation Result for Pulse Generation of PPM UWB Signal*

The PPM UWB signal is generated by using the Manchester NRZ signal and the OOK UWB signal. First Manchester NRZ is passed through the pulse generation and the resulted pulses are added to the OOK UWB then PPM UWB is obtained. PPM uses a delay to distinguish the pulse representing the binary one from the binary zero pulse as shown in Figure 9(b).

The neural data is sorted and detected in order to reduce the data bandwidth and thus making it suitable for reliable wireless communication as shown in Figure10.

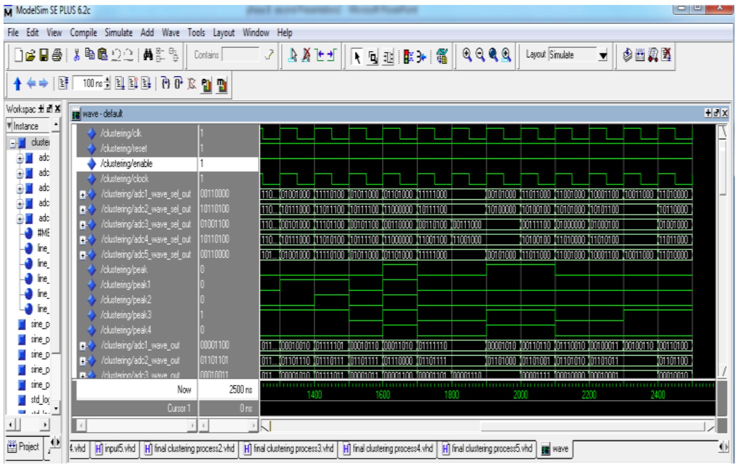

Figure 10.*Simulation Result for spike detection and sorted process*

It transmits only the spike indication and avoids sending the raw signal. Whenever the signal reaches the threshold limit peak is enabled as shown in Figure10. So this method requires much lower communication bandwidth and also requires less power**.**

Table 1 and Table 2 shows the comparison of the synthesis report of the proposed system based on sequential turn-on and sorted method for 10 channels and 20 channels. From the table, it is inferred that the proposed work based on sorting outperforms the sequential turn-on method with respect to memory usage and power consumption.

V. Conclusion and Future Works

Thus, the proposed work focuses on the two different programming modes of Digital Signal Processor. The work based on sorting method consumes less power and less memory when compared with sequential turn-on. The proposed work has detected the spike based on hard decision. The future work will be to minimize the power consumption and memory usage by means of IT(integral transform algorithm).

VI .SYNTHESIS REPORT FOR SEQUENTIAL TURN-ON-METHOD

Table 1. Synthesis report for sequential turn-on and sorting method for 10-channels

SPECIFICATION	No. of channel=10	No. of channel=10 in sequential turn-on-mode	No. of channel=10 in hard decision algorithm
Speed Grade	-5	-5	-5
Minimum period	174.019MHz	166.889MHz	167.757MHz
Minimum input arrival time before clock	4.349ns	4.349ns	4.331ns
Maximum output required time after clock	5.331ns	5.331ns	11.454ns
Total memory usage	89204 kilobytes	92916 kilobytes	85092 kilobytes
Power consumption	179mW	143mW	125mW

Table 2. Synthesis report for sequential turn-on and sorting method for 20-channels

SPECIFICATION	No. of channel=20	No. of channel=20 in sequential-turn-on-mode	No. of channel=20 in hard decision algorithm
Speed Grade	-5	-5	-5
Minimum period	166.889MHz	166.889MHz	158.39MHz
Minimum input arrival time before clock	4.331ns	4.349ns	4.349ns
Maximum output required time after clock	10.715nsns	5.331ns	11.454ns
Total memory usage	113716 kilobytes	123572 kilobytes	102052 kilobytes
Power consumption	305mW	179mW	145mW

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