A Platform for Real-Time Measurement and Analysis of Electroencephalogram

[1]Jeadong Lee, [*2]Yong-Hwan Lee

[1, First Author] *LG Electronics,Korea*
yofule@naver.com
[*2,Corresponding Author] *School of Electronic Engineering, Kumoh National Institute of Technology, Korea, yhlee@kumoh.ac.kr*

Abstract

In this paper, we present a portable platform for real time electroencephalogram(EEG) measurement and analysis system. EEG signal from the electrodes on the scalp is very weak ranging from a microvolt to dozens of microvolt and its frequency range is from 0.5 Hz to hundreds of Hz. Thus, the gain of amplifier should be 10,000 and more to obtain valid EEG signal. Filters are used to filter the incoming continuous signal before it is sampled by the analog-to-digital converter. Low pass filter is applied in order to eliminate the component of breathing and high-pass filter is used to remove power supply noise. The FPGA processes the signal frequency by the ADC to transform time domain signal into frequency domain signal using 256 point radix-2 decimation-in-frequency as an FFT algorithm. This platform is easy to reuse due to its simple block structure. The platform is prototyped in the Xilinx Virtex4 FPGA Development board and will be implemented to a single chip. We have also established Wi-Fi connections between this platform and mobile device.

Keywords*: EEG, Platform, Real-time, Electroencephalogram Measurement, Portable Platform*

1. Introduction

Electroencephalography obtained from scalp electrodes is a recording of the brain's electric activities. Electrodes are placed on the scalp to detect the microvolt-sized signals that result from synchronized neuronal activity within the brain[1]. There are five major EEG signal distinguished by their different frequency bands. There frequency bands from low to high frequencies respectively are named alpha (α), theta (θ), beta (β), delta (δ), and gamma (γ). The amplitudes and frequencies of this signals differ from a human state[2]. The delta waves have the frequency range of 0.5-4 Hz and detectable in infants and sleeping adults. The theta waves have the frequency range of 4-8 HZ and are obtained from children and sleeping adults. The alpha waves have the frequency spectrum of 8-13 Hz and can be measured from the occipital region in an awake person when the eyes are closed. The frequency band of the beta waves is 13-30Hz; these are detectable over the parietal and frontal lobes[3]. So the EEG signal should be measured and analyzed with real time system.

This paper is divided into two major sections. In the first part, an entire system architecture has been proposed. It is organized by analog part and digital part. The analog part is composed of band-pass filter and operational amplifier for a converter and FPGA to transform an EEG signal from a time domain to a frequency domain. In the second part, we analyze an experiment result.

2. System architecture

* Corresponding Author
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An EEG signal is measured on the scalp by the electrodes. The magnitude of the EEG signal is microvolt and frequency is 0.1Hz - hundreds of Hz. So, An EEG signal for a measurement needs for a high gain amplifier and the band-pass filter.

As shown in figure 1, EEG signals on the scalp by the electrodes which are placed by instrumentation amp because they are micro-sized voltage signals. The band-pass filter is composed of the high-pass filter with cut-off frequency at 0.5Hz and the low-pass filter with cut-off frequency at 60Hz. after filtering the signal, the analog EEG signal is transformed into a digital signal by analog to digital converter with 12 bit resolution.

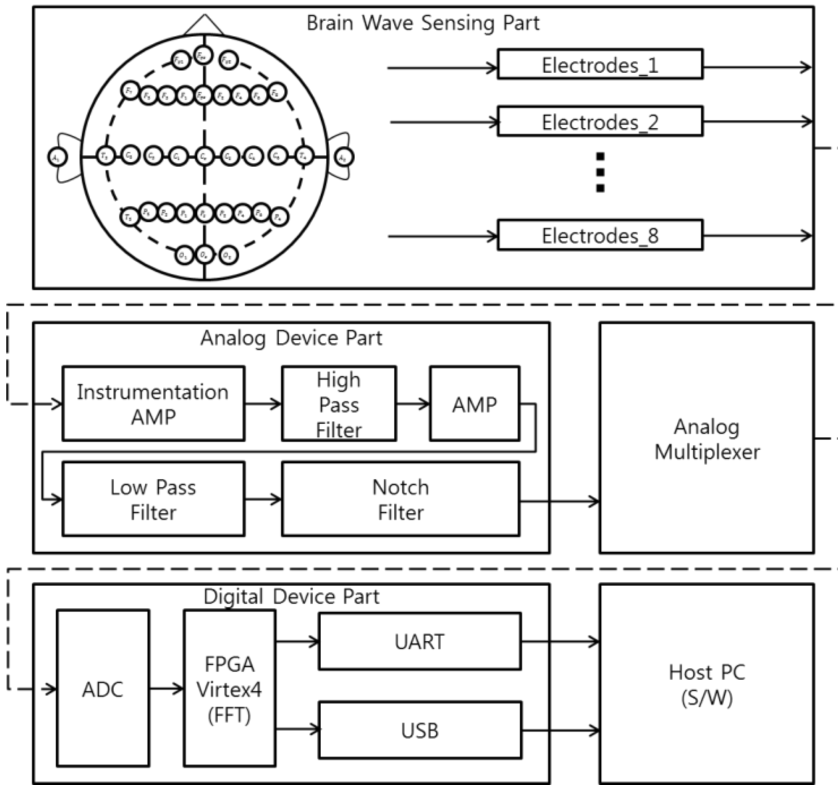


Figure 1. System architecture

The digital EEG signal is transformed from the time domain into the frequency domain by the Fourier transform hardware on the FPGA. These data are sent to the mobile device via Wi-Fi. Figure 2 illustrates a mobile monitoring system.

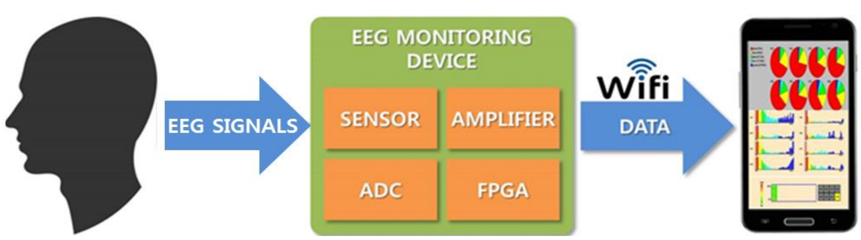


Figure 2. EEG monitoring system

3. Detailed blocks

3.1. Filter

We used high-pass filter and low-pass filter[4] with a cut-off frequency at 0.5Hz and 30Hz respectively. High-pass filter using passive filter with a cut-off frequency of 0.5 Hz is used to remove the disturbing very low frequency components such as those of breathing. The low-pass filter with a cut-off frequency of 30 Hz, as shown in figure 3, is an active filter. Because the frequency band of power supply at 50Hz and 60Hz can be mixed to electroencephalogram signal, it is necessary to remove this signal. A notch filter that passes most frequencies unaltered is used to remove such signal. Figure 4 and Figure 5 show the results of our filters.

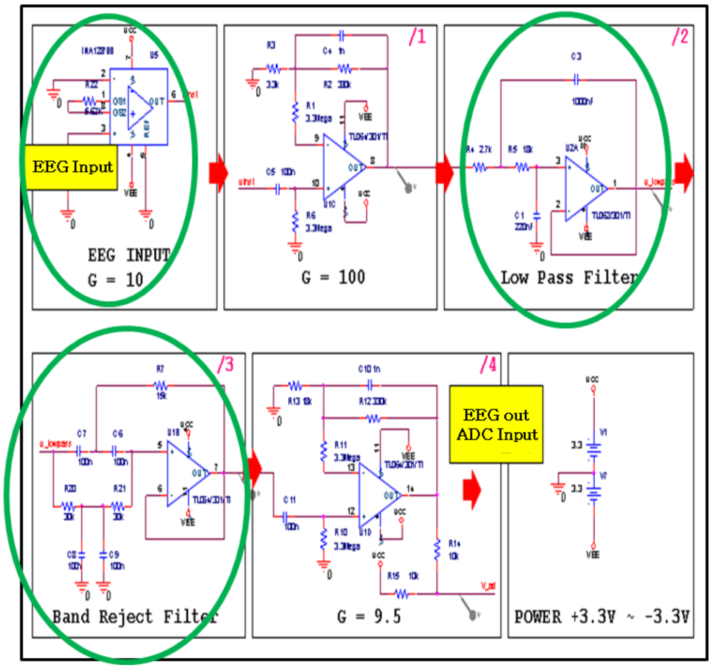


Figure 3. EEG sensor signal filter and amplifier circuit

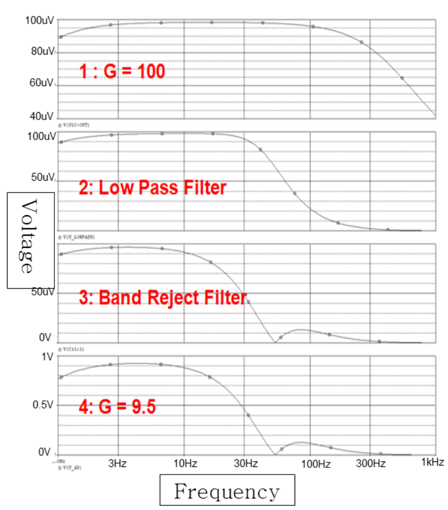
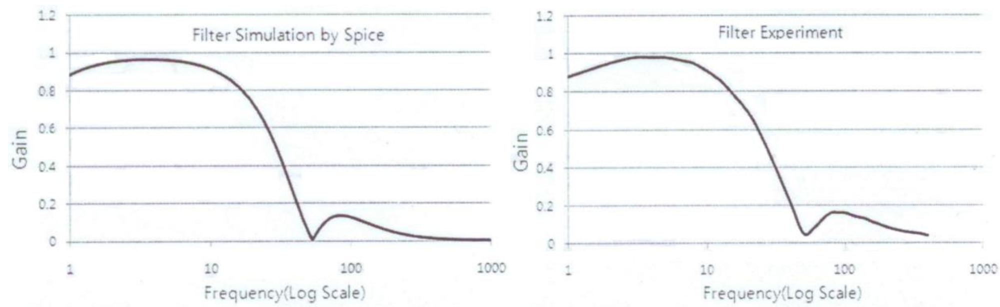


Figure 4. EEG sensor signal filter and amplifier circuit



(a) **(b)**

Figure 5. Results from (a) simulation and (b) actual experiment of the filter

3.2. FFT

The Electroencephalogram signal is transformed into frequency band using the Fourier transform. The Fourier transform is defined by equation (1).

$$G(k) = \sum_{n=0}^{N-1} g[n]\left(cos\left(\frac{-j2\pi nk}{N}\right) + j\,sin\left(\frac{j2\pi nk}{N}\right)\right), k = 0, 1, \dots, N-1 \quad (1)$$

We use 256 point decimation-in-frequency as radix-2 fast Fourier transform algorithm[5] to improve the speed of the calculation. Radix-2 FFT has been implemented in hardware description language Verilog HDL using fixed point arithmetic on FPGA. Also, Forward transform is only implemented because original signal exists in buffer.

The EEG signal as input data has been broken into eight parallel data stream. In our implementation, input data is stored to a single port RAM whose size is 8x256x12. To avoid read and write conflict, we control data flow in memory using double buffering with two single port RAMs. The output data is stored to a single port RAM whose size is 1x256x12 and sent to USB or UART FIFO.

The Hamming window function[6] as shown in equation(2) is applied to the sample before calculating the Fourier transform. It's basically a smoothing function that will make our samples look a bit nicer. The FFT class has a function by which we can enable Hamming window smoothing.

$$w[n] = 0.54 - 0.46\cos\left(\frac{2\pi n}{N}\right), 0 \le n \le N-1 \quad (2)$$

3.3. PC interface

The EEG signal is sent to the hose PC via RS232 or USB. USB device that uses USB2.0 high speed protocol transmits a packet with a unit of 2,048 bytes to the hose PC two times. The used USB transfer mode is bulk mode. Although the bulk mode guarantees the delivery of data transfer, it doesn't guarantee the bandwidth of data transfer. So we need a FIFO of appropriate size. This paper used FIFO which is 16 times bigger than packet.

3.4. Spectral analysis

What is important in this system is not whether the signal is part of the sine or cosine series but how much information is contained at a particular frequency[7]. Therefore, we are interested in the absolute value of the FFT coefficients. The absolute value will provide the total amount of information contained at a given frequency, the square of the absolute value as shown in equation (3) can be considered as the power of the signal. Equation (4) shows the calculation in log scale.

$$|X[k]|^2 = Re(X[k])^2 + Im(X[k])^2 \quad (3)$$

$$10\log_{10}|X[k]|^2, \quad k = 0, 1, \ldots, N/2 \tag{4}$$

4. Results

Figure 6 (a) shows EEG signal which is stored to PC after processing the filtering and amplifying. Figure 6 (b) shows EEG frequency spectrum that is transformed to the Fourier transform by FPGA.

Electrodes is placed on F3, F4, C4, P3, P4, O0 and O1 as shown in figure 7 according to international 10-20 electrodes system. The interval of the data stored to PC as shown in figure 6 is 2.5 second. As shown in the frequency spectrum, it shows the signal is not affected by the notch filter with the frequency of a power supply at 50Hz-60Hz. Figure 8 illustrate the results of analysis according to the display mode which can be set.

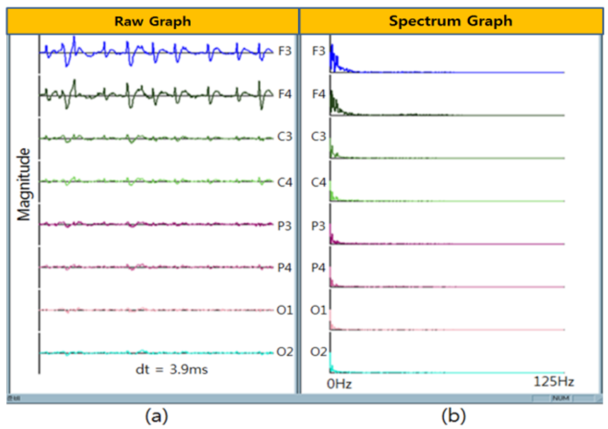


Figure 6. (a) EEG signal (b) EEG frequency spectrum

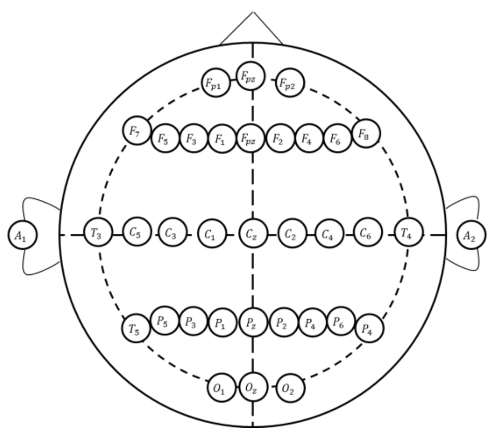


Figure 7. International 10-20 electrodes system

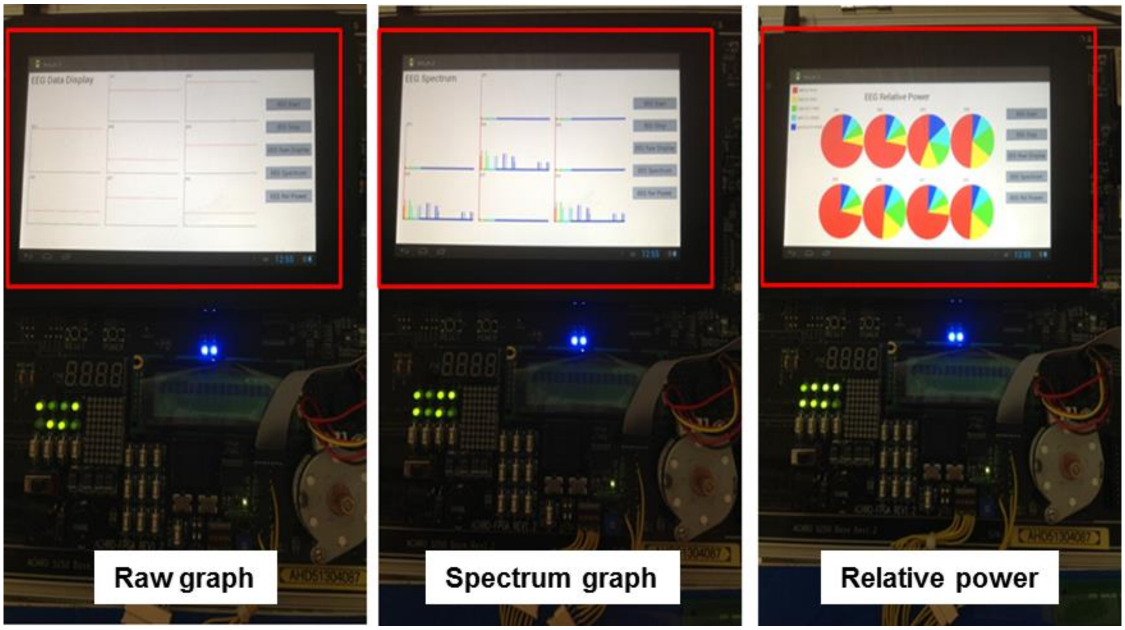
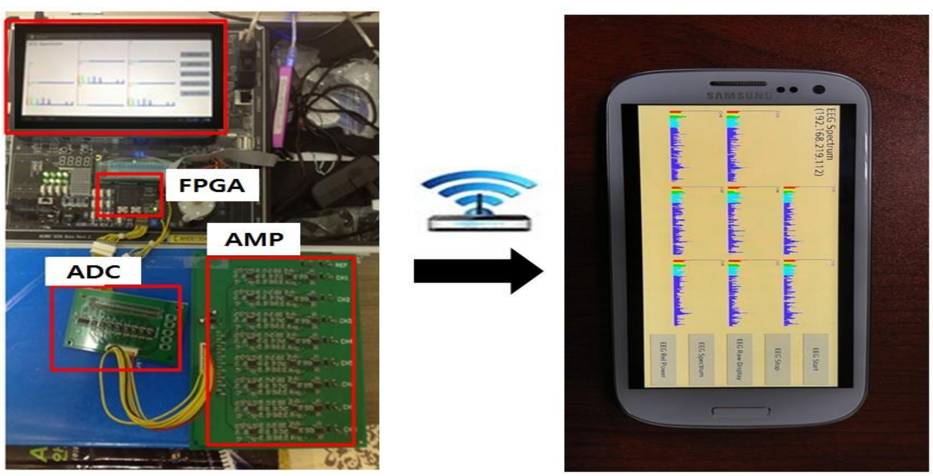


Figure 8. EEG analysis

5. Conclusions

Figure 9 shows the platform for real-time EEG analysis system. This platform is composed of the analog part and digital part. The analog part processes EEG signal that swings within few microvolts at particular frequency. The digital part analyzes the EEG signal using Fourier transform and the signal is transferred to mobile device via Wi-Fi. The platform has been implemented on FPGA development board. The platform can be made as portable and self-diagnostic device and used for other simple applications. Finally, the real-time EEG analysis system can be used as experimental system and assistant tool for the brain wave laboratory as well.



(a) **(b)**

Figure 9. Entire system structure of the platform for EEG signal; (a) FPGA board; (b) smart phone

6. References

[1] Casson A, Yates D, Smith S., J Duncan, E. Rodriguez-Villegas, Wearable Electroencephalography. IEEE Engineering in Medicine and Biology Magazine v.29 no.3. 2010;44–56.
[2] Samei S, Chamber J. EEG signal Processing. John Wiley & Sons, Ltd; 2007.
[3] Jaakko Malmivuo, Robert Plosey, Bioelectromagnetism. Chapter 13.5; 1995.
[4] Chung-Heon L, Gyu-dong K. A study on mobile based EEG display and device development. IEEK. 2009;145–147.
[5] Ryan Thomas Bone. FPGA Design of a Hardware Efficient Pipelined FFT Processor, BS Thesis;2005.
[6] Applcation Note14. Understanding FFT Windows, Application Note 14 LDS Dactron.
[7] Brian D.Storey. Computing Fourier Series and Power Spectrum With MATLAB, Lecture Note.