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# Modular, Bluetooth Enabled, Wireless Electroencephalograph (EEG) Platform

Joseph A. Lovelace, Tyler S. Witt and Fred R. Beyette, Jr. *Member, IEEE*

*Abstract*—**A design for a modular, compact, and accurate wireless electroencephalograph (EEG) system is proposed. EEG is the only non-invasive measure for neuronal function of the brain. Using a number of digital signal processing (DSP) techniques, this neuronal function can be acquired and processed into meaningful representations of brain activity. The system described here utilizes Bluetooth to wirelessly transmit the digitized brain signal for an end application use. In this way, the system is portable, and modular in terms of the device to which it can interface. Brain Computer Interface (BCI) has become a popular extension of EEG systems in modern research. This design serves as a platform for applications using BCI capability.**

## I. INTRODUCTION

Electroencephalography (EEG) is used for medical, research, and commercial applications. A number of neurological pathologies can be assessed by use of EEG, including epilepsy, coma, brain death, as well as a number of sleep disorders [1]. As such, EEG technologies are being brought to the forefront of medical research, and the designs for these systems are continually improving in quality, size, and portability.

The current EEG systems are large, stationary systems that require the patient to be tethered to the system via a wired connection. The signal passes through this connection to an amplification and processing system, then on to a display, where the user can view the signals. The hardware described in this paper consists of two main modules that are wirelessly paired together. The first module includes multiple subsystems that, together, will acquire the brainwaves and digitally transmit them via Bluetooth to the Target Device. The preferred embodiment of the Target Device is a wireless electronic device, such as a tablet computer, which will allow the user to view the EEG data remotely and efficiently.

In many recent attempts to design modern EEG systems, the applications and uses can be quite narrow in nature. The hardware platform of this system is designed such that the "master" device on which the EEG is to be viewed and possibly further processed can be interchangeable to an extent. The only requirement is that the Target Device must be Bluetooth enabled to be compatible with the proposed system. Furthermore, the acquired EEG will not be band-limited or preprocessed in any way that destroys useful signal.

Despite these advances in portability and adaptability, the integrity of the EEG signals being acquired and transmitted will be verified through a comparison test with a calibrated system; namely, the g.USBamp 3.0 system [2]. This system, manufactured by g.tec Inc., allows for up to sixteen channels of EEG data acquisition per USB amplifier. The g.USBamp allows for 24-bit resolution and will simultaneously sample all channels at a rate that reaches a maximum of 38.4kSPS. While the g.USBamp system is an FDA-listed medical device, its utility is limited by the fact that it is a fully wired solution which communicates its data through a hardwired connection via USB protocol. In addition, the system is large (shoe box sized) and relatively expensive rendering it impractical for real-time evaluation of mobile subjects. While the g.USBamp is not well suited for mobile application, it provides an excellent standard for performance comparison. Thus, by evaluating our design's accuracy and competency by the standards of the g.tec system we can show that our system is comparable in EEG signal quality and superior in portability, affordability, and adaptability.

A major extension of this EEG platform design is to facilitate the use of Brain Computer Interfacing (BCI technologies). BCI is a technology which first appeared in the 1970's, and whose main focus is to use the mind to control some external circuitry/hardware (such as a prosthetic limb) [3]. EEG is a popular platform for signal acquisition in BCI applications due to its non-invasive nature. In recent research, EEG based BCI systems have been able to control complex mechanics such as a motorized wheelchair and many other systems which can increase mobility and quality of life of paralyzed individuals [3]. The proposed platform, being very portable and wireless, would allow for many applications of BCI, both medical and commercial.

## II. ELECTROENCEPHALOGRAPHY

EEG is a non-invasive method of measuring brain signals from the scalp. The method is conducive to repeated application and involves very little risk of physical harm [4]. The normal range of amplitude in recorded brain waves is from 0 to 100uV in EEG (signal amplitude is 100 times lower than ECG, and 500 times lower than EMG). The frequency range of clinically and BCI relevant EEG signals

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Joseph A. Lovelace is with the University of Cincinnati School of Electronics and Computing Systems, Cincinnati, OH 45221-0030 USA (phone: 513-556-4588; fax: 513-556-7326; e-mail: lovelajh@mail.uc.edu).

Tyler S. Witt is with the University of Cincinnati School of Electronics and Computing Systems, Cincinnati, OH 45221-0030 USA (e-mail: wittts@mail.uc.edu).

Fred R. Beyette Jr. is with the University of Cincinnati School of Electronics and Computing Systems, Cincinnati, OH 45221-0030 USA (e-mail: Fred.Beyette@uc.edu).

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is from ~0.5 Hz to ~50 Hz [5]. These signals can provide very useful data about a person based on the general principle that signals in the brain co-vary with cognitive processes and respond quickly to stimulus [6]. Thus, capturing signals accurately and quickly is an important aspect of EEG.

EEG is used today in two major areas; Clinical and Research. In clinical systems, working parameters are well defined and the focus is on isolating EEG signals in the classical sense. This method requires time to individually prepare each of the electrode locations, attachment of the electrodes and application of conductive gel. A trained EEG technician typically performs these steps. Research level systems have a much wider variety of applications and goals. In such systems, a design tradeoff between specificity and portability is commonly made in the early stages. Recently attempts have been made [7,8] to attain adaptability and portability in the same device, as is the goal of this work.

## III. DEVICE DESCRIPTION

The system that is described in detail below serves to simplify and improve on existing designs, particularly in terms of portability, adaptability, and modularity.

### *A. General overview*

The system can be divided into a number of subsections, each of which is comprised of individual hardware components. See Fig. 1 for a general block diagram of the system. The first subsection that the subject comes in contact with is the electrodes. The electrodes and the leads from them provide a channel for the brain waves to reach the Analog Front End (AFE). The AFE is the portion of the hardware that will collect the brainwaves from the subject and convert them to digital signals. The next subsection of the hardware is the Digital Control and Processing subsection. This subsection contains the hardware that will control the AFE, as well as the hardware required to transmit the digitized data via Bluetooth to the final Target Device. The Target Device is designed to do additional signal processing and allow the processed data to be viewed.

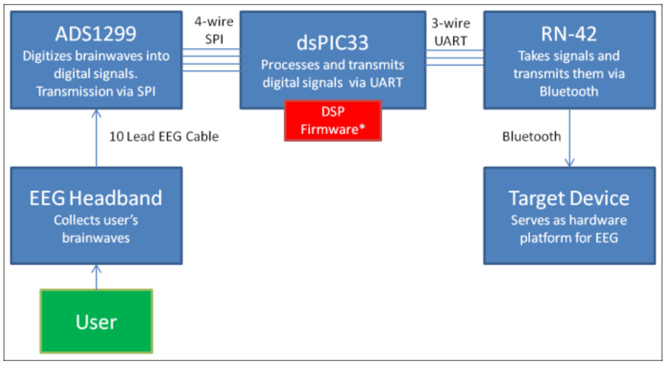

Figure 1: Block Diagram of EEG System

### *B. Analog Front End*

Dedicated EEG acquisition integrated circuits are commercially available which provide necessary amplification and analog-to-digital conversion. The specific IC used in this device is the Texas Instruments ADS1299. This AFE features eight channels capable of simultaneous sampling at up to 16 kSPS [9]. Each channel has an independent low noise programmable gain amplifier (PGA) and 24-bit Delta-Sigma Analog-to-Digital Converter (ADC). Figure 2 shows a logical block diagram of the ADS chip and its general inputs and outputs. The IC is highly configurable in terms on the physical arrangement of the reference and measurement channels. Each channel is a differential amplifier that can switch between the negative pin of that channel and the reference as the negative input to the differential amplifier, via control inputs. This makes the ADS1299 ideally suited to test various reference configurations while also providing functionality to do on chip testing and temperature measurement.

The IC contains the majority of what is needed to realize the EEG acquisition function. A custom PCB will be created to surface mount the ADS1299, current limiting components and power supplies. In this manner it would be possible to locate the AFE directly behind the electrode, only utilizing one of the measurement channels. However, as this particular AFE is highly configurable and exhibits very low input-referred noise, it is an appropriate platform to test the relationship between Signal-to-Noise (SNR) and the length of wire for connection of electrodes to the ADS1299.

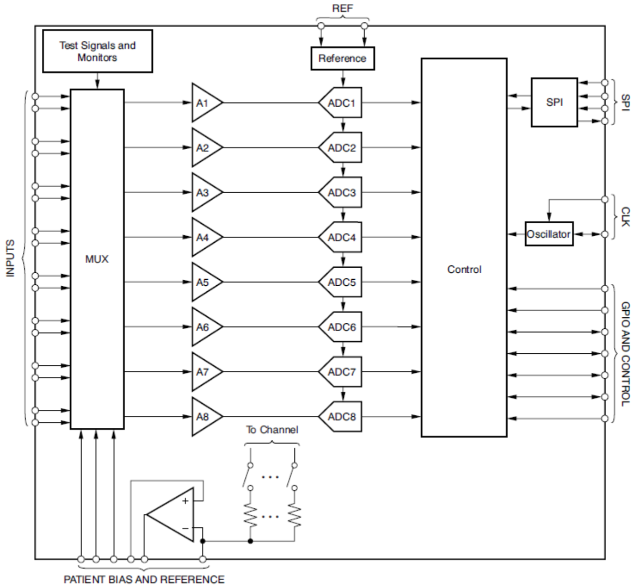

Figure 2: Logical block diagram of TI ADS1299 with general inputs and outputs from datasheet

### *C. Digital Control and Processing*

The Digital Control and Processing subsection of the hardware platform is designed to be the core component of the system. A DSP (digital signal processor) and a Class 2 Bluetooth Module were chosen as the individual components for this subsection of the hardware. More specifically, the dsPIC33FJ256GP710A dsPIC from Microchip and the RN-42 Bluetooth Module from Roving Networks were chosen [10-11]. The dsPIC33 provides the speed and size that is necessary to transmit the large amount of data created by the AFE successfully. The main functions of this subsection are to accept the digitized data from the AFE, to setup and control the AFE hardware, and to communicate via Bluetooth to the Target Device.

To handle data transfer and set up of the AFE, the dsPIC must communicate using the SPI communication protocol. The proper firmware application must be loaded onto the dsPIC such that the configuration registers of the ADS1299 are properly setup for the application's purposes. In addition to this, the dsPIC firmware must also contain the correct task scheduling and usage of the UART & SPI communication protocols such that all Bluetooth communications and interactions are properly handled. While the AFE only requires the use of the SPI communication protocol, the RN-42 Bluetooth Module requires the use of an on board EEPROM that can be controlled by the dsPIC via SPI, as well as direct communication to the Bluetooth Module via UART.

### *D. Target Device*

The Target Device subsection of the hardware is the end-user application portion of the hardware. This subsection is designed to be interchangeable in the sense that a similar visualization of the EEG data can be expressed on a similar device (PC, laptop, tablet, etc.). Portability is the main focus of this design and as such, the initial plans for the target device hardware are to use a tablet to interface with the Digital Control and Processing subsection via Bluetooth and view the results in real-time. A similar software platform can be created for a number of different devices such that the EEG data can be visualized real-time.

### *E. Electrodes*

A custom electrode is proposed which will feature concentric, electrically isolated rings of metal prongs protruding from the 12mm diameter base, toward the scalp of the subject. The proposed electrode is an adaptation of a novel design by Matthews et al [7]. Depending on the particular measurement configuration desired the outer ring of prongs could be used as ground, reference, or even a second measurement channel. The inner prong ring will be electrically attached to the positive terminal on the AFE's measurement inputs.

### *F. DSP Techniques*

DSP techniques, employed to obtain useful information from the raw EEG signals, are an important component of this hardware platform. Such techniques can help to extract the frequency content of the EEG signal, as well as to remove any motion artifacts that may not be a true representation of the brain waves. The latter is extremely important in a portable system such as this.

The primary challenge of creating a portable system is dealing with a mobile subject. Any movement in the upper body causes Electromyography (EMG) to dominate the EEG signal. Similarly, any movement of the electrodes relative to the patient's head will cause motion artifacts to dominate the data. Methods of overcoming these two sources of interference are the object of a great deal of research. One such method is the Independent Component Analysis (ICA) algorithm. ICA analyses a group of signals and discerns the components that make up those signals. It has been shown that eye blink artifacts, and potentially many other, can be removed [12]. By rejecting non-regular components, original or partially original EEG data can be recovered.

The second important processing technique is to derive the frequency content of the EEG signal. Autoregressive algorithms used for spectrum analysis of frequency content can be a powerful tool in the processing of EEG signals [13]. In filter design, autoregression is often thought of as an infinite impulse response filter [14]. While both this method and the Fast Fourier Transform (FFT) are being used for this premise, this system chooses to use the autoregressive approach due to the adaptability of autoregressive systems and the limitations of the FFT approach [15]. This algorithm may be employed either at the Digital Control and Processing subsection, or in the Target Device subsection. Either way, this algorithm will help to display the digitized brain waves in a format that is easier for a user (or software) to recognize EEG events.

## IV. CURRENT RESULTS AND ONGOING WORK

The ADS1299 was tested in three configurations. First, as a single channel unit, with the measuring electrode connected directly to a measurement pin on the IC, i.e. as close to the input of the IC as possible; secondly, as a four channel unit with a wire length of 50 mm wires between the input pin and the measuring electrode; finally, all eight channels of the ADS1299 were used with 100 mm wires between electrode and pin. A 50mV peak to peak sine wave, at a frequency of 1 Hz, was applied to the measurement electrodes and noise approximations were made. The noise was averaged per channel and is presented in Table I as Signal-to-Noise Ratio. For all three configurations a SNR of 35 dB was calculated, with negligible variations. This implies wires of 100 mm or less between the electrode and AFE input pin have little to no effect on the signal quality.

TABLE I. SNR FOR DIFFERENT WIRING CONFIGURATIONS

| *Wiring Configuration Description* | *Wire Length (mm)* | *SNR* |
|---|---|---|
| Indiv. Electrodes, Direct, No wire | 1 | 35.568 |
| 4 Electrodes, Short Wires | 50 | 35.405 |
| 8 Electrodes, Long Wires | 100 | 35.203 |

TABLE II. DATA RATE LIMITATIONS

| *# Channels* | *Bits/sample* | *SPS* | *bits/s* | *Kbps* | *Mbps* |
|---|---|---|---|---|---|
| 1 | 24 | 4000 | 96000 | 93.75 | 0.0915527 |
| 2 | 24 | 4000 | 192000 | 187.5 | 0.1831055 |
| 4 | 24 | 4000 | 384000 | 375 | 0.3662109 |
| 8 | 24 | 4000 | 768000 | 750 | 0.7324219 |
| 16 | 24 | 4000 | 1536000 | 1500 | 1.4648438 |

dsPIC Limitation: 4 Mbps in High Speed UART
RN42 Limitation: 921 Kbps

A main concern when choosing the individual components for this design was data bandwidth capabilities. As can be seen from Table II, the various data transfer rates are detailed to show that the hardware can handle the data transmission properly. Also shown in the table is the point at which the hardware design would break down.

The TI ADS1299 is capable of output data rates up to 16kSPS, and multiple ADS1299's can be put in parallel to increase the amount of channels [10]. From the data above, it is apparent that if the data rate (for eight channels) is pushed past the 4000SPS mark, the data becomes too much for the RN42 Bluetooth module to handle [12]. Finally, if more channels are desired, the sample rate must be limited such as to fit the limitations of the RN-42.

As a preliminary functional test, the ADS1299-EVM and the g.tec g.USBAmp were used to collect EEG from the same subject at adjacent times. An EEG cap was used which has measurement electrodes at standard 10-20 locations FP1, FP2, O1, and O2. After electrodes were applied to the test subject and checked for proper impedance levels, a simple set of tests were performed to ensure proper functioning of the acquisition system. The subject was asked to close their eyes and relax. During this time, alpha waves should be prevalent in O1 and O2. The subject was then asked to open their eyes, and blink three times. Three characteristic EMG pulses should be observed on channels FP1 and FP2. This test is standard practice in most clinical EEG procedures as a logical step to ensure the EEG acquisition system is functioning properly. Screen captures from both systems are presented side by side in Figures 3.

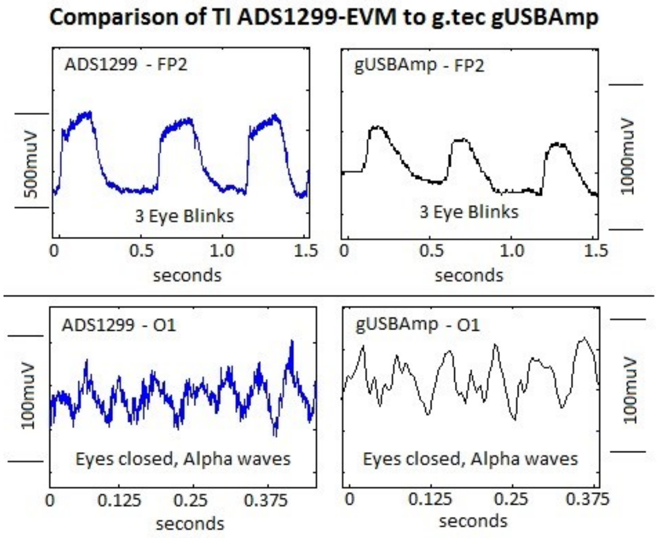

Figure 3: Comparison of ADS1299-EVM to g.tec gUSBAmp functionality test.

The ADS1299-EVM is an evaluation board for the ADS1299 that feature no enclosure or shielding of any kind. It is also important to note that only a notch filter was used to remove 60 Hz noise on the ADS1299, otherwise the EEG signal is completely raw.

## V. CONCLUSIONS

Preliminary experimentation indicates that the purposed design is capable of creating an EEG platform with signal acquisition quality comparable to current systems. The improvements that this design exemplifies are its portability and adaptability. The portability of the platform will allow the system to be utilized during patient activity. In addition to this, the wireless transmission and small size of all components will allow remote observation of relevant EEG data. The adaptability of the system will allow a variety of end application users, including non-medical personnel.

A study using EEG to assess the fatigue of firefighters while on duty provided the initial design considerations. The compact, modular form of this design will allow the system to be implanted in a helmet where it can be worn unnoticed for long periods of time. An additional medical application would be to allow an epileptic patient to wear an EEG cap for long term, remote assessment and observation of seizure events. Many research based, BCI applications also exist. A novel example of this would be to create a completely mind-controlled exoskeleton to allow a paraplegic patient to function independently.

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