# BCI Implementation Report

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***Abstract*—As research progresses, the original tools purchased from OpenBCI are no longer able to meet the needs of electroencephalogram (EEG) signal acquisition. There is an urgent need by our client for a low-cost EEG acquisition systems' hardware with higher amounts of channels and strong customizability. This report presents the capstone project of CSE453 of the University at Buffalo. The goal of the design is to manufacture a PCB board that can support multiple channels for capturing EEG signals at a lower cost. Our project only contains a PCB design and a prototype board that is built on the breadboard so far for now. However, This rebuilds hardware from scratch to minimize the cost of future upgrades. Currently, the prototype supports 4-Channel EEG signals acquisition and can receive digital data by using Bluetooth. The source code and design diagrams are available at https://github.com/Tyson-Hu/Brain-Computer-Interface_Project.**

***Index Terms*—brain-computer interface, rapid prototyping, open-source, electroencephalogram**

## I. Introduction

This project is our CSE453 capstone, designed and implemented with the topic "Brain-Computer Interface". We implemented a 4-Channel EEG signal prototype with 100Hz frequency input and designed the PCB board with 16-Channel. Our project has features of

- Low Cost. Compared to OpenBCI boards, our project product can get the same features for a quarter of the price.
- Higher amounts of channel. Based on our 4-Channel EEG signal prototype, the amounts of channel can be customized by following the Daisy-Chain Configuration, which the rest AD converter will transfer their digital data to the AD converter that is connecting to micro-controller, through the connection between DAISY_IN and DOUT.
- Open Source. Our resource code is based on GitHub code with GNU GENERAL PUBLIC LICENSE, so the code is free to use and change.

## II. Components

The whole prototype is combined with three components, which are Analog Digital Converter, Bluetooth, and micro-controller. Through the three components, the 4-Channel EEG signal prototype can read analog signals from electrode input, convert analog to digital, and send the digital to a peripheral device that is connected to Bluetooth.

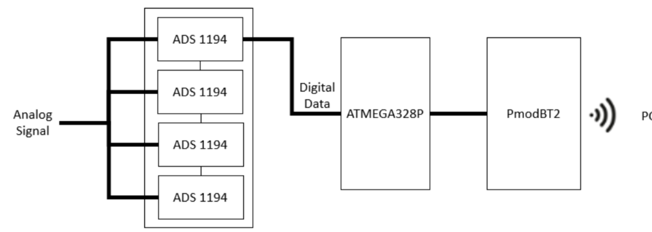


Fig. 1. Prototype-board component connection

### A. Analog Digital Converter

This component will receive the input analog signal from electrodes, and convert it to digital data. We chose the ADC chips from Texas Instruments with the model of ADS119X family - ADS1194. The ADS1194 is used with low-power and supported 4-Channel and 16-Bit Analog Front-End measure, so the final PCB board will be manufactured with four ADS1194 chips to configure as 16-Channel.

Once ADS1194 receives a command on the DIN pin from the micro-controller through SPI communication, ADS1194 will process the data, and send data back to the micro-controller. The commands are included and follow the order below

- `RESET`: Reset to Default Setting
- `SDATAC`: STOP Read Data Continuous mode (must called after `RESET`)
- `START`: Turn ON / OFF ADS1194 to convert input
- `RDATAC`: Enable Read Data Continuous mode
- `WREG`: Overwrite ADS1194 registers
- `RREG`: Read ADS1194 registers

ADS1194 has input with 100Hz frequency by 250 SPS and Gain 1. To operate the ADS1194, we set up its Analog supply (AVDD-AVSS) to 5 V and Digital supply (DVDD-DGND) to 3 V, and connect VCAP and VREF to ground with capacitors.

### B. Micro-controller

This component is mainly used to communicate with Analog Digital Converter and Bluetooth as SPI communication and UART communication. The communications are provided by the ATMEGA328P micro-controller on Arduino UNO Rev3, which has 4 SPI pins (SCK, CIPO, COPI, & SS), and 2 UART pins (TX & RX).

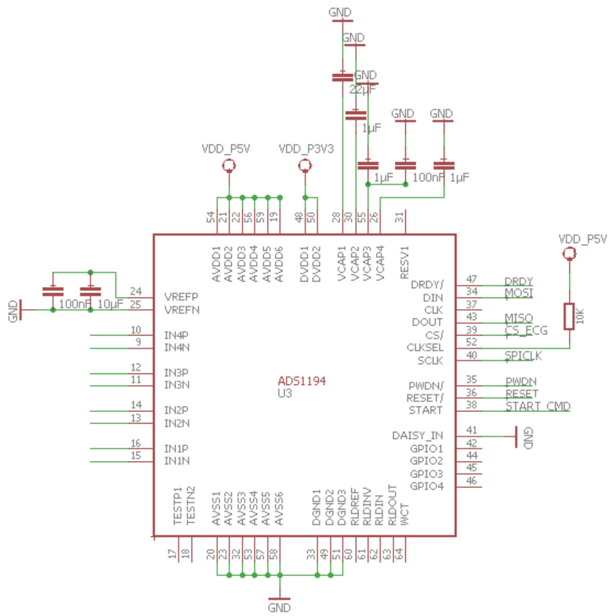


Fig. 2. ADS1194 Schematic

The ATMEGA328P is compiled by Arduino IDE. From the Arduino IDE, we send commands and set up registers to the ADS1194 chip by SPI communication, and also send digital data to the Bluetooth module by UART communication. To set up the registers of ADS1194, we called the `WREG` function in Arduino IDE to send `WREG` commands with the register addresses and data,

TABLE I
REGISTER CONFIGURATION

| **Address** | 0x1 | 0x2 | 0x3 | 0x5 - 0x8 |
|---|---|---|---|---|
| **Register** | Config1 | Config2 | Config3 | CHnSET |
| **Bit 7** | 0 | 0 | 1 | 0 |
| **Bit 6** | 0 | 0 | 1 | 0 |
| **Bit 5** | 0 | 1 | 1 | 0 |
| **Bit 4** | 0 | 0 | 0 | 1 |
| **Bit 3** | 0 | 0 | 1 | 0 |
| **Bit 2** | 1 | 0 | 1 | 0 |
| **Bit 1** | 0 | 0 | 0 | 0 |
| **Bit 0** | 1 | 0 | 0 | 1 |

*For more information, check ADS119X User Manual [1].

the registers will be set as Table I above with settings of

1) `Config1`
   a) Daisy Chain Model [Bit6]
   b) Oscillator clock output disabled [Bit5]
   c) 250SPS [Bits2-0]
2) `Config2`
   a) Test signals are driven externally [Bit4]
   b) –1 × (VREFP – VREFN)/2.4mV [Bit2]
   c) Pulsed at Pulsed at $f_{clk}/2^{21}$ [Bits1-0]
3) `Config3`
   a) Enable internal reference buffer [Bit7]
   b) VREFP is set to 4V [Bit5]
   c) Open [Bit4]
   d) RLDREF signal (AVDD – AVSS)/2 [Bit3]
   e) RLD buffer is enabled [Bit2]
   f) RLD sense is disabled [Bit1]
   g) RLD is connected [Bit0]
4) `CHnSET`
   a) Normal operation [Bit7]
   b) 1 PGA gain [Bits6-4]
   c) Normal electrode input [Bits2-0]

To communicate with both ADS1194 and Bluetooth, we set the SPI baud rate to typical 1MHz, and the UART baud rate to 115200 bps. Then we follow the step below to interact with the two components

1) Power-Up oscillator by active $\overline{PWDN}$ to high
2) Send `RESET` and `SDATAC` commands to reset ADS1194
3) Send `START` command to start ADS1194 conversion
4) Send `RDATAC` command to read and convert analog data
5) Receive Digital Data from ADS1194 from CIPO pin
6) Transfer Digital Data to Bluetooth through TX pin

### C. *Bluetooth*

With the PmodBT2 component, data can be transmitted wirelessly between the peripheral device and our board. This component, developed by Digilent, uses a UART interface with a default baud rate of 115200 bps to transfer 8 data bits. To synchronize the PmodBT2 with our ATMEGA328P micro-controller, we also set the UART baud rate to 115200 bps. When digital data is received from ADS1194 by our ATMEGA328P micro-controller, it will transfer the data through the TX pin to the PmodBT2 RXD pin via UART serial communication. The result will automatically display on the Serial Terminal.

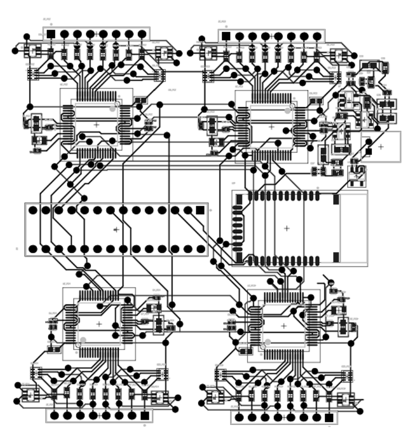

Fig. 3. Final PCB Layout

## III. PCB DESIGN

The final PCB design is a 2 layer board with a size of 3.1 X 3.3 inches. The design contains the 4 ADCs surrounding the microprocessor and Bluetooth module. Placing the 4 ADCs on the outer edges leads to the pin headers being on either side of the board, which is not an efficient design. This was chosen to simplify the routing and reduce the layers of the board.

## IV. Testing

Our team has developed a prototype for a 4-Channel EEG signal and 16-Channel PCB design. Extensive testing was conducted using Analog Discovery 2 to simulate and generate an ideal analog sine wave for testing purposes. The results showed that the analog wave created by the digital data captured was identical to the 20 Hz input sine wave. Even when the frequency was increased from 20 Hz to 100 Hz, the sine wave can still be captured with little noise.

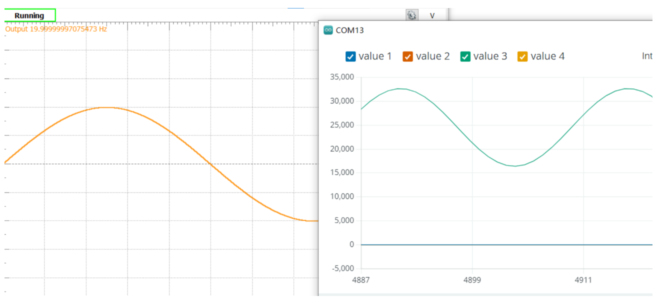


Fig. 4. Simulation Test Result

Since the simulation result works well, the first EEG signal acquisition started. Figure 5 below doesn't look like a brain wave, because the wave frequency is too low.

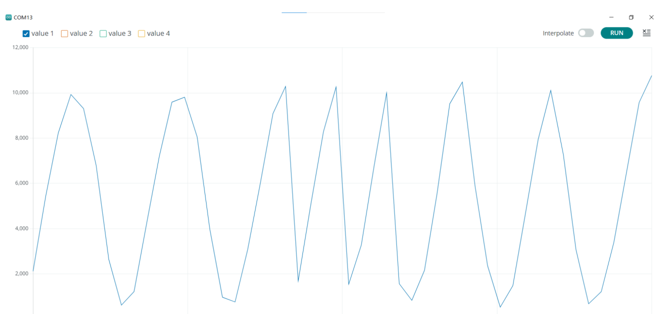

Fig. 5. Initial Test Result

After increasing sample acquisition as Figure 6, the brain-wave is now much more reasonable.

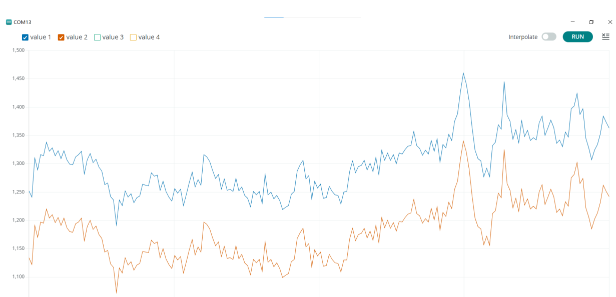

Fig. 6. Initial Test Result After Zoom Out

Figure 7 from Wikipedia [2] shows several types of brain-waves based on the different frequencies of the wave. Since our prototypes focus on the EEG signal with 100 Hz frequency, the brainwave will be a high Gamma wave that is between 70–150 Hz.

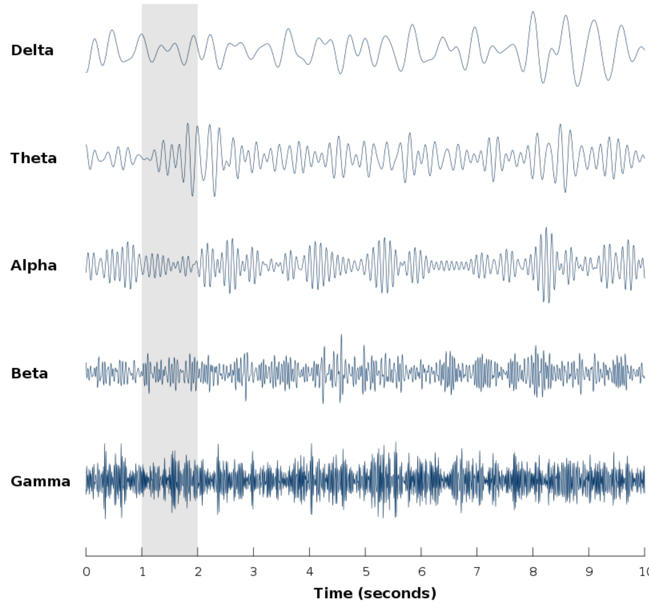


Fig. 7. Normal Brian-wave Looks

Based on the Gamma wave look, we knew that a high Gamma wave will have fast frequencies and high amplitude Spike, which in Figure 8, our result also achieves all the features of a high Gamma wave by increasing the sample rate to 250 with PGA Gain 1.

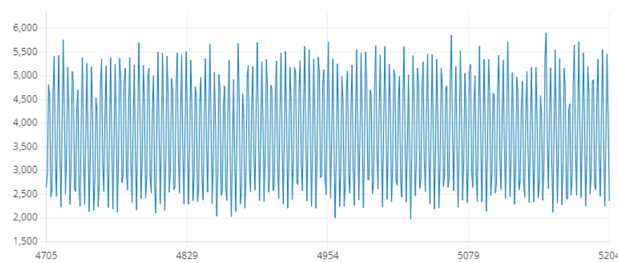


Fig. 8. Test Result after resolution

## V. Future

There are still far away from the initial design, and it could be done in the future with the following updates:

- Extended 4 channel to 16 channel
- USB connection (Power & Data transfer)
- SD card storage
- WiFi module

### A. Daisy-chain Mode

As said before, our project supports higher amounts of channels through Daisy-Chain Configuration. The Daisy-Chain Configuration extends the input of the board from 4-Channel to 16-Channel, and the ATMEGA328P micro-controller will communicate with all 4 ADS1194 at the same time.

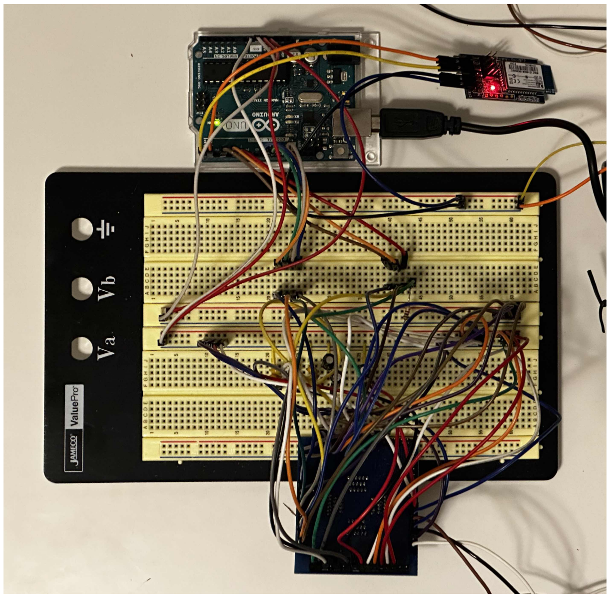

Fig. 9. Prototype Board

To configure the Daisy-Chain, only a few steps to implement

- As Figure 10 shown, the rest ADS1194 DOUT should be connected to the DAISY_IN of previous ADS1194, and the last one ADS1194 DAISY_IN should be connected to ground.
- All 4 ADS1194 pins (CS, SCLK, & DIN) needed to share the same digital signals from ATMEGA328P pins (CS, SCLK, & MOSI).
- An 2.048MHz external clock should be connected with all ADS1194 to replace the current 2.048MHz internal clock from an ADS1194 to keep consistency. Otherwise, it has 4 internal clocks, and may cause unexpected data by being asynchronous (FLP).

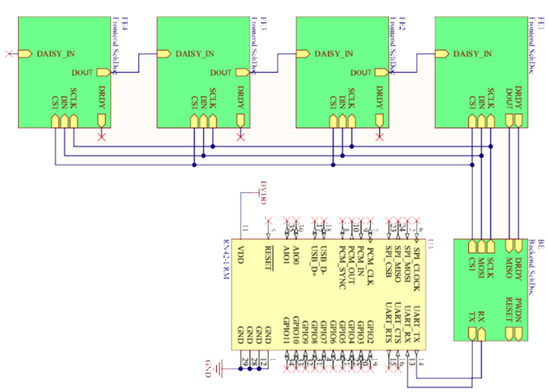


Fig. 10. Daisy-chain Mode

### B. USB connection

The original design only used a 3.3V rechargeable battery as the power supply. However, this is not an all-time function support based on the capacity limitation of the battery. A USB connection add-on could be used for both data-transfer and power supply which improves the board's flexibility.

### C. SD card storage

Having SD card support enables the board to capture and store data even when you're unable to immediately process it. This feature also serves as a backup for data transmission issues through Bluetooth.

### D. WiFi module

When considering options for transmitting large amounts of data, it is worth noting that Wi-Fi provides greater bandwidth and speed when compared to Bluetooth. This advantage is evident not only in our four-channel prototype, but also becomes increasingly effective as the number of channels and sample rate increase. Therefore, Wi-Fi is a reliable choice for those seeking to transmit significant quantities of data.

## REFERENCES

[1] None. (April 2010). Low-Power, 8-Channel, 16-Bit Analog Front-End for Biopotential Measurements. Texas Instruments. Retrieved from https://www.ti.com/lit/ds/symlink/ads1194.pdf

[2] None. (April 2023). Neural oscillation. Wikipedia. Retrieved from https://en.wikipedia.org/wiki/Neural_oscillation