By

Aidan Stahl

Kavin Bharathi

Vikram Chakravarthi

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TA: Hossein Ataee

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# Contents

# 1. Introduction

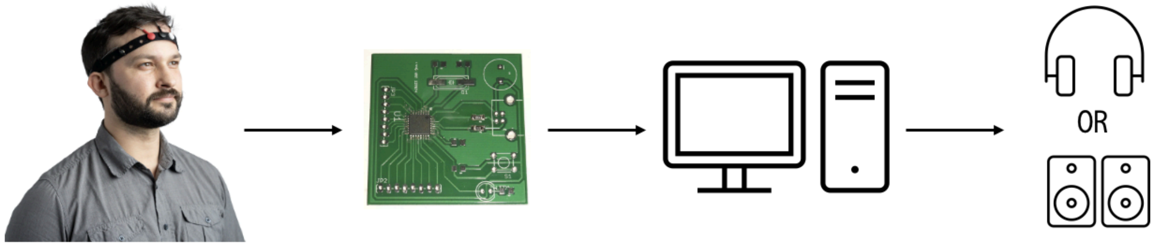
Briefly describe the science or engineering problem to be addressed in the report, as well as the purpose and usefulness of the device or system you have built. Summarize the contents of the upcoming chapters as well as the main conclusions of your project, to be elaborated in the last chapter.

Many common neurological conditions like Alzheimer's disease, depression, and memory issues are associated with patients receiving lower quality sleep. Specifically, these issues often stem from a lack of a specific type of sleep known as slow wave sleep (SWS). As individuals age, sleep disorders and other sleep-related issues lead to a lack of overall sleep. As a result, the amount of time an individual spends in SWS and the quality of SWS they experience typically declines with age, contributing to many of the issues mentioned above. Our team is trying to improve sleep quality using a wearable device that is non-invasive and cost effective. This device will record EEG waves and then detect when the user is in Slow Wave Sleep (SWS) using the aid of specialized software. Once the user enters SWS, the system emits carefully timed bursts of pink noise through an auditory interface to enhance slow wave activity and extend its duration. The team that we're working with, Team 05 - Acoustic Stimulation to Improve Sleep, has cited studies that back up the effectiveness of pink noise bursts during SWS in improving overall memory.

High Level Requirements:

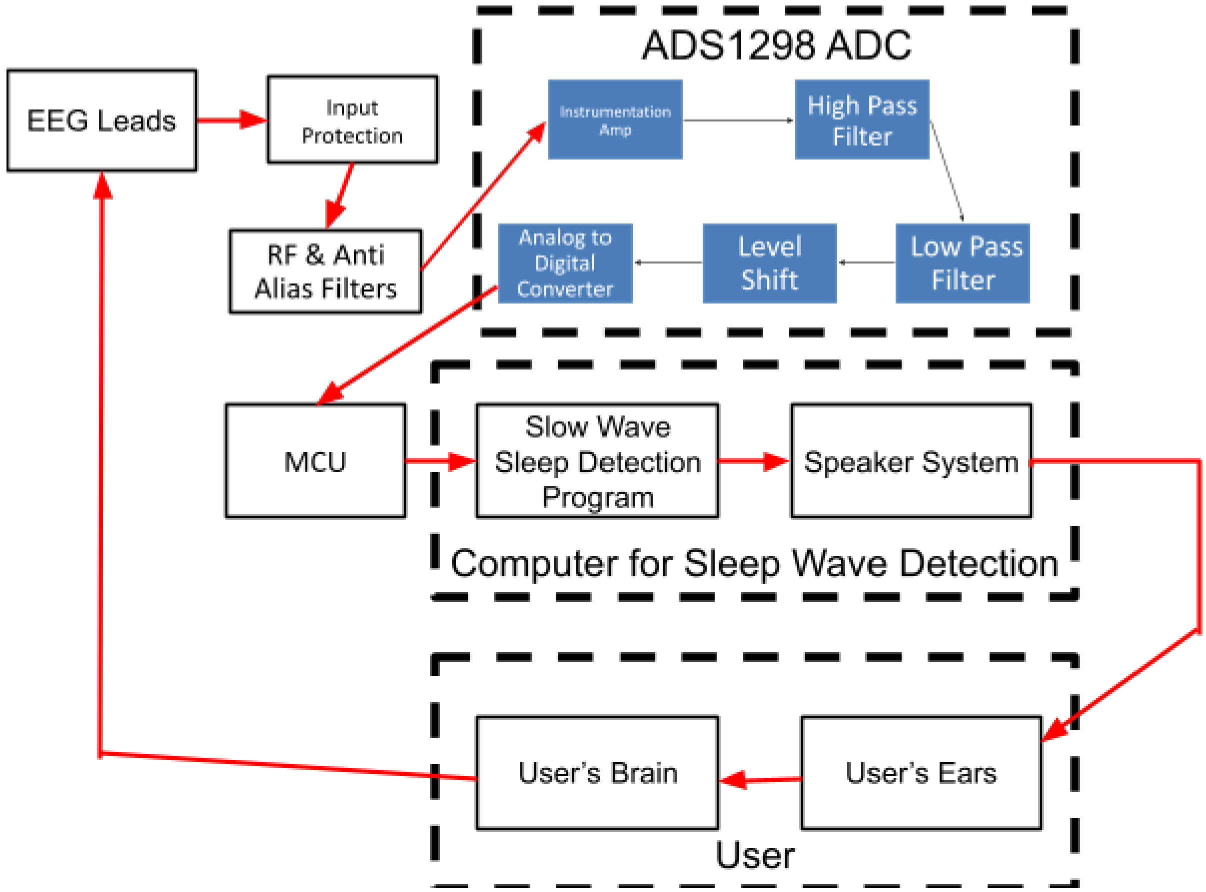
- Pink noise should play within 300 ms of detecting slow wave sleep.
- The average comfort rating of the headset should be a ⅘.
- The entire design should be able to support 10 hours of consecutive sleep, meaning the battery should last at least 10 hours.

Visual Aid:


OR

# 2 Design

## 2.1 Block Diagram




## 2.2 Alternate Parts we took into consideration

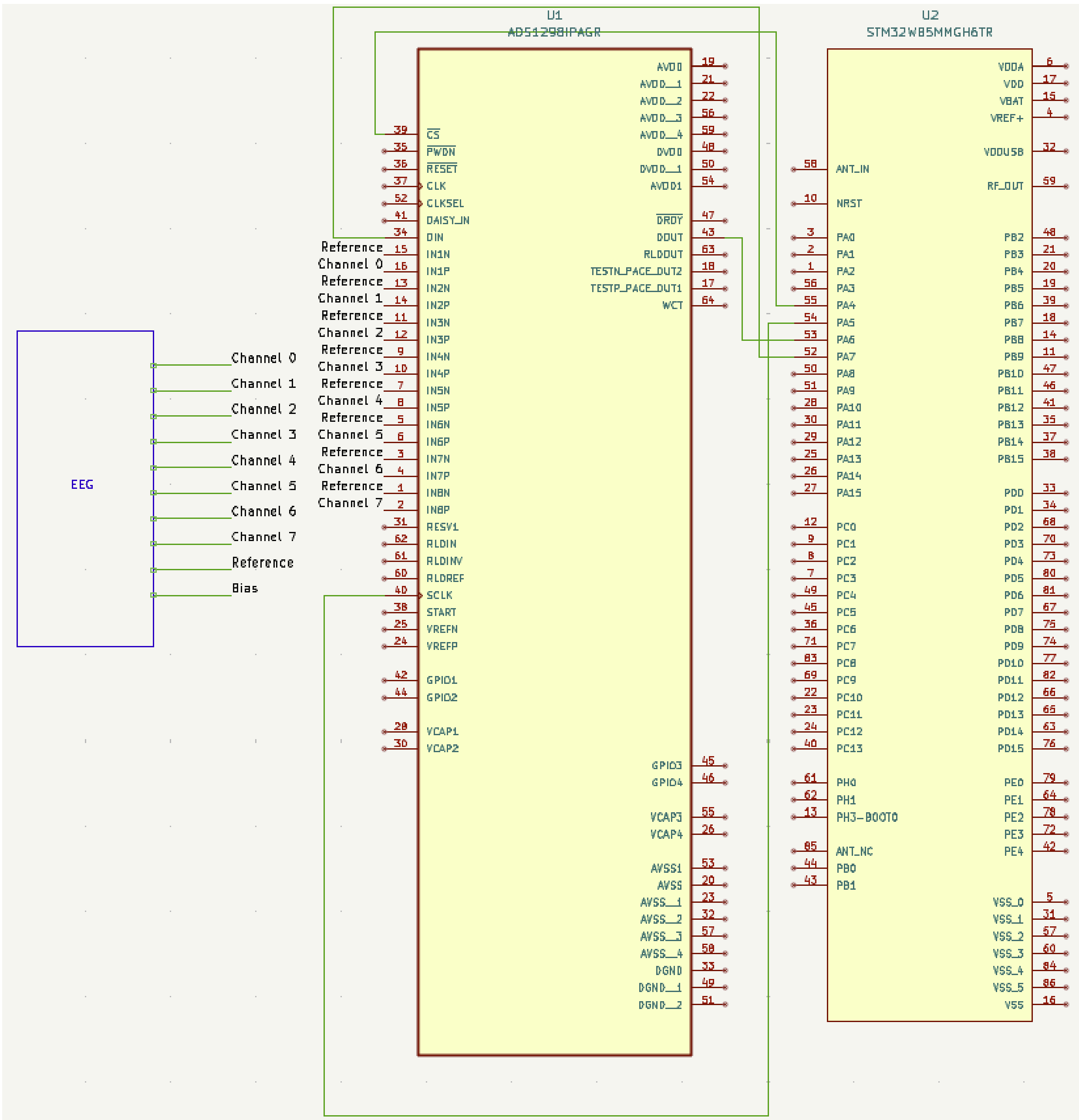
We considered working with alternative Analog Front End chips when deciding our PCB. One option was the ADS131E08IPAGR. Initially considered it because it was the cheapest option while offering the same resolution and # of channels of output. We could not use it because the sampling rate was not satisfactory for reading biomedical data. It is not optimized for extremely small bioelectrical signals.

Our other option was the ADS1299 Analog Front End. This was the most expensive option, but it has been widely used for EEG amplification and digitizing. It has very low input-referred noise and extremely small input bias current which makes it ideal for scalp electrodes. One ADS1299 chip was $73.25, and we had to account for buying multiple if one fails. As a result, we could not go with this chip because it ate up most of our budget

ADS1298 belongs to the same family as ADS1298 but is intended primarily for ECG and general biopotential monitoring. It still contains integrated PGAs, lead-off detection, and 24-bit simultaneous-sampling converters , but it has higher noise performance than the ADS1299 and fewer EEG-specific optimizations. The price for the ADS1298 was $45.80, so we have enough money to buy a spare chip without compromising our project budget. This led us to sticking with the ADS1298 for our board.

## 2.3 Basic Circuit Schematic

This KiCAD schematic only includes our two major components (STM32 and ADS1298)



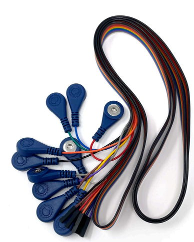
## 2.4 Tolerance Analysis

One component that could be a point of failure is using the STM32 Bluetooth functionality to send digitized EEG data. We looked at other available boards for this purpose, and many of them use a proprietary “RFDuino” Protocol to achieve higher data rates. We are steering clear from this option, so we are not sure if this decreased performance with BluetoothLE will have significant effects on functionality. To demonstrate the feasibility of using BluetoothLE, we need to make sure we also minimize latency in other areas of data collection and transfer outside of the microcontroller.

# 3. Design Verification

## 3.1 EEG Leads

This subsystem contributes to the overall system by providing the differential microvolt EEG signals required for slow wave detection. The EEG headset uses dry electrodes placed on the scalp that detect the tiny electrical signals produced by neuron activity in the brain. Neural activity produces extracellular field potentials in the range of 10-100µV. The brain waves are usually in a frequency between 0-100Hz. In order to measure the ‘voltage at the electrodes’, a reference electrode, which defines a common baseline potential, is used to pick up voltage differences. There are totally ten leads. Eight of the electrodes are connected to the positive inputs of the ADS1298 which is the Analog to Digital Converter (ADC). The ninth lead is a reference electrode, and the 10th electrode is used as a bias to minimize error in readings. This system requires both the reference and bias electrodes, otherwise the readings will not be accurate due to no reference voltage and interference thus giving incorrect brain activity results.



## 3.2 Input Protection

This subsystem contributes by ensuring safe and reliable signal acquisition before digitization. The inputs from the electrode are highly sensitive to electrostatic discharge and events with relatively high voltage that could occur when the electrodes are touched or moved. Series protection resistors of the order of tens of kilo-ohms will be used to limit current into the ADS1298 (ADC). In addition, ESD protection diodes will be used to limit extreme voltages in order to prevent biases that could distort the microvolt signals from the electrodes. Since the voltages being sent to the ADC are of very small value, even small disturbances could potentially give wrong readings of EEG. Hence, it is important to exercise careful routing of the signals from the electrodes to the ADC to prevent errors. In addition, the user and the Integrated Circuits will be protected with these safety precautions. It must keep the input voltages within the ADC range, otherwise spikes in voltage can damage the ADC and prevent accurate EEG measurement.

## 3.3 RF & Anti Alias RC Filters

This subsystem contributes by conditioning signals so only valid EEG frequencies reach the EEG. The electrode leads that are being used from the headset could potentially act as antennas and pick up radio-frequency signals from the Bluetooth and Wifi activity. So, we will use a small capacitor in the order of pico-Farads to ground so that the high frequency signals will be sent to the ground leaving the low-frequency relevant EEG signals (relevant waves are between 0-100Hz for our use case). In addition, a low-pass filter will be used to remove higher frequency noise potentially from muscle activity and other sources that could potentially be recorded. This also prevents possible aliasing. The sampling frequency used by the ADC is finite and recording higher frequencies could aliasing if the Nyquist criterion is not satisfied. These components are used to ensure that the signals received at the ADC are as accurate as possible. Removing this would affect the sleep detection because this filters out the frequencies above 100Hz which would cause aliasing.

## 3.4 ADS1298 ADC Converter

This subsystem contributes by converting conditioned analog EEG signals into synchronized digital samples. This is one of the most important parts of the PCB. The ADS1298 is an analog to digital converter (ADC) which has an eight-channels and a 24-bit resolution. It also contains programmable gain instrumentation amplifiers, a multiplexer, simultaneous delta-sigma ADCs, internal references generation, and digital filtering. The device is optimized for biomedical applications for microvolt measurements. The channels are sampled simultaneously so as to maintain phase alignment so that it is more precise for applications such as working with brain activity and other medical applications. This subsystem is essential as without it the analog signals will not be able to be converted to digital and thereby preventing any further processing to detect the slow wave sleep stage.

### 3.4.1 Instrumentation Amp

This subsystem contributes by amplifying microvolt EEG signals into the ADC range. The instrumentation amplifier stage amplifies microvolt-level signals. It has a programmable gain. The amplifier has a high input impedance which prevents current flow through the electrode-skin interface, which minimizes the signal distortion. Incorrect gain causes clipping or loss of resolution, making measurements unusable.

### 3.4.1 Digital Conversion and Sampling

This subsystem contributes by producing accurate digital EEG data through oversampling and filtering. The delta-sigma modulators work at a high oversampling rate which is essential for biomedical applications. It has a decimal decimation filter that removes quantization noise. It outputs a high-resolution 24-bit stream at a specified sampling rate. The reason why there is oversampling is so that the resolution of the low-frequency EEG band is improved. If the sampling rate violates the Nyquist requirement, gaps occur and sleep detection cannot function.

### 3.5 Microcontroller (STM32WB5MMG)

The STM32 Microcontroller receives the ADC samples from the ADC through the SPI interface. The role of the microcontroller is to package the multi-channel samples into Bluetooth packets which are timestamped and sent to the host computer. It is also responsible for configuring the ADS1298 registers, manages the start-up configuration, and maintains the sampling synchronization. The BLE protocol provides a low-power transmission which is continuous and therefore suitable for an overnight application such as this one.

### 3.6 Slow Wave Sleep Detection Program

This subsystem contributes by transferring real-time EEG data to the host computer via Bluetooth. Uses an open source Command-line sleep analysis tool called YASA (Yet Another Spindle Algorithm) to read digitized EEG data and determine if the user is experiencing slow-wave sleep. Our Python script plays pink noise from the laptop that the sleep analysis tool is running on. The processing will run simultaneously to the data acquisition to allow real-time detection and response. If interrupts or transmissions fail, gaps occur and sleep detection cannot function.

### 3.7 Speaker System

This subsystem contributes by delivering audio stimulation once slow-wave sleep is detected. Plays an audio file with “Pink noise” once Slow wave sleep is detected. Headphones connected to the laptop’s audiojack play the Pink noise MP3 file. If playback delay is excessive, the stimulation becomes ineffective.

### 3.8 User

This subsystem represents the end goal of the system. The user hears pink noise while experiencing Slow-wave sleep and reaps its benefits. If any previous subsystem fails, the user will not receive stimulation during slow-wave sleep.

## 4. Costs

### 4.1 Parts

Following is a starter table for parts costs. Add cell contents as well as rows and, if necessary, columns. Update the table number according to your sequence. Note that columns 1 and 2 are set up for centered text (words) and columns 3-5 (numbers) are set up for right-alignment so that decimal points align.

**Table X Parts Costs**

| Part | Manufacturer | Retail Cost ($) | Bulk Purchase Cost ($) | Actual Cost ($) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Analog to Digital Converter (ADS1298IPAGR (8-ch AFE, TQFP)) x 2 | Texas Instruments | 45.80 | 37.50 | 91.60 |
| Microcontroller (STM32WB5MMGH6 TR (BLE module)) x 2 | STMicroelectronics | 12.14 | 9.53 | 24.28 |
| IC Battery Cntl (MCP73811T-420I/OT ) x 2 | Microchip Technology | 0.69 | 0.53 | 1.38 |
| Linear Voltage Regulator (MIC5365-3.3YC5-TR) x 2 | Microchip Technology | 0.12 | 0.09 | 0.24 |
| Ferrite beads (BLM18PG121SN1D) x (5 - 10) | Murata Electronics | 0.10 | 0.02 | 1.00 |
| ESP Protection Diodes (VBUS052BD-HTF-GS 08) x (1 per connection or per line) | Vishay General Semiconductor | 0.10 | 0.02 | 5.00 |
| Input RC filter parts (MEM2012S25R0T00 1) x (8 channels x (2 parts) + extras) | TDK Corporation | 0.33 | 0.16 | 6.60 |
| Decoupling caps (JMK105BJ105KV-F) x 50 | Taiyo Yuden | 0.08 | 0.004 | 4 |
| Bulk capacitors (CL05A106MP5NUNC ) x 10 | Samsung Electro-Mechanics | 0.08 | 0.004 | 4.00 |

| | | | | |
|---|---|---|---|---|
| SWD / programming header (ARM-JTAG-SWD) x 1 | Olimex LTD | 5.86 | | 5.86 |
| 3 x AAA Battery Holder with On/Off Switch and 2-Pin JST x 2 | Adafruit | 1.95 | 1.56 | 3.90 |
| Buttons (TL2285OA) x 6 | E-Switch | 1.02 | | 6.12 |
| **Total** | | | | 150.78 |

## 5. Ethics

This project comes with several ethical considerations that we must take into account when designing. First, we must add voltage surge protection connected to the EEG output leads because if the voltage were to surge, the user could be harmed. Another potential ethical concern is patient information. Our device is going to be used in a medical/healthcare application. HIPPA cites established guidelines for protecting patient information that must be followed. Any use of patient information in our development and/or testing stages must abide by these guidelines.

These safety and ethical guidelines are further enforced by following IEEE and ACM standards. More specifically, this project follows the IEEE Code of Ethics Principles 1 and 3, and aligns with the Association for Computing Machinery Code of Ethics Principles 1.2, 1.6, and 2.5. IEEE Principle 1 prioritizes the health, safety, and welfare of the public through ensuring that the EEG headband is non-invasive and ensuring that safe levels of pink noise are played. IEEE Principle 3 emphasizes being transparent with how effective this device is for sleep-enhancement. ACM Code of Ethics is followed by securing healthcare data according to widely accepted standards.

## References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