Brain Computer Interface using Functional Near Infrared Spectroscopy (fNIRS)

CDR

Team
Tristan Valenzuela
Thang Pham
Shovan Shakya

Advisor: Dr. Ashwin B Parthasarathy

TROPICS LAB

Problem Statement

Aiming to fulfill a need in the Brain-Computer Interface (BCI) and Biomedical Optics field.

Planning to develop one of the first multi-channel Functional Near Infrared Spectroscopy (fNIRS) based BCI systems.

Main goal: Develop a multi-channel fNIRS headset.

Auxiliary goal: Implement the headset as a BCI system.

Noting that current off-the-shelf fNIRS headsets cost over $1,000.

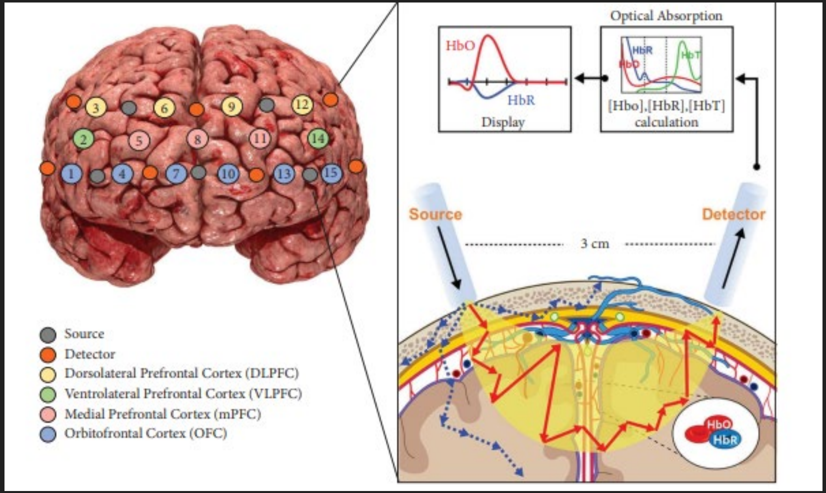
Seeking to create a **low-cost, open-source** alternative to improve accessibility and further BCI research.

Design Approach

By using sources (NIR LEDs) and detectors (Photodiodes) in specific orientations, brain activity can be detected through a process known as Neurovascular Coupling.

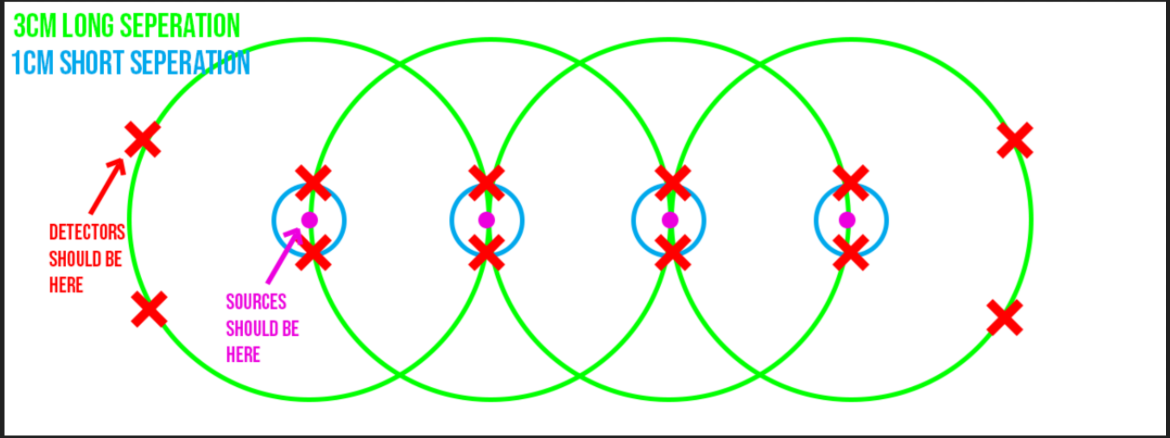
When the brain activates in a certain region, it extracts oxygen from surrounding hemoglobin.

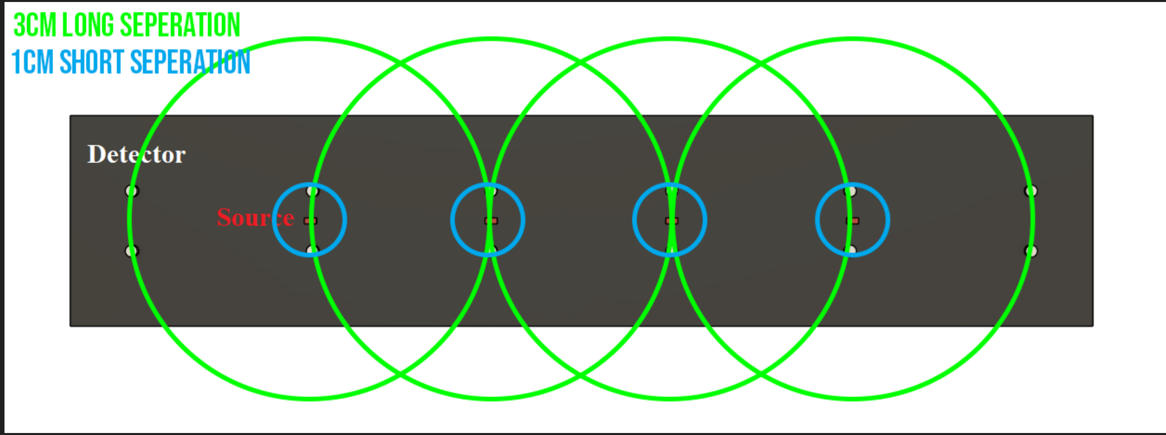
The change in hemoglobin oxygenation can be detected through NIR due to the relationship between oxygenation and light absorption.



Design Approach Cont.

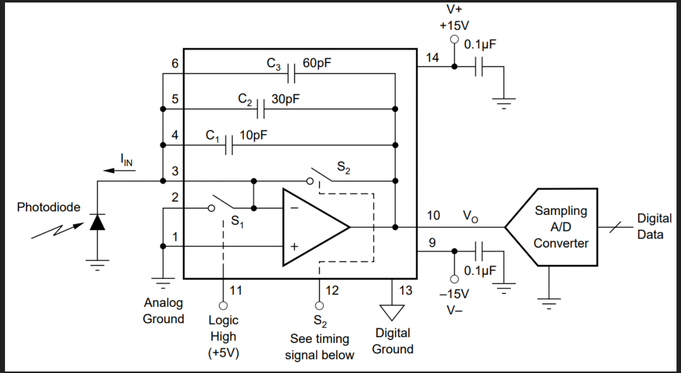
To gather accurate readings from specific areas of the brain, a source-detector layout was created to efficiently capture 3CM long separation (captures deeper light reflections which come from the brain) and 1CM short separation (captures noise)





Design Approach Cont.

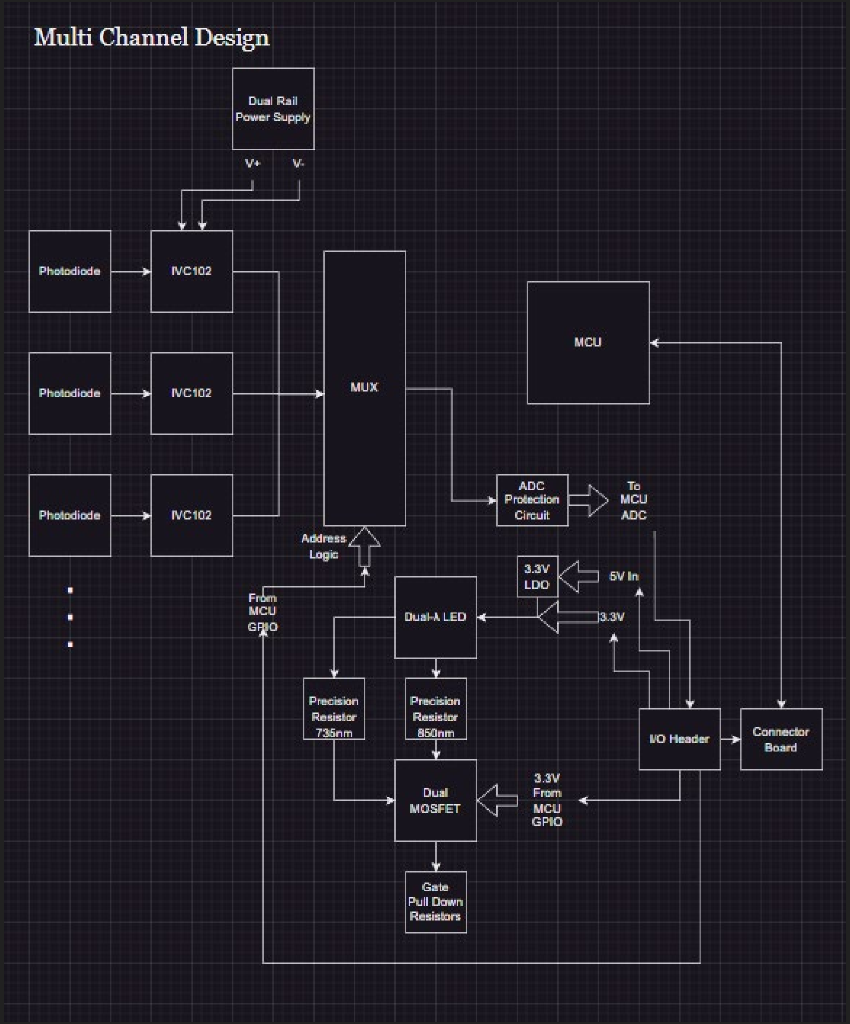
Photodiodes convert light intensity into current, which can be directly converted to voltage through a Transimpedance Amplifier (TIA).



The voltage can then be converted to absorbance using the modified Beer-Lambert Law.

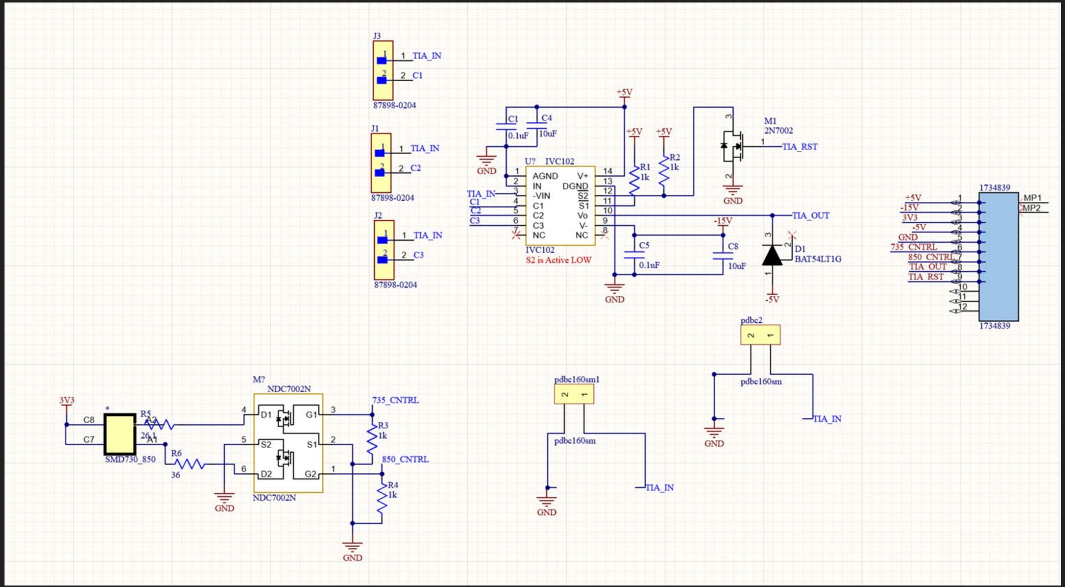
$$A=\log(Vo/V)$$

System Block Diagram



Design of Components

Single Channel Flexible Board



Source and Detector choice:

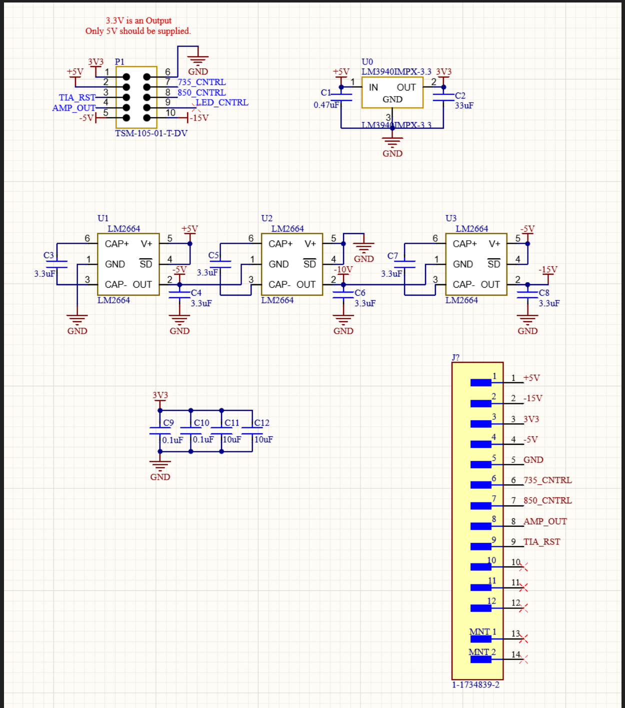
- LED wavelength and intensity directly correlates to how deep light can penetrate into the tissue. 735nm and 850nm are efficiently paired to support the detection of HbO and Hb. Chosen NIR LED has both wavelengths in one package and outputs 15-20mW of irradiated power.

- TIA is chosen which supports variable gain which is necessary for long and short separation.

- PN photodiode diode is chosen due to larger surface area compared to PIN photodiode. Also does not need biasing.

Design of Components

Single Channel Breakout



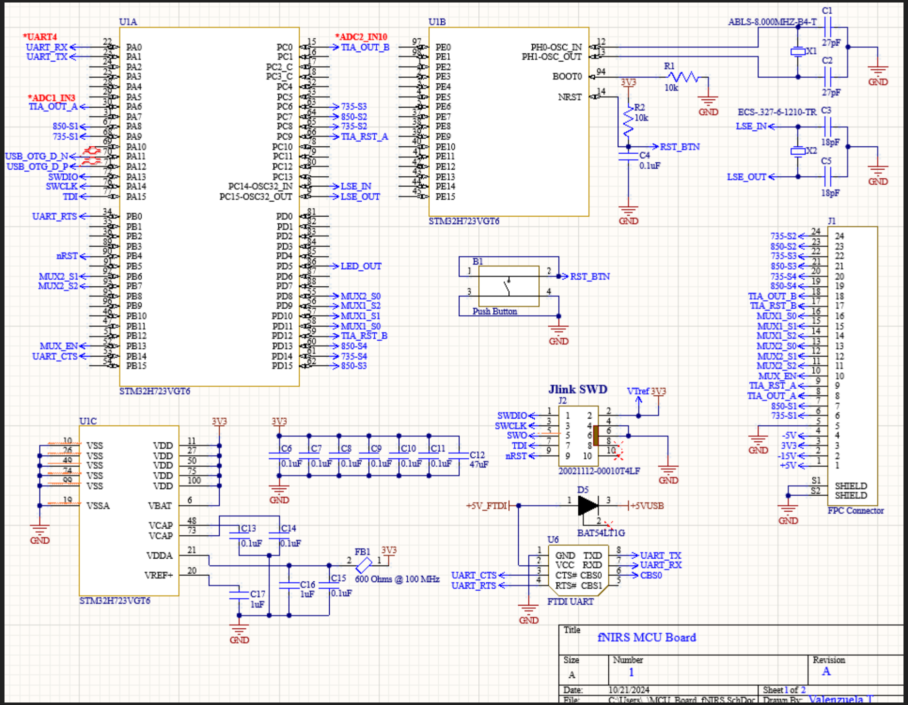
Power Supply Choice:

- Series connected charge pump regulators provide required power output for TIA while maintaining lower noise due to no inductance.

- 3.3V LDO chosen to convert USB 5V to STM32 VDD of 3.3V. MAX Current output also supports current req. of all NIR LEDs powered on.

Design of Components

Final Microcontroller Board



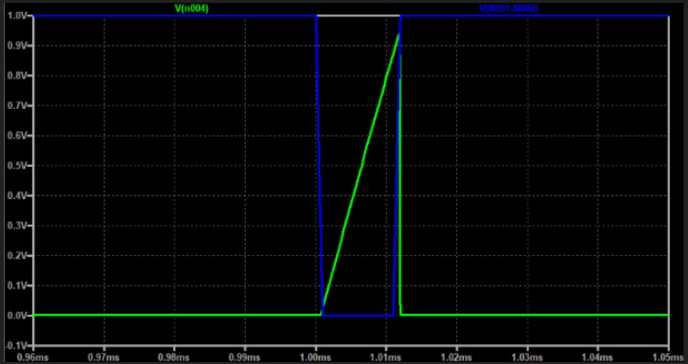
MCU Choice:

- High system clock frequency.
- Supports future wireless and ethernet development for higher-speed capture
- High ADC sampling rate
- High number of GPIO pins

NIR LED Choice:

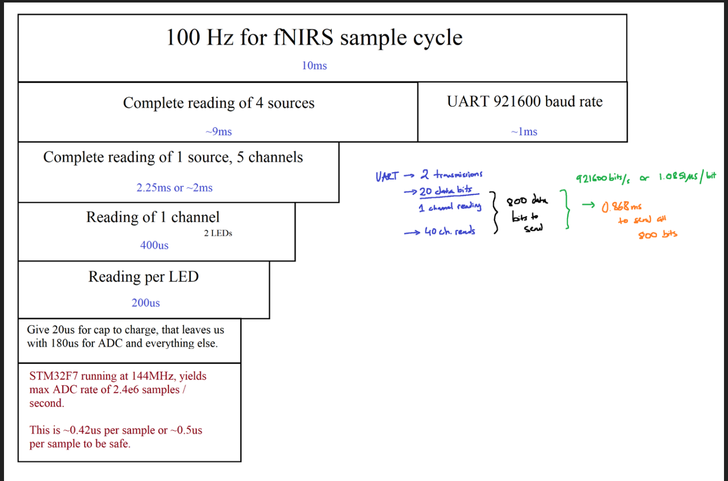
- 735nm and 850nm is the optimal wavelength for fNIRS applications

Simulations and Calculations



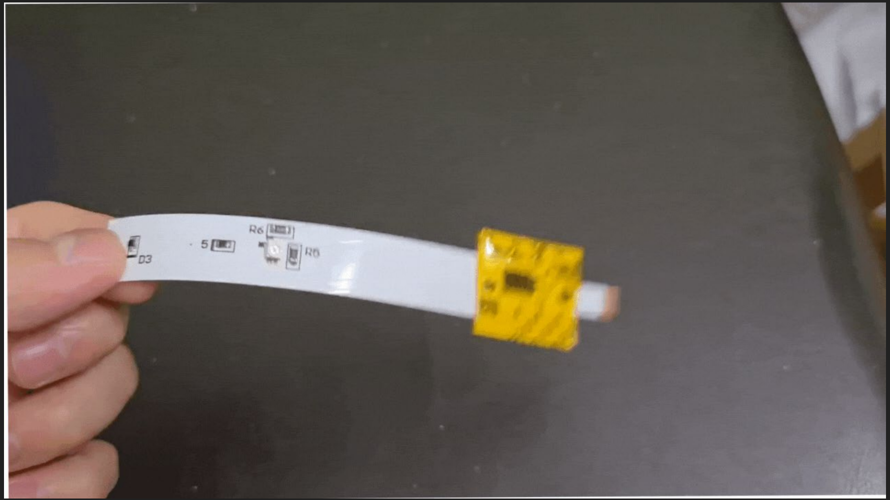
Simulated TIA circuit behavior based on ideal photodiode current given to find integration time.

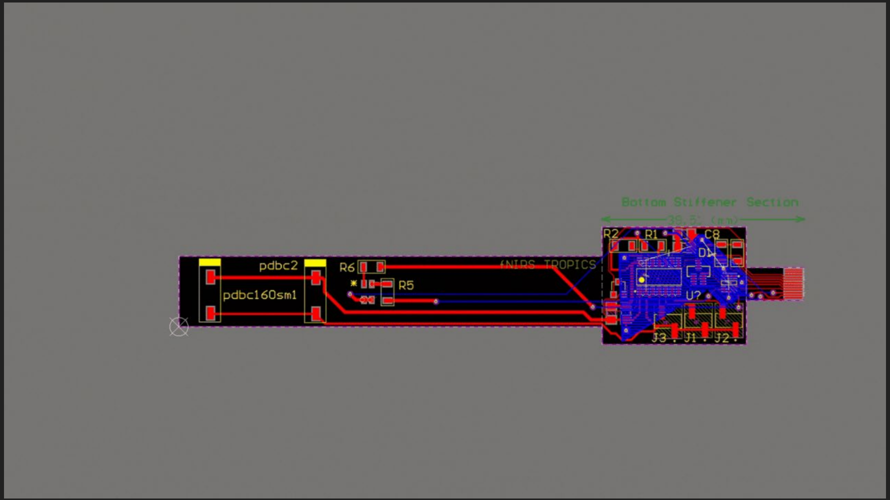
Timing requirements calculation.



Hardware Development

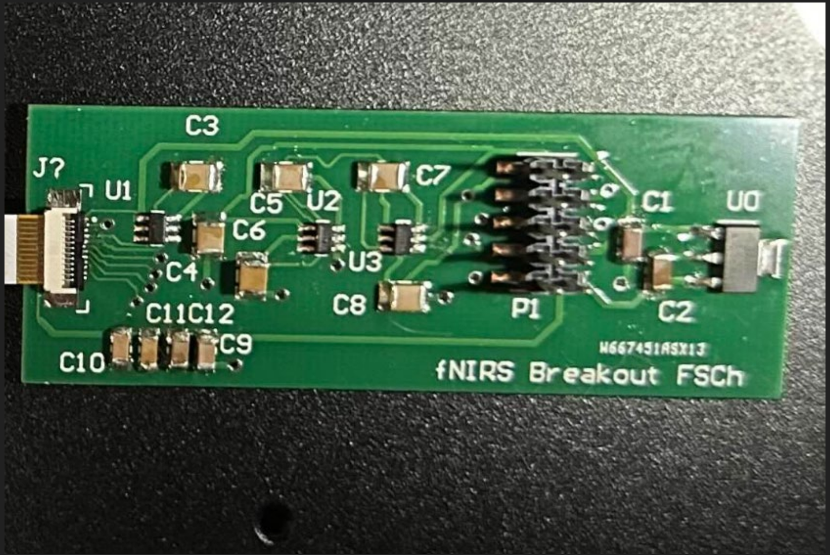
Single Channel Flexible PCB

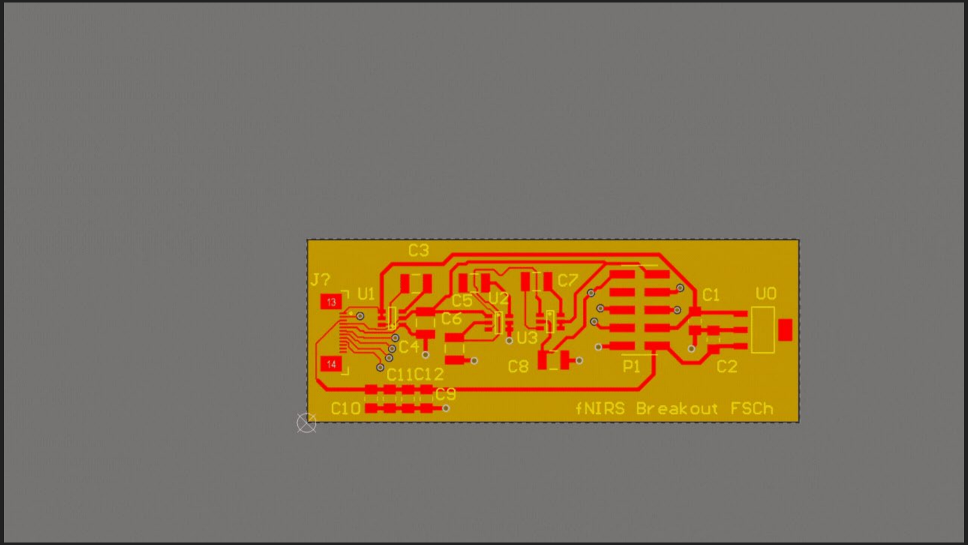




Hardware Development

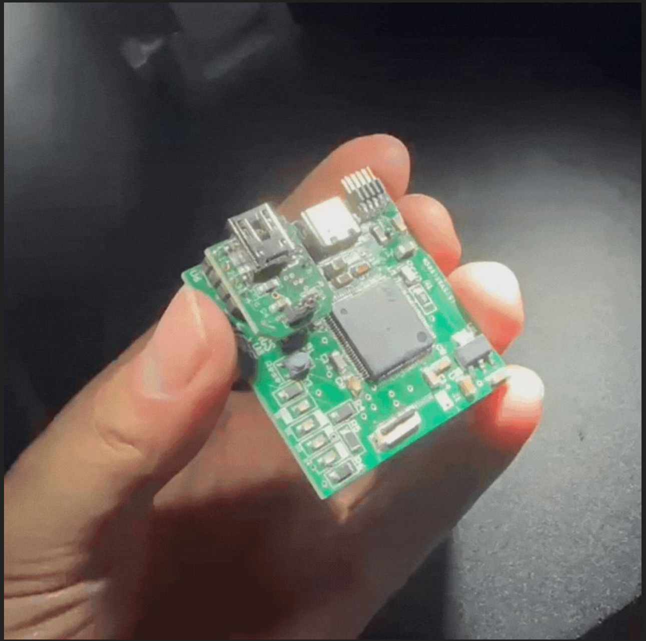
Single Channel Breakout

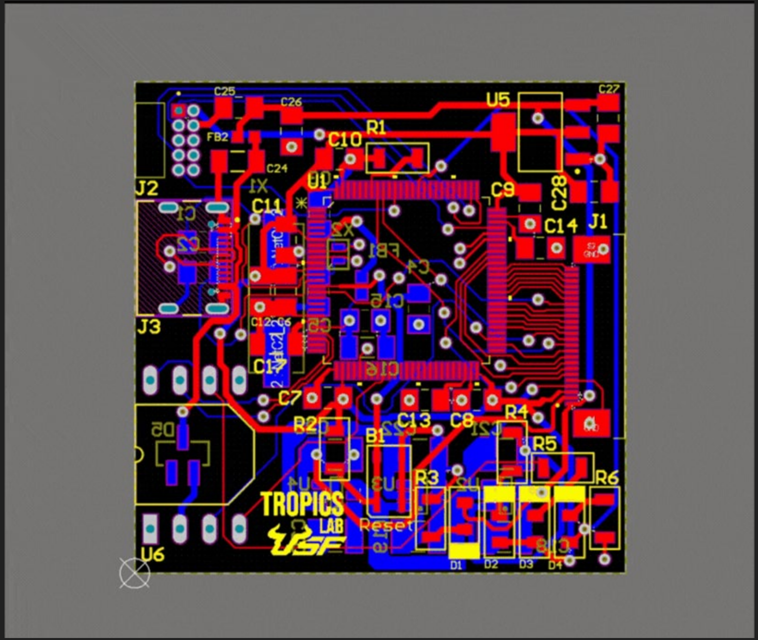




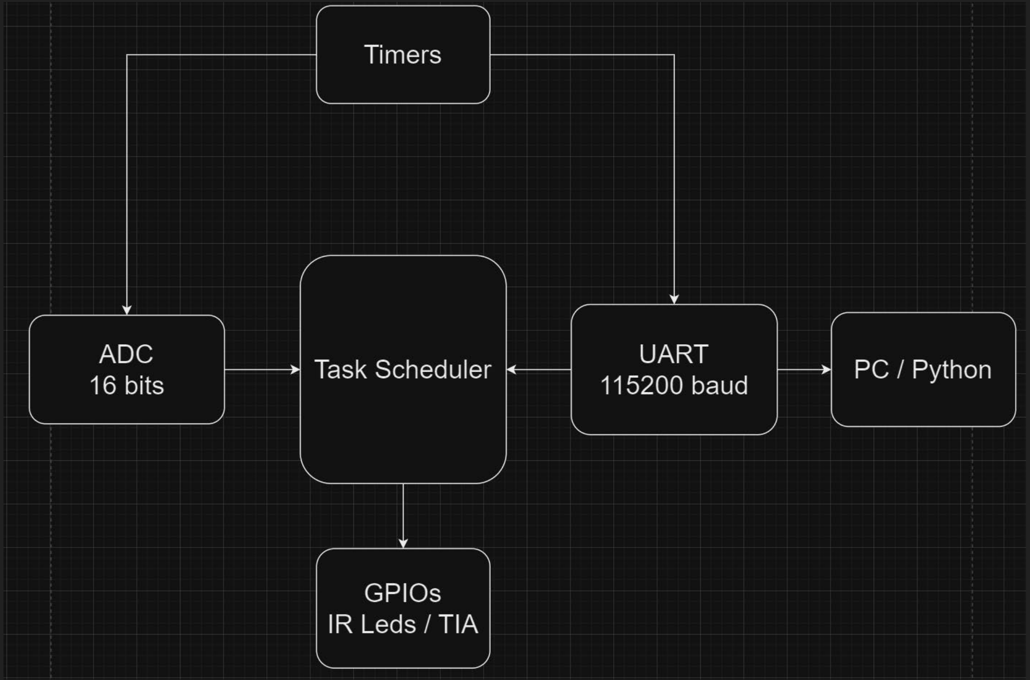
Hardware Development

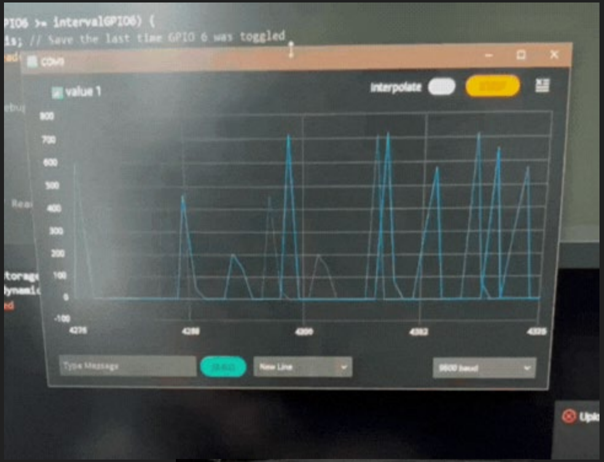
Final Microcontroller Board

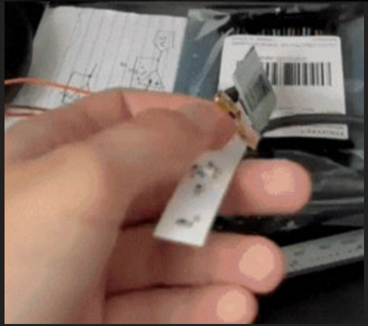




Embedded Software Development







BCI Software Development

Machine Learning

Bidirectional 1D-CNN Model uses time series data to classify cognitive load level.

Layer (type)	Output Shape	Param #
conv1d (Conv1D)	(None, 19, 64)	576
max_pooling1d (MaxPooling1D)	(None, 9, 64)	0
batch_normalization (BatchNormalization)	(None, 9, 64)	256
conv1d_1 (Conv1D)	(None, 8, 128)	16,512
max_pooling1d_1 (MaxPooling1D)	(None, 4, 128)	0
batch_normalization_1 (BatchNormalization)	(None, 4, 128)	512
bidirectional (Bidirectional)	(None, 4, 128)	98,816
dropout (Dropout)	(None, 4, 128)	0
flatten (Flatten)	(None, 512)	0
dense (Dense)	(None, 50)	25,650
dense_1 (Dense)	(None, 1)	51

Under development….

Testing Plan

- Attach the flex board on the head firmly.
- Remove potential sources of infrared noise from the environment.
- Collect data of baseline low cognitive load.
- Collect data of high cognitive load.
- Test our classifier machine learning algorithm on incoming data.

Work Division

Hardware:
Tristan Valenzuela (Lead)
Shovan Shakya

Embedded Software:
Thang Pham (Lead)
Tristan Valenzuela
Shovan Shakya

BCI Software:
Shovan Shakya (Lead)
Thang Pham