EMG-BASED SYSTEM

EEE 192 2nd Semester AY 2021-2022 Project Brief

Introduction

Electromyography (EMG) is a concept that deals with the detection, analysis, and utilization of electrical activity produced by the skeletal muscles of the human body. EMG enables us to generate force, create movements, and allow us to do other functions through which we can interact with the world around us. Throughout the years, a wide variety of applications have been developed utilizing EMG. It is being used for clinical applications as a diagnostic tool for neurological disorders, including the assessment of patients with motor control impairments. EMG also has applications in applied research, physical therapy and rehabilitation, sports medicine, ergonomics research, and hobbyists who want to utilize myoelectric signals to execute various functions. An example of EMG-based systems used by hobbyists and engineers is the MyoWare EMG Muscle Sensor System shown in Figure 1.

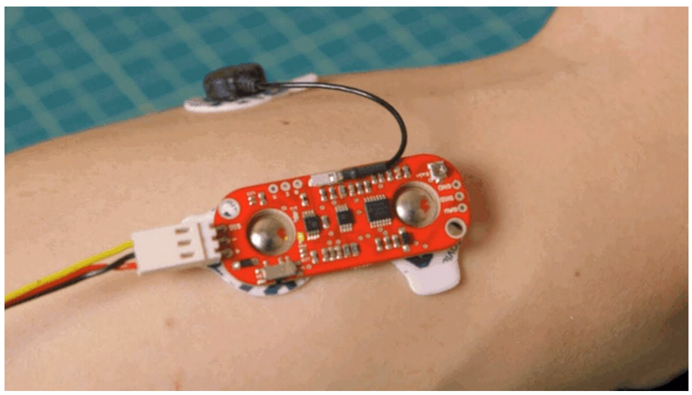


Figure 1. MyoWare EMG Muscle Sensor System

The design and implementation of an EMG-based system serves as an introduction for undergraduate students to biomedical engineering. The activity also incorporates multiple EEE disciplines such as hardware and embedded systems design, instrumentation engineering, wireless communications, and digital signal processing. With numerous possible features that can be integrated to the core system functionality, the project can also serve as a learning experience on systems-level design thinking and project management.

Project Objectives

For this challenge lab, the student teams should be able to design and implement an open-loop EMG-based system composed of the following units:

- An **analog front-end unit** that acquires, amplifies, and filters surface EMG signals using skin electrodes.
- A **transceiver unit** that (1) converts analog data to digital format, (2) transmits data to the receiver module, and (3) unpacks received data prior to digital signal processing.

- A **signal processing unit** that uses digitized data and (1) reconstructs the received EMG data, (2) displays an EMG envelope or a raw EMG, and (3) detects muscle activation times (EMG ON and OFF times) using thresholding method.

Specific Objectives

At the end of the project implementation, the student team should be able to meet, present, and demonstrate the general objectives of this project. They will provide a specific objectives section that reflects the design specifications for each block, initially provided by the course handlers. It is the responsibility of student teams to further break down the general objectives into S.M.A.R.T. Goals: Specific, Measurable, Attainable, Realistic, and Timebound.

System Block Diagram

A general system block diagram of an open-loop EMG-based system is shown in Figure 2. It can be divided into three major blocks: the **analog front-end unit**, the **transceiver unit**, and the **signal processing unit**. The team will divide each unit into circuit blocks that can be assigned to each team member and integrated to test and perform its intended function.

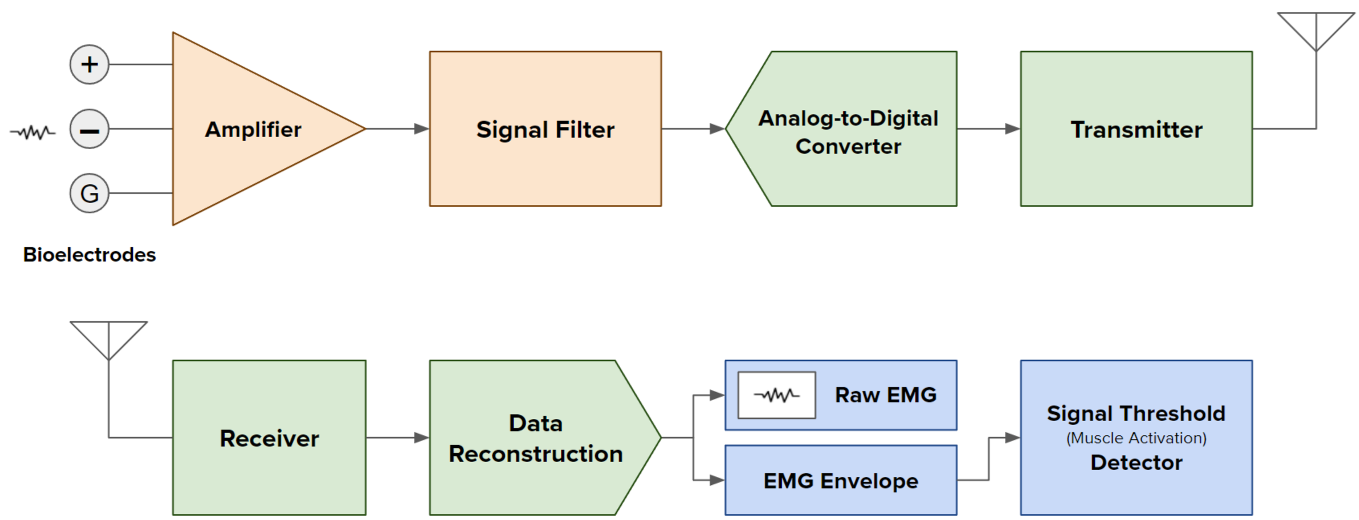


Figure 2. EMG-Based System Block Diagram

Team members are advised to always take note of the input and output of his/her assigned circuit block, either from a given design specification or from an output signal of another teammate's work. The challenge lab is an exercise on co-design, bringing and involving each team member into the design process. The goal is to have a seamless integration of each circuit block and unit, resulting in a fully-functional EMG-based system.

Design specifications and guide questions for each unit will be released as the semester progresses in the coming weeks. These should give each team an idea on the concepts that can be researched and studied in preparation of the circuit design and implementation. For this version of the Project Brief, the design specifications and guide questions for the analog front-end unit are introduced below.

Analog Front-End Unit

Design Specifications

- EMG Input Range: 11 mV
- Output Range: 5 Vpp
- Dual Supply or Single Supply allowed
- On-Board EMG Filter covers bandwidth of desired muscle(s)
- Filters powerline and other types of environmental noise

Note: For three-person teams, we advise that teams proceed with adding a second amplifier stage between the signal filter and ADC block. The additional stage will carry out the extensive amplification, allowing the design of the first amplifier stage to focus on the effective elimination of common signals with less stringent gain requirements.

Guide Questions

When designing your analog front-end unit, please take into consideration the following guide questions.

1. **EMG Electrodes and Signal Characteristics**
   1.1. What are the types of EMG electrodes? How are they different from one another?
   1.2. Why is skin preparation and correct electrode placement important for EMG signal acquisition?
   1.3. What are the electrical characteristics of an EMG signal?
   1.4. From your answer in 1.3, how do you plan on addressing the presence of electrical noise and its effect on an EMG signal?

2. **Signal Acquisition and Amplification**
   2.1. How is an EMG signal generally acquired? How does the number of EMG electrodes in place change the type of circuit configuration used?
   2.2. What is common-mode rejection ratio or CMRR? Why is this an important metric to consider for EMG signal acquisition?
   2.3. From your answers in 1.3, 1.4, and 2.2, what amplifier is best suited for an EMG-based system? Why is it desirable over other amplifier types?
   2.4. For a given amplifier circuit, what are the practical advantages of using a single-supply over a dual-supply configuration and vice-versa?

3. **Signal Filtering**
   3.1. What are the advantages and disadvantages of using active over passive filters and vice-versa?
   3.2. What is the typical range of frequencies that contains useful information in an EMG signal? Are there differences in the frequency ranges for different muscles?
   3.3. What filter topologies and types are normally used to process EMG signals? How do they differentiate between each other?
   3.4. For a given set of operational amplifiers, what specifications are considered when choosing an op-amp for use in active filter design and implementation

Resources

- Review Lecture slides: Introduction to EMG-Based Systems
  - EMG signal acquisition and configurations
  - Instrumentation amplifiers

- Electrical design considerations: amplification and filtering
- Noise in EMG Signals

Transceiver Unit

Analog EMG signal must first be digitized using an Analog to Digital Converter (ADC) to allow further signal processing and analysis using computers. Digitized data are then wirelessly transmitted, received and reconstructed for further processing.

Design Specifications

The design specifications that must be met for a successful ADC and transceiver unit implementation are as follows:

- ADC resolution: 10-bit ADC data for signals amplified to 5 Vpp
- 16-bit data packet format: (start of packet) 1 – ADC Data – P – 0001 (end of packet)
  - Parity bit P for error detection of transmitted packets; use EVEN parity in the design
- Sampling frequency selected must satisfy Nyquist Theorem
- Binary Frequency Shift Keying (BFSK) modulation and demodulation scheme for wireless data transmission

Guide Questions

1. **Analog to Digital Conversion**

The following guide questions will guide you through several design considerations that have to be taken into account while converting EMG signals into digital format. They also provide guidance on the ADC implementation using the MCUs available in TINACloud and MPLAB.

1.1. What three (3) things must be considered when digitizing an analog EMG signal? Given the characteristics of the EMG signal acquired discussed in the previous block, what is an acceptable setting for these 3 things?
1.2. What is the function of a parity bit? What are the differences between even and odd parity?

A microcontroller unit (MCU) is needed in interfacing sensors, displays, and memory, as well as communicating with other peripheral devices. Any MCU available in TINACloud may be used by the students. However, since most are already familiar with Microchip Technologies' PIC MCUs through the use of MPLAB, we recommend the use of [PIC32MX120F032C] for EEE 192. Instructions on how to import files from MPLAB to TINACloud will be provided for the implementation of the ADC.

1.3. For the given MCU, what are the electrical characteristics of each port? How will these affect the input and output requirements of the ADC?
1.4. How is polling implemented for an ADC? How can this be created using the given MCU?
1.5. How is the desired bit rate achieved on the output bitstream of the MCU?
1.6. What are the benefits of adding a DC offset to a signal input to the MCU? What situations would require you to do this type of signal modification?
1.7. What are the considerations taken when choosing the delays in system, function, or clock?
1.8. For a given sampling time, how is interference of the packet creation/bitstream output with the sample/conversion of the ADC prevented?
1.9. When performing simulations, what time step would result in a clear output waveform? Would there be any possible consequences of this in the data reconstruction stage in MATLAB?

2. Wireless Data Transmission

Binary Frequency Shift Keying (BFSK) modulation and demodulation scheme will be used as the transmission scheme for this design project.

2.1. Transceiver Specifications

Before designing the BFSK modulator and demodulator, teams must first establish the design specification of the transceiver.

2.1.1. Take note of the design decisions made in the previous section specifically, the quantization scheme and sampling rate selected. Given this information, what is the expected data rate of your design?

A sample BFSK modulated signal is shown in Figure 3. BFSK uses a pair of discrete frequencies to transmit binary (0s and 1s) information. With this scheme, the 1 is called the mark frequency (f_{mark}) and the 0 is called the space frequency(f_{space}).

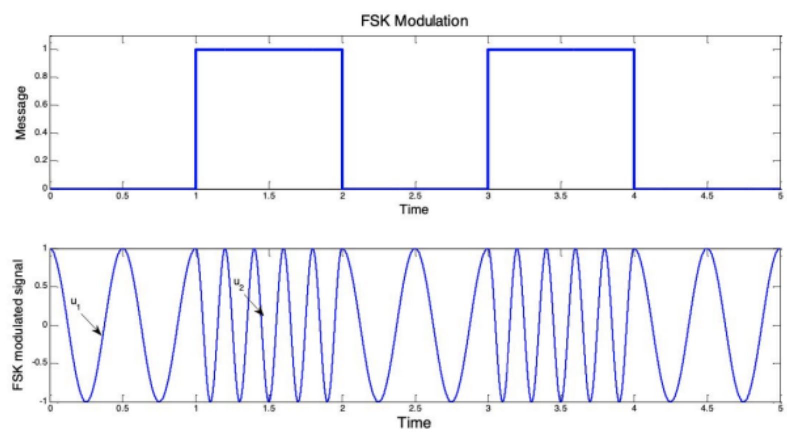


Figure 3. Sample FSK Modulated Signal

2.1.2. What are the characteristic differences between the mark and space frequencies? How do you set these values?

2.1.3. How is the slew rate value affected by the set mark and space frequencies? What components are affected by the value of the slew rate?

The formulated transceiver specifications should work on the following assumptions and include the following information:

- Sampling Rate (fs)
- Quantization scheme (number of bits)
- Data rate
- Digital input signal frequency (f_{in})
- Sample test signal for BFSK testing: f_{in} with expected min and max values of analog front-end circuit
- Mark and space frequency
- Minimum slew rate requirement for max frequency

2.2. BFSK Modulator

[XR-2206 Monolithic Function Generator]() can be used for FSK generation. Reviewing the datasheet of XR-2206 will help answer the succeeding guide questions. The datasheet also provides guidance on how to design a BFSK modulator. *Hint: Review pin assignments and descriptions.*

2.2.1. Using XR-2206, how can f_{mark} and f_{space} be adjusted? What are the pins of interest?
2.2.2. Is there a difference in circuit setup for FSK generation when operating at single-supply versus dual supply?
2.2.3. What pins are used for FSK input and FSK output?

Hint: XR-2206 datasheet provides additional tips and information on how to better design the BFSK modulator and how values for R and C needed for the mark and space frequencies can be set.

2.2.4. What is the maximum operating frequency and lowest practical frequency? What are the values of R1 and C at these frequencies?
2.2.5. Suppose you want to operate at the optimum temperature stability, what is the range of recommended values for R and C? Given these recommended values, what is your desired frequency of operation for optimum temperature stability?
2.2.6. The peak output voltage of the modulator can be regulated by the resistor R3 at Pin 3. What is the maximum output swing of the XR2206 for a triangle or sine-wave output? What values of R3 can be used?
2.2.7. Figure 5 at the XR-2206 datasheet shows R versus Oscillation frequency. It provides guidance in selecting the appropriate value of R1 and R2 needed to set the mark and space frequencies. What are possible R and C values to generate the selected f_{mark} and f_{space} frequencies? Note: Use the Typical Value line in figure 5 to select R and C values.
2.2.8. Given all the considerations above, build your FSK modulator circuit in TINACloud.

2.3. Antenna

After designing the FSK modulator, you will need to design a power amplifier block that will drive a special antenna, ANTT. This provides a 50-Ω load to the power amplifier. The sub-block is illustrated in Figure 4 with a sample design of the power amplifier in Figure 5.

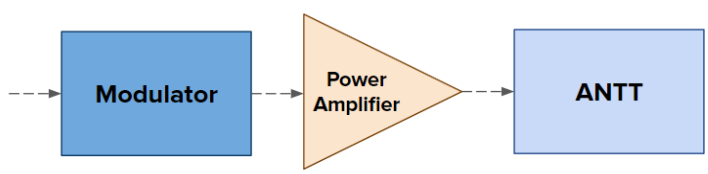


Figure 4. Modulator - Power Amplifier - Antenna Sub-block

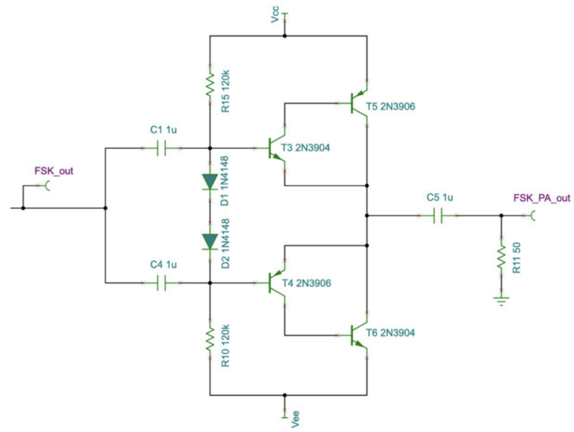


Figure 5. Sample Power Amplifier Design with a 50-Ω Antenna Load

2.3.1. Perform a transient analysis and frequency spectrum analysis of your BFSK modulator and modulator cascaded with the power amplifier design. Are the results consistent with the expected output?

2.4. ***BFSK Demodulator*** *(for three-person teams only)*

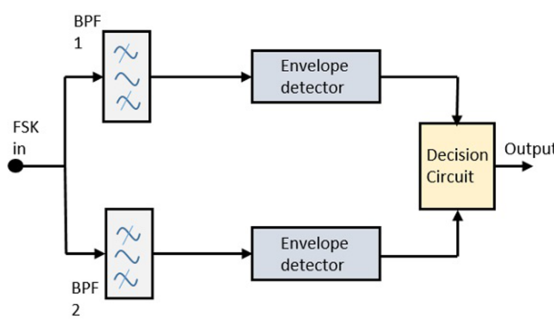


Figure 6. BFSK Demodulator Block Diagram

Bandpass Filter Design. The recommended specifications for bandpass filter design is a 4th order filter with center frequencies at f_{mark} and f_{space}. There are several possible combinations for implementing this design. Note that the filter design for the BFSK demodulator is similar to the approach done when designing the filters in the analog front-end circuit. *Read: Sallen-Key filter topologies*

2.4.1. What are the circuit schematics for a Sallen-Key lowpass, highpass, and bandpass filter? What will you implement and why?

2.4.2. What type of analog filter (Chebyshev, Butterworth, or Bessel) is appropriate for this application? *Hint: Compare the frequency response of each filter*

2.4.3. **Op-Amp Selection.** Several parameters must be considered when selecting the appropriate op-amp for the intended application.

2.4.3.1. What is the minimum unity gain bandwidth needed to operate the filter without interference of the dominant pole of the op amp?

2.4.3.2. What is the minimum slew rate needed?

2.4.4. **Envelope Detector.** How does an envelope detector work? Why is it needed in the demodulator circuit?

2.4.5. **Decision Circuit.** The comparator can be thought of as a decision-making circuit. How does the comparator work?

Signal Processing Unit

Once sensor data is received and demodulated, the next step is to reconstruct the signal for processing and analysis.

Design Specifications

- Time vector from the demodulator output data is reconstructed, allowing display and further analysis of the received EMG data
- Data reconstruction algorithm is able to detect error in received data
- Digital signal rectification done via MATLAB
- Output data labels approximate onset and offset time locations (sample labeled plot below)

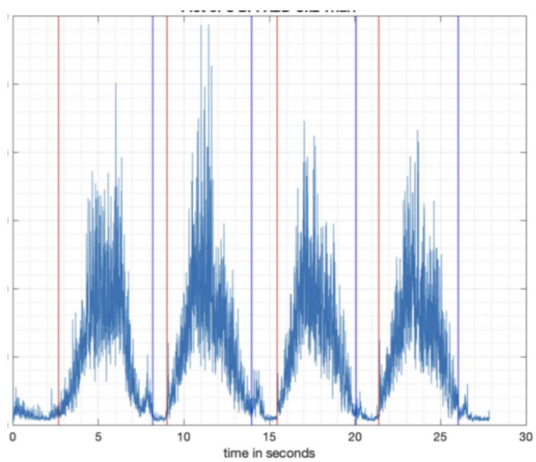


Figure 7. Sample labeled onset and offset times calculated using thresholding method. Algorithms may be found in the succeeding flowchart. Red = ON time, Blue = OFF time.

Guide Questions

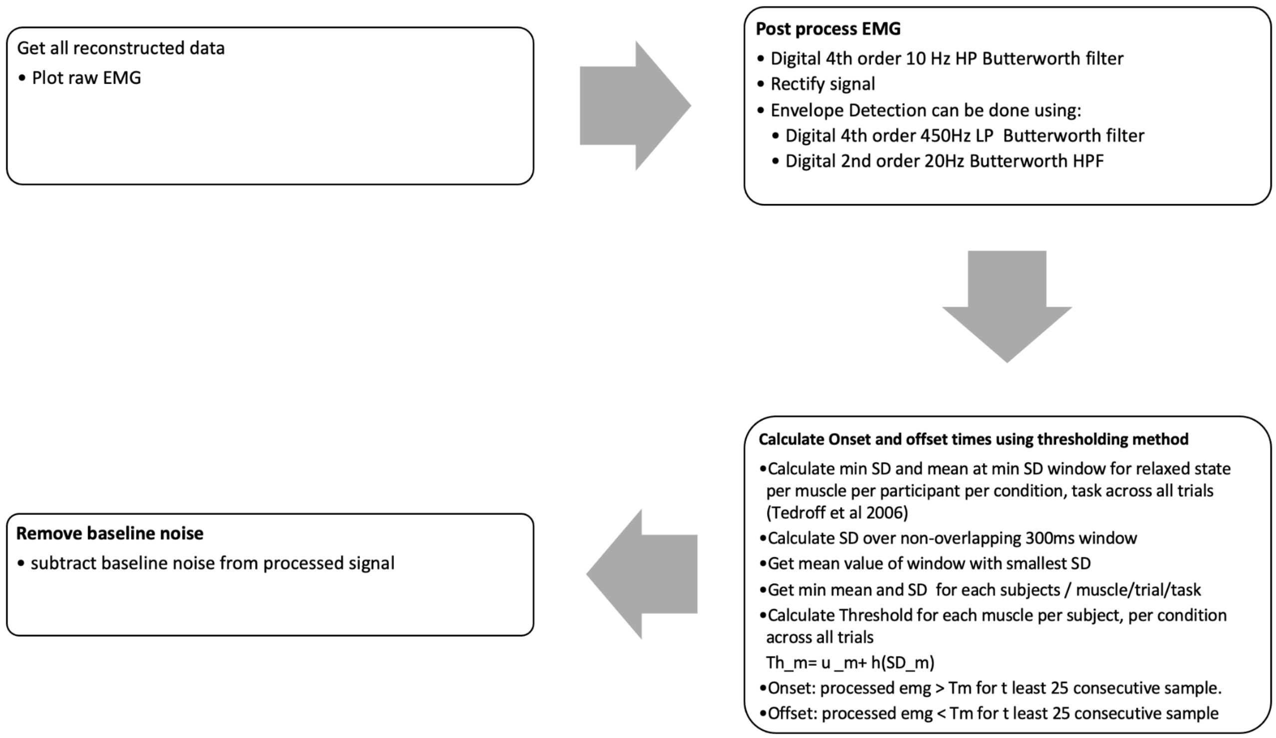
1. **Data Reconstruction**

   After demodulation, your data should be exported from TINA as a file and imported to MATLAB for data reconstruction and processing. As you write the code for data reconstruction through MATLAB, take note of the following guide questions:

   1.1. What is the expected file from TINA when the demodulator output is exported?
   1.2. What is the expected range of values of the demodulator output? What frequency?
   1.3. How will you extract the ADC data from the data packets received?
   1.4. How will you know if the data received are correct? What is meant by an odd and even parity?
   1.5. How will you recreate the time vector to allow display and further analysis of the received EMG data?

2. **EMG Signal Analysis**

   Student teams may follow the following pseudocode for EMG signal processing and analysis using MATLAB.



References

- Tedroff K, Knutson LM, Soderberg GL. Synergistic muscle activation during maximum voluntary contractions in children with and without spastic cerebral palsy. Dev Med Child Neurol. 2006 Oct;48(10):789-96. doi: 10.1017/S0012162206001721. PMID: 16978457.
- Hodges PW, Bui BH. (1996) A comparison of computer-based methods for the determination of onset of muscles contraction using electromyography. Electroencephalogr Clin Neurophysiol 101: 511–519.

Verification and Validation (V&V)

EMG Test Data for Verification and Validation

To demonstrate the functionality of their design projects, ideally, students will acquire EMG data from their skin using surface EMG electrodes and use this as input to the analog front-end unit of their EMG system. However, due to the remote learning implementation of EEE 192, this will not be possible for this semester's iteration. This does not mean that we will not be able to test system functionality and acquire EMG signals. Students are provided with a set of noisy EMG data signals acquired using a commercial EMG sensor. These data are converted to .wav files which will then be used as input to the circuit designed by the students in TINACloud. By the end of the semester, these students should be able to demonstrate that they are able to amplify, filter, rectify, and post-process the noisy EMG signals.

Data Description

The Data set provided were obtained from EMG measurements from both limbs of three (3) human participants with an upper type brachial plexus injury. EMG measurements were classified into two groups:

Group A: Upper extremity with an upper type brachial plexus injury that has undergone nerve transfer (BPI)

Group B: Normal contralateral upper extremity (NORMAL)

The participants were tasked to perform a shoulder abduction movement (ABD): Shoulder abduction in frontal plane and adduction back to resting position. This movement is demonstrated in the video shown during class orientation (See video under Piazza Resources) Surface EMG electrodes were placed on the middle deltoid (MD). EMG measurements were done using Delsys Trigno Wireless EMG Sensor and were sampled at 2kHz.

For EEE 192, these EMG data were corrupted to include noise acquired by EMG electrodes during the signal acquisition stage. They were also attenuated to remove the amplification done by the Trigno Delsys Sensors. This process results in a corrupted EMG signal that simulates raw EMG data collection from a human participant. A sample test data to be used as input to the analog front-end circuit is shown in Figure 8. p-terminal and n-terminal signals are provided as differential input to the instrumentation amplifier of the front-end circuit to simulate the bipolar configuration of surface EMG signal acquisition.

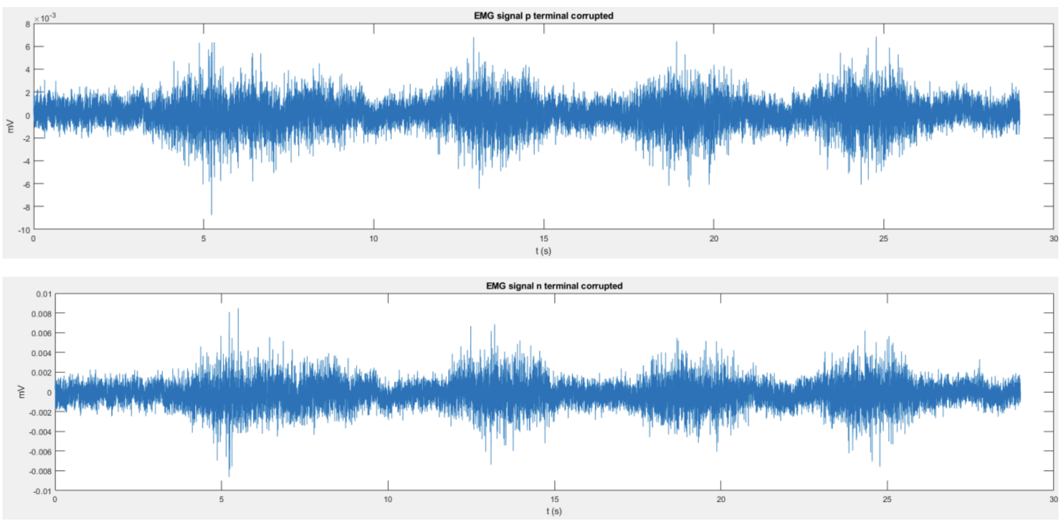


Figure 8. Sample Corrupted Differential EMG Signal

Block Output Milestones and Demonstration Requirements

To show a successful implementation of each unit and the entire project, student teams must demonstrate the following output milestones.

1. ***Analog Front-End Unit.*** Student teams should be able to successfully filter and amplify the ~30s long Noise EMG dataset provided by the course handlers. This noise EMG dataset is fed to the input of their analog front-end unit as a differential input. The output signal must satisfy the design specifications indicated for this block.
2. ***Transceiver Unit.*** Due to the simulation times required by TINA, it's **not advisable** to use the ~30s long test EMG data used in the analoog front-end unit. Hence, to demonstrate functionality of the transceiver unit, **students may use ideal test data as their input to the ADC** (e.g., square wave, sinusoid). They may also adjust the transient time to shorten the simulation time needed by TINA. After the demonstration, they should be able to show that all design requirements are met. It's the task of the students to define test scenarios they will use to justify the functionality of this unit.

3. ***Signal Processing Unit.***
    a. Data Reconstruction. Students will **NOT** be asked to use the output file produced by the demodulator as input to their data reconstruction algorithm in MATLAB. Instead, they will be using a **new set of data reconstruction test data provided by the course handlers** to test the functionality of their algorithm for data reconstruction. Note that this test data is different from our noise EMG dataset. Students may access the input for the data reconstruction block through this link. Please read the README.txt
4. ***Integration***
    a. End-to-End Integration. Due to the simulation constraints of TINA, end-to-end integration of the 3 main blocks (analog front-end, transceiver, and signal processing) will **NOT BE REQUIRED** for EEE 192. Instead, students should ***focus on the V&V of each block as specified by the Block Output Milestones and Demonstration requirements*** indicated in items 1-3 and 4b (EMG Signal Analysis and Analog Front-End Unit Integration)
    b. EMG Signal Analysis and Analog Front-End Unit Integration. As indicated in the requirements of the project, students should be able to demonstrate that they are able to amplify, filter, rectify, and post-process the noisy EMG signals. To show this, students will use the **output of their analog front-end circuit** as input to MATLAB as perform EMG analysis. This includes showing a plot of the filtered EMG data and EMG envelope via MATLAB, and labelling of onset and offset times. This integration means connecting the orange and blue blocks indicated in Figure 2.

Proposed Project Implementation Timeline

Figure 9 provides a sample 14-week Gantt chart for the implementation of the project. The Gantt chart shows the two phases of development for an EMG-based system under the remote setup, along with the milestones that can be checked throughout the course. Students can use this as reference in formulating the Gantt chart for their respective teams.

Sample EMG Project Implementation Gantt Chart (Student Teams)

Project Phase	Tasks / Deliverables	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13	WK14	FINALS
Phase 1: Project Planning and Preliminaries	**Project Planning and Preliminaries**															
	Read Project Brief															
	Establish Team Communication															
	Explore TINA and MATLAB															
	Review Circuit Design and Input Data															
	Accomplish Team WBS															
	Prepare Team RACI Matrix															
	Prepare Project Gantt Chart															
	Presentation of WBS, RACI, Gantt Chart, PM Assignments															
Phase 2: Project Implementation	**Project Implementation**															
	Block 1: Implement and Test Analog Front-end Unit (TINA)															
	Block 2: Implement and Test Tranceiver Unit (TINA)															
	Block 3: Implement and Test Signal Processing Unit (MATLAB)															
	Integration and Finalization Period															
	End-to-End Integration Testing															
	Submission of Technical Report															
	Final Presentation															
Progress Updates	Present Progress Updates to Handler															
	Project Documentation															

Figure 9. Sample Preliminary Gantt Chart for EEE 192 Version 2

References and Additional Resources

- Gohel, V., & Mehendale, N. (2020). Review on electromyography signal acquisition and processing. Biophysical reviews, 12(6), 1361–1367. Advance online publication. https://doi.org/10.1007/s12551-020-00770-w
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- Farina D., Rainoldi A. Compensation of the effect of subcutaneous tissue layers on surface EMG: A simulation study. Med. Eng. Phys. 1999;21:487–497

Release Notes Summary available (public link) (editable doc)