ECE 445

Fall 2022
Senior Design: Design Document

Bruxism Treatment Device

Edric Lin [edricl2]; Jaewoong (Justin) Song [js52]
Group 6
TA: Mingjia Huo
Professor: Arne Fliflet
September 29, 2022

Contents

1 Introduction

1.1 Problem and Solution

1.1.1 Problem

Bruxism, more commonly known as tooth grinding, is a condition where one grinds or clenches their teeth unconsciously. Depending on the particular study, anywhere from 10-30% of the population can be affected by this condition. Should bruxism be severe and frequent enough, it can lead to jaw disorders, headaches, damaged teeth, and other problems. There is not one singular cause for bruxism and as such, current solutions act more as a temporary measure to minimize damage rather than address the issue itself. For example, common dental solutions include using a mouth guard and, in some cases, undergoing dental correction. Similar to treatments, medication serves mostly as a reactionary measure where they attempt to address issues and complications that arise from bruxism.

1.1.2 Solution

Our proposed solution to Bruxism is to develop a system that relaxes the muscles while the user is clenching their teeth. This will be done via a two part system: detection and prevention. The detection part will be outside of the mouth and focus on the jaw muscles and any noises made by the tooth grinding. It will consist of an EMG in conjunction with audio sensors. These signals will be transmitted into a control circuit that will save the data (via a MicroSD card) for later viewing, activate a TENS (transcutaneous electrical nerve stimulation) unit to relax the jaw muscles, and sound an alarm to serve as an audio indicator. Aside from electrodes for the EMG and TENS modules and an external audio detector, the entire device will be contained within a small portable box that can be placed, for example, upon a desk while one works.

1.2 Visual Aid

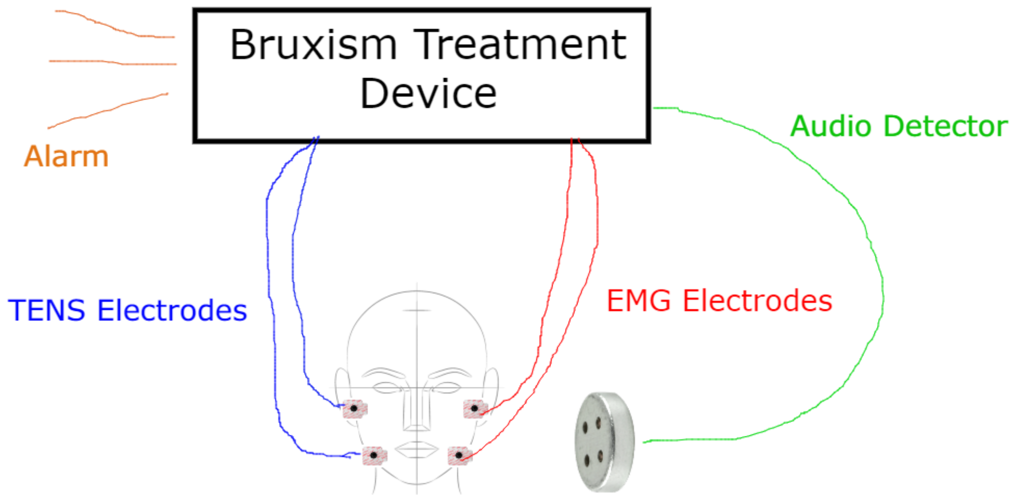

Figure 1: Overview of the Bruxism Treatment Device with patient's teeth.

1.3 High-level Requirements

- Detection section detects teeth grinding and sends appropriate signals to control circuit
  - The EMG module will take EMG signals (up to 10 mV) from the electrodes attached to the side of user's jaw. It will then output the amplified analog signals (up to 5 volts) to the control subsystem.
  - The Audio Detector module will detect grinding and crunching noises. It will filter the audio and amplify the analog signal before then sending it to the control subsystem. Further data of the appropriate frequency range to filter and the allowable voltage range will need to be collected before more specific values can be given.
- Prevention section responds appropriately according to input from control circuit
  - The Alarm module will output an auditory notification at around 60 dB (± 10 dB) when the control subsystem gives the signal to do so. It will turn off and stay below 10 dB when the control subsystem gives the signal to do so.
  - The TENS unit will output square wave signals that are no more than 40 volts in magnitude and will give no more than 50 mA of current. The frequency of these signals will be no higher than 100 Hz.
- Data section collects data appropriately and allows for retrieval for later viewing
  - The data is to be collected via a flash memory device, presently proposed to be a MicroSD Card.
  - The microcontroller will write to the memory card via SPI.

2 Design

2.1 Block Diagram

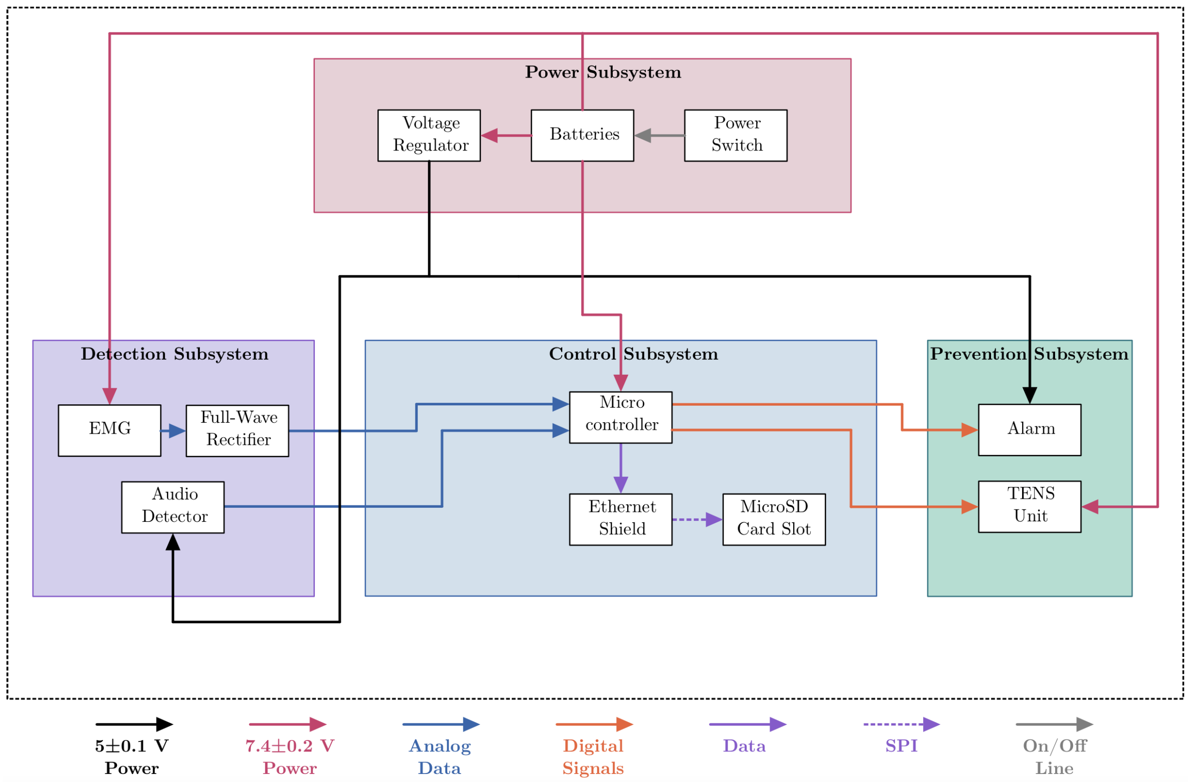

Figure 2: **Block diagram of entire system.**

This Bruxism Treatment Device consists of four separate subsystems: Power, Detection, Control, and Prevention. The Power subsystem is responsible for providing three stable DC voltages to the entire device: positive 7.4 volts, negative 7.4 volts, and 5 volts. It will consist of four Lithium-Ion batteries and an LDO that takes an input of positive 7.4 volts and outputs 5 volts. It will also contain two switches that will act as on/off switches. The Detection subsystem will be responsible for detecting teeth grinding and sending the appropriate signals to the control subsystem. The subsystem will contain an EMG circuit and an Audio Detector circuit. Further detailed descriptions for both can be found here and here respectively. The Control subsystem will be responsible for processing the information input from the Detection subsystem and will output appropriate response signals to the Prevention subsystem. It will consist of a Micro-controller (details for which can be found here), an Ethernet Shield (details for which can be found here), and a MicroSD Card Slot. These will be discussed in further detail later. The Prevention subsystem will be responsible for preventing the user from grinding their teeth. It will consist of an Alarm Circuit and a TENS Unit Circuit (details for which can be found here and here respectively).

2.2 Physical Design

The overall physical design of the system will be encased in a box with electrodes as the main outward facing input for the user. The Bruxism Treatment Device will be small enough to be portable and will be able to be set upon a table. The device is designed to be battery operated for extra portability and there will be a power button to turn on the device (with a power LED indicator). The box will have a cutout for a MicroSD card slot.

2.3 Power Subsystem

2.3.1 Battery Module

The Battery Module of the Power Subsystem will be made out of four 3.7-volt Lithium-Ion batteries. They will be connected in series so that the module can provide the positive 7.4 volts and negative 7.4 volts DC voltages. The battery capacities are 2500 mAh, resulting in 10000 mAh total. We also intend to use batteries that are replaceable and rechargeable so that the user can switch batteries in the event the device does run out of charge. The batteries will be controlled by two mechanical switches to either connect or disconnect the battery module from the rest of the system. These switches will be the on/off buttons of the device. The switches will additionally power on LEDs to indicate that the supply voltage is turned on. We will use a blue LED to indicate that the positive 7.4 volt supply is connected and a yellow LED to indicate that the negative 7.4 volt supply is connected. For a visual reference, refer to Figure 3.

Number	**Requirements**	**Verifications**
1	Supply Positive 7.4 ± 0.2 Volts	Probe positive 7.4 volt node with respect to ground node with voltmeter while connecting the batteries to a load that draws 500 mA.
2	Supply Negative 7.4 ± 0.2 Volts	Same as number 1 but probe negative 7.4 volt node with respect to ground node.
3	Blue LED turns on when supplied 7.4 Volts with respect to ground and turns off when supplied 0 volts	Supply DC 7.4 volts to the Blue LED. Verify it shines. Ground input of the Blue LED. Verify it doesn't shine.
4	Yellow LED turns on when supplied 0 volts with respect to DC negative 7.4 volts and turns off when DC negative 7.4 volts is shorted	Same as number 3.

Table 1: Requirements and Verifications for battery module.

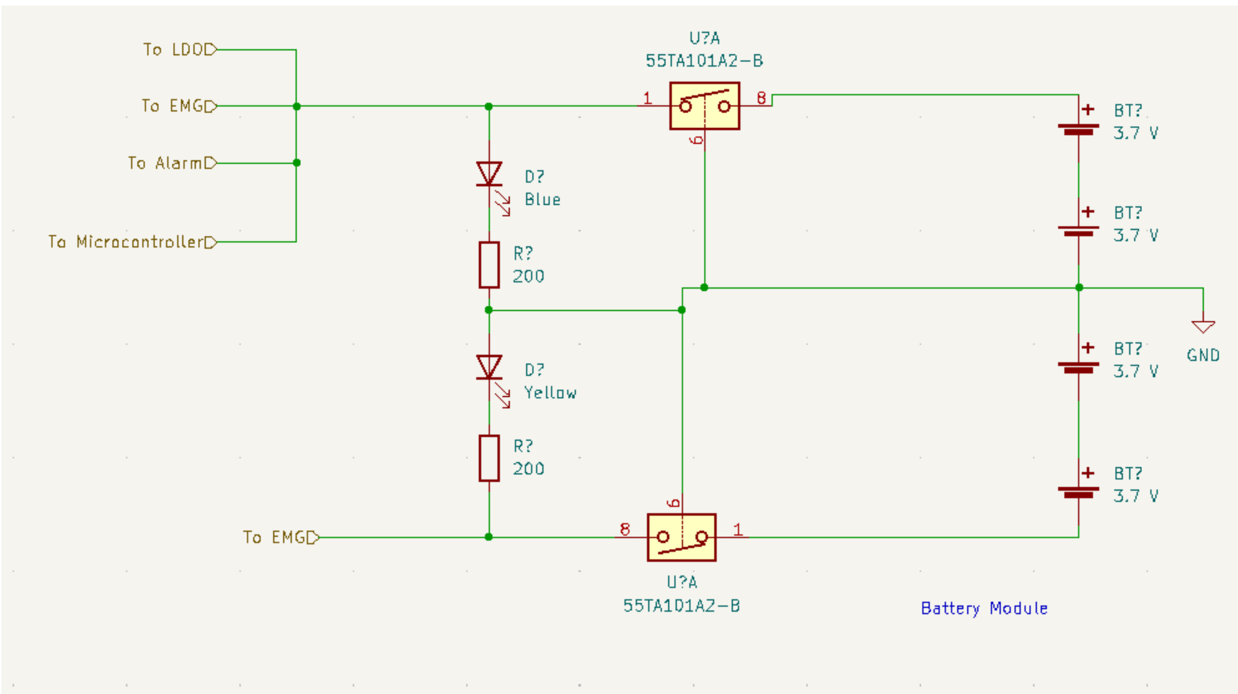

Figure 3: **Battery Module schematic.**

2.3.2 Voltage Regulator

The Voltage Regulator of the Power Subsystem will utilize an AZ11171H LDO. It will have an input of 7.4 Volts and will output 5 Volts. As recommended from the data sheet, the input will have a shunt capacitor of 10 μFs and the output will have a shunt capacitor of 22 μFs. We intend to use the adjustable version of the AZ11171H, and will thus use four 100 Ω resistors to adjust the output of the regulator to 5 volts. The resistors will be placed in series, and the ADJ pin of the LDO will be connected to the resistors in such a way that it divides the resistors into an effective 100 Ω part and an effective 300 Ω part. This division was selected based off of the equation for a desired output voltage formula provided in the LDO's datasheet. For a visual reference, refer to Figure 4.

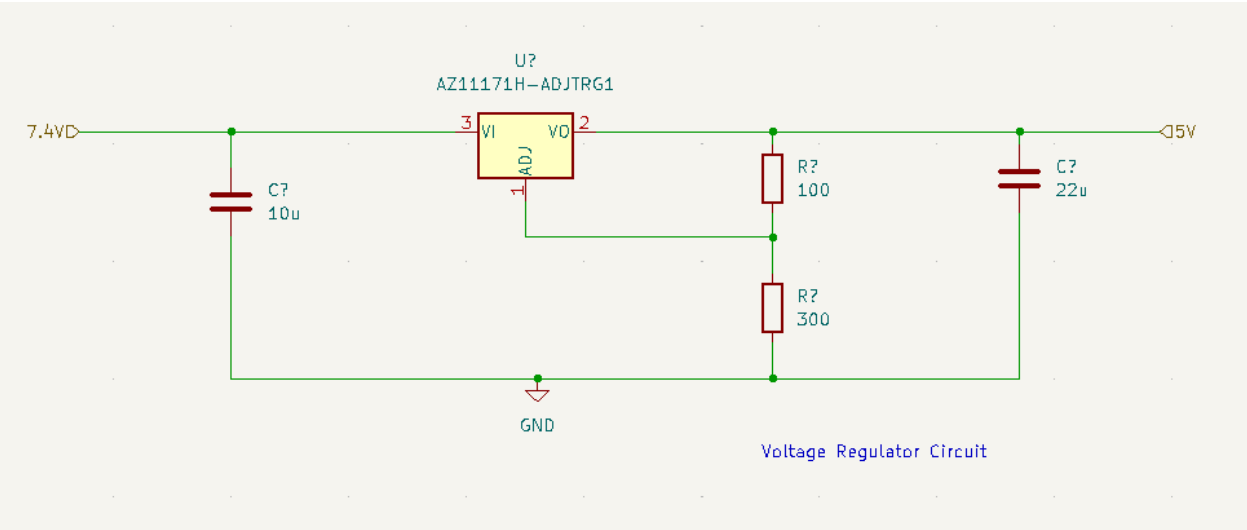

Figure 4: **LDO circuit schematic.**

Number	**Requirements**	**Verifications**
1	Output of the LDO must be a constant 5 volts with an error of ± 0.1. It must not exceed a current of 100 mA	Probe the input of the LDO with voltmeter when 3.7 batteries are connected to input and Vout is kept at constant 5 volts. After confirmation, measure the output current with an ammeter to make sure it is less than 100 mA with a resistive load of 2.2 kΩs.

Table 2: Requirements and Verifications for voltage regulator.

2.4 Detection Subsystem

2.4.1 EMG Module

The EMG will be responsible for detecting muscle movement within the user's jaws and sending an amplified version of the signal to the control subsystem. To detect the movement, the EMG will use electrodes that are stuck upon the user's jaw muscles. The output of the electrodes will be fed into an AD8221ARZ-R7 instrumentation amplifier. The instrumentation amplifier will be powered directly by the Battery Module. As EMG signals are usually around 10 mV, we selected a resistor value of 100 to set the gain of the amplifier to 500. The amplitude range of the amplified signal is negative 5 to positive 5 volts, which falls within the operating voltage range of the amplifier (negative 7.4 volts to positive 7.4 volts). As the most useful frequency range of EMG signals lies in between 50 - 150 Hz, the output of the AD8221ARZ-R7 will be fed into a bandpass filter that attenuates signals outside of the 50-150 Hz range. The output of the bandpass filter will then be fed into the precision full-wave rectifier. Each DC power rail will have a 0.1 μF shunt capacitor to aid in protection. For a visual reference, refer to Figure 5.

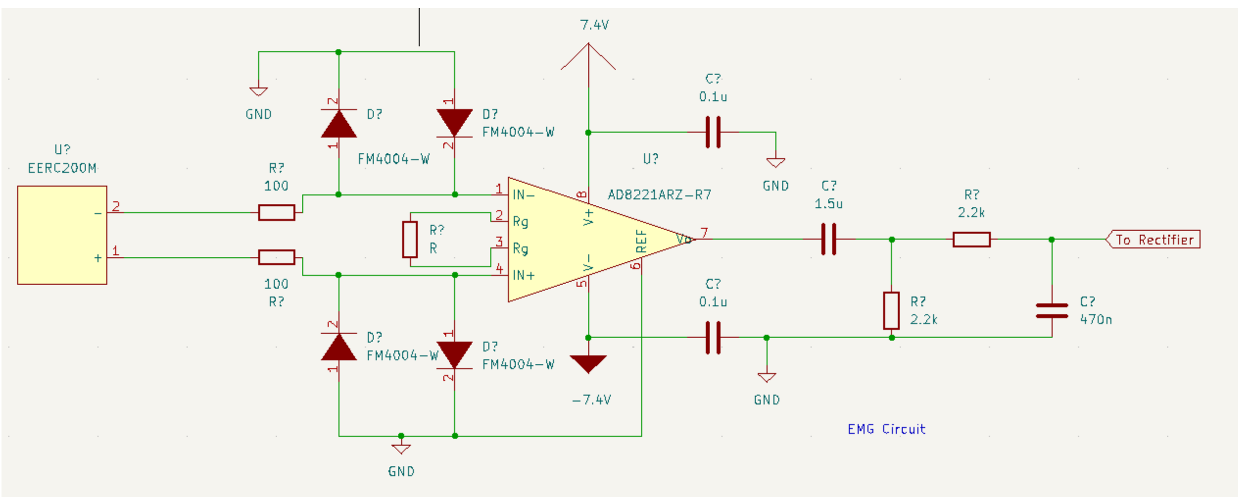

Figure 5: **EMG circuit schematic.**

Number	**Requirements**	**Verifications**
1	Electrodes must be able to detect EMG signals of up to 10 mV	The electrodes may be placed in parallel with a load resistor. The resistor is probed with an oscilloscope to verify the amplitude (in the range of 0-10 mV).
2	The Instrumentation Amplifier must have a gain of 500 at 150 Hz.	Ground the In- pin of the amplifier while feeding a 10 mV 150 Hz sinusoidal wave into the In+ pin. The Rg pins are connected through a resistor of 100 Ω, and the positive and negative supplies are connected to positive 7.4 volts and negative 7.4 volts respectively. Attach a resistive load at the output, and use an oscilloscope to probe the voltage across the load. The output voltage should be a sinusoidal with an amplitude of 5 volts with an allowable error of 0.5 volts.
3	The bandpass filter must filter signals that have frequencies outside the range of 50 - 150 Hz. An error of 10 Hz on each extreme is allowed.	Probe the output of the bandpass filter with a spectrum analyzer. Verify that the most pronounced frequency range is within 50 - 150 Hz range.

Table 3: Requirements and Verifications for EMG module.

2.4.2 Precision Full-Wave Rectifier

The precision full-wave rectifier will take the filtered, amplified signal of the EMG output and will output a fully rectified signal. We will be using a precision amplifier since this is commonly used with other EMGs and we cannot implement a simple full wave bridge rectifier. It will consist of two LM358 operational amplifiers configured with five 10 kΩ resistors and two diodes. This module will be directly powered by the battery module.

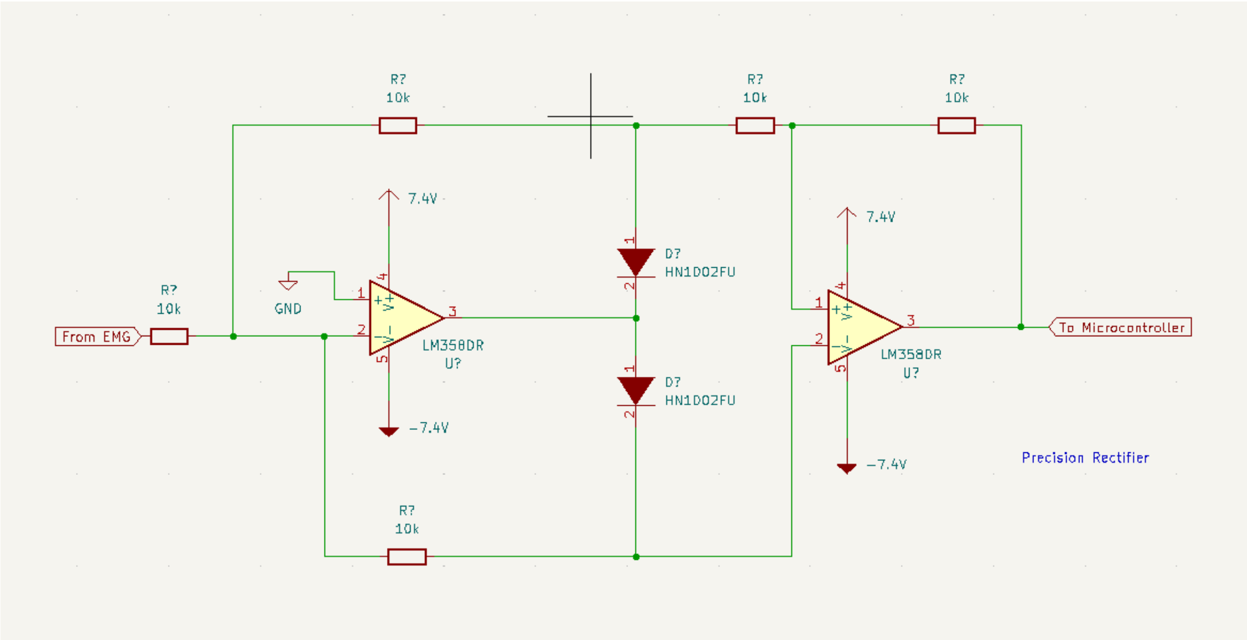

Figure 6: **Precision Full Wave Rectifier circuit schematic.**

Number	**Requirements**	**Verifications**
1	The precision full wave rectifier must be able to invert the negative half of the AC input signal that has a maximum peak voltage of 5V	Use a signal generator to input a 5V peak-to-peak sinusoidal wave into the precision full wave rectifier. Probing the output should result in the full-wave rectified version of the input with ~1V magnitude loss due to parasitic components (i.e. the absolute value of the input signal).

Table 4: Requirements and Verifications for Precision Full-Wave Rectifier.

2.4.3 Audio Detector Module

The Audio Detector Module will be responsible for detecting the sound of teeth grinding while the user is experiencing Bruxism. This will be primarily done by the PMOF-9767NS-40DQ analog microphone. As recommended by its datasheet, it will be connected to a 2.2 kilo-Ω resistor to the operating voltage of 5 volts and a 1 μF capacitor to it output. We plan to additionally filter the microphone's output and amplify the signal to an accurate and processable signal. However, the designs of the filtering circuit and amplification circuit will only be possible after taking and analyzing empirical data from physical testing. The 5 volt supply will be from the Voltage Regulator module of the Power Subsystem. For a visual reference, refer to Figure 7.

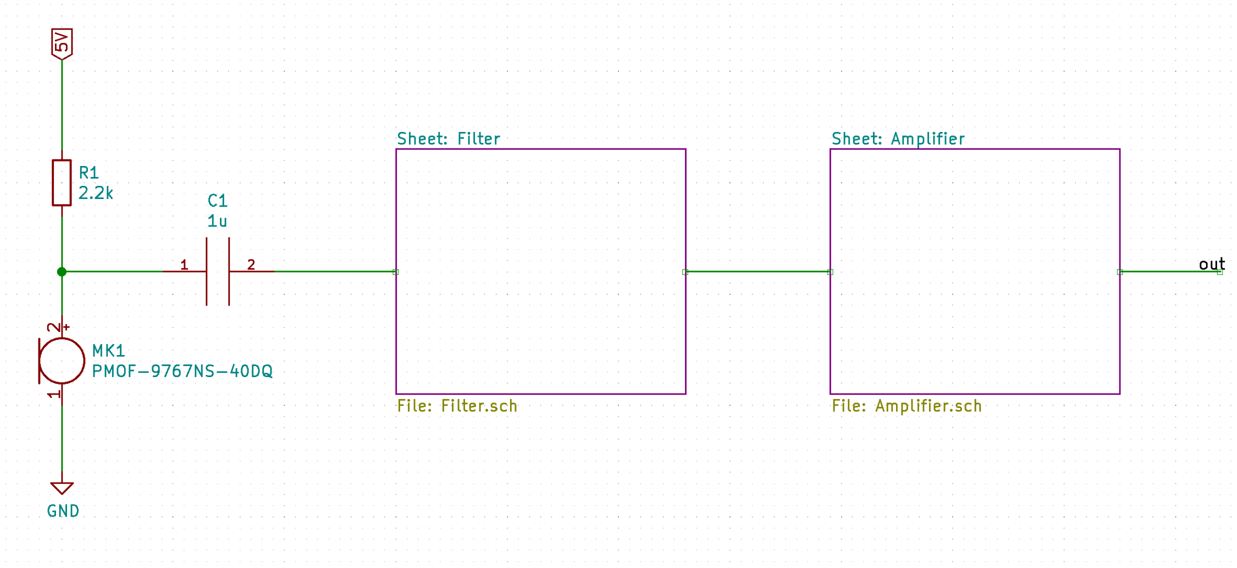

Figure 7: **Audio detector circuit schematic.**

Number	**Requirements**	**Verifications**
1	Conduct physical testing of teeth grinding and collect empirical data to analyze frequency range of noise.	Record teeth grinding with separate microphone and obtain the data as an audio file. Convert the audio file into a viewable waveform on a computer with Audacity.
2	Determine the voltage output range of the PMOF-976NS-40DQ.	Attach a resistive load to the intended output of the circuit. Probe the output with an oscilloscope to detemine the voltage range.

Table 5: Requirements and Verifications for audio detector module.

2.5 Control Subsystem

2.5.1 Microcontroller

The Arduino Uno Rev3 SMD has been chosen as the microcontroller that will be used in the Control Subsystem. The microcontroller will take in analog inputs from the precision full wave rectifier and the audio detector. Within the logic of the microcontroller, once both are above a certain threshold (i.e. taking the logical AND of the two signals), then the microcontroller will send signals to both the alarm and the TENS unit in the Prevention Subsystem to activate both of them. It will be powered at 5 volts supplied by the Voltage Regulator module. It will additionally supply 3.3 volts to an LED that will indicate that the system is on.

Number	**Requirements**	**Verifications**
1	Recieves data from 2 analog sources and performs analog to digital conversion to a digital signal.	Feed 2 analog signals from 2 signal generators (one sinusoidal, one triangle, both with 3 volt magnitudes) into 2 analog pins of the Arduino. After iterating though code that performs analog to digital conversion, it will output a digital signal (0 V or 3.3 ± 0.3 V) that can be probed with an oscilloscope.
2	Process analog EMG signal into digital data to be stored on Micro-SD card	A continuation of number 1. The sinusoidal signal will be processed as digital data and be saved as a csv type file to be written into an Micro-SD card

Table 6: Requirements and Verifications for microcontroller.

2.5.2 Ethernet Shield and MicroSD Slot

The Ethernet Shield is primarily used for its MicroSD Card slot, which will serve as a way for the user to export their data in a convenient way. Additionally, the shield allows for future feature expansion in the sense that the data can be exported wirelessly via Ethernet. It will be powered by the Arduino.

The data (referenced below in Table 9) will consist of moments in time when the device detected teeth grinding (the method of which is described in the Prevention Subsystem section). The protocol for writing to MicroSD cards are done through (SPI) Serial Peripheral Interface, which is a synchronous serial communication interface specification. The code for interfacing with the MicroSD card will be done in the microcontroller.

Number	**Requirements**	**Verifications**
1	Can receive data from Arduino. The data will be moments in time when the device detected teeth grinding.	Run code that outputs a success message when data from Arduino is received while testing in conjunction with Arduino.
2	Can write data to SD card with a targeted latency of approximately 1 second. The data will be moments in time when the device detected teeth grinding.	Same as number one but output message when successfully storing data on SD card. Will also verify by reading MicroSD card on external computer system.

Table 7: Requirements and Verifications for the shield.

2.6 Prevention Subsystem

2.6.1 Alarm Module

The Alarm Module is a speaker which serves as an audio indicator when the device detects teeth grinding. It's loudness will be tun-able via a potentiometer. It will consist of an LM386 audio amplifier configured with a gain of 20 according to its datasheet recommendations. It will be powered by the Voltage Regulator module's 5 volts and have a speaker (CDS-4028-16) with a load of 16 Ω. A 0.1 μF shunt capacitor is added to the power rail of the amplifier for further protection. For a visual reference, Figure 8.

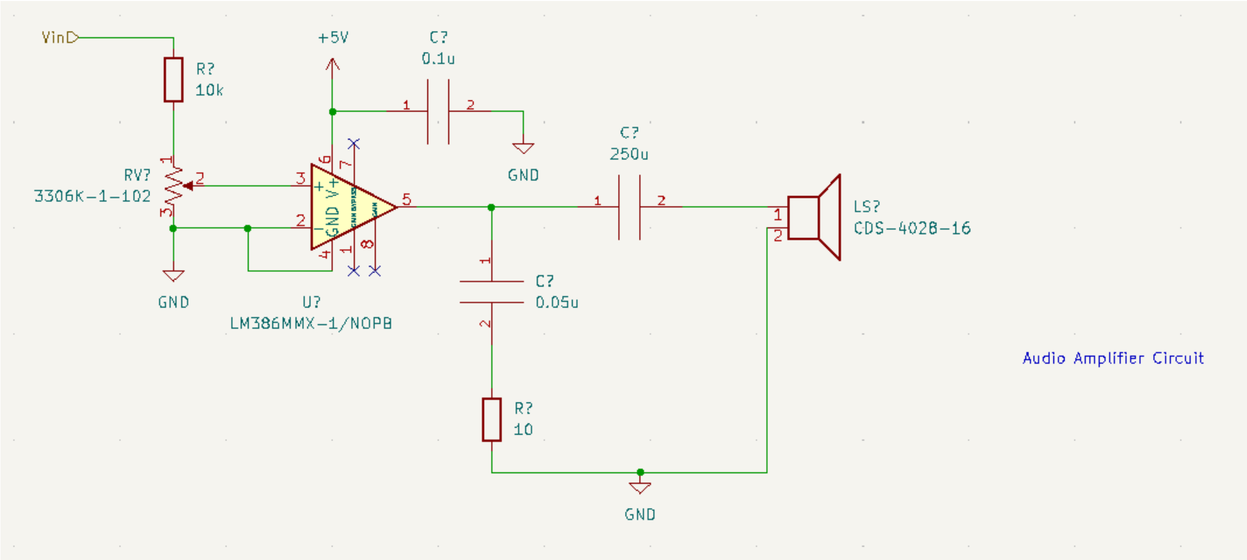

Figure 8: **Audio amplifier circuit schematic.**

Number	**Requirements**	**Verifications**
1	The amplifier must have a gain of 20 at DC	Feed a 100 mV sinusoidal input into the V+ pin of the amplifier. Probe the output of the amplifier with an oscilloscope to verify that the amplitude of the output is 2 volts (with an acceptable error of 0.2 volts).
2	Sound intensity should not exceed 60 dB	Feed a DC 3.3 volt source into Vin of the module. Verify that the sound intensity changes when the potentiometer is turned. Use a decibel meter to ensure that the output sound is at max 60 dB.

Table 8: Requirements and Verifications for alarm module.

2.6.2 TENS Unit

The TENS (transcutaneous electrical nerve stimulation) unit will deliver voltage signals back to the user's jaw muscles to get them to relax, thereby stopping the teeth grinding. This design was taken from a shared project online, originally published in Elektor Electronics Magazine by Klaus Rohwer. It will be turned on and off from the Control Subsystem and it will be directly powered by the Battery Module when on. The output voltage can be adjusted by a potentiometer. Voltage limiting of the output will need to be determined after further empirical testing. For a visual reference, refer to Figure 9.

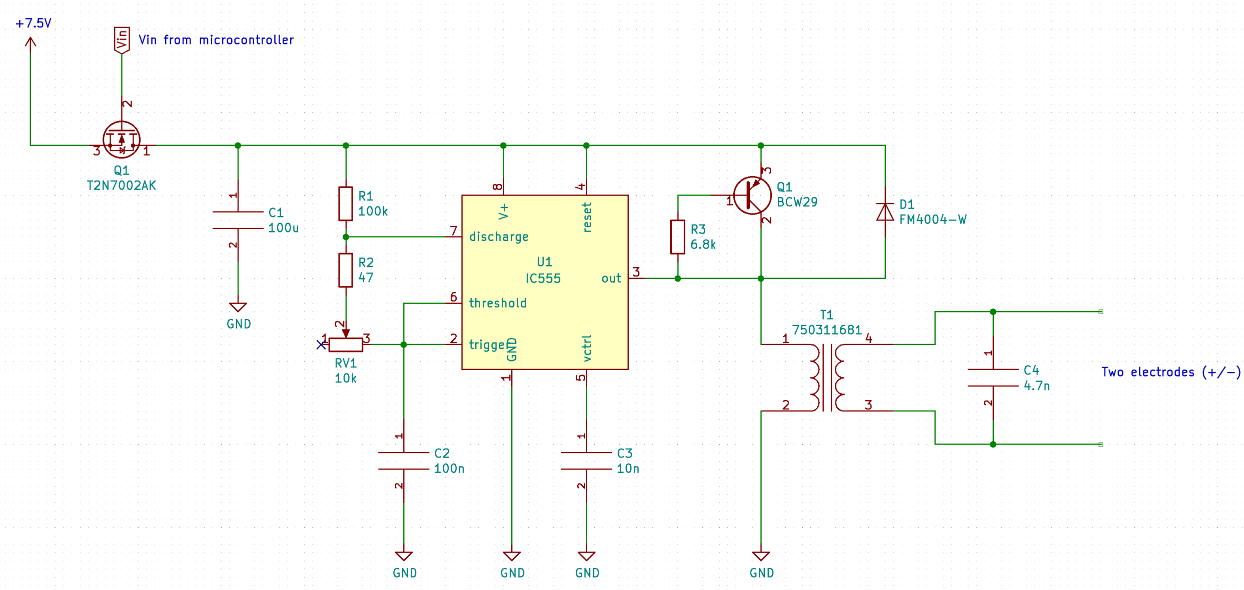

Figure 9: **TENS Unit circuit schematic**

Number	**Requirements**	**Verifications**
1	Turns on and off accordingly	Attach a digital signal generator at the circuit's voltage controlled switch. Measure voltage across the secondary coil of the transformer with an oscilloscope and verify that the max voltage is 40 volts.
2	Voltage output can be adjusted	Set the switch to constant on. Measure the voltage across the secondary coil with an oscilloscope. Observe if any significant changes in voltage occurs when turning the potentiometer. The max voltage should not exceed 40 volts.
3	Output current is no more than 50 mA	Continuation of number 2. Attach secondary coil leads to 1000 Ω load (resistance of human skin). Measure current across it with ammeter.

Table 9: Requirements and Verifications for TENS unit.

2.7 Tolerance Analysis

2.7.1 Microcontroller

The greatest risk to the successful completion of our project lies in the implementation of the microcontroller within the Control subsystem. Simultaneously handling the inputs from the Detection subsystem and then streaming the data both to the Prevention subsystem and the SD card poses the greatest challenge in the project. Specifically for the MicroSD card port, verification of a MicroSD card insert and then writing the processed data can prove to be challenging.

Based on the requirements necessary for the control subsystem and the entire device, the microcontroller board being based on the ATmega328P is a major consideration that will be held in mind throughout the design process. The main computational draw from the microcontroller at the moment should be taking in the analog inputs, processing them in order to write to the MicroSD card, and sending it out to the prevention subsystem. This portion of the subsystem must be monitored carefully to ensure that the microcontroller performance does not drop significantly.

2.7.2 TENS Unit

The TENS unit may not work as intended (such as being unadjustable or producing too high of an output voltage), and thus may need either a complete rework or new solution. Research and analysis will be required to figure out exactly how to use the TENS unit effectively in terms of electrode placement among other things. Regardless, the TENS unit will require a lot of thorough testing to determine whether it will be sufficient for the project or not appropriate for the application the device is aiming for.

2.7.3 Detection Subsystem

The detection subsystem comprises of many modules that will require extensive testing to ensure proper functionality and operation. Since a big portion of this subsystem (and its connection to the control subsystem) concerns taking analog signals (namely voltages), filtering, and amplifying it to an appropriate level such that the microcontroller can properly read it, there exists multiple potential difficulties that will need to be worked out.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Parts

Part Description	Manufacturer	Part Number	#	Unit Cost ($)	Total Cost ($)
LDO	Diodes Incorporated	AZ11117IH-ADJTRG1	1	0.40	0.40
22 μF Cap	Samsung	CL21A226MPQNNNE	1	0.18	0.18
10 μF Cap	Samsung	CL21A106KPFNNNF	1	0.11	0.11
100 Ω Resistor	KOA	RK73B2ATTDD101J	20	0.034	0.68
Instrumentation Amplifier	Texas Instruments	AD8221ARZ-R7	1	8.28	8.28
2.2 kΩ Resistor	YAGEO	RC0805FR-132K2L	3	0.10	0.30
470 nF Cap	Samsung	CL21B474KOFNNNF	1	0.10	0.10
1.5 μF Cap	Wurth Elektronik	885012207023	1	0.22	0.22
0.1 μF Cap	Wurth Elektronik	885012207072	10	0.079	0.79
Microphone	Mallory Sonalert	PMOF-9767NS-40DQ	1	1.16	1.16
1 μF Cap	Samsung	CL21B105KAFNNNG	1	0.10	0.10
Blue LED	CREE LED	C566D-BFE-CU0W0351	1	0.19	0.19
Yellow LED	Wurth Elektronik	151034YS03000	1	0.17	0.17
Mechanical Switch	Shin Chin	55TA101A2-B	2	3.70	7.40
Audio Amplifier	Texas Instruments	LM386MMX-1/NOPB	1	1.65	1.65
10 kΩ Resistor	Bourns	CRM0805-FX-1002ELF	10	0.085	0.85
1 kΩ Potentiometer	Bourns	3306P-1-102	1	0.49	0.49
10 kΩ Potentiometer	Bourns	3306P-1-103	1	0.49	0.49
Rectifier Operational Amplifiers	Texas Instruments	LM358DR	1	0.37	0.37
10 Ω Resistor	YAGEO	SQP10AJB-10R	1	0.81	0.81
0.05 μF Cap	KYOCERA	SA105E503ZAA	1	0.38	0.38
250 μF Cap	Vishay	TVA1161	1	4.57	4.57
Speakers	CUI Devices	CDS-4028-16	1	3.12	3.12
100 μF Cap	Murata	GRM31CR61A107MEA8L	1	0.56	0.56
100 kΩ Resistor	YAGEO	RC0805FR-13100KL	1	0.10	0.10
47 Ω resistor	KOA	RK73B2BTTDD470J	1	0.10	0.10

10 Nanofarad Cap	Samsung	CL21B103KDCNNNC	1	0.10	0.10
4.7 Nanofarad Cap	Walsin	YP501472K100B20C6P	1	0.21	0.21
PNP BJT	Nexperia	BCW29	1	0.10	0.10
Diode	Rectron	FM4004-W	10	0.228	2.28
Rectifier Diodes	Toshiba	HN1D02FU,LF	2	0.43	0.86
IC555 Timer	Texas Instruments	NE555DRE4	1	0.38	0.38
Transformer	Wurth Elektronik	750311681	1	4.69	4.69
NMOS	Toshiba	T2N7002AK	1	0.16	0.16
Arduino Uno	Arduino	Rev3 SMD	1	26.30	26.30
Arduino Shield	Arduino	Ethernet Shield 2	1	29.80	29.80
Electrodes	Biomedical Life Systems	EERC200M	12	0.874	10.49
3.7 Volt Batteries	TinyCircuits	ASR00050	4	4.47	17.88
					126.82

Table 10: Material costs for all parts.

3.1.2 Manual Labor

Calculations for manual labor are below. The following numbers are assumed (on a per person basis):

- Hourly Salary: \$40
- Hours of Work Per Week: 10 $\frac{\text{hours}}{\text{week}}$
- Total Weeks Worked: 16 weeks

With two people on this team:

$$(2 \text{ people}) * \left(\frac{\$40}{\text{hour}}\right) * \left(\frac{10 \text{ hours}}{\text{week}}\right) * 16 \text{ weeks} = \$12800$$

3.1.3 Total Cost

The total cost is \$12920.08. The calculations are as follows:

$$\text{Total Material Cost} + \text{Total Labor Cost} = 120.08 + 12800 = 12920.08$$

3.2 Schedule

Week	Important	Edric	Justin
0 (9/26)	-	Footprints and PCB Design of Power and Detection Subsystems Design testing methodology for detecting teeth grinding	Footprints and PCB Design of Control and Prevention Subsystems Learn position of electrodes
1 (10/3)	Design Review PCB Board Review	Fix PCB Design Order parts Test teeth audio	Fix PCB Design Order parts Learn how electrodes work in relation to our design
2 (10/10)	First Round PCB Orders	Continue week 1 work Talk to machine shop	Continue week 1 work Talk to machine shop
3 (10/17)	-	Build and test Power Subsystem	Build and test Detection Subsystem
4 (10/24)	-	Build and test Prevention Subsystem	Build and test Control Subsystem (including programming + debugging)
5 (10/31)	Second Round PCB Orders	2nd PCB order if necessary Begin integration of subsystems	2nd PCB order if necessary Begin integration of subsystems
6 (11/7)	-	Continue integration and package everything (machine shop)	Continue integration and package everything (machine shop)
7 (11/14)	Mock Demo	Integrate feedback from mock demo	Integrate feedback from mock demo
8 (11/21)	Fall Break	Fix any last minute mistakes	Fix any last minute mistakes
9 (11/28)	Final Demo	Create and prepare presentation	Create and prepare presentation
10 (12/5)	Final Presentation Final Paper	Last check for final submission	Last check for final submission

Table 11: Week by week overall tasks and assigned responsibilities.

4 Discussion of Ethics and Safety

Overall, we intend to follow the IEEE Code of Ethics and the ACM Code of Ethics and Professional Conduct.

This project contains an element of human testing that should be scrutinized over for the safety of the user. As such, we intend to uphold §7.8.I.1 of the IEEE Code of Ethics wherein we "hold paramount the safety, health, and welfare". §7.8.I.2 of the IEEE Code of Ethics also applies to us, as we go through the stages of designing and testing our project. Many TENS devices have received FDA approval, which says something about the safety of such devices. However, this fact will not decrease the caution taken when using, testing, and integrating the device into our system.

As this project may carry risks that may be more than minimal risk in testing and showcasing the final product, we intend to follow the University of Illinois Office for the Protection of Research Subjects guidelines. Namely, we will contact the office and determine whether or not IRB approval will be needed. We also do not intend to seek out other test subjects besides ourselves.

Regarding data collection and usage, we will follow §1.6 − 1.7 of the ACM Code of Ethics and Professional Conduct. There will be no identifying information related to the user other than the actual teeth grinding data. The data will be directly written to a MicroSD Card that the user provides. The data will not be saved or shared with any parties or entities without the explicit consent of the user nor will it contain any personally identifying information.

5 Citations and References

[1] R. Martinek et al., "Advanced Bioelectrical Signal Processing Methods: Past, Present, and Future Approach—Part III: Other Biosignals," Sensors, vol. 21, no. 18, p. 6064, Sep. 2021, doi: https://doi.org/10.3390/s21186064.

[2] M. B. I. Raez, M. S. Hussain, and F. Mohd-Yasin, "Techniques of EMG signal analysis: detection, processing, classification and applications," Biol Proced Online, vol. 8, pp. 11–35, Mar. 2006, doi: 10.1251/bpo115.

[3] K. Rohwer, "Transcutaneous electrical nerve stimulator (TENS) circuit diagram," Learning Electronics. [Online]. Available: https://www.learningelectronics.net/circuits/transcutaneous-electrical-nerve_03.html. [Accessed: 29-Sep-2022].

[4] S. Gozani, "TENS Under the Hood: Maximum Voltage," Quell, 20-May-2020.

[5] Megcircuitsprojects, "EMG Sensing Circuit," Instructables, 20-May-2019. [Online]. Available: https://www.instructables.com/EMG-Sensing-Circuit/. [Accessed: 29-Sep-2022].

[6] D. Mercer, "Activity: Precision Rectifiers, Absolute value circuits, For ADALM1000," Analog Devices Wiki, 03-Nov-2021. [Online]. Available: https://wiki.analog.com/university/courses/alm1k/circuits1/alm-cir-precision-rectifier. [Accessed: 29-Sep-2022].

[7] Center for Devices and Radiological Health, "Electronic muscle stimulators," U.S. Food and Drug Administration. [Online]. Available: https://www.fda.gov/medical-devices/consumer-products/electronic-muscle-stimulators. [Accessed: 29-Sep-2022].