MOTION SENSING GUITAR PEDAL CONTROLLER

By

Luke Hilgart
Nick Oberts
Spencer Siegellak

Design Document for ECE 445, Senior Design, Spring 2026
TA: Po-Jen Ko

27th Feb 2026
Project No. 96

Contents

1. Introduction

1.1 Problem and Solution

Modern guitar effects pedals allow musicians to shape tone using parameters such as gain, delay time, and modulation depth. However, adjusting these parameters in real time often requires manual knob turning or additional expression pedals, which can interrupt performance flow. While some professional systems allow limited foot-based control, expressive lower-body motion is largely unused as a control input. Musicians performing live often move dynamically as part of their performance. Currently, these gestures have no direct interaction with the audio processing system.

A device that translates natural motion into real-time control of audio effects would enhance expressive capability without requiring additional manual adjustments. We propose a design of a two-part, PCB-based embedded system that integrates real-time signal processing with motion sensing to create a gesture-responsive multi-effects guitar pedal switching system. The sensing device detects when the user kicks near each LED indicator to switch pedal effects on and off, improving the flow of a guitarist's performance, as the upper body is already preoccupied. A pedal control device will wirelessly communicate with the sensing device to route the guitar's signal through the pedals as desired. An LED display attached to the sensing device will also help the guitarist track which pedal effects are on and off during the performance.

1.2 Visual Aid

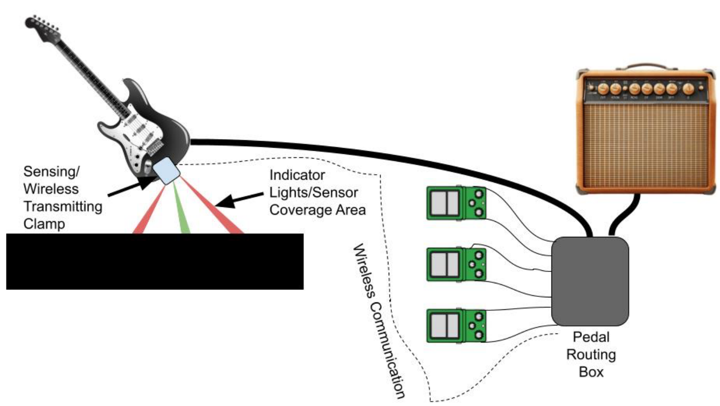

Figure 1: Visual Aid of Guitar Pedal System Setup

1.3 High-Level Requirements

1. Motion sensing toggles the desired pedals after gesturing in front of the sensor.
2. Each pedal zone must provide a clear visual indication of its on/off status using LEDs to ensure visibility under stage lighting conditions.
3. The device must process and output the corresponding audio effect quick enough so that guitar play is smooth and uninterrupted to ensure performance suitable for live guitar playing.

2 Design

2.1 Block Diagram

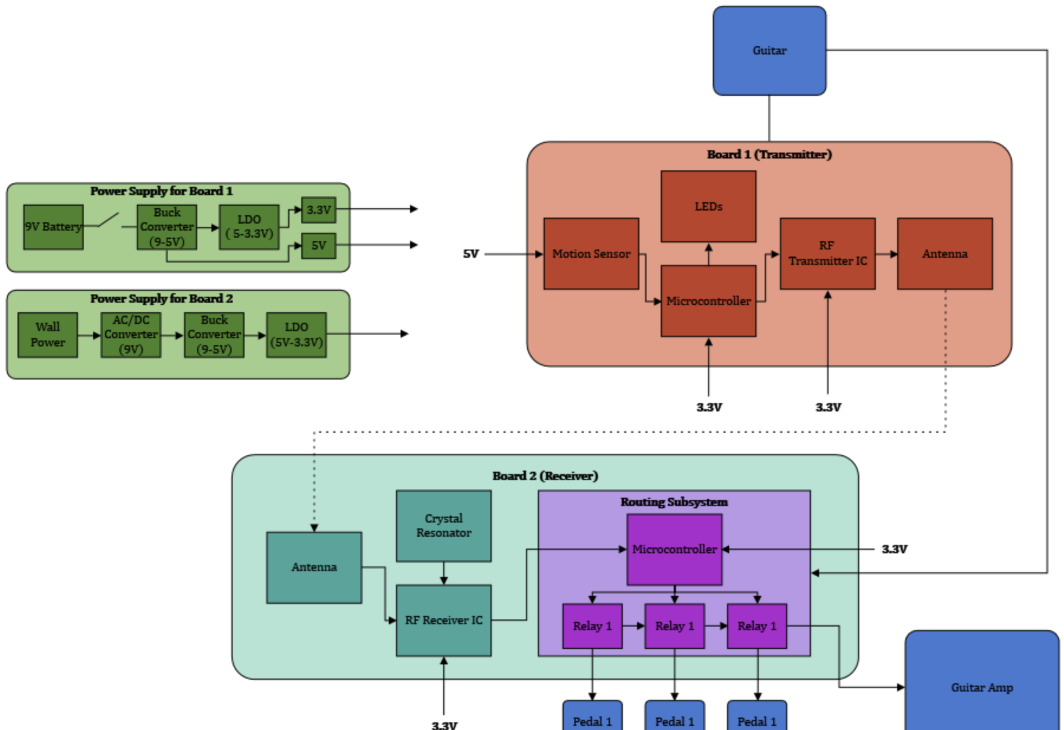

Figure 2: Block Diagram

2.2 Subsystem Overview

2.2.1 Power Management Subsystem

Both PCBS (one for transmitting/sensing and one for receiving/routing) will need consistent DC power supplied to operate. The transmitting/sensing PCB will be battery powered by a 9V battery, attached to the PCB via a battery mount. These batteries provide a maximum discharge current of 1500mA, which is more than enough to accommodate the entire PCB. The PCB will also contain a linear dropout regulator and a buck converter, one to step down to 5V and one to step down to 3.3V. The 3.3V Rail will power the microcontroller, the wireless communication circuit, and the LEDs. The 5V rail will power the IR sensors. Each board will have the same

The receiving PCB will be powered by wall power with an AC/DC converter. The 9V DC coming from the converter can be sent through a linear dropout regulator to 3.3V to supply the relays, microcontroller, and wireless communication system on the receiving/routing PCB. On the transmitter board, we need a buck converter to 5 V for the sensing system, and then the LDO will drop to 3.3 V for the microcontroller, LEDs, and transmitter.

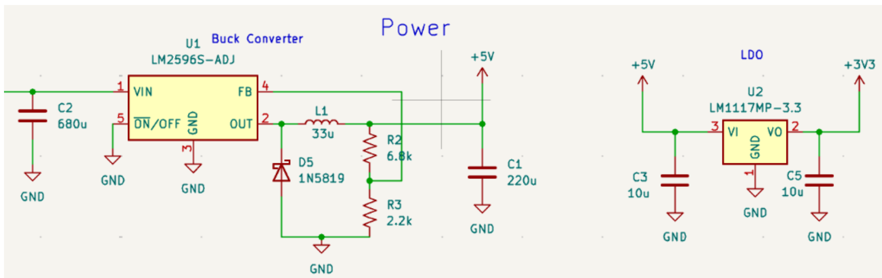

Figure 3: Power Schematic

Table 1: Requirements and Verification of Power Subsystem.

Requirements	Verification
• Each board must provide within 5% of the designated voltage value for each IC (i.e. buck converter or LDO).	• Test voltage outputs with a digital multimeter at both the power IC and the IC requiring that voltage level • Consistently probe each rail before each use of the board to ensure that the power subsystem can stay within 5% for the several weeks of testing
• The 9 V battery connected to the transmit board will provide a lifespan of the entire semester	• After each use, the battery will be probed to verify that voltage was not significantly lost. • Additional protection circuitry may be implemented if it is confirmed that the battery will not last long enough

2.2.2 Sensing Subsystem

The sensing subsystem consists of 3 analog distance sensors (GP2Y0A21YK0F) connected to the Transmitting/Sensing PCB via 3 separate 3 Pin JST Connectors. There will be a 5V and GND pin for powering the sensor as well as an analog output pin. These sensors emit infrared light and output an analog voltage proportional to the distance of an object from the sensor in the range of approximately 10–80 cm with a typical analog output voltage between 0.4V and 2.3V. Each sensor is mounted near the PCB such that all three sensing zones are pointed radially away from each other from the bottom of the guitar towards the ground. When a foot enters the detection zone, the voltage output rises, allowing the microcontroller to detect the presence of the foot. The analog voltage output interfaces with the STM32 microcontroller's ADC input, providing real-time data for decision making.

To translate the three analog signals into on/off signals for each of the three relays, we will use the microcontroller to store three bits of data indicating the state of the relays. When any of the three sensors detect a voltage above the threshold voltage of 0.4V, the sensor with the largest voltage value will flip its corresponding bit stored in the MCU to initiate a relay switch. The MCU will be programmed to ignore any other analog input for 2 seconds after the switch to ensure no unintended switching.

Table 2: Requirements and Verification of Routing Subsystem

Requirements	Verification
• Each sensor must be able to correctly detect an object within 80cm and update its associated relay status bit accordingly.	• Before mounting each sensor, connect it to the PCB via the JST connector and keep the MCU connected via USB to a debugger. • Wave in front of the sensor at 80cm, 55cm, and 10cm, each time observing the corresponding status bit to make sure it flips. • Repeat for all three sensors.
• The sensing subsystem must only flip one bit per detection, allowing a new flip two seconds after the previous one.	• Connect all three sensors to the PCB via their JST connectors, keep the MCU connected via USB to a debugger, and mount all three sensors in a manner similar to the final guitar attachment mounting. • Wave in front of one of the sensors, then wave in front of all three sensors for the next two seconds. • Ensure that only the first status bit has flipped and nothing else.

2.2.3 Lighting Subsystem

The lighting subsystem provides visual feedback to indicate the on/off status of each pedal. Each pedal zone is equipped with an RGB LED (XPLDCL-00-0000-0000HC6AAAE2) and is controlled by the microcontroller located on the transmitting/sensing board. The LEDS are bright enough to project a region of color onto the ground in the general direction of the sensing area so that the user knows where to kick to activate the motion sensors.

Each LED has four different display colors but we will only utilize red and green. Red will indicate off, while green will indicate on. Each LED is 3.3V and has a typical operating current of 90mA, therefore we will include a 50Ohm resistor in series with each terminal of the LED in use. The LEDs will be turned on and off by a low side switch utilizing an NMOS that uses a GPIO signal from the MCU as the gate voltage. A total of 6 switches will be used, two for each of the three LEDs. The red switches will have a GPIO signal equal to the inverted status relay bit meant to turn the LED on and off. The green switches will have a GPIO signal equivalent to the relay bit. This way, when the relay bit is high (indicating a pedal effect in use), the LED will be green. When the relay bit is low, the LED will turn red since the inverter bit will activate the red LED low side switch.

Table 3: Requirements and Verification Table for Routing Subsystem

Requirements	Verification
• LEDs correctly display status bits stored in the MCU	• Code the microcontroller to set the three status bits to 0, representing all off-state LEDs. • Probe all six LED GPIO lines to ensure correct voltages (3.3V for logical 1 lines). The three inverted GPIO lines going to the red switches should represent a logical 1, and the three normal GPIO lines going to the green switches should represent a logical 0. • Verify that all three LEDs display a red light to confirm the switches and GPIOs function correctly. • Repeat except reverse the three status bits, probe for opposite voltages, and look for green lights instead.

2.2.4 Wireless Communication Subsystem

The wireless communication subsystem enables the two STM32 microcontrollers to exchange pedal states in real time using an RF transmitter and receiver. The transmitter subsystem consists of a microcontroller connected to an RF transmitter integrated circuit (PIC12LF1840T39A-I/ST), which is connected to a 433MHz antenna via an SMA connector. Between the transmitter IC and antenna, we designed a matching network to ensure maximum power transfer from the transmitter to the 50Ohm antenna. The receiver subsystem consists of an identical antenna to that of the transmitter, matching network, RF receiver integrated circuit (MICRF229YQS-T5), and a crystal resonator IC (ABM3-13.560MHZ-B2-T) connected to two pins (RO1 and RO2) of the receiver acting as a local oscillator. The microcontroller connected to the sensing subsystem encodes pedal activation/deactivation as digital pulses using on-off keying (OOK) at 433 MHz and transmits them wirelessly to the receiver connected to the microcontroller that is part of the routing subsystem. Each pedal's state is represented by a distinct digital pulse sequence, ensuring proper communication between the transmitter and receiver. We plan to have an 8-bit sequence indicating the beginning of a pedal toggling, followed by three information bits, each of which representing whether the respective pedal should be on or off, followed by 6 bits indicating the end of the communication. This bit sequence will only be transmitted when there is an update to the relay state bit in the transmitter PCB's MCU. Both the transmitter and receiver ICs will be powered by 3.3V. This subsystem contributes directly to the high-level requirement for real-time detection and feedback, allowing pedal activations to trigger LEDs and audio effects with minimal latency.

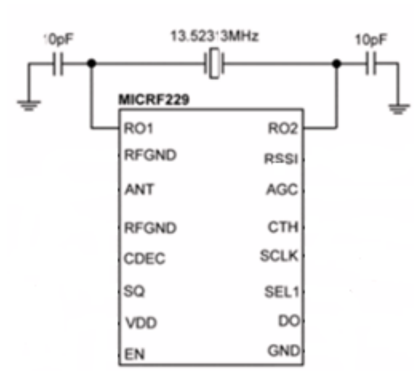

Figure 4: MICRF229YQS-T5 integrated circuit connected to ABM3-13.560MHZ-B2-T crystal [4]:

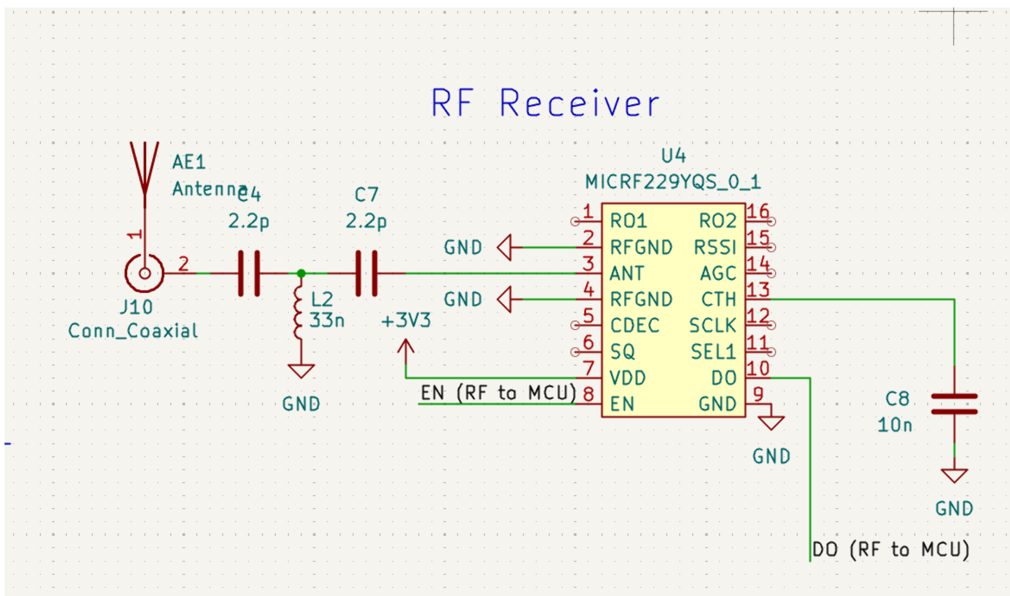

Figure 5: RF receiver connection to antenna through matching network (excluding crystal):

Table 4: Requirements and Verification of Routing Subsystem

Requirements	Verification
Must communicate all pedal states simultaneously over a distance of at least 5 meters, suitable for a typical pedalboard layout.	• Tests at different distances in a 5-meter radius circle around the pedal board to confirm communication at different locations • Spectrum analyzer tests will confirm whether the pulses are being transmitted wirelessly through the antennas
Must correctly encode and decode which pedals are to be activated/deactivated.	• Tests for every possible combination of pedal states (8 total)

	• Stating which pedal should be toggled before motioning to confirm the system works as desired • Spectrum analyzer tests will confirm whether potential bugs are caused by issues with the signal or with the routing subsystem

2.2.5 Audio Signal Routing Subsystem

The signal routing subsystem will consist of three 3V Double Pull Double Throw electromechanical relays (AGQ200A03) connected in series, one for each guitar pedal connection. The three relays will be located on the Receiving/Routing PCB. When the relays are in the off position and the coil is de-energized, the relay directs the audio signal directly from the input of the relay to the output without routing it through the associated pedal. When the coil is energized, both switches flip to the guitar pedal connections, effectively applying the pedal effect between the input and output of the relay. The audio signals will be provided to the PCB by eight audio input jacks, 2 for each of the 3 pedals, as well as one for the guitar input and one for the output to the amp.

To energize and de-energize the coil of each relay, the STM32 microcontroller will output a logical 1 or 0, which will feed into the gate of an NMOS low side switch powered by the 3.3V rail from the power subsystem. A logical 1 will correspond to an energized coil, and a 0 to a de-energized coil. The low side switch will also include a flyback diode connected across the coil of the relay for protection, as well as a 100Ohm resistor connecting the gate of the NMOS to the GPIO to protect the MCU. We chose 100Ohms for the resistance value to allow no more than 3.3V/100Ohms = 33mA to the GPIO during switching. Figure 5 below shows the schematic of one of the relays. Note that pins 12 and 21 are the connections to other relays.

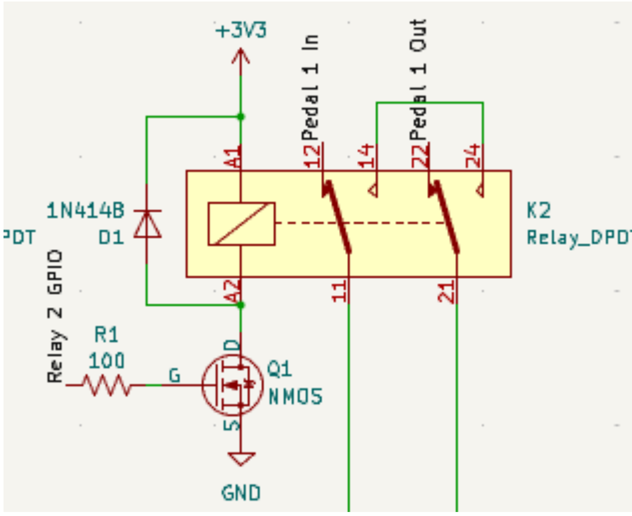

Figure 5: Relay Schematic

Table 5: Requirements and Verification Table for Routing Subsystem

Requirements	Verification
• Allow a free path for the audio signal when the MCU outputs a logical 0 to the relay.	• Program Microcontroller to tie relay GPIO pins PA13, PA14, and PA15 to LOW. • Plug in the guitar and amp to their associated audio jacks on the PCB and turn them on and play the guitar to generate an audio signal. • Probe the audio signal at the input and output pins of each relay with an oscilloscope and verify that the signals are nearly identical.
• Apply desired pedal effects to the guitar signal based off logical 1 GPIO outputs from the MCU.	• Program Microcontroller to tie one of the three relay GPIO pins to 1 and the other two to 0. • Plug in the guitar and amp to their associated audio jacks on the PCB as well as the selected guitar pedal and turn all the devices on. • Play the guitar while probing the audio signal at the input and output of the relays, verifying that the signal is mixed and the pedal effect has been applied. • Connect the guitar directly to the pedal and the pedal directly to the amp, play the guitar again, and listen to verify the correct effect was applied before. • Repeat once each for all three relays.

2.2 Tolerance Analysis

A potential risk in the power subsystem is the thermal dissipation of the voltage regulator when stepping down from 6 V to 3.3 V, particularly because the regulator's heat must be dissipated through the limited area of the PCB. Excessive heat could lead to thermal shutdown or reduced reliability, violating the requirement for continuous, stable operation. High power LEDs will also draw a lot of current, so it is vital that we protect circuits from these LEDs.

Assume the 3.3 V subsystem draws a maximum current of:

$$I_{\text{load}} = 250 \text{ mA}$$

The regulator must drop:

$$V_{\text{drop}} = V_{\text{in}} - V_{\text{out}} = 6 - 3.3 = 2.7 \text{ V}$$

Power dissipated in the regulator:

$$P_{\text{dissipation}} = V_{\text{drop}} \cdot I_{\text{load}} = 2.7 \cdot 0.25 = 0.675 \text{ W}$$

Assuming a regulator thermal resistance to ambient through the PCB of:

$$\Theta_{JA} \approx 80 \text{ C/W}$$

The expected junction temperature at $T_A = 40$ C ambient:

$$T_J = T_A + P_{\text{dissipation}} \cdot \Theta_{JA} = 40 + 0.675 \cdot 80 \approx 94 \text{ C}$$

This is below typical maximum junction ratings (125–150 °C), but it leaves little margin for higher ambient temperatures or increased current draw.

In terms of protecting the LEDs and surrounding circuitry:

3 LEDs x 30 mA = 90 mA per LED

4 x 90 mA = 360 mA total for the four options of colors in each LED. 360 mA is easily accounted for by the PCB.

Adding current resistors will limit overheating and power through the LED from our buck converters:

2.7 V / 30 ohms = 90 mA which is more than enough to power the red LED. By choosing a resistor of around 30 ohms, we limit the current to a close value required for the LED, ensuring proper operation and thermal safety.

Each color requires a different voltage. Green requires 3.3V which means a 36 ohm resistor would satisfy the current requirement. It is important that the microcontroller switches between colors without overheating anything.

3. Cost and Schedule

3.1 Cost Analysis

Table 6: Parts cost table

Parts	Manufacturer	Quantity	Price	Total Per Part	Total Cost
3 Pin JST-Connector: B3B-PH-SM4-TB	JST Sales America Inc.	3.00	$ 0.52	1.56	$ 128.89
AC/DC WALL MOUNT ADAPTER 5V 2.8W	Phihong USA	1.00	$ 2.28	2.28	
Antennas	Kaunosta	1.00	$ 9.99	9.99	
CAP ALUM 680UF 20% 35V SMD	Panasonic Electronic Components	2.00	$ 1.49	2.98	
CAP CER 1.5PF 50V C0G/NP0 0402	Johanson Technology Inc.	1.00	$ 0.16	0.16	
CAP CER 10000PF 16V X7R 0402	Murata Electronics	2.00	$ 0.08	0.16	
CAP CER 10PF 50V C0G/NP0 0402	Murata Electronics	3.00	$ 0.10	0.3	
CAP CER 10UF 10V X5R 0402	Murata Electronics	4.00	$ 0.08	0.32	
CAP CER 2.2PF 50V C0G/NP0 0402	Johanson Technology Inc.	3.00	$ 0.18	0.54	
CAP CER 220UF 2.5V X6S 1206	Murata Electronics	2.00	$ 0.92	1.84	
CAP CER 8.2PF 50V C0G/NP0 0402	Murata Electronics	2.00	$ 0.15	0.3	
Crystal Resonator ABM3-13.560MHZ-B2-T	Abracon LLC	1.00	$ 0.96	0.96	
DC POWER JACK, SMT, HORIZONTAL	GCT	1.00	$ 0.95	0.95	
FIXED IND 22NH 500MA 500 MOHM	Murata Electronics	2.00	$ 0.16	0.32	
FIXED IND 33NH 50MA 2.1 OHM SMD	KEMET	3.00	$ 0.10	0.3	
FIXED IND 33UH 10MA 3.12 OHM SMD	Murata Electronics	2.00	$ 0.20	0.4	

FIXED IND 56NH 100MA 3.9 OHM SMD	Murata Electronics	2.00	$ 0.20	0.4	
Flip Switch: Multicomp 1MS1T1B1M1QE	ECE Shop	2.00	$ 3.41	6.82	
IC MCU 32BIT 32KB FLASH 32LQFP	STMicroelectronics	2.00	$ 1.82	3.64	
IC REG BUCK ADJ 3A 8SOIC	Texas Instruments	2.00	$ 1.65	3.3	
LDO LM1117MP	Texas Instruments	2.00	$ 1.41	2.82	
MOSFET N-CH 60V 4A SOT223	STMicroelectronics	9.00	$ 1.59	14.31	
Motion Sensor: GP2Y0A21YK0F	SHARP/Socle Technology	3.00	$ 9.43	28.29	
RELAY TELECOM DPDT 2A 3V	Panasonic Electric Works	3.00	$ 1.93	5.79	
RES 100 OHM 1% 1/4W 1206	YAGEO	9.00	$ 0.10	0.9	
RES 2.2K OHM 1% 1/10W 0603	YAGEO	2.00	$ 0.10	0.2	
RES SMD 6.8KOHM 0.01% 1/10W 0805	Susumu	2.00	$ 3.28	6.56	
RF Receiver: MICRF229YQS-T5	Microchip Technology	1.00	$ 2.78	2.78	
RF transmitter: PIC12LF1840T39A-I/ST	Microchip Technology	1.00	$ 2.28	2.28	
Schottky Diode: 1N5819HW-FDICT-ND	Diodes Incorporated	4.00	$ 0.29	1.16	
Through Hole Audio Jack: 2223-MJ-63022A-ND	Same Sky	8.00	$ 1.44	11.52	
XLAMP LEDs	Cree LED	3.00	$ 4.92	14.76	

Labor Costs:

We decided a fair wage would be $20/hr for each of us, and we plan to work on the project for an average of 15 hours per week. Therefore, each of us should get paid an average of $300 per week. We plan to finish the project in 10 weeks, but we will not be working over spring break. This puts us at a total of $2700 per person, and $8100 total for labor cost.

3.2 Schedule

Table 7: Schedule

Week	Luke	Spencer	Nick
3/2	Receiver board PCB design/order (All) Design review with instructor/TA	Transmitter board PCB design/order (All) Design review with instructor/TA	Transmitter board PCB design/order (All) Design review with instructor/TA
3/9	(All) Breadboard demo for both boards (All) Teamwork evaluation (All) New PCB order (if necessary)	(All) Breadboard demo for both boards (All) Teamwork evaluation Transmitter board soldering (All) New PCB order (if necessary)	(All) Breadboard demo for both boards (All) Teamwork evaluation Receiver board soldering (All) New PCB order (if necessary)
3/23	Transmitter microcontroller programming (All) New PCB order (if necessary)	Receiver microcontroller programming (All) New PCB order (if necessary)	PCB performance checks with power, wireless communication, etc. (All) New PCB order (if necessary)
3/30	(All) Testing and debugging	(All) Testing and debugging	(All) Testing and debugging
4/6	(All) Team contract assessment (All) Progress demo	(All) Team contract assessment (All) Progress demo	(All) Team contract assessment (All) Progress demo
4/13	(All) Testing and debugging (All) Begin final report	(All) Testing and debugging (All) Begin final report	(All) Testing and debugging (All) Begin final report
4/20	(All) Testing and debugging (All) Mock demo/presentation (All) Complete final report first draft	(All) Testing and debugging (All) Mock demo/presentation (All) Complete final report first draft	(All) Testing and debugging (All) Mock demo/presentation (All) Complete final report first draft
4/27	(All) Final demo/presentation	(All) Final demo/presentation	(All) Final demo/presentation
5/4	(All) Finish and submit final report	(All) Finish and submit final report	(All) Finish and submit final report

4. Societal Impact, Engineering Standards, Ethics, and Safety Considerations

As engineers, we are responsible for designing safe, reliable, and socially responsible devices. Our motion-sensor guitar pedal system will be built with consideration for user safety and accessibility. We will ensure that the device does not pose hazards to performers or audiences, avoids misuse of laser or infrared components, and respects privacy (no cameras or audio recording will be used beyond the user's guitar input). Additionally, we will document all limitations and instructions clearly to prevent misuse.

The motion-sensor guitar pedal project has positive societal impacts including increased accessibility for musicians with limited hand mobility and an easier way to integrate multiple sound modifications into one guitar performance. Potential negative impacts are minimal but include the possibility of distraction from bright LEDs. These risks are mitigated through user instructions and proper labeling to ensure the device contributes positively to musical performance.

The primary safety concerns for this project include electrical safety, mechanical integrity, and heat management. Low-power, eye-safe LEDs will be used, positioned to interact with the user's foot only, with housing and shielding to prevent stray light from escaping the enclosure or projecting in the wrong directions. Heat-generating components such as voltage regulators and op-amps will be properly rated, with heat dissipation considered in PCB layout and enclosure design. Bench testing and stress testing will be conducted before live use to ensure user safety.

5. Citations

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[8] *Low-Dropout Linear Regulator Datasheet (LM1117m) https://www.ti.com/lit/ds/symlink/lm1117.pdf*

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