Remote Wah Guitar Effect Pedal

Julian Brookfield (jbrook32), Chris Read (clread2), Luna Rathod (drathod2)

Introduction:

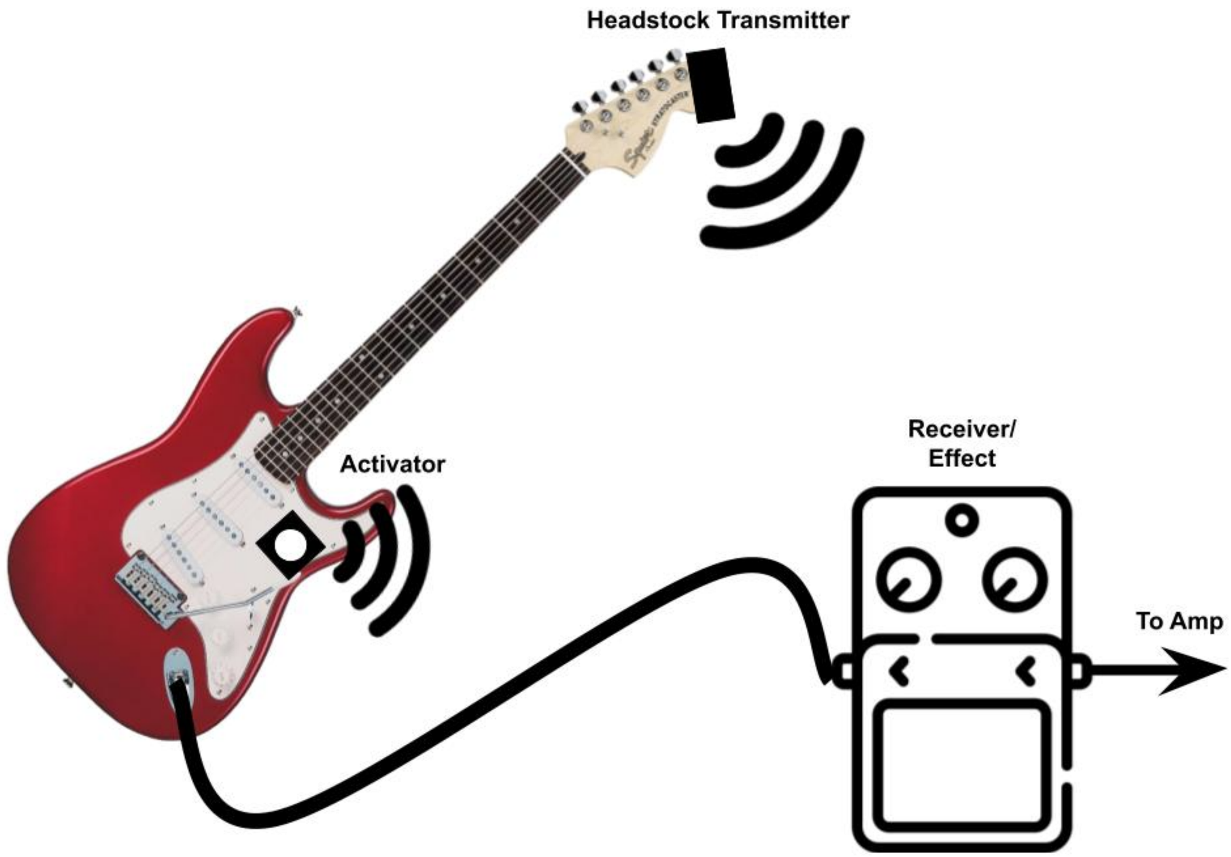
Problem:

Guitar and bass players have a wealth of effects pedals to choose from in order to modify the sound of their instrument, such as adding distortion, echo, reverb, etc. In most cases, the parameters for effects pedals are set by the player beforehand and turned on and off with a footswitch, or controlled by a foot treadle to modify a single parameter, such as the sweep of a high-Q bandpass filter in a wah pedal. However, this requires the player to remain fixed in place while using the effect, which can get in the way of the performance aspect of playing live music. It would be very convenient & expressive to have a way of controlling the parameters of certain effects while maintaining the ability to move around a stage unimpeded.

Solution:

Our idea is that rather than using a foot treadle to control the filter sweep of a wah pedal, the range of the filter sweep is controlled by a sensor mounted to the headstock of a guitar/bass. This allows achieving the characteristic sweep sound of a wah by swinging your guitar up and down rather than using a foot treadle, which allows the use of the effect anywhere on stage (after you switch it on) and makes for an interesting visual accompaniment that is suited for live performance (it would look pretty cool). To further aid in freedom of movement, the effect will have the ability to be remotely activated via a button mounted to the body of the guitar within convenient reach of the player.

Visual Aid:



High Level Requirements:

In order to satisfy the core of our goals for this project, we should meet the following criteria:

- Successful linkage between receiver and transmitters to control circuit hardware, including switching effect on and off and controlling the filter sweep
- The receiver is able to process the raw transmitter IMU data into a usable digital potentiometer range
- The wah circuit is able to implement a suitably high-Q filter sweep across a broad range of the audible spectrum, namely 400 Hz to 2.5 kHz

Design:

Block Diagram:

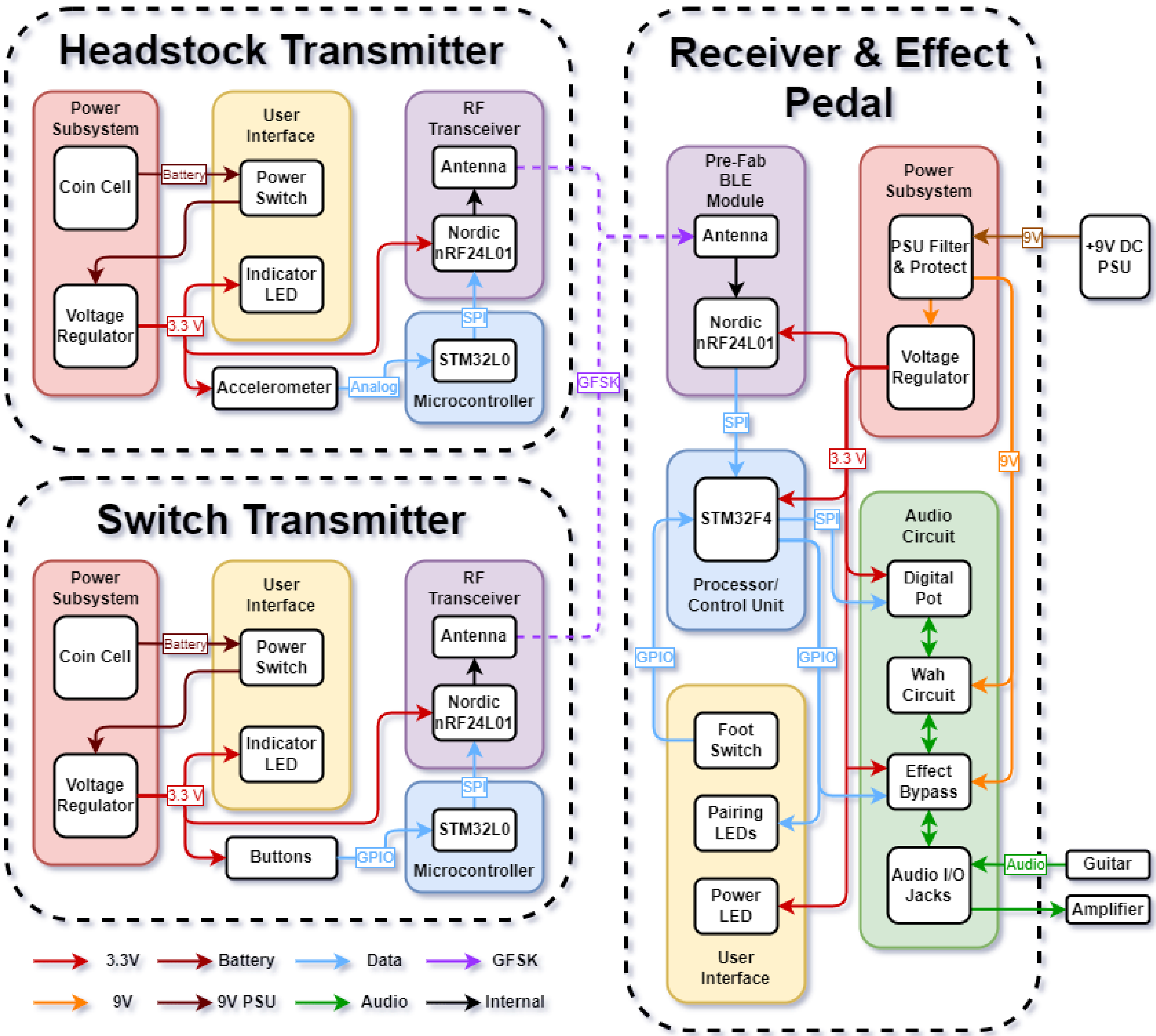


Figure 1: Block Diagram

Subsystems:

Subsystem 1: Headstock Transmitter

Overview:

This will be a small device mounted to the headstock of the guitar. It will include some sort of inertial measurement unit (IMU) to gather data about the motion of the guitar's headstock as it moves up and down. This data is then transmitted wirelessly to the receiver pedal through a prefabricated RF module. The transmitter will run off of a commonly available button-cell battery and include a simple power indicator LED and an on/off switch that is activated before/after a performance. It should be housed in a small non-metal (probably 3D-printed) enclosure to allow transmission of RF signals, and should be attached to the headstock via an elastic strap. For simplicity, the transmitter will continuously send data to the receiver while it is on, however this can later be changed to sleep while the effect is off and transmit data only when the effect is on in order to save battery life.

Modules:

Power:

The power module adapts the power from a coin-cell battery via a voltage regulator to supply 3.3 Volts to the Headstock Transmitter subsystem.

UI:

The UI will be used to turn power for the headstock transmitter on or off with a switch, as well as providing feedback on the state of the power switch in the form of an LED.

Microcontroller:

The microcontroller is used to convert the signal from the accelerometer into binary values, and format the data into SPI for communication with the RF transceiver module.

RF Transceiver:

The RF transceiver is responsible for transmitting accelerometer data to the floor pedal receiver. It will contain a Nordic chip and a built-in antenna, and can act as transmitter or receiver depending on the system that utilizes it.

Accelerometer:

The accelerometer measures the acceleration of the headstock and is transmitted to the pedal and processed for digital pot control.

Subsystem Requirements:

• Accelerometer axes output ± 990 mV from 1.5 V bias point through range of motion, within a maximum ± 25% tolerance [(1)]	1. Connect accelerometer supply rail and ground to + 3.3 V external supply

	2. Connect accelerometer axes test points to oscilloscope 3. Record output voltage reading from the accelerometer while moving it at the maximum reasonable speed the device will be used, and verify reading is within acceptable boundaries.
● Output of power supply maintains 3.3V across maximum load of 150 mA within ± 5%, including both voltage sag and power supply ripple	1. Plug in coin cell battery, or attach 3V supply to the input test point of boost converter 2. With all internal power rails disconnected, attach 47 Ohm resistor to LDO output test point 3. Measure output voltage across load across resistor and verify it remains within ± 5% of 3.3 V

Subsystem 2: Effect Switch

Overview:

This will be our simplest subsystem, contained in a small non-metal enclosure that will attach to the guitar near the base of the instrument, ideally on the front where it can be easily reached by the musician's right hand while performing. The only sensor in this subsystem will be an "ON" button accessible from the outside of the enclosure. This button will serve as the main switch to activate our project; it will communicate wirelessly with the floor pedal via an RF transceiver module. Similar to the headstock transmitter, it will run off of a coin-cell battery and include a simple power indicator LED. This subsystem will be complete once it is able to toggle on and off our wah effect from a distance. It can also potentially be expanded to toggle other pedals in addition to the Wah effect if time permits.

Modules:

Power:

The power module adapts the power from a coin-cell battery via a voltage regulator to supply 3.3 Volts to the Effect Switch subsystem.

UI:

The UI is used to turn power for the Effect Switch on or off with a switch, as well as providing feedback on the state of the power switch in the form of an LED.

Microcontroller:

The microcontroller is used to convert the information from the button state into SPI format for communication with the RF transceiver module.

RF Transceiver:

The RF transceiver is responsible for transmitting the button data to the floor pedal receiver. It will contain a Nordic chip and a built-in antenna, and can act as transmitter or receiver depending on the system that utilizes it.

Button:

The button is used to determine if the effect is or bypassed. The on/off state of the button will be transmitted to the Receiver & Effect Pedal subsystem.

Subsystem Requirements:

• The corresponding LEDs for each button behave according to our specification, as highlighted above and in the Software section	1. Plug in coin cell battery, or attach 3.3V supply to the V_SYS test point 2. Press buttons in various sequences and verify correct LED & signal behavior is being observed
• Output of power supply maintains 3.3V across maximum load of 70 mA within ± 5%, including both voltage sag and power supply ripple	1. Plug in coin cell battery, or attach 3V supply to the input test point of boost converter 2. With all internal power rails disconnected, attach 47 Ohm resistor to LDO output test point 3. Measure output voltage across load across resistor and verify it remains within ± 5% of 3.3 V

Subsystem 3: Receiver & Effect Pedal

Overview:

This will be the main heart of the project, it will contain our primary PCB and microcontroller. This subsystem is functionally divided into an analog half and a digital half. The analog half will include the wah effect & bypass circuit that the guitar is routed through. A large part of the classic sound of wah effects has to do with the particulars of which inductor is used to create the peaking filter, so this part is best left analog. It also avoids any latency in the guitar signal since the audio path remains completely analog. The digital half will receive and process the Effect Switch on-button and Headstock Transmitter accelerometer data into useful control signals that control the analog half. This includes processing the raw accelerometer data into a useful range that controls a digital potentiometer, which in turn controls the sweep of the analog filter in the wah effect side. This sweep must be calibrated by a footswitch, which is configured before the performance to allow for any range of motion of the guitar to generate a useful sweep of the wah. The range of the sweep will be formatted to control a digital potentiometer, which will interface to the MCU with SPI, thus the MCU has to process the accelerometer data into a range that controls the digital potentiometer across its full sweep. The button data will also be processed into a signal that controls an analog mux to either activate or bypass the wah effect.

Modules:

Power:

The power module filters and adapts the power from a +9 Volt power supply via a PSU filter and voltage regulator to supply 3.3 Volts to the Receiver & Effect Pedal subsystem.

UI:

The UI module is used to calibrate the received IMU data to ensure a usable sweep. The footswitch will be used to initiate calibration and set positional limits. A pairing LED indicates if the pedal is in pairing mode or paired to the transmitter, and a power LED indicates if the pedal subsystem is on or off.

RF Transceiver:

The RF transceiver is responsible for receiving wireless accelerometer and button data and sending it to the control unit. It will contain a Nordic chip and a built-in antenna, and can act as transmitter or receiver depending on the system that utilizes it.

Audio Circuit:

The audio circuit will feature the analog “Wah” effect with the potentiometer being digital to control expression by interfacing with the control unit. The bypass will enable or bypass the “Wah” effect. An input and output ¼” jacks will be used to connect the circuit’s input to an instrument and output to an amplifier/speaker.

Control Unit:

The control unit will be responsible for interpreting signals received by the RF module to enable/disable the bypass, calibrating the POT sweep, and control the digital POT value for pedal expression. It principally consists of an STM32 microcontroller.

Subsystem Requirements:

• Receiver pedal is able to receive data from both transmitters simultaneously	1. Power on all transmitters and receiver 2. Pair both transmitters to receiver, verify that indicator lights display correct status 3. Test that button data and accelerometer data is correct using procedures below
• Digital potentiometer implements a voltage divider which is able to output a voltage from 0 V to 9 V, ± 5%	1. Power on board with 9V supply 2. Connect outer pins of pot output connector to +9V and GND, and center pin to a multimeter/ oscilloscope 3. Create test program for microcontroller which increases the number of taps slowly between 0 - 1023 4. Measure output voltage and verify that it sweeps from rail to rail, 0 V to 9 V.

• Microcontroller maps accelerometer data to a 10 bit position value which is able to sweep the digital potentiometer from 0V to 9V, ΔV ± 5%	1. Power on board with 9V supply 2. Connect outer pins of pot output connector to +9V and GND, and center pin to a multimeter/ oscilloscope 3. Pair headstock transmitter to receiver pedal and load accelerometer data processor program 4. Move headstock transmitter up and down and record potentiometer output voltage, verifying that it sweeps between 0 V and 9V rail to rail.
• Button is able to select between dry and wet audio signals, with attenuation of less than 3 dB	1. Turn on and pair button transmitter and pedal receiver 2. Connect inputs of analog mux pins to two voltage sources outputting sine tones of different frequencies 3. Load button control program to microcontroller 4. Verify that the frequency of dry input is present at the output with button off, and wet input frequency is present at the output with button on 5. Connect analog mux output to oscilloscope and verify that it is attenuated less than 3 dB from the input signal amplitude
• Footswitch calibrates	1. Turn on and pair headstock transmitter and pedal receiver, connect digital pot leads to their

	respective outputs 2. Run accelerometer data processor program and verify that it works as previously stated 3. Move headstock transmitter to different starting location, press footswitch, and again move transmitter up and down and verify that the digital pot outputs a voltage sweep between 0 V and 9 V
● Power supply can accurately supply 9 V output up to 50 mA with ΔV ± 1% and 3.3 V at 100 mA with ΔV ± 1% simultaneously	1. Disconnect all internal PCB power rails 2. Connect 9V external power supply 3. Connect ~180 Ohm resistor to 9 V output test point, and measure voltage across resistor, verifying it remains within 9 V ± 1% 4. Connect ~33 Ohm resistor to 3.3 V output test point, and measure voltage across resistor, verifying it remains within 3.3V ± 1% 5. With both loads connected, measure voltages across each load and verify they both still operate within specified range

● Circuit sweeps frequencies from lower-mid to upper-mid range (400Hz to 2.5kHz) with 15-20 dB amplification.	1. Connect input of wah circuit to external AC power supply 2. Connect output to oscilloscope

	3. Create test program for microcontroller which sets the number of taps for the digital potentiometer to 0 or 1023 4. Perform a spectral analysis on the oscilloscope with the number of taps at maximum. Note the peak and -3dB range for the minimum frequency boost. 5. Perform a spectral analysis on the oscilloscope with the number of taps at zero. Note the peak and -3dB range.
• Filter voltage gain must be between 1dB to 19dB	1. Connect input of wah circuit to external AC power supply 2. Connect voltmeter to filter block input and ground 3. Connect output to oscilloscope 4. Create test program for microcontroller which sets the number of taps for the digital potentiometer to 0 or 1023 5. Measure output voltage for each potentiometer setting

Tolerance Analysis:

The success of this project relies heavily on being able to generate a good sweep of a digital potentiometer based on the output of an accelerometer. While ideally we are able to generate a continuous potentiometer sweep as with a mechanical pot, we have to approximate a continuous sweep using the steps of a digital potentiometer. The smallest difference in relative pitch that a human can detect is around 0.5% [1], which applied to a worst-case minimum value of our filter sweep range $f_L \approx 400Hz$ gives us the maximum frequency step we can allow to maintain audible continuity:

$$f_L * JND = 400 * 0.005 = 2Hz$$

To find the number of steps required to achieve this, we divide the total range of our filter sweep (with worst-case maximum value of $f_H \approx 2.4kHz$) by the maximum frequency step to get:

$$BW = f_H - f_L = 2.4k - 400 = 2kHz$$

$$N_{steps} = \frac{BW}{f_{step}} = \frac{2k}{2} = 1000 \approx 1024 = 2^{10}$$

Or 10 bits of resolution. This means we need to use a digital pot with 1024 taps and at least a 10 bit ADC. The built in ADC of the STM is 12 bits, so sampling resolution will not be an issue.

However, we must now verify that the accelerometer can output a wide enough voltage range to provide enough step resolution with the quantization of the ADC. Operating at 3.3 V with 12 bits of resolution, this works out to:

$$R = \frac{V_{DD}}{N_{samples}} = \frac{3.3}{2^{12}} = 0.806\frac{mV}{sample}$$

Our accelerometer has 3g sensitivity, with g being the acceleration of gravity, $g \approx 9.8\frac{m}{s}$. This is used to scale the per-g sensitivity of the accelerometer to achieve a wider output voltage swing for a given acceleration. Dividing the total sensitivity of the accelerometer by the resolution of our ADC gives us the maximum number of steps that can be generated by its output:

$$N_{steps} = \frac{n_g * S}{R}$$

Which, when rearranged, allows us to find the minimum sensitivity we can allow:

$$S_{min} = \frac{N_{steps} * R}{n_g}$$

Plugging in our values of $N_{steps} = 1024$ for the digital pot, $R = 0.806 \frac{mV}{sample}$ for the resolution of our ADC, and $n_g = 3$ from the datasheet, we get:

$$S_{min} = \frac{1024 * 0.806}{3} = 275 \frac{samples}{g}$$

According to the ADXL335 datasheet [21], the worst-case sensitivity listed is $270 \frac{samples}{g}$ at 3 V, which means we should be able to achieve our “continuous” sweep.

In an effective wah pedal, a band pass filter is used to boost frequencies that shift with the control of a potentiometer. The resonant peak should shift from centering the lower-middle frequencies (roughly 350 hertz) to the upper-middle frequencies (roughly 2.2kHz), as indicated in pedal-manufacturer Dunlop’s own wah pedal frequency ranges [2]. Variations on which part of this range is covered are also demonstrated in Dunlop’s own pedal designs, so as long as the extremes of this range are not exceeded, issues with increased resonance at higher or lower frequencies will not be a concern. The inductor used is 560 mH with a 10% tolerance [3]. As the inductor value is essential in defining the boosted frequency range, we must explore if the range of inductor values will result in acceptable frequency ranges. To do this, the audio circuit was simulated using LTSpice, adjusting the inductor value to the extremes of the tolerance range (504 - 616mH) and adjusting the digital potentiometer (represented by digital_POT) to the extremes of the wiper (0 - 1).

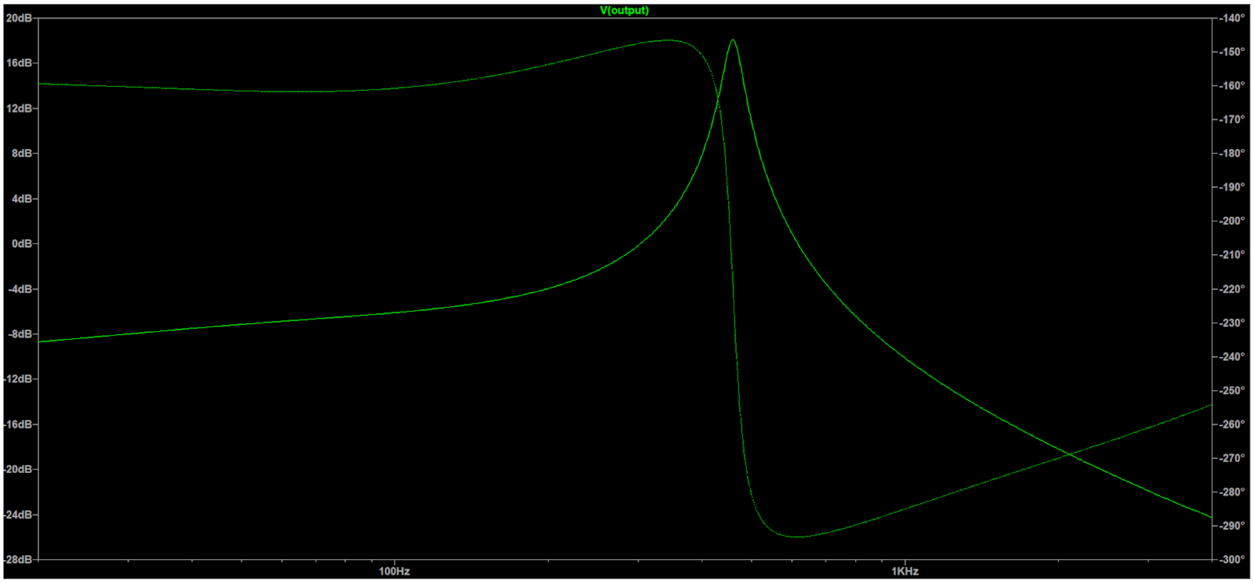


Figure 2: Boosted Frequencies - Inductance = 504mH, Wiper = 1

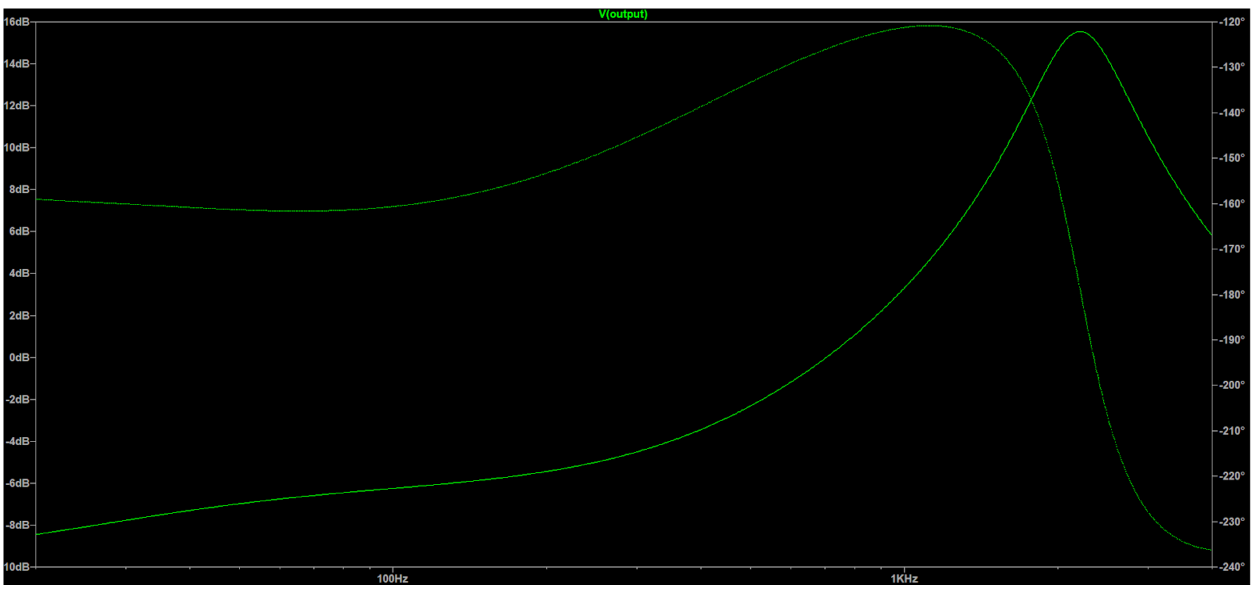


Figure 3: Boosted Frequencies - Inductance = 504mH, Wiper = 0

The above two charts show that at the low end of the inductor tolerance, the center of the boosted frequencies ranges from 460 Hz to 2.2 kHz.

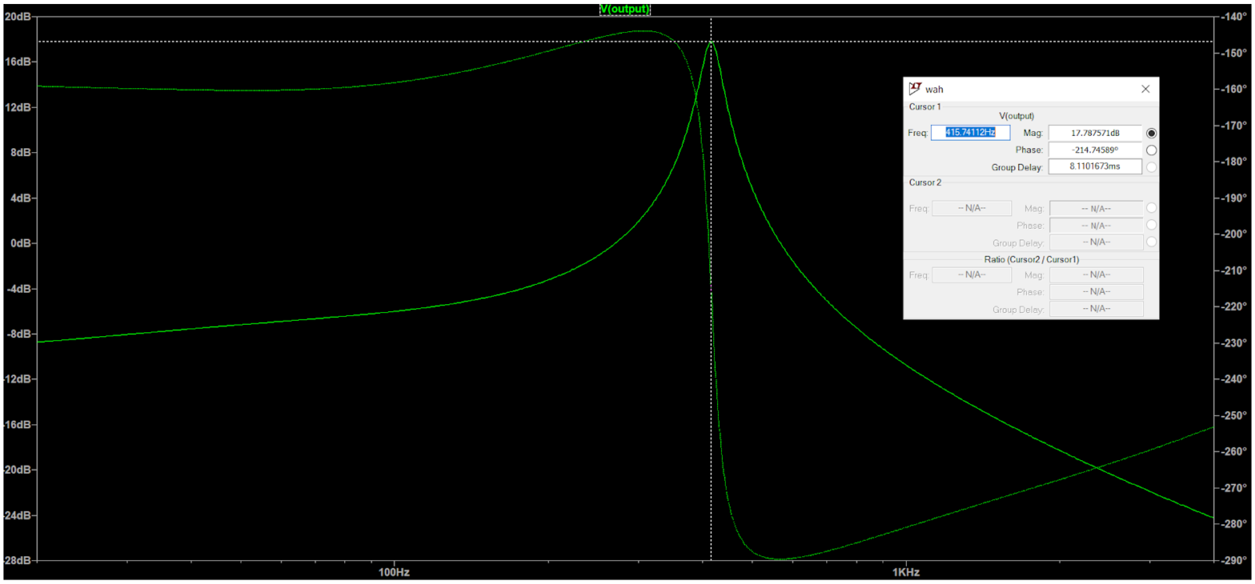


Figure 4: Boosted Frequencies - Inductance = 504mH, Wiper = 1

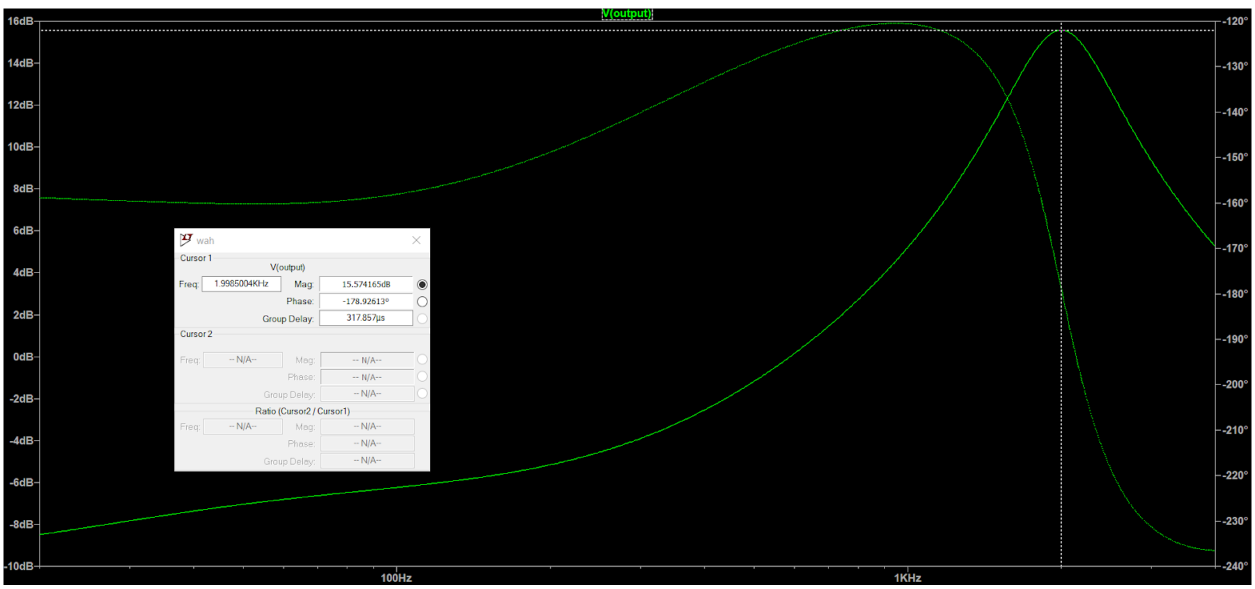


Figure 5: Boosted Frequencies - Inductance = 504mH, Wiper = 1

The above two charts show that at the low end of the inductor tolerance, the center of the boosted frequencies ranges from 415 Hz to 2.0 kHz. Both minimum and maximum tolerance values for the inductor create acceptable boosted frequency ranges, with the latter being preferable for having better low-mid frequency response.

Ethics:

In keeping with ethical guidelines outlined by IEEE [4], consideration for the safety of the end user is our highest priority. We have made design choices when possible to minimize any risk involved in the operation of our project. For powering our subsystems, we chose to use standardized and regulated power supplies, be it our voice of 9V wall supply [5] or our choice to use coin cells instead of dealing with the risk inherent with a rechargeable Li-Ion battery supply. Ethically, as far as the environment is concerned, a rechargeable power supply solution would be advisable in the future, but given our very limited development time we felt it safest to use a power source that is readily available and minimizes risk. Our choice of RF modules are also in compliance with FCC regulations on ISM band devices [6]. Finally, we will ensure the quality of our designs through seeking criticism and advice not only through mandatory design reviews, but by seeking the guidance and advice of others with experience in the scope of our project.

Citations

[1] "Critical Bandwidths and Just-Noticeable Differences," *www.phys.uconn.edu*. https://www.phys.uconn.edu/~gibson/Notes/Section7_2/Sec7_2.htm#:~:text=Between%20these%20two%20mechanisms%2C%20the (accessed Sep. 29, 2023).

[2] "RANGE OF EXPRESSION: FIND YOUR CRY BABY® WAH - Lifestyle - Dunlop," Oct. 08, 2021. https://lifestyle.jimdunlop.com/find-your-cry-baby-wah/ (accessed Sep. 26, 2023).

[3] "Axial Shielded Power Chokes," *Allied Components International*, Nov. 12, 2020. https://www.alliedcomponents.com/storage/through_hole_inductors_chokes/pdfs/aspc80.pdf (accessed Sep. 28, 2023).

[4] IEEE, "IEEE Code of Ethics," *ieee.org*, 2020. https://www.ieee.org/about/corporate/governance/p7-8.html

[5] "1 SPOT® – Truetone." https://truetone.com/1-spot/ (accessed Sep. 29, 2023).

[6] "Regulatory and Compliance Standards for RF Devices White Paper," 2007. Accessed: Sep. 29, 2023. [Online]. Available: https://infocenter.nordicsemi.com/pdf/nwp_010.pdf