1. Introduction:

1.1 Problem:

A lot of guitarists these days, especially in the metal/indie scene, like to double/harmonize their guitar parts with synthesizer parts overlayed on top [1]. This is usually done note-for-note, and usually wastes a lot of effort as the guitarist has to re-record the synth parts over the guitar tracks. Even if the synth is not played but merely programmed in through MIDI, there is a lot of wasted effort that is directly proportional to how complex/fast the guitar parts are.
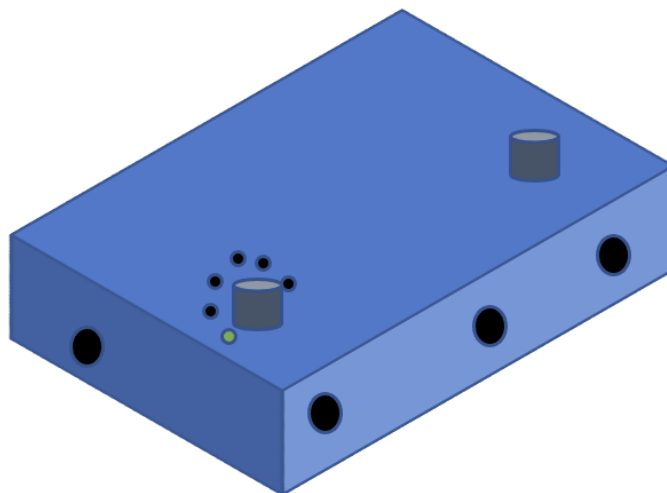
1.2 Solution:

This product is meant to act as a device (guitar pedal) that add musical context/layering on the notes played on a guitar.
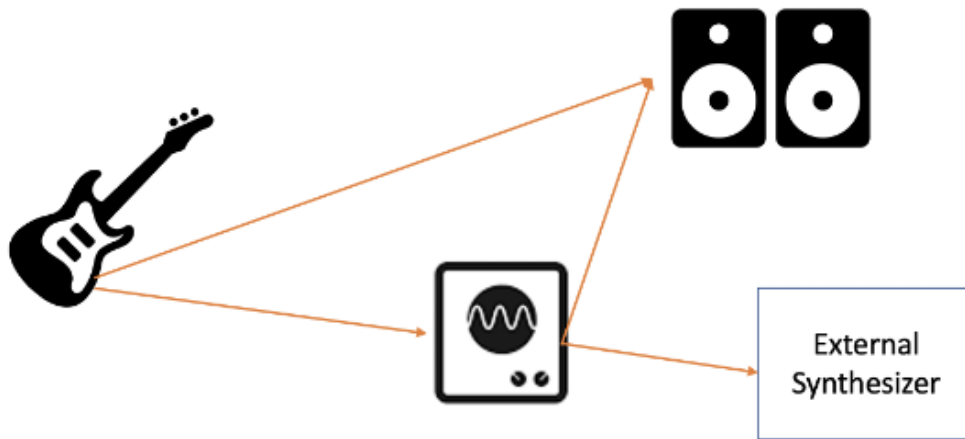
The guitarist will benefit from this product in that he/she can create more specialized sounds by blending together different notes and/or chords. This would make it easier for the musician to achieve the specific sound/note that they desire.

Our product is marketable because the cost will save a lot of time for the artist when they are tracking guitar parts and doubling them with synths, as well as cut down on the amount of stage gear they need when performing live. Our approach is to use a DSP-capable microprocessor (such as the MK20DX256VLH7 on the Teensy 3.2 or Daisy Seed) to implement a novel kind of guitar pedal – one that will add electronically synthesized harmonies to an analog guitar note played by the guitarist. This will be in the form factor of a normal pedal, and the knobs will give the guitarist the option to select what kinds of harmonies they want to overlay (Major 5th, Major triad, 7th, etc).

1.3 Visual Aid:

We envision the chassis being of dimensions equal to or less than (20 cm, 15cm, 8cm), and having 2 female ¼ inch connectors, one MIDI out, and one 9V DC power input. We want the dimensions to be such that it fits on a standard guitar pedal board and is compatible with the rest of the guitarist's signal chain. In terms of controls, we want the guitarist to be able to specify the harmony they would like to generate as well as the type of waveform (from square, sawtooth, or sinusoidal).

The electric guitar's output will be connected to the input female ¼ inch connector on the pedalboard. The guitarist can use the harmony selector knob on the pedal to select what harmonies to generate as MIDI notes, and the waveform selector knob to select what waveform to generate. If the guitarist wants to use their own external synth with a more elaborate/customized waveform generator or signal chain, they can route the MIDI notes generated to the external synth. The output of the pedal would then be connected to either an amplifier or the rest of the guitarist's pedal chain.
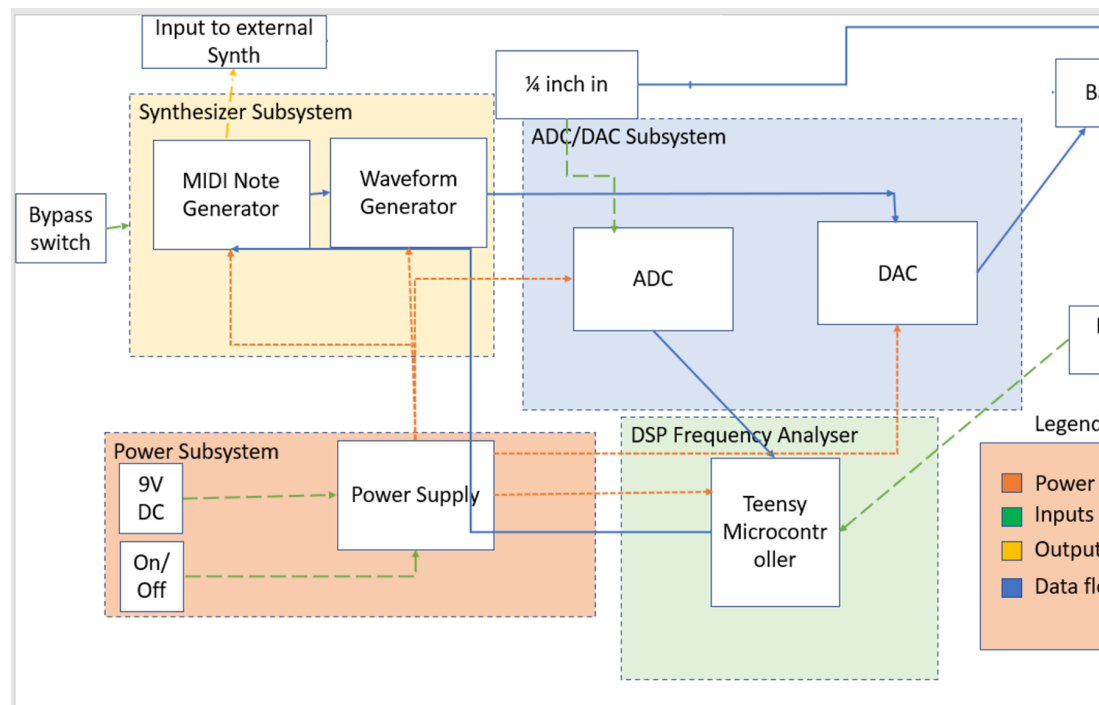
The guitar signal itself will bypass the entire circuit and be mixed and balanced with the pedal output. This is because we don't want there to be any tone-shaping of the guitar signal itself, we only need the guitar signal to calculate the harmony notes for the synth module.
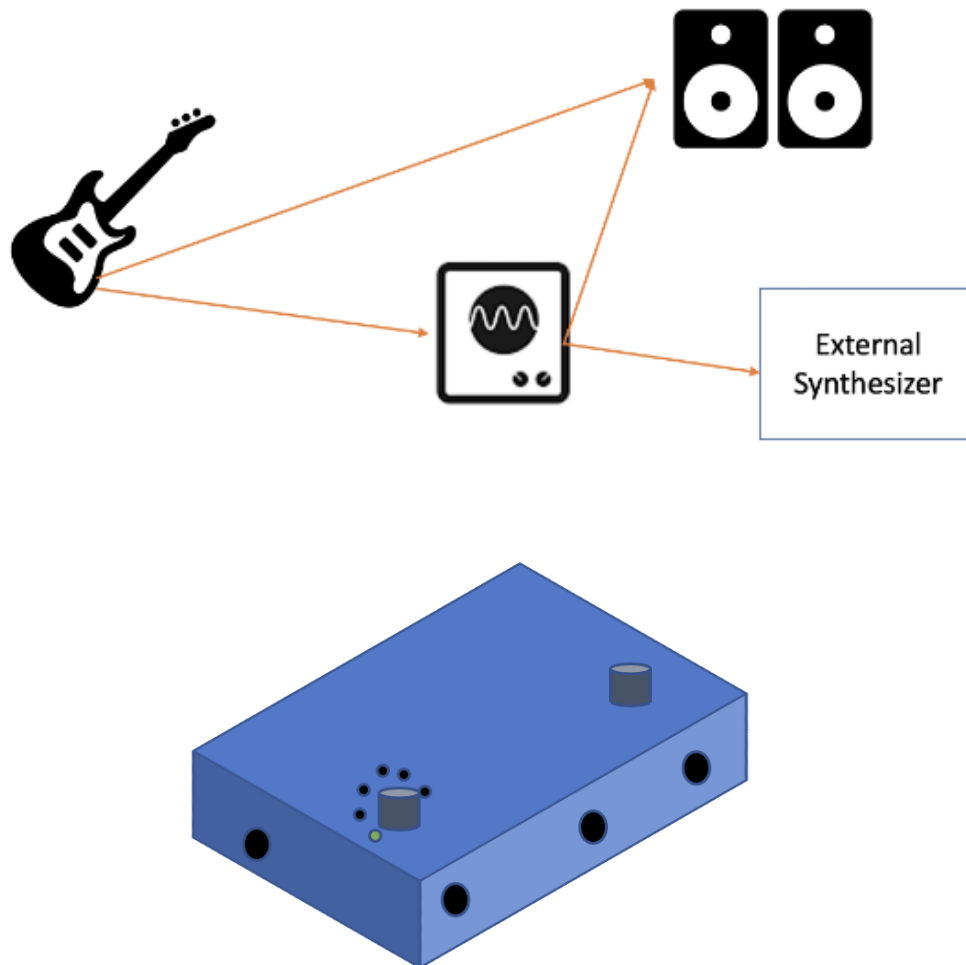
1.4 High Level Requirement List:

1. Can resolve a frequency in the range 50-1500 Hz to the closest note in 12-tone equal temperament tuning system with A at 440 Hz. Error tolerance of +/- 5%.
2. ADC/DAC should be at a sample rate of at least 44.1 kHz and at least 16-bit resolution. This is because CD quality audio has 16-bit resolution and is sampled at 44.1 kHz.

3. Total Harmonic Distortion is less than 2% for a pure guitar note.

4. Block Diagram

5. Physical Design (if applicable)

6. Requirements & Verification Tables

5.3 DSP Frequency Analyser
- The purpose of this subsystem is to recognize the note that the guitarist has played (after A/D conversion).
- This will be done by mapping the frequency of the played sound to the closest note in the 12-tone equal temperament, A at 440Hz system.
- *Requirements:*
  - *Should be able to resolve a frequency to the nearest 'correct' note within 5 milliseconds.*
  - *Tie-break to the higher note.*

- *Verifications:*
  - *Use a serial monitor to log the timestamped output of the ADC as well as the timestamped output of the frequency analyzer. The difference should be less than 5 ms.*
  - *Use a guitar tuner to check the frequency of the note played and compare it with the output of the frequency analyzer. They should match.*

5.4 Synthesizer Subsystem
- This subsystem purpose is to select the note and the type of waveform that will be combined with the original signal and output at the end.

  2.4.1 MIDI Note Generator
  - The Midi Node Generator will receive the note from the tuner and choose what MIDI note to harmonize with the note input from the tuner. This will only happen each time the note played by the guitarist changes, to avoid a situation where tremolo picking or sustained notes causes a 'stuttering' effect as the same harmony is continuously generated.
  - It will split its output to the external synthesizer and the other to the internal synthesizer.
  - *Requirements:*
    - *Latency should be under 5 milliseconds.*
  - *Verifications:*
    - *Use a serial monitor to log the timestamped output of the frequency analyzer as well as the MIDI signal. The difference should be under 5ms.*

    2.4.1.1 Harmony Selector
    - The input that chooses the type of harmony to produce.
    - *Should be able to calculate at least the following harmonies: unison, fifth, major third, minor third, major 7th, minor 7th. Advanced functionality may include picking a key and generating the diatonic chords.*

  5.4.2 External Synthesizer output
  - The external synthesizer is optional based on the user. If the user what's the effects of our internal synthesizer this subsystem will not exist.

5.4.2 Waveform Generator/Internal Synthesizer

- The purpose of the internal synthesizer is to decide what timbre the notes from the MIDI Note Generator will have. It serves to display the waveform and has a selector deciding whether it will change the waveform of the note to be a square wave, sinusoidal. The chip used for this synthesizer is the MK20DX256VLH7 which will be prototyped on the Teensy 3.2 board. This chip is chosen because the Teensy Audio Library has extensive support for Digital Signal Processing Applications in real time.
- *Requirements:*
  - *Be able to generate sine, square, and sawtooth waveforms of frequencies between* 50-3000 Hz.

5.5 ADC/DAC Subsystem

- This subsystem manages converting the signal from analog to digital and vice versa which is critical to being able to harmonize the signals. Both ADC and DAC will be implemented on the Teensy Audio Shield because the DAC onboard the MK20DX256VLH7 on the Teensy board is only capable of a bit depth of 12 instead of 16.

2.5.1 ADC

- Requirement - Input is equal to or less than $1V_{rms}$. This is because 1Vrms is a little more the highest guitar output voltages[2].
- Requirement- for 5VDC of internal power in the DC the current is limited to 10mA
- Requirement- for 3.3VDC of internal power in the DC the current is limited to 1mA
- Requirement- The input impedance is greater than 100kOhms to prevent signal attenuation
- Requirement- The input signal frequency is correctly read with an error tolerance   of +/- 5%
- Requirement- The digital signal is communicated to the microcontroller.
- Requirement- should be able to convert in the frequent range of 50-1500Hz

5.5.2 DAC

- The DAC will also be implemented through a Teensy audio shield,

- Requirement- for 5VDC of internal power in the DC the current is limited to 10mA
- Requirement- for 3.3VDC of internal power in the DC the current is limited to 1mA
- Requirement- Output to amplifier if limited to $1V_{rms}$
- Requirement- The output analog signal frequency has +/- 1% error tolerance with respect to the digital frequency
- Requirement- The input impedance is greater than 100kOhms to prevent signal attenuation

5.6 Balancer

- This will be implemented on the PCB board with resistors to combine the synthesized signal with the signal of the original note played. The output of the balancer will be the Amp.
- Requirement- the input signals must match up without delay of either to properly harmonize the notes
- Requirement- The two input signals should be balanced in volume
- Requirement- the output signal should be of the same impedance as other guitar pedals so that users can mess with the volume, pitch, etc of the signal.

5.7 Power Subsystem/supply

- Since the guitar pedal is ideally meant to be as easy to plug in and use for the player as possible, we want it to be compatible with the power supply of the rest of the pedal chain. Guitarists often have a single 9V DC adapter and simply attach multiple 5.5mm * 2.1mm connectors to them for each pedal in a 'daisy chain' [4].

5.7.1 Power Supply

- *Requirements:*
  - *Be powered by an external 9V DC power supply rated under 500mA with a 5.5*2.1mm barrel connector with negative polarity in the center.*

5.7.2 On/off

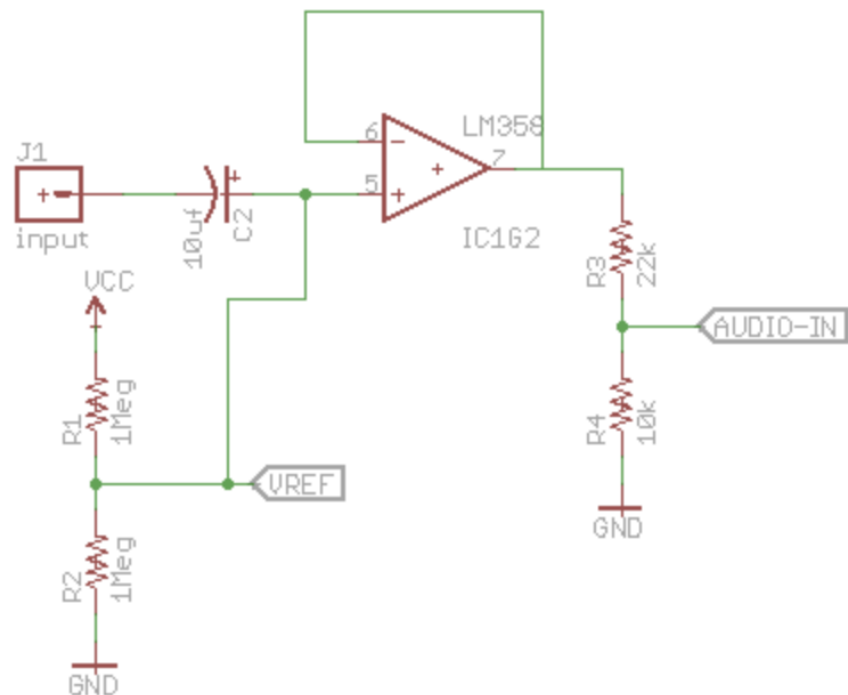- A switch that will turn on and off the power supply for when the project is not in use.

6 Tolerance Analysis:

- For our tolerance analysis calculations we want to consider the signal to noise ratio SNR.
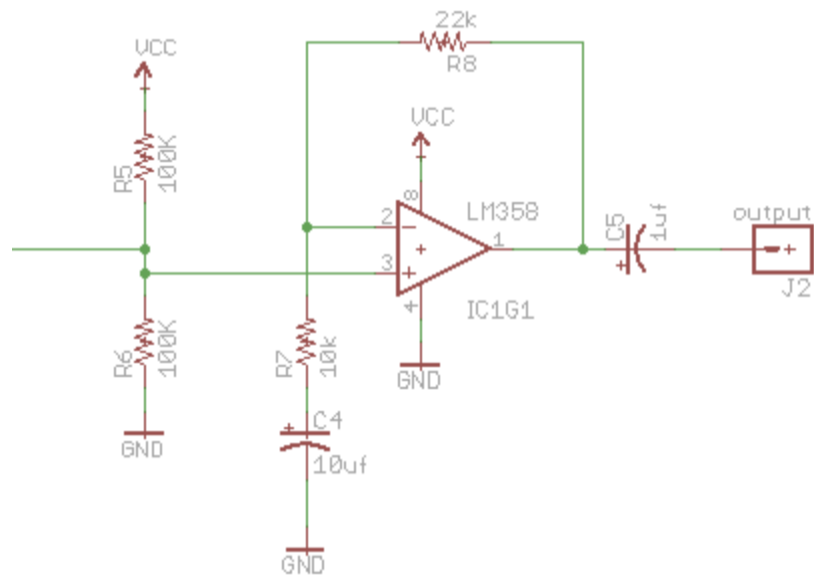 - SNR=Audio Signal Voltage/Noise Voltage

- The reason for this is that the biggest risk to our project is the noise interruption that can occur to our output audio at stages such as the amplifier. There is risk that the noise will reduce the quality of the audio output enough to essentially ruin the effect of our project.
- SNR of 15db would allow for noise to still exist. A sufficient SNR for our project would be at least 25dB will allow for the noise to be overpowered by the audio and be almost unheard by the human ear.
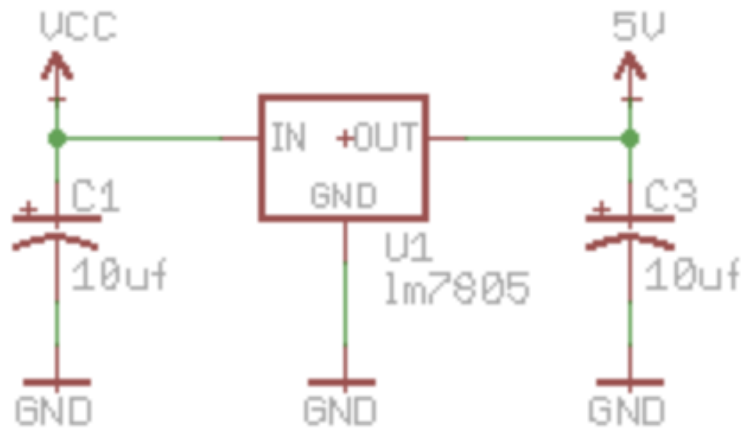
7. Circuit Schematics
Input Buffer circuit schematic:

Output Buffer circuit schematic:

Voltage Regulator circuit schematic:

7. Tolerance Analysis
   1. Identify an **important part** that you need to perform some quantitative analysis on. This part should have quantitative

values critical to the design and require you do calculations and make trade-offs in order to achieve your best design.
   2. Common mistake: Many students do calculations for tangential parts to pad the space.
   8. Safety & Ethics

As the IEEE code of ethics says we must "hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development." In order to do this we must consider the fact that someone can be unaware of the risks of the system and make the audio output louder than safe for people's ears. Anything 80 db and above can cause hearing damage. To comply with an ethical standard our product will include a warning with the range of dB that can cause hearing damage.

It is also a concern that because we are using circuitry that our design is rain proof. Water can cause short circuiting which is a fire safety hazard. To do this we must make sure that our circuit design is sealed enough to not let any water in. We would also need to ensure that all voltages and currents are appropriately grounded so as to not make the strings of guitar live wires. This can be extremely dangerous for the player and adhering to design standards will help prevent this.

The risk of electrical shock if mishandled also would be a safety hazard to children. From the AMC ethic code 1.2 to avoid harm our team wants to avoid any possible risk to anyone's safety. Our team plans to put a safety warning on the product to keep away from small children to avoid a hazard like this from occurring.

As stated by the IEEE code of Ethics, it is our responsibility to be technically competent so that we are qualified by training and experience in order to avoid hazardous malpractice during lab work. It is equally important that we restrain from any and all illegal conduct during any professional activity that is performed during this experiment. Finally, IEEE promotes and encourages fair criticism of technical performance in order to correct errors as well as properly credit the members of the group for their contributions.

   9. Citations

[1] https://blog.zzounds.com/2017/12/20/doubling-guitar-tracks-with-synthesizers/

[2]
http://tomsguitarprojects.blogspot.com/2014/12/electric-guitar-output-voltage-levels.html

[3]
https://www.churchproduction.com/education/latency-and-its-affect-on-performers/

[4] https://neunaber.net/blogs/neunaber-audio-blog/13849473-pedal-power-basics

[5] https://www.ieee.org/about/corporate/governance/p7-8.html