LightsaberFX

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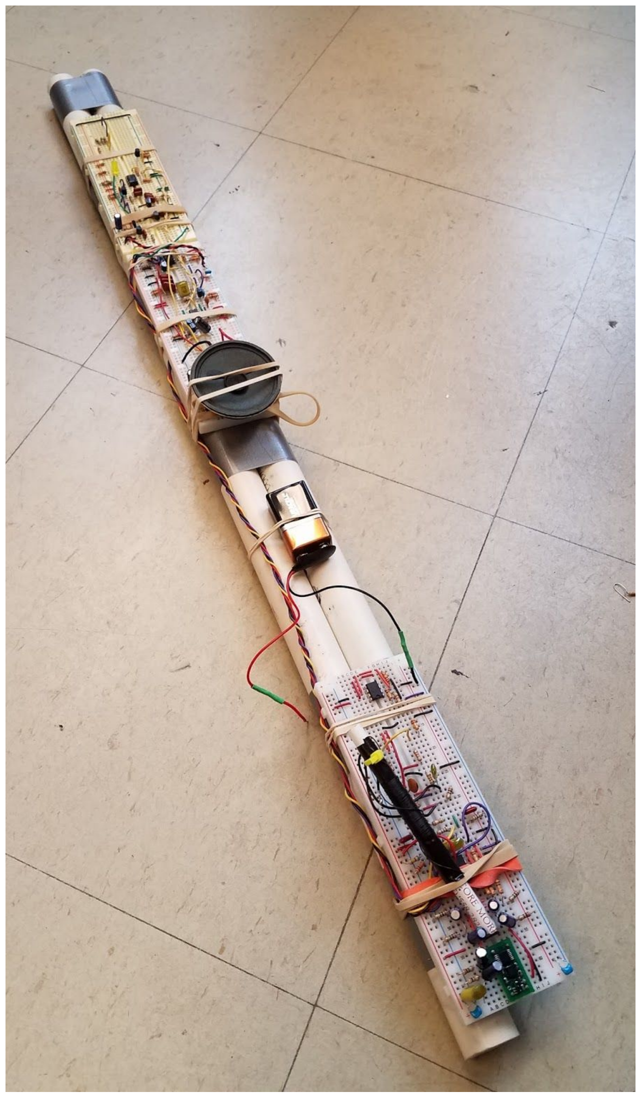

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1. Abstract

LightsaberFX is a system that aims to emulate the quintessential sound effects representative of the classic Star Wars franchise. Toys have long since captured the attention of children, and recent advancements in electronic toys have only added to the fun. The aim of this project is to add an extra dimension to the kid-toy interaction through a toy's response to the user to any saber-like object the user has at hand. By attaching an accelerometer to a lightsaber-like object, movement data is acquired in three axes, is processed to differentiate regular swinging motions from lightsaber impact, and is assigned various speed, acceleration, and duration thresholds to particular sounds created by analog oscillators, filters, and modulators. Thus, when swung in all three directions, the lightsaber produces a low sound that varies in pitch proportionally to the change in total acceleration, and when struck against another object, a higher-frequency impact noise is activated for two seconds. This system is designed using a 9V battery with switches that automatically open and turn off the system after a period of nonuse, and close to turn on the system once the user has moved the saber. After ten seconds of no movement, the power to the sound generation circuitry turns off, but when swung again, the sound is reactivated. Overall, LightsaberFX has succeeded in achieving the goal of introducing to the world a lightsaber module attachable to any saber-like object.

2. Introduction

We all grew up with the magic of play-pretend - a branch becomes a powerful sword, a bear becomes a trusty explorer. With the lack of real weapons and heros, we used our imaginations to fill in the rest of the details and create our own worlds - we can reflect on memories of holding invisible swords, making sounds with our mouths and shining flashlights at each other to replicate intergalactic battles. However, sometimes frustration can arise with keeping track of small but vital details, like making the sound of a lightsaber, while leaving room for generating plot and action scenes. For our project, we would like to encourage people to foster their imaginations by developing a module that can be attached to any object, whether a toy or an everyday object, and turn it into a lightsaber. This allows for endless possibilities for entertainment and innovation as kids find various ways and places to attach the module and wave it around.

LightsaberFX aims to create an interactive experience by generating lightsaber sound effects according to the user's awesome bladework. Movement data can be acquired in three axes by attaching an accelerometer to a lightsaber, and can be transformed using operational amplifiers and filters to send to a sound generator. Through a series of analog oscillators, filters, and modulators, sounds can be generated as a function of the acceleration of the lightsaber. In order to for the sounds to be appreciated, design of a power supply using a battery and an amplifier are necessary. An automatic switch that opens after a period of nonuse and closes upon detection of lightsaber motion can further reduce power consumption and allow for less battery use. Ultimately, the goal is to develop a wireless system that sends acceleration data and hitting event recognition through fiber optic transmission to the sound system.Through this project, the user can realize their inner lightsaber warrior at present, in a galaxy not too far away.

3. Design

3.1 Overview

The project can be divided into two main portions, as shown in Figure 3.1.a. The motion data acquisition involves using an accelerometer to obtain and process information about acceleration and impact, and the sound generation modulates signals from a series of oscillators to create lightsaber sound effects. The goal is produce sound effects that change in pitch with different movement as well as triggering an impact sound effect when the lightsaber hits something. The entire system is powered by a single 9V battery, and uses virtual ground at 4.5V for reference.

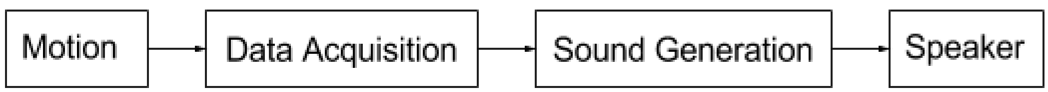

Figure 3.1.a: High level block diagram of LightsaberFX

3.2 Data acquisition

3.2.1 Accelerometer

Motion data is acquired using a DE-ACCM3D tri-axis accelerometer, which outputs voltage as a function of acceleration in the x, y, and z axes relative to the chip. Output voltage on all three axes includes approximately 2 V DC voltage when the chip is stationary, but may change in value depending on the orientation of the chip as a result of acceleration due to gravity with respect to the chip's axes. The DE-ACCM3D contains a 3.3 V regulator, allowing for a voltage operating range of 3.5 V-15 V. When its 3.3 V regulator is in operation, the DE-ACCM3D has a sensitivity of 333 mV/g, but can reach a maximum sensitivity of 360 mV/g at higher operating voltages when the regulator is unused. Additionally, the accelerometer draws 0.9 mA of current, and can accurately drive 500 Ω loads.

3.2.2 Data Processing

The overall schematic for the data processing portion is shown in Figure 3.2.2 a. The portions of this module are as follows: the tri-axis accelerometer to collect motion data, a high pass filter for each output to normalize the DC offset voltages, and an op amp voltage summer, which produces the summed acceleration. The detection of a hitting event is directly downstream of the voltage summer, and includes a high pass filter to normalize DC offset voltage, a comparator that outputs high voltage when the input voltage is higher than the baseline, and a low pass filter that takes the time average of the comparator output.

Instead of calculating the total acceleration via vector addition, for the purpose of combining data from all three axes, simply adding the three voltage outputs proved sufficient to demonstrate noticeable change in speed in any direction. Since the output voltages all operate from slightly varying DC output voltages, in order to normalize the DC offset to virtual ground at 4.5 V so as to prevent railing when adding the voltages, a second-order passive high pass filter consisting of a 1 μF capacitor in series with a 1 MΩ resistor tied to virtual ground was implemented for each axis output. This results in a time constant of 1 second, a filter cutoff frequency of approximately 0.16 Hz, and a roll-off slope of -40 dB/decade. This cutoff and roll-off slope were sufficient to remove DC offset voltage, while still retaining the majority of the motion signal. Once the DC offset with respect to virtual ground was removed, the three voltage signals go through a voltage adder with a gain of 2 using an LF353 op-amp. This output goes directly to the sound generation portion of the circuit.

In order to detect events when the lightsaber hits some surface, a passive high pass filter in series with a comparator and a passive integrator were used. Upon contact with some surface, the accelerometer outputs a waveform reminiscent of a short impulse train riding on top of the gross acceleration signal. Passing the output of the voltage summer through a passive high pass filter removes the gross acceleration signal while retaining the pseudo-impulse train indicative of a “hit.” This was done using a 100 nF capacitor and a 1 MΩ resistor tied to virtual ground, resulting in a cutoff frequency of 1.6 Hz with a roll-off slope of -20 dB/decade. Since the impulses vary in height, this output passes into the non-inverting input to a comparator, whose reference voltage is 4.8 V, slightly higher than virtual ground, in order that the comparator outputs a pulse of height
4.5 V for each impulse in the output. These pulses then pass through a second order passive low pass filter, which acts as an integrator to take the time average of the pulses. The low pass filter consists of a 10 MΩ resistor followed by a 100 nF capacitor tied to ground, resulting in a time constant of 1 second, 16 Hz cutoff frequency, and -40 dB/decade roll-off slope. Thus, if many impulses occur within the time constant of 1 second, then the integrator outputs a signal of relatively high amplitude, and removes any spurious signals from quick acceleration or deceleration of the lightsaber.

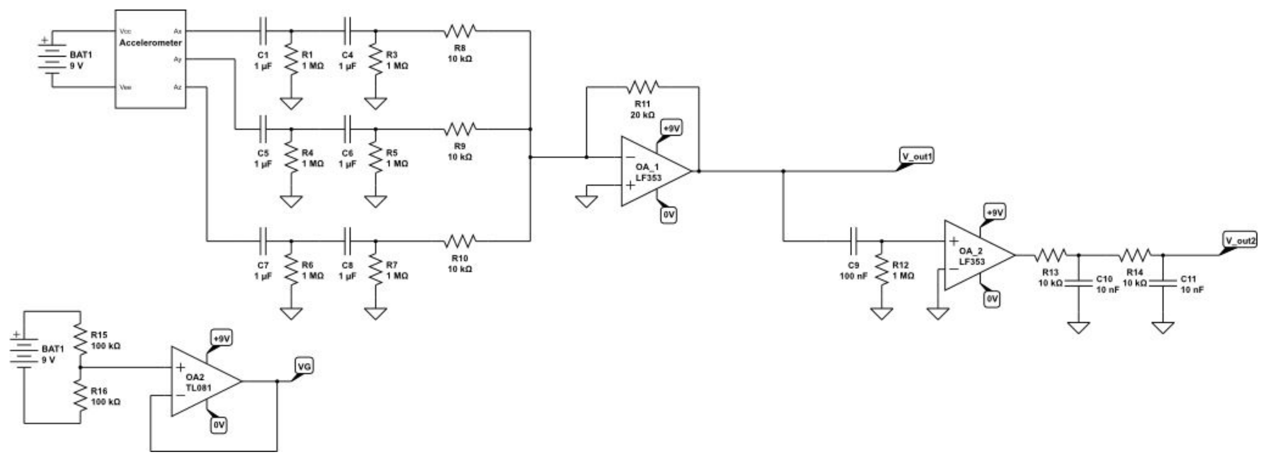

Fig. 3.2.2 a) Overall schematic for data acquisition and processing. Includes circuit that sets virtual ground.

3.1 Sound generation

3.1.1 Frequency selection

In order to decide how to create the lightsaber sounds, MATLAB was used to process sound files of lightsaber sound effects found online and generate their Fourier transforms. From the resulting plots, the most prominent frequencies were noted for each type of sound effect. For the regular "hum" effect of the lightsaber motion, the most prominent frequencies were 61 Hz, 75 Hz, and 219 Hz. For the impact sound, the frequencies observed were around 200 Hz and 550 Hz. These will be the frequencies that will be modulated and combined to generate the lightsaber sound effects for the project.

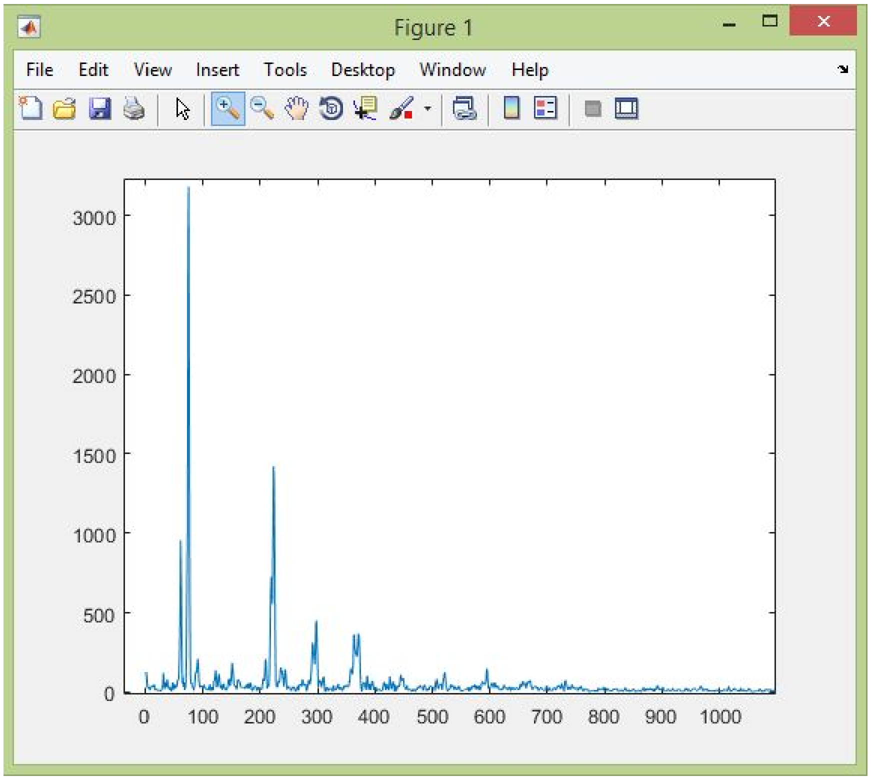

Figure 3.3.a: Fourier transform magnitude plot for “buzzing” sound effect

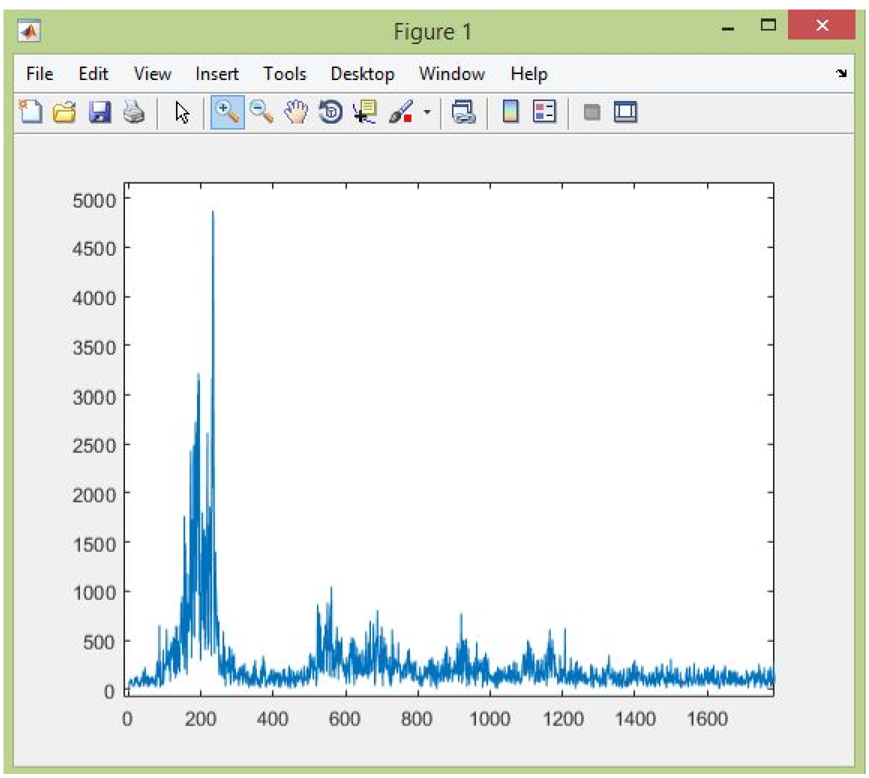

Figure 3.3.b: Fourier transform magnitude plot for impact sound effect

3.3.2 Phase shift oscillators (PSO)

To produce the various desired frequencies, a number of phase shift oscillators were built in the general configuration seen in Figure 3.3.c. Each resistor-capacitor pair in the configuration acts as a low-pass filter which produces a phase shift of 60°. The connection of the three RC filters creates a total phase shift of 180° which, in combination with the feedback loop, allows this circuit to oscillate with a sine wave output. The frequencies are determined by the equation:

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

One thing to note was that not every combination of resistor and capacitor values would work to create oscillation - for lower frequencies, simply increasing the resistance was not sufficient - the capacitance had to be raised to allow proper charging. The value of the feedback resistor R_f was also important because the RC pairs produce an attenuation of 1/29, so for the circuit to function, $R_f > 29R$.

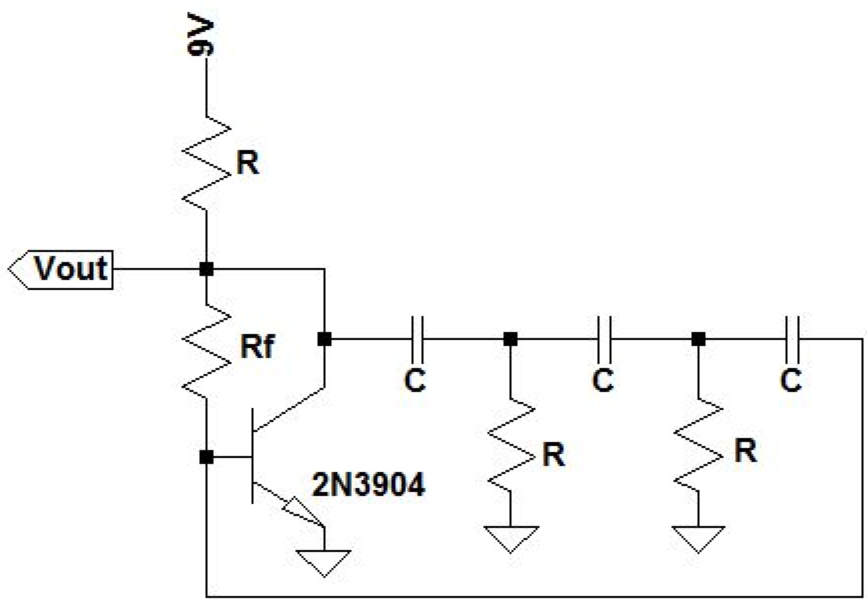

Figure 3.3.c: Phase shift oscillator configuration

3.3.3 Voltage controlled oscillator (VCO)

One feature of the project was to have the sound effect change in pitch with different intensities of motion. This involves varying the frequency of the output signal based on the acceleration voltage reading, or in other words, frequency modulation (FM). The configuration in Figure 3.3.d shows a voltage controlled oscillator circuit which works by using an integrator controlled by a 2N7000 MOSFET to charge and discharge capacitor C1 to produce a triangle wave, which is then passed through a Schmitt trigger comparator to produce a square wave [add more detail].

The square wave from the output of this circuit will increase in frequency as the input voltage increases, which makes it perfect for controlling pitch. The resistances are set to give an output frequency range from 100-300 Hz, which is ideal for acting as the carrier frequency for later modulation with a 60 Hz sinusoidal signal to produce the motion signal.

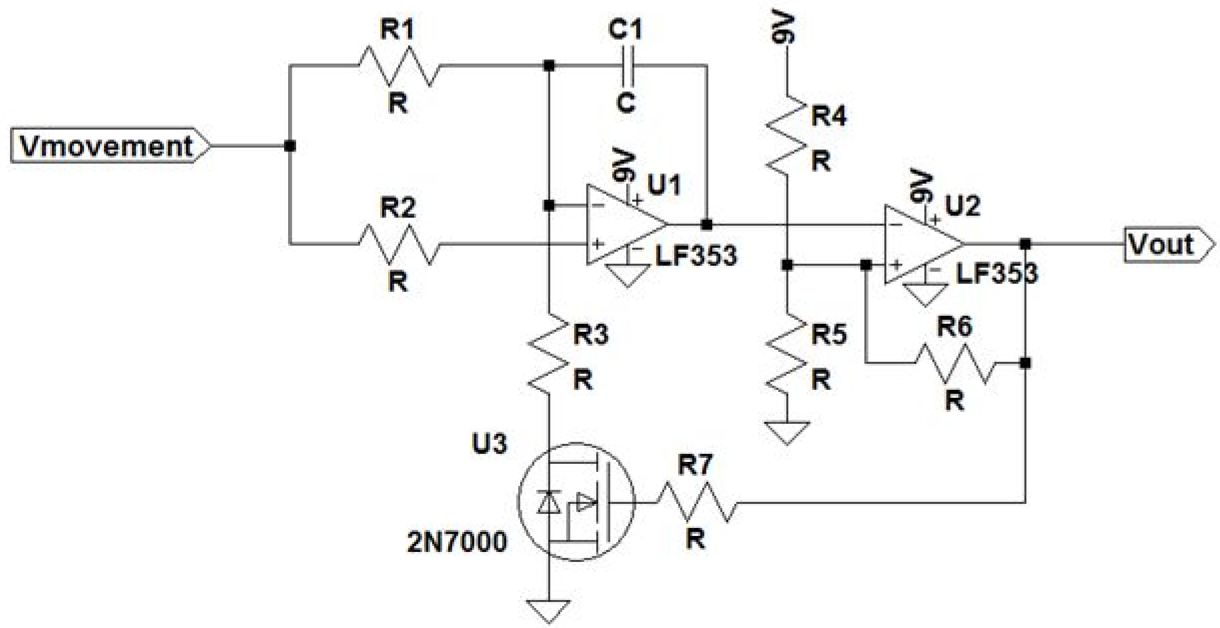

Figure 3.3.d: Voltage controlled oscillator

3.3.4 Modulation

To create more complicated sounds, pairs of waveforms at different frequencies were amplitude modulated together. To perform amplitude modulation, the circuitry in Figure 3.3.e was built. To produce the movement sound, the ~200 Hz square wave was modulated with a 60 Hz sinusoidal wave, while for the impact sound, two sinusoidal waves of approximately 200 Hz and 600 Hz were modulated together. In each case, the waveform of the higher frequency acted as the carrier signal for modulation.

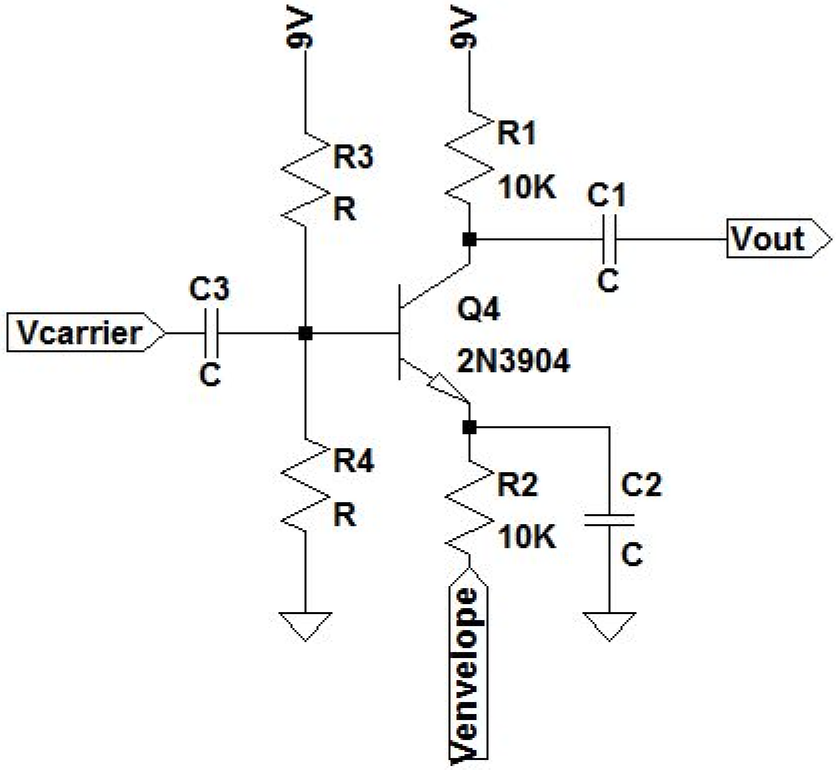

Figure 3.3.e: Amplitude modulation (AM) circuit

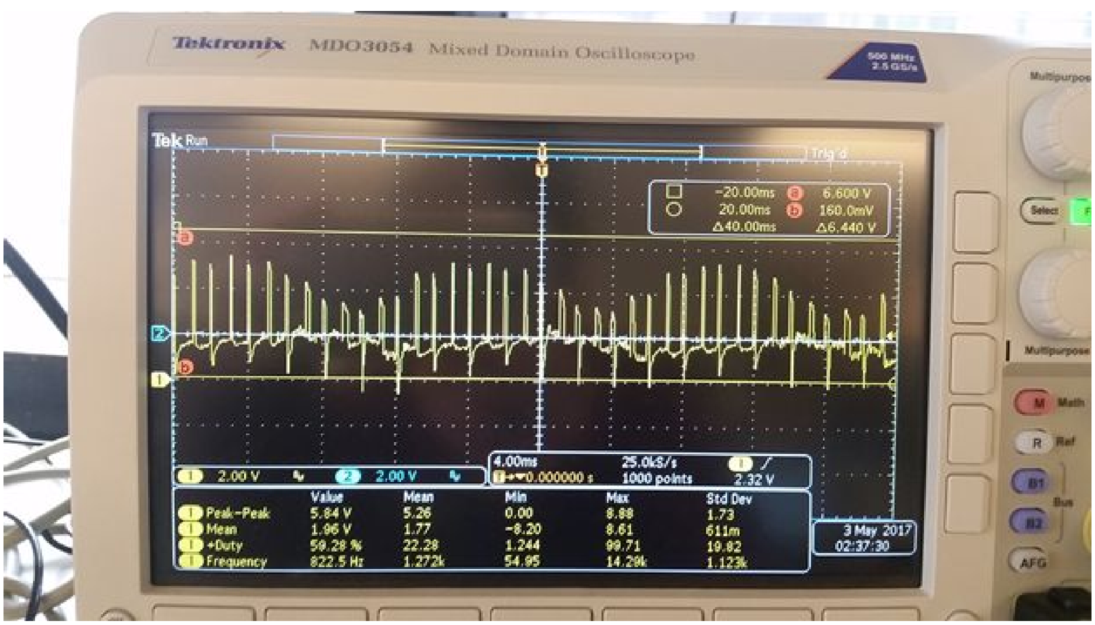

Figure 3.3.f: AM modulation of two input signals of different frequencies

3.3.5 Mixer

When the impact sound is triggered, the impact sound circuitry is powered on and the impact signal is combined with the motion signal by a mixer biased at a 4.5 V virtual ground. The mixer is created with an inverting summer with resistances equaled to produce a unity gain with the same weight given to both the impact and motion sounds. The initial design is shown in Figure 3.3.g. Voltage followers biased to 4.5 V were added before each of the audio signals to prevent stray current from changing the waveform shapes and to center both the waveforms on 4.5 V (Figure 3.3.h).

This circuitry worked well because when the impact sound was turned off, the motion signal waveform passed through unaltered as if the mixer were a unity gain inverting amplifier. However, the moment the impact sound was turned on, the two signals were summed together to produce a new higher-pitched clashing sound.

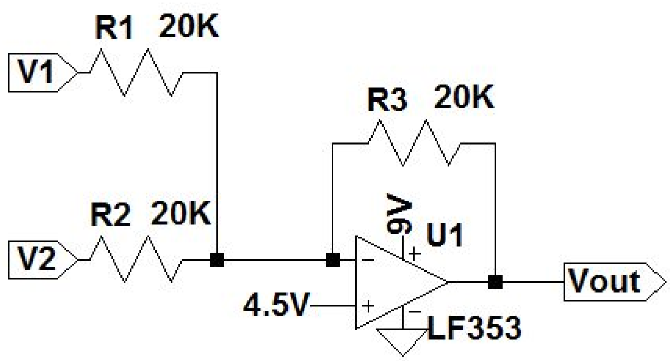

Figure 3.3.g: Basic mixer circuit

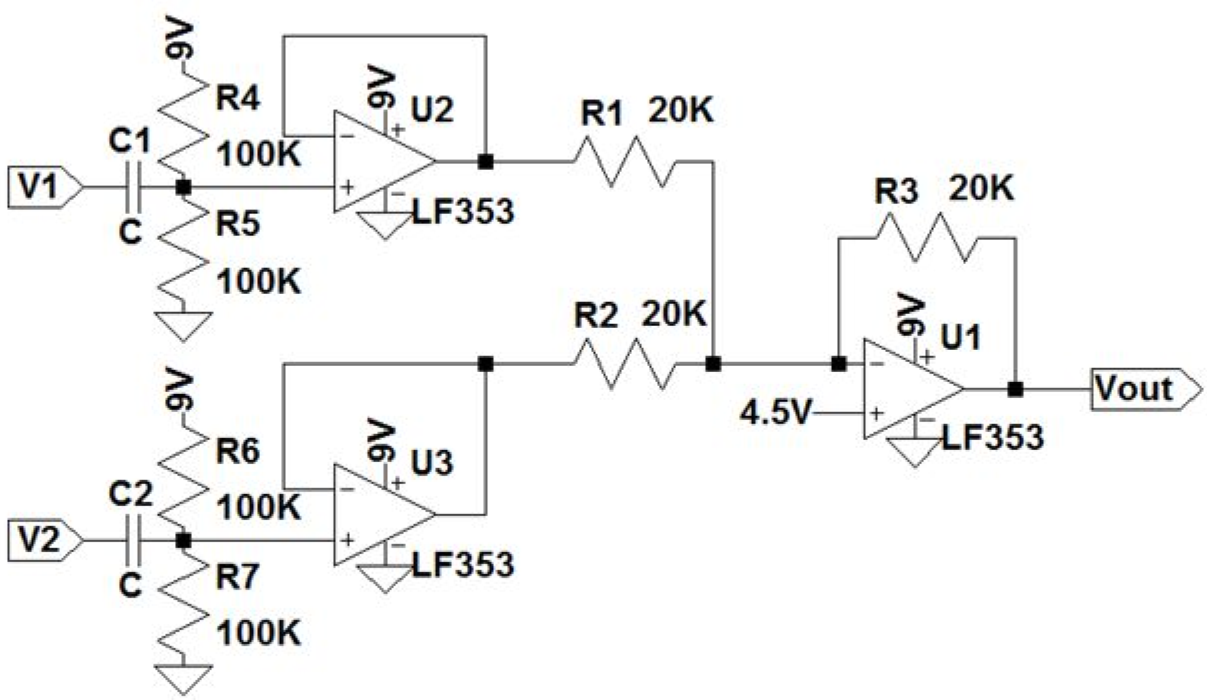

Figure 3.3.h: Mixer with input signals buffered by AC voltage followers

3.3.6. Amplifier

A class AB push-pull amplifier was built to drive the speaker. This type of amplifier was chosen because a class AB amplifier reduces crossover distortion and is more efficient compared to a class A amplifier. This is because the push-pull configuration keeps only one transistor on at a time when the signal is nonzero. The schematic for the amplifier is shown in Figure 3.3.i. The amplifier provides a unity gain of voltage at the output but amplifies the current by the beta value. The two npn and pnp transistors were chosen such that their beta values were as close as possible.

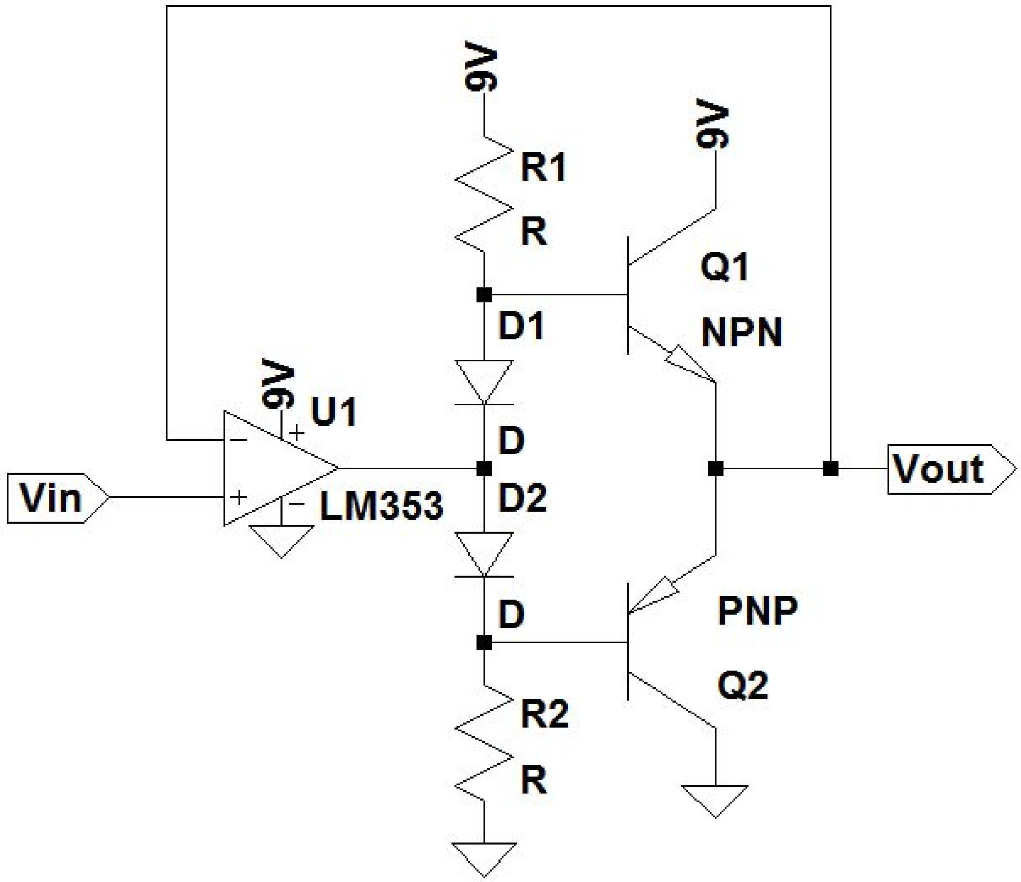

Figure 3.3.i: Class AB push-pull amplifier

3.4. Switches

3.4.1 Auto turn on/off

With any electronic toy, there is the concern that a child might forget to turn it off after playing and accidentally drain the battery. To account for this potential problem, an automatic turn-off feature was added to the project - when the lightsaber is at rest, the power to the sound circuitry is turned off after ten seconds. Furthermore, when the lightsaber is in use and there is motion, the sound generation circuitry is powered back on. A switch was designed with two MOSFETs shown in Figure 3.4.a. When the movement data voltage rises above the low gate threshold voltage of <1 V in the TN0702 N-channel MOSFET, chosen to allow for increased sensitivity to small movements, the TN0702 turns on. This allows the capacitor to charge to turn on a ZVP410 P-channel MOSFET, which powers the sound generation portion of the circuit via the 9 V battery.

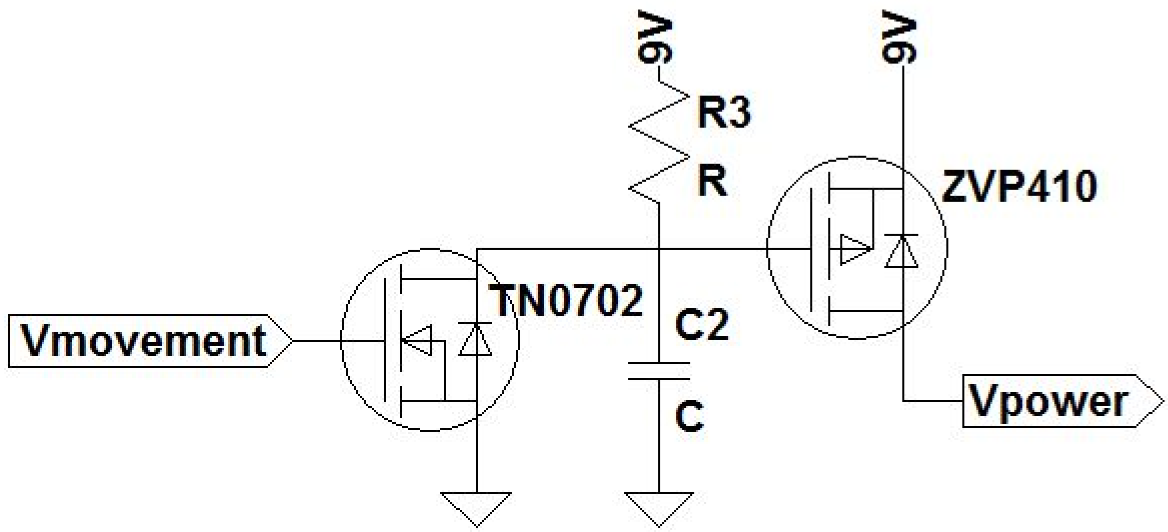

Figure 3.4.a: Auto turn-on and off circuitry

3.4.2. Impact noise switch

Similar to the auto turn-on/off circuit, a switch was designed to activate the impact sound to only turn on with the impact data voltage is high enough to turn on the N-channel MOSFET gate. When the impact switch is off, the output voltage of the impact sound circuitry is 0 V, which has no effect when mixed with the regular motion sound.

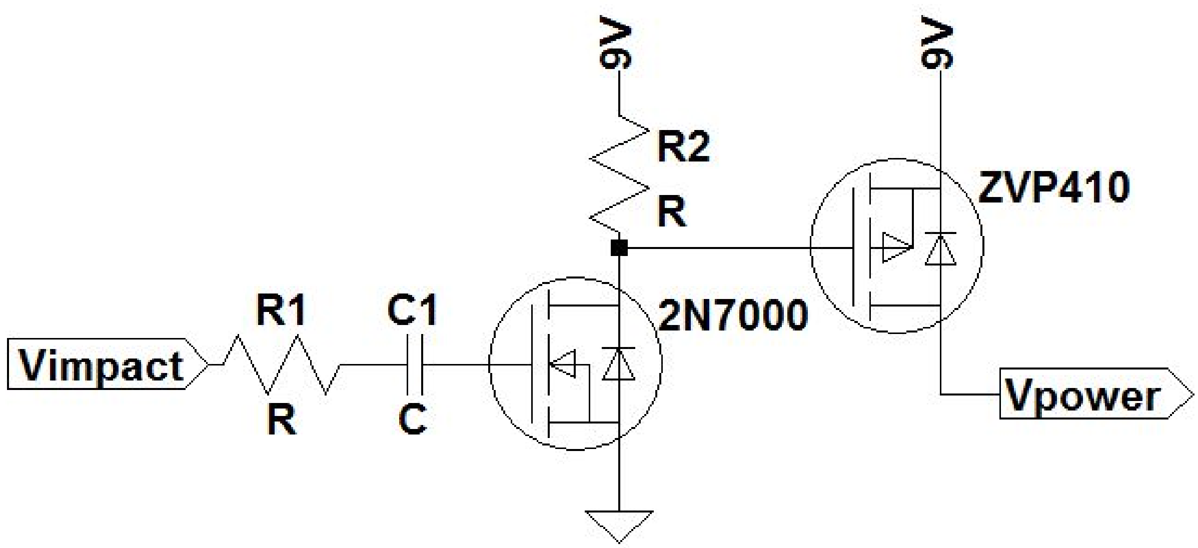

Figure 3.4.b: Impact noise switch

4. Next Steps

4.1 Boost Converter

A boost converter was considered as a means to power the system using 2 AA batteries, a 3 V supply. A 300 mH power inductor, 1N1418 diode, 100 nF capacitor, and a low gate voltage MOSFET were used in the test design to attempt to drive a 1 kΩ load to simulate the resistance of the breadboard power rail. Using a square wave provided by the function generator with peak-to-peak voltage of 3 V and a duty cycle of 80% in order to turn the MOSFET on and off, it was possible to obtain about 9 V DC voltage from a single AA battery, or a 1.5 V supply. The schematic is shown in Figure 4.1.1 a.

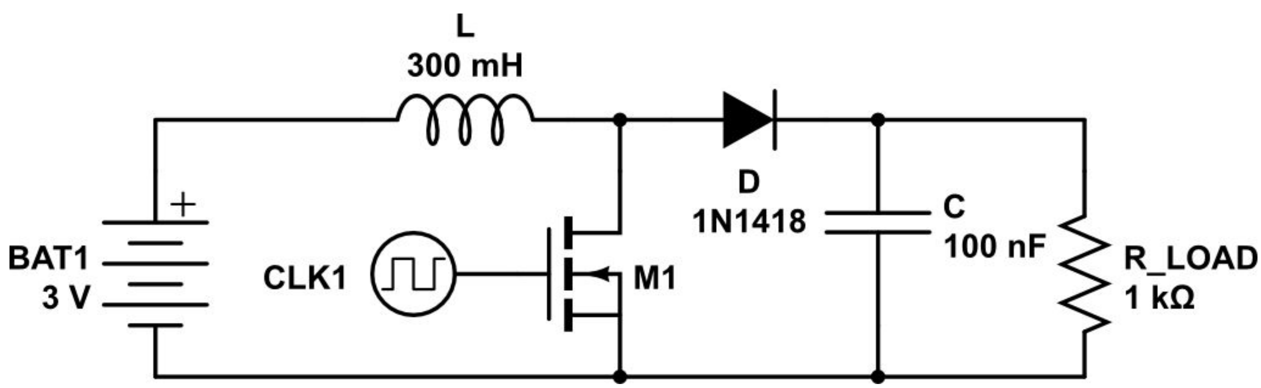

Fig 5.1a) General Schematic for Boost Converter

In order to supply the switching voltage for the MOSFET, a Colpitts oscillator was tested (Fig 4.1.1 b). Since the Colpitts oscillator outputs a sine wave, in order to create a square wave with variable duty cycle, a differential amplifier circuit (Fig. 4.1.1 c) using a potentiometer to adjust the reference voltage was considered. However, the Colpitts oscillator utilized did not output enough power to drive the MOSFET: upon connection between the oscillator output and the MOSFET gate, peak-to-peak voltage significantly decreased, and was not sufficient to turn the MOSFET on. As a result, the boost converter was unable to supply voltages higher than the supply, namely 3 V.

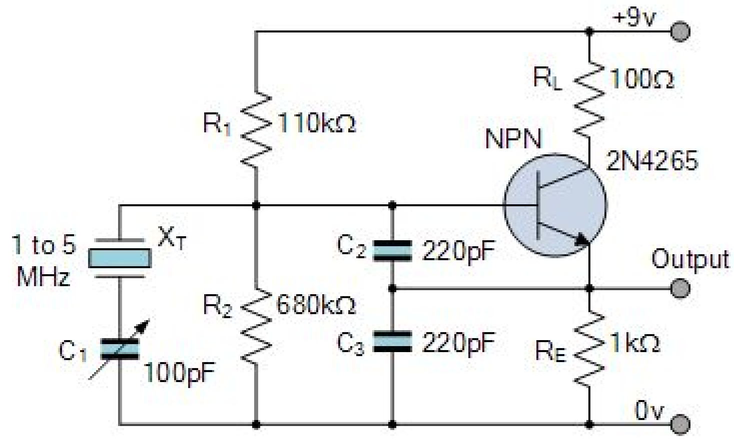

Fig 5.1 b) Schematic for a Colpitts Oscillator using an RC crystal

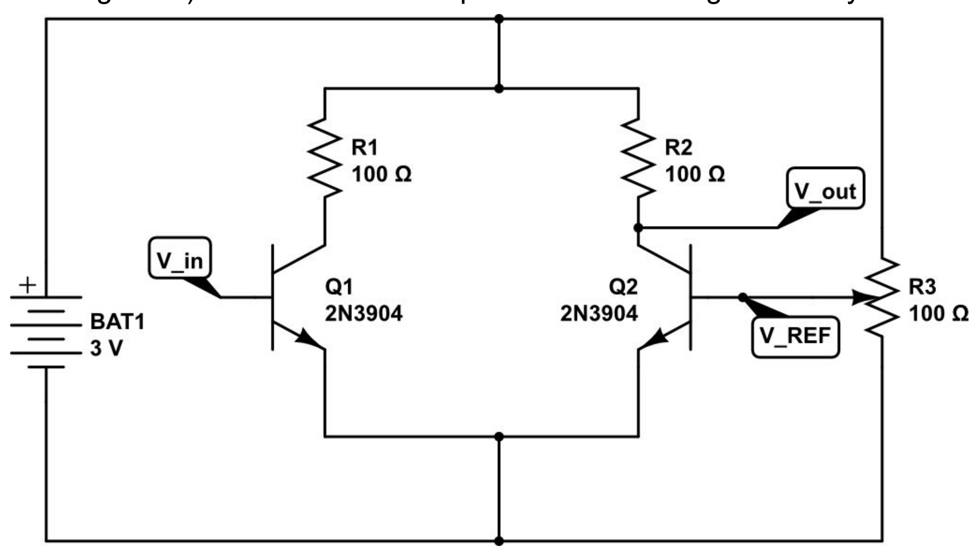

Fig 5.1 c) Differential Amplifier/Comparator Schematic

4.2 Fiber Optic Signal Transmission

To allow for variable lengths for the lightsaber system to attach to, a fiber optic transmission using amplitude modulation was considered. Since two separate signals are being sent to the sound generation portion of the system, it is necessary to modulate each signal on a different frequency separated by a large enough band gap such that both signals can be sent down the fiber optic cable without mixing the signals or losing information.

To implement this, two Colpitts oscillators fixed at two significantly different frequencies in series with a comparator to output rectangular waveforms can be used as the modulating signals. To prevent aliasing, both signals of interest can be passed through a passive low pass filter. The rectangular waveform and the signal of interest are both inputs to a mixer, as described above. The now-modulated signal then gets sent to the SFSH757 fiber optic transmitter, which consists of a reverse-biased LED in series with a resistor. This emits light signals that travel down the fiber optic cable, and is then picked up by the SFH250 fiber optic receiver (Fig 4.1.2. a), a reverse-biased photodiode that produces current when light impinges on it. This current passes through a transimpedance amplifier so that the current converts to voltage, and the signal is then split by 2 wires. Each wire leads to a mixing circuit, whose inputs are the received signal and the modulating signal used in the transmission portion. The output of the mixer then is passed through a low pass filter to remove the higher frequency copies and retain the original desired signal.

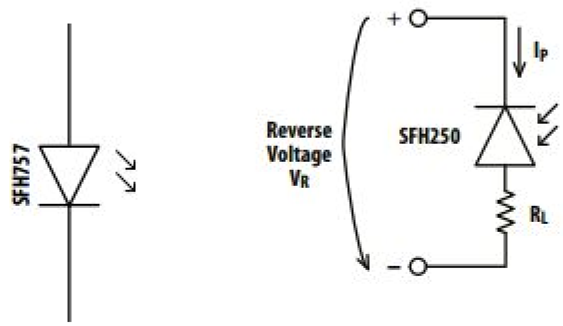

Fig. 4.1.2 a) Fiber Optic Transmitter and Receiver Pair

A potential problem that may arise from the fiber optic signal transmission and reception is the loss of signal power as a result of the demodulation. In the case when a signal is multiplied by a sine wave in the frequency domain, the amplitude of the signal halves, and is further decreased by a factor of one half when multiplied by the sine wave when trying to retrieve the original signal of interest. Thus, the signal amplitude is reduced by a factor of 4, not accounting for any reductions due to voltage drops that occur as a result of circuit elements. Thus, it is necessary to implement a gain of at least 4 in the final low pass filter to allow for a similar range of operating voltages for the sound generation portion of the circuit.

4.3. Light effects

One extension for this project is to make it more visually interactive. Currently, the circuit boards have two indicator LED lights that turn on to show that there is movement and impact. These lights can be improved to become fun light effects for the lightsaber, if we were to increase the number of LEDs and allow movement data to dictate the intensity and color of the lights to go along with the sound effects.

5. Challenges and Lessons Learned

Once challenge with this project was with the speaker load and the amplifier - because of the current limitations from the op amp providing the 4.5 V virtual ground, the amplifier could not output the correct waveform when the speaker, which had a very low impedance of 8 Ω, was attached to the circuit. The amplifier could also be made more power efficient by trying a Class D configuration instead of a Class AB.

The sound itself could be worked on to be more complicated (involving more than just pairs of modulated signals). Given more time, the sound effects could have been designed to have more features such as echo or distortion or varied envelope shape.

During testing, the wires would often come loose from the breadboard holes, causing confusion. An improvement would be to mount the entire project on a PCB board - this would have reduced errors caused by loose wire connections on the breadboards and also made the modules less bulky to attach to the lightsaber rod.

6. Conclusion

Lightsaber FX has succeeded in creating a module that takes acceleration data from three axes, process it such that sounds generated change in volume and pitch as a function of acceleration, and create a separate sound for the event when impact is detected. Additionally, the system was able to turn off during a period of nonuse of approximately 10 seconds, and turn on immediately when the user moves the lightsaber module.

7. Acknowledgements

We would like to thank Gim Hom for closely advising our project and providing lots of good advice, as well as Yanni Coroneo, Jason Yang, and the rest of the 6.101 teaching staff for helping us in our analog journey. We would also like to extend our thanks to Dave Custer and the CIM staff for helping us learn how to convince other people that pet projects are indeed worth investing in.

8. References

Figure 3.3.e) was taken from from http://www.srmuniv.ac.in/downloads/lab1.pdf
Figure 4.1 b) is from http://www.electronics-tutorials.ws/oscillator/crystal.html
Figure 4.1.c) is inspired by 6.101 Lab 4
Figure 4.2 a) was taken from the AV02 Fiber Transmitter and Receiver Data Sheets