WIRELESS MAGNETIC PICKUP WITH EFFECTS

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Abstract

This product took an input from an acoustic guitar and wirelessly transmitted it to an amplifier. This was done using FM transmission. There is also an option to pass the signal through 3 effects: Distortion, Octave-Up, and Octave-Down. There were many successes in the project. Generally the effects were functional, the first pickup prototype, a pre-amplification stage, and also the transmitter were successful.

A fully integrated product was not achieved. This was do to some flaws in the design of the system. There was however some integration accomplished, and the modules were able to be tested individually.

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1. Introduction

Our goal is to create a cost efficient wireless pickup that does not damage the body of the guitar while at the same time being able to create guitar sound effects. We will use a magnetic pickup which will then send the audio signals to the effects module and from there will be sent to the FM transmitter. An FM receiver will then detect the signal and pass it to the amplifier. The effects module will implement 3 effects: Distortion, Octave-Up, and Octave-Down.

There were many aspects to consider when designing this product. The size of the finished product was a major concern. This is due to the fact that the product has to be easily fitted and removed from the sound hole of an acoustic guitar. Functionality of the modules is key to the design of the product as well, and many tests were ran to ensure each module was working as intended.

1.1 Background

Acoustic guitars are an ancient instrument. They have been around for nearly 4000 years, and there are theories that suspect it was developed based on the lute or ancient Greek kithara [1]. Despite being such an old instrument, they continue to be widely used today. As time moved on, people began to want louder guitars, and began to explore electric amplification. The first electric guitar was made around 1931 by George Beauchamp and Adolph Rickenbacker [2]. This brings us to the modern age. The problem is that many acoustic guitars are not built with the capability to transmit their signal to an amplifier to make it louder. The ones that do have this capability are generally more expensive than ones that do not. For example, a Fender CD-60S is priced at 199.99 dollars, but essentially the same model with a pickup, the CD-60SCE, is priced at 299.99 dollars [3]. Vintage acoustic guitars also do not have this capability. It also is desirable to put effects on the sound of the guitar. This can be done with various pedals or one multi-effect pedal. These pedals can also be relatively expensive, with prices ranging from around 50 to about 1500 dollars [4].

There are 4 basic types of pickups used in an acoustic guitar: undersaddle, magnetic, contact, and microphones or blended systems. Many of these systems require modifications to the guitar itself. This is undesirable if someone does not wish drill holes, cut holes, etc. in their guitar [5]. There is a product that solves this problem but it costs about 200 dollars [6]. This product, however, does not incorporate effects. There are other products out there are simply a pickup. From personal experience these pickups do not work very well due to the quiet output of the amplifier. The amplifier had to be turned up extremely loud before there was noticeable difference in volume.

Our pickup should be as affordable as possible. Ideally the product would be less than 100 dollars. This will make it an economical option for somebody who wishes electrify their acoustic guitar but does not want to spend the money on an integrated system. It will also greatly reduce the cost of adding effects to the sound of the guitar.

1.2 High Level Requirements

During the design of this project we strove to meet 3 high level requirements. First, the product should be as affordable as possible. The goal here was drive down the price of the already available products that are similar to this. Next, the sound of the output should be crisp and clean. This means that the sound of the pure guitar should be replicated through our electronic manipulation. Lastly, the product should be able to be inserted and removed from the sound hole an acoustic guitar easily without having to modify the guitar itself.

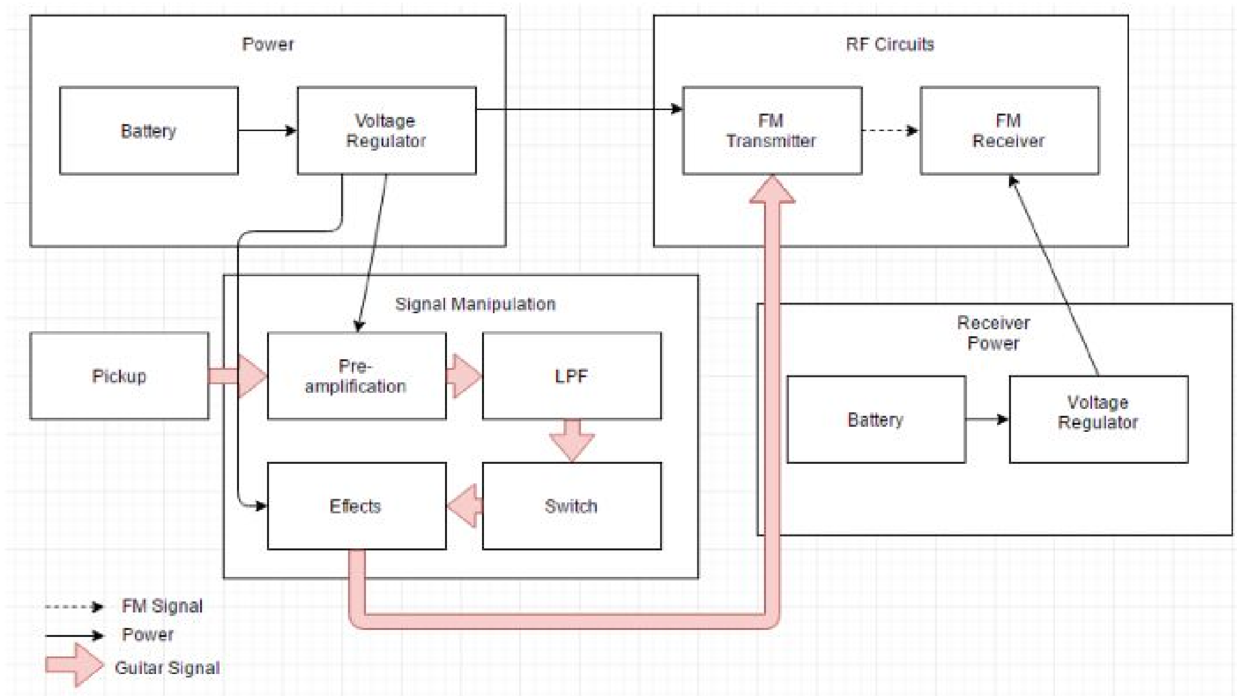

Figure 1 High level block diagram of the product outlining the general path of all signals propagating through it.

2 Design

Our product will consist of 4 main modules: a power supply, magnetic pickup, signal manipulation, and FM transmission and reception circuits. The flow of the signals is outlined in the block diagram which is shown in Figure 1. The power module provides the necessary voltage to bias the pre-amplification module and provide dc power to the distortion effect as well as the FM transmitter. The magnetic pickup will sense the input signal coming from the strings of the guitar. The signal manipulation module consists of a pre-amplification circuit as well as an effects module. The pre-amplification serves to increase the amplitude of the signal from the pickup. The effects module will be able to apply 3 effects: distortion, octave-up, and octave-down. Finally, the signal reaches the transmitter which sends the signal to the receiver and allows the sound to be heard through an amplifier.

Our design approach was somewhat flawed. Due to our lack of knowledge in RF transmission, we should have begun working on these modules much sooner than we actually did. As a result, our wireless communication circuits were lacking.

2.1 Physical Design

A major design aspect of this project was the fact that the entire design had to easily fit into the soundhole of an acoustic guitar. Trying to come up with an enclosure that could be easily installed and removed from the guitar proved to be somewhat difficult. The soundhole of the guitar used is roughly

Figure 2   The enclosure is shown inserted into the soundhole of an acoustic guitar. The battery pack is shown on the left and the pickup (top) and effects switch (right) can also be seen.

circular in shape and had a diameter of approximately 4 inches. The design of the enclosure we came up with needed to be able to hold all of the electrical components within it. We also needed it to be able to be installed underneath the guitar strings. This gave us a limited depth to work with. The final dimensions of the enclosure were as follows: the radius was 4 inches, the inside cavity had a depth of 0.75 inches, and the height of the enclosure was 3 inches. Holes were also bored into the top of it to allow the pickup to be fitted through it and also allow a switch to select which effect was going to be heard. The final design is shown in Figure 2.

2.2 Power

The device is going to be powered with a 9 volt battery. The battery will be followed by a voltage regulator that will regulate the voltage to 8 volts. This is done to ensure that any variations in the battery voltage can be handled. We will be using an LF80C voltage regulator to regulate the voltage to this value. Values of typical 9 volt batteries can range from 8.4-9.6 volts. The schematic for the voltage regulator for both the full device and the FM-Receiver can be found in Figure 3.

2.3 Magnetic Pickup

The magnetic pickup is the heart of this device. Its purpose is to sense the vibrations of the guitar and convert them into a voltage signal. The magnets in the coil, Neodymium in our case, magnetize the strings above the pickup. When a string is plucked, the change in the magnetic field induces a voltage in the coil of wire wrapped around the magnets. This voltage is then sent to the pre-amplification module

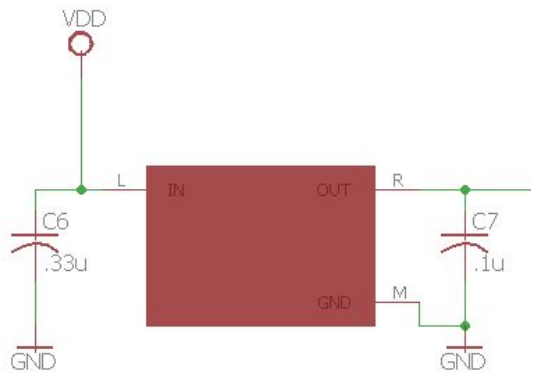

Figure 3 Schematic for the Power Module. This is the recommended setup as shown in the datasheet for the voltage regulator.

to be increased in magnitude.

2.3.1 Design Process

In order to design the pickup, the desired output must be defined. We wished our pickup to output a voltage of 50 mV when a string of 250 Hz was plucked. In order achieve that the number of turns must be calculated for the windings on the pickup. This was done using Equation 1. Knowing the desired output voltage (V), strength of the magnets used (B), the frequency of the string plucked (f), and by estimating the area changing the flux (A), the number of turns (N) necessary to achieve this output was calculated to be approximately 5000 turns.

$$V = \frac{NBA}{f} \tag{1}$$

Using the relationship for the impedance of an inductor and the frequency of the signal passing through it coupled with Ohm's Law will provide a performance analysis of the pickup. As the frequency increases the impedance will also increase. If the output current remains constant this results in a greater output voltage. The opposite holds true for when the frequency decreases.

Physically making the pickup proved to be very difficult. Various methods were tried to wind the pickup, but ultimately it had to be wound by hand. This was very time consuming and, due to the thickness of the wire, it took many tries to get a finished product because it kept breaking. A photo of the final pickup is shown in Figure 4.

2.4 Pre-Amplification

The signal from the pickup will then be passed into the pre-amplification module. The pre-amplification module will be a 3 stage amplifier consisting of two common-source and a common drain amplifier. This will amplify the voltage signal. The common-source amplifier works very well for high resistance loads. However, when the load resistance is low, the gain from the amplifier drops off significantly. For this reason, the common-drain amplifier is cascaded to keep the load resistance of the common-source amplifier near infinite. The common-drain amplifier's gain does not depend on its load resistance, so the load can have a small resistance value and the gain is preserved. The final schematic for the

Figure 4   Photo of the final revision of the magnetic pickup.

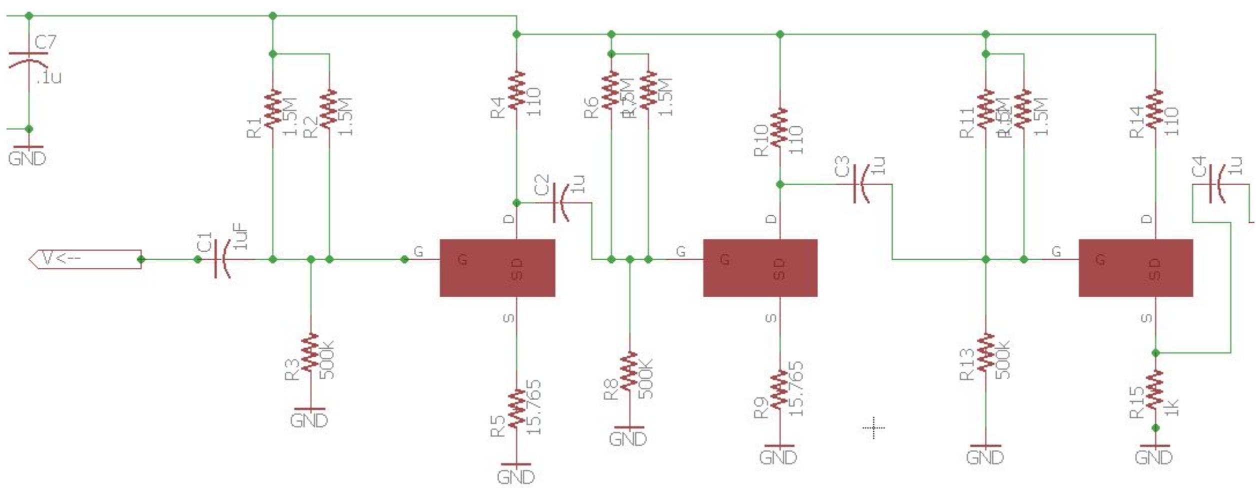

Figure 5   Shown is the schematic for the pre-amplification module. The transistors used for the amplifiers are shown as the red blocks. Notice the first 2 stages take the output from the drain of the transistor and the last stage takes its output from the source of the transistor.

for the pre-amplification module is shown in Figure 5.

2.4.1 Design Process

It is necessary for the signal coming from the pickup to be pre-amplified before entering the effects or the FM transmitter. This is so the signal is not too greatly affected by losses in these modules. The gain of a common source amplifier depends on the load resistance so a common drain amplifier needs to be cascaded after it. A MOSFET needs to be biased in saturation mode in order for amplification to occur. For biasing the gate voltage was selected to be 3.5 V. This is done using a voltage divider to determine the necessary resistances. The R_2 (bottom in the schematic) was chosen to be 500kΩ. Using Equation 2, R_1 (top in the schematic) was found to be 785.7 kΩ. These resistor values need to be large so little current flows through them. The overdrive voltage was then calculated using the threshold voltage and Equation 3 of the 2N7002 transistor which is 2.1 V. The overdrive voltage was found to be 0.4 V. Once this value is known, the only other condition required to meet is that the drain to source voltage needs to remain higher than the overdrive voltage. To meet these requirements V_{DS} was chosen to be 1 V. Now that the FET is biased, the drain current can be calculated. Using Equation 4 this was found to be 64 mA. Then using Ohm's law, R_D was found to be 110 Ω and R_S was 15.625 Ω. Once the resistances are known the gain of the amplifier can be found using Equation 5. This was found to be 5.867. The same configuration was used for the common drain amplifier, and its gain was calculated to be 0.833 using Equation 6. After simulating the circuit, it was seen that R_S of the common drain amplifier needed to be larger to preserve the gain of the entire amplifier.

$$V_G = V_{CC}\frac{R_2}{R_1+R_2} \tag{2}$$

$$V_{OV} = V_{GS} - V_{th} \tag{3}$$

$$I_D = \frac{V_{OV}g_{fs}}{2} \tag{4}$$

$$A_V = \frac{-g_{fs}(R_D||R_L)}{1+g_{fs}R_S} \tag{5}$$

$$A_V = \frac{g_{fs}R_S}{1+g_{fs}R_S} \tag{6}$$

2.5 Distortion

The distortion effect will produce a gritty, distorted sound by clipping the amplitude of the signal. There are two types distortion. Hard clipping occurs by abruptly clipping the amplitude to give a harsher sound. Soft clipping gradually clips the amplitude. The effect was design for hard clipping. The distortion schematic is shown in Figure 6.

2.5.1 Design Process

The circuit is designed similar to an amplifier circuit. By biasing the transistor and amplifying the input signal, the signal will become clipped since the device's capacity is less than what is being inputted.

2.6 Octave-Up

The octave-up effect is achieved usually by using a full wave rectifier on the signal which will double the frequency of the original signal. The amplitude of the signal should be maintained. The octave-up schematic is shown in Figure 7.

2.6.1 Design Process

In order to create the full-wave rectifier, it was initially planned to use op-amps. However this circuit design required the use of two batteries in order to provide a positive and negative voltage to the op-amps. Thus, the usage of transistors to replace the op-amps were deemed more effective and space

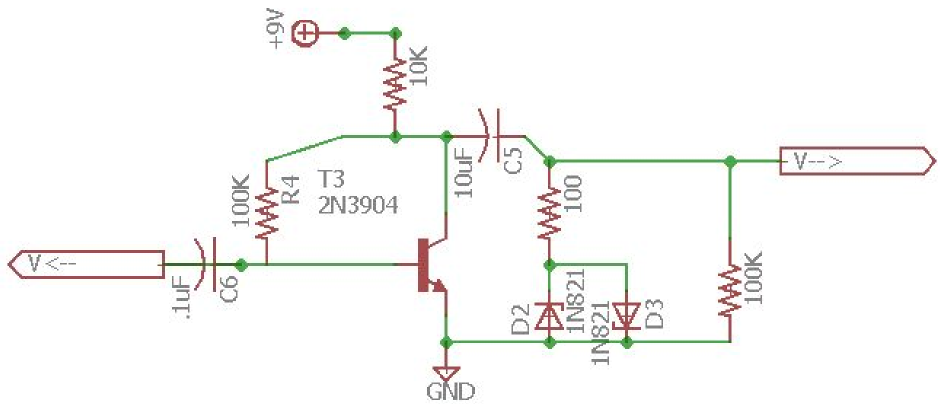

Figure 6 Shown is the schematic for the distortion effect.

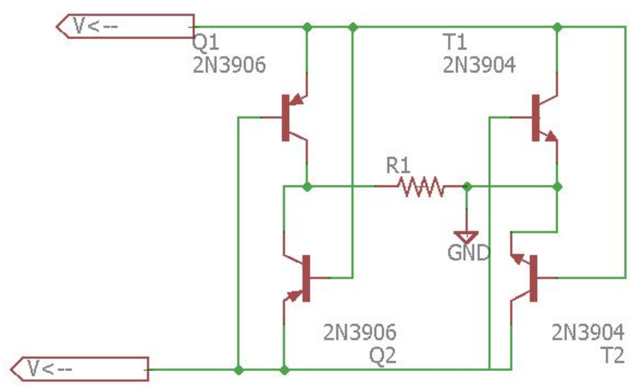

Figure 7 Shown is the schematic for the octave-up effect.

efficient. The transistors would act as switches and would produce a full wave rectification of the signal with a slight delay between amplitudes. This is due to the voltage on times for the transistors.

2.7 Octave-Down

The octave-down effect is achieved by halving the original input frequency. The octave-down schematic is shown in Figure 8.

2.7.1 Design Process

The initial design was to you an op-amp as a half-wave but similar to the octave-up, this design was changed due to the usage of two batteries. The design was experimented on by using transistors, diodes and then finally a Schottky diode.

2.8 FM Transmitter

The FM Transmitter needs to be able to transmit up to 40 feet and transmit at the desired frequency to the FM receiver. The transmitter schematic is shown in Figure 9.

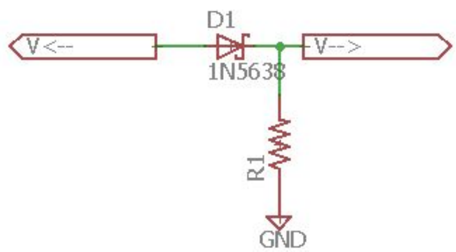

Figure 8 Shown is the schematic for the octave-down effect.

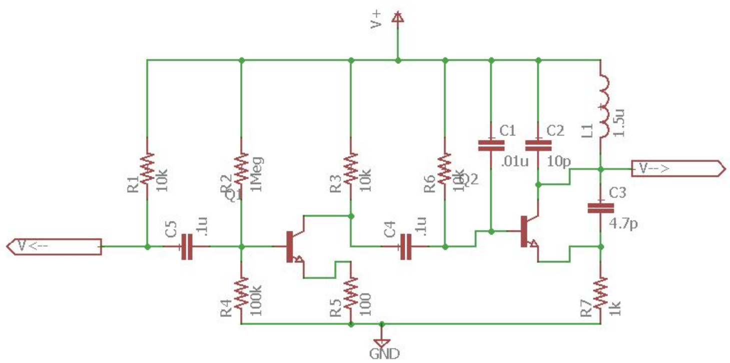

Figure 9 Shown is the schematic for the FM transmitter.

2.8.1 Design Process

The design of the Transmitter is seen in Figure 9. It is essentially an amplifier with a tank circuit. The tank circuit determines at what frequency the signal will modulate at. The LC frequency relationship is shown by the equation below. Using Equation 7, we originally set the frequency to be within an ISM band of 2.5GHz. However due to time constraints and convenience of testing we modified the circuit to output the signal at approximately 92MHz.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{7}$$

2.9 FM Receiver

The FM receiver needs to be able to be tuned into the carrier frequency of the transmitter. It will be able to detect the signal and decode it to recover the audio signal. The receiver is then plugged into an amplifier so the audio signal can be heard.

2.9.1 Design Process

Having little experience with FM technology proved to make this portion of the project extremely difficult. Because of this many different circuit topologies were researched, and we settled on a basic as shown in Figure 10[7]. We originally were trying to work within the ISM band of 2.5 GHz, as mentioned in the transmitter design. This, however, proved not to feasible due to the miniscule values of the inductors and capacitors needed to perform the modulation of the signal. The basic circuit was modified to fit the needs of our device. This meant resizing the demodulation LC tank in order to be able to be tuned into the transmitter.

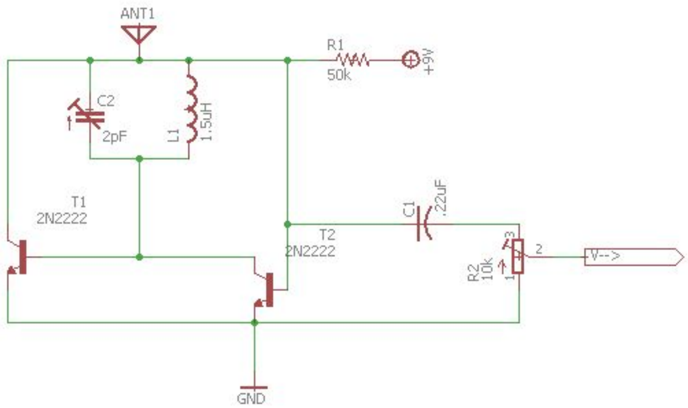

Figure 10 Shown is the schematic for the FM receiver.

3. Design Verification

Many tests were performed in order to ensure that our design met the requirements for each block. Data was taken while conducting the tests in order to verify our results.

3.1 Power

The power module is a simple yet important aspect of the product. We placed 3 requirements on this module to ensure its functionality: battery life, output voltage, and current limitation. These requirements were chosen based on the power consumption of the entire design as well as the ratings on the components used in other modules. Based on these factors the voltage regulator chosen could perform to these standards.

3.1.1 Battery Life

Battery life is key to the functionality of the project. We deemed that 2 hours of life was necessary to a successful product. This is due to the fact that when playing live a set can run anywhere from 30 minutes to about 2 hours, and it would not be ideal to have this stop working in the middle of a set.

Testing the battery life was fairly simple. We plugged all of the circuits into a standard 9 volt battery and then passed a signal through it for 2 hours. The voltage from the battery was probed every 15 minutes. We deemed that once the battery voltage dropped below 8 volts the voltage regulator would no longer output the correct value and would cause the project to not work as is intended. The results of this test can be found in Appendix B shown in Figure 11. It can be seen from the figure that the battery voltage does indeed stay above the 8 V mark for the duration of the test.

3.1.2 Output Voltage/Current Limit

The transistors in the pre-amplification module need to biased in a certain way in order for the circuit to function properly. For this reason, the output voltage of the power module needs to be within 5% of 8 volts. Due to the power ratings of the components used the current draw cannot exceed 1 amp. The only reason this high of current would be drawn would be if a short were to occur in the circuit somewhere. Otherwise, the normal current draw of the entire circuit was around 100 mA. The voltage regulator has this function built in and will not allow more than 1 A of current to be drawn through it.

Testing the output voltage of the module was again an easy task to accomplish. The voltage regulator was hooked up to a dc power supply and a range of input voltages were passed through it. The output voltage was then probed using a DMM (digital multimeter). This was done over the range of many commercial 9 V batteries. The test was conducted at higher voltages also to show that no matter the possible input, the output was still within spec. The results of this test can be found in Appendix B shown in Figure 12. Over the range of the input signals the power module would be functional. It meets the requirement at an input of 8.9 V with the output being 7.6 V. At lower input values the circuits would still function, but they would not perform at the level we designed them to.

3.2 Magnetic Pickup

The pickup is a very important part of this project. Its functionality is key to the success of the project as a whole. There 2 main requirements placed on this component: the output voltage signal must have the same frequency as the string plucked, and the amplitude of the voltage signal must be at least 50 mV when a string of 250 Hz is played.

3.2.1 Output Frequency/Voltage Amplitude

In order to test the functionality of the pickup, it was placed beneath a string and it was plucked. This signal was probed and displayed on an oscilloscope. The results of this test can be found in Appendix B shown in Figure 13. The string plucked was approximately 250 Hz, and it can be seen that the voltage has a frequency that matches this. The amplitude of the voltage hits the 50 mV mark at the beginning of the data collection and then dies off as time goes on which is to be expected.

3.2.3 Problems

While we were testing the first prototype of the pickup, an internal winding wire was severed causing an open circuit in the pickup. This proved impossible to repair and a new pickup had to be wound. The second pickup did not perform to the standards that we wanted it to. This is in part because we ran out of wire and were thus limited to the amount of turns we were able to put on it. This greatly affected the output of this module, and the signal was not able to be interpreted by the pre-amplification module during integration testing. Despite the issue with the second pickup, the other modules were able to be integrated and tested using a signal generator to provide the input signal.

3.3 Pre-Amplification

The pre-amplification module increases the amplitude of the signal coming from the pickup so that it can be manipulated in the effects module. There were 2 requirements placed on this block: the overall gain had to be greater than 5, and the output had to be in phase with the input.

3.3.1 Gain/Phase

In order to be able to determine if the pre-amplification stage met requirements, a small ac signal was provided to the input of the amplifier. This signal was also probed and displayed on an oscilloscope. The output voltage signal was also probed and displayed on an oscilloscope. The results of this test can be found in Appendix B shown in Figure 13. It can be seen that the overall gain is about 11. This passes the requirement. It can also be seen that the output is in phase with the input by studying the waveforms and seeing that the peaks and valleys of the signal occur at the same instance in time.

3.4 Distortion

The distortion effect should maintain the original frequency with hard clipping. To verify these requirements the signal was passed through the effect and the output was displayed on an oscilloscope. The results of this test can be found in Appendix B shown in Figure 14. The hard clipping is characterized by the large flat regions of the signal. It can also be seen that the original frequency of the input signal is retained.

3.5 Octave-Up

The octave-up effect had the requirements that the amplitude of the signal should be maintained while also doubling the frequency of the signal.

3.5.1 Frequency/Amplitude

A test was conducted in order to verify the requirements set on this effect. Due a grounding issue the input ground had to be isolated from the output signal. The input was passed into the effect and the output was probed on an oscilloscope. Cursors were used to measure the time difference between the peaks of the signal. This allowed for the frequency to be calculated and it is shown that it did indeed double. These results are summarized in Appendix B shown in Figure 15.

A feature of this type of full-wave rectifier is that the only voltage drop seen across the transistors is the drop across the on resistance. This resistance is on the order of milliohms so the voltage drop is small compared to that of a diode. The amplitude of the signal is greater retained for higher input voltage amplitudes. During our tests about 60% of the input amplitude was retained. Had the input amplitude been larger, a greater percentage of the signal would have been retained.

3.6 Octave-Down

The octave-down effect also was required to maintain the amplitude of the signal and the frequency of the output signal should be half of the input signal. The effect would be similar to a half-wave rectifier. The requirements for this effect were not fulfilled due to its design flaw. However, the results of our tests can be found in Appendix B shown in Figure 16.

3.6.1 Problems

The approach for the octave-down was similar to the octave-up which led to the downfall of this effect. By implementing the half-wave rectifier using a schottky-diode, the signal was rectified however the frequency of the signal was not halved. The logic of halving the frequency was flawed here. In order to output half the frequency, more needs to be done since frequency is measured by peak to peak. Using a half-wave rectifier will keep the same amplitudes and thus keep the same frequency.

3.7 FM Transmitter

The transmitter was required to modulate the signal onto a carrier wave with a frequency of 90.0MHz +/- 5% and should be able to transmit within a 40 foot radius.

3.7.1 Problems

The transmitter was designed with the tank circuit to output at around 92.3MHz. After probing the signal using a radio, the signal was heard clearest at 89.3 MHz. Testing was also done on the distance the transmitter was able to reach. It was approximately 2 ft. In order to reach 40 ft, the transmitter would need more power or a change in the antenna. Possible changes could be increasing the length of the antenna or using an impedance matched antenna.

3.8 FM Receiver

The receiver was meant to tie the project together. Its job was to detect and decode the signal coming from the transmitter. This did not happen as expected and this module was not functional.

3.8.1 Problems

There were many factors that contributed this module not functioning correctly. The first was time and inexperience. The way we approached the design of the project was a linear method. This means that we started at the beginning and worked our way to the end of the signal path. With our inexperience in FM technology, it caused us to run out of time testing the wireless communication circuits. We also had major problems trying to tune into the transmitter. We believe this is due to the trimmer capacitor not being very reliable. When adjusting the capacitor the modulation signal was not noticeably changing.

These problems could be fixed by finding finding a higher quality trimmer capacitor. This would ideally have a wide range of capacitance values so the modulation frequency could more accurately tuned. Another possibility is to use a microcontroller to perform the modulation. This would allow for much greater accuracy when trying to tune into the signal from the transmitter.

4. Costs

4.1 Parts

Table 1 Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Neodymium Rod Magnets	Magcraft	.30	2.00	2.00
44 AWG Magnet Wire	Remington	3.00	3.00	3.00
SPDT ON/ON 6AMP TOGGLE	Alcoswitch	6.80	6.80	6.80
SPST 4-Position Dip Switch	Grayhill	1.71	1.71	1.71
NTE964 Positive Voltage Regulator 8V	NTE	1.60	1.60	1.60
2N3947 NPN Bipolar	Central Semiconductor Corp.	.02	.08	.08
2N3906 PNP Bipolar	ON Semiconductor	.43	.86	.86
9 Volt Battery	Energizer	1.70	1.70	1.70
Resistors		.10	2.60	2.60
Capacitors		.10	1.20	1.20
Diodes		.25	.75	.75
2N7002 N-Channel MOSFET	Fairchild	.43	1.28	1.28
Inductors		.40	.80	.80
PCB	PCBWay	.50	1.00	1.00
Total				**25.38**

4.2 Labor

Table 2 Labor Costs

Name	Hours Invested	Hourly Rate	Total
Dylan Ouart	100	$30	$7,500
Wilson Ngai	100	$30	$7,500
Machine Shop	5	$20	$100
Combined	205	N/A	$15,100

4.3 Grand Total

Table 3 Total Costs

	Cost
Parts	$25.38
Labor	$15,100
Grand Total	$15,125.38

5. Conclusion

Even though we were unable to fully integrate a functional product, we still view this project as a success. It was very interesting to gain an in depth look at how a signal is sensed from a guitar by using various types of pickups. We also saw how this signal can be manipulated to apply effects to it and replicating these effects.

5.1 Accomplishments

There were a few accomplishments that we are very proud of. We are happy that our first prototype of the homemade pickup actually worked before it was broken during testing. We were able to produce 2 out of our 3 effects. Had there been an actual guitar signal we believe the distortion sound would have been more prevalent than just using the signal generator as an audio source. Also having little to no experience with FM, we were happy to get a signal transmitting to an empty radio station.

5.2 Uncertainties

We did not find an effective way to debug our FM Receiver. This we believe would have been much easier had the transmitter been transmitting correctly sooner. We think this comes down to a lack of time and starting to debug this circuit at too late of a date.

5.3 Ethical considerations

There are a few potential safety hazards that can occur in use with our project. If the pickup shorts there is a possibility of burning the circuits and with the battery in the pickup it may explode. Using a PCB in an enclosure will prevent the chances of a short happening. The 9-Volt battery could also become a hazard since the two positive and negative points are on the same side which means if they become shorted it could spark and cause a fire within the circuit and burn the guitar (and your hand). Using a 9 volt battery connector will prevent a short from happening. We will provide a casing for this battery to also prevent any chance of something piercing the battery. Using an abs enclosure which has a glass transition temperature of 221 degrees F. All safety concerns must be disclosed to the end user. We will address these safety concerns in accordance with 1 of the IEEE code of ethics which states "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment"[8].

There is also the risk of our product to emit radio waves that are not under ISM. ISM stands for industrial, scientific and medical radio band. These frequencies are allocated for testing products while nearby frequencies are reserved for other specific uses. Using those reserved frequencies are considered illegal without proper licenses. We initially designed to transmit in one of the ISM bands for these reasons. Due to problems encountered, we modified our transmitter so it would be able to transmit to an empty radio station. Moving forward and once the circuits were effectively debugged, the carrier frequency could then be changed back to conform to these standards.

The dangers associated with the device should be relatively small. All necessary measures will be taken to ensure that injury will not occur when somebody is using the product. This aligns with 9 of the IEEE code of ethics which says "to avoid injuring others, their property,..." [8]. The location of the pickup puts it in close proximity with the person who is playing the guitar, so extra precautions will be taken to ensure the safety of the user.

Designing a magnetic pickup from the ground up proved difficult. The differences in signals it will output could vary greatly from those of a professionally designed pickup. It would have been all too easy to fake a nice signal coming from the pickup. This would not have been the ethical thing to do as our pickup was not fully functional. This follows 3 and 7 of the IEEE code of ethics [8]. All data taken will be the real data no matter how noisy or bad it may be, if this problem occurs.

5.4 Future work

Moving forward we hope to continue research and development of this project in order to complete a fully functional device. This would require a few design modifications however.

5.4.1 Pickup

A couple of methods to improve the design of the pickup were explored. By using stronger magnets, the magnetic field would be stronger. This would increase the sensitivity of it allowing for greater response when the guitar is played. Moving the pickup as close as possible to strings would also greatly increase the output. The main issue we ran into was there were not enough windings on our pickup. Creating a new pickup with a sufficient amount of windings would help to allow the guitar signal to propagate throughout the entire device.

5.4.2 Effects

There were a couple of design flaws in our effects module. The first issue we discovered was a grounding problem. The octave-up effect utilizes a full-wave rectifier. If the output ground is shorted to the input signal ground the effect becomes a half-wave rectifier. The output is no longer the desired effect. To combat this issue a 1:1 transformer could be implemented at the beginning of the effects module to isolate the input ground from the output ground.

The octave-down design itself was flawed. It did not actually cut the frequency in half as hoped. By using comparators, D flip-flop, and a switching device, the effect would be more efficient. Passing the input signal to the comparator will change the signal from analog to digital. The signal will be then passed into the flip-flop with a feedback in order to create essentially a clock that will be half the frequency of the original signal. By using a transistor acting as a switch that only turns on when the clock signal is high, this will effectively halve the input signal.

There was also a backtracking observed at the output signal. This affected the output signal in a way that it was not as clean as desired. We believe the output was propagating backwards through the effects and this was adding to the output. Fixing this problem could be as simple as moving the selector switch to the output of the effects instead of the input. This would prevent any one output from being able to travel back into the other effects.

5.4.3 Wireless Communication

There were issues with the distance that our transmitter was able to transmit data. More power could be supplied to the transmitter, and this would boost the signal. An impedance matched antenna would also help to reduce the amount of the signal being reflected back into the circuit. This would maximize the power being transmitted through the air.

There was a major issue when trying to tune the receiver to the transmitter. We believe this was due to our trimmer capacitor. Getting a higher quality capacitor could help to solve this. The demodulation portion of the receiver could also be implemented using a microcontroller. This would allow for greater accuracy when trying to tune into the signal also.

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Appendix A Requirement and Verification Table

Table 4 Pickup Requirements and Verifications

Requirements	Verifications
1. Must be able to output a voltage signal with the same frequency of the note on the string being played 2. Voltage output must be 50 mV or greater at 250 Hz. (per calculation for pickup)	1. Place the pickup under a string Using a tuner measure the frequency of the string to be plucked Pluck the string and probe the output voltage of the pickup Display this voltage on the oscilloscope and measure the frequency of the signal 2. Probe the output voltage of the pickup when a string is plucked Measure the amplitude of this voltage to check if 50mV or greater

Table 5 Power Requirements and Verifications

Requirements	Verifications
1. Must be able to power the system at full load for 2 hours 2. Output must stay at 8 V +/- 5% 3. Must not allow current to to be greater than 1A. (per power ratings for components in other modules.	1. Power up the system and send a signal through it for 2 hours 2. Probe the output voltage of the power module and check the deviation from 8 V 3. Set voltage to rated voltage. Attach the circuit to load the power Supply. Probe the current to make sure it does not exceed 1 A.

Table 6 Pre-Amplification Requirements and Verifications

Requirements	Verifications
1. Must have an overall gain of 5 or greater 2. Output voltage must be in phase with the input voltage	1. Probe the input test voltage of 100mV and display on the oscilloscope Probe the output voltage and display the ac coupled signal on the oscilloscope Measure the amplitudes of input and output voltage then check the output amplitude is at least 5 times greater than the input voltage 2. Probe the input and output voltage as in step 1 Measure the phase difference between the two waves

Table 7 Distortion Requirements and Verifications

Requirements	Verifications
1. Ouput distorted signal should maintain original frequency 2. Signal should “hard clipped” 3. Audio output should sound gritty and distorted	1. Measure the output frequency using an oscilloscope 2. Observing the amplitude of the output signal should show an abrupt flattening which is consistent throughout (not gradual) 3. Play guitar and listen for distortion

Table 8 Octave-Up Requirements and Verifications

Requirements	Verifications
1. Output "humps" of the rectified waveform should have the same peak value within 10%. 2. Output waveform should have a frequency that is double that of the input frequency	1. Probe the output signal of the effect on the oscilloscope. Use cursors to measure the voltage difference between the original positive hump and the rectified negative hump to ensure equal peak value. 2. Observe voltage waveform on an oscilloscope and use cursors to measure the time between peaks of the signal.

Table 9 Octave-Down Requirements and Verifications

Requirements	Verifications
1. Output amplitude must be the same amplitude as input signal 2. Output frequency should be half the input frequency	1. Probe the input signal and output of the effect Compare the input voltages and output voltages using an oscilloscope 2. Probe the input and output signal and measure the frequency. Compare.

Table 10 FM Transmitter Requirements and Verifications

Requirements	Verifications
1. Modulate signal onto a carrier wave with a frequency of 90.0 MHz +/- 5%. 2. Signal should be able to be transmit data within a 40 foot radius.	1. Apply power to the transmitter terminals. Probe the signal using an oscilloscope across the modulation LC tank Measure the frequency of the oscillating signal. 2. Tune an FM radio to the frequency of the carrier wave. Check that the output audio signal is able to be heard by placing the radio close to the transmitter. Move the radio further away from the transmitter up to a distance of 40 feet to check that the transmitter is capable of transmitting that distance.

Table 11 FM Receiver Requirements and Verifications

Requirements	Verifications
1. Demodulation frequency should be 90.0 MHz +/- 5%. 2. Output signal should match the input signal of the transmitter. 3. Output signal amplitude should have an amplitude of at least .5 V.	1. Apply power to the receiver circuit. Probe the signal using the oscilloscope Across the demodulation LC tank. Measure the frequency of this signal. 2. Probe the output signal of the receiver using an oscilloscope and compare this signal to the signal entering the transmitter. 3. Probe the output signal using an oscilloscope. Measure the amplitude of the signal.

Appendix B Verifications Results and Waveforms

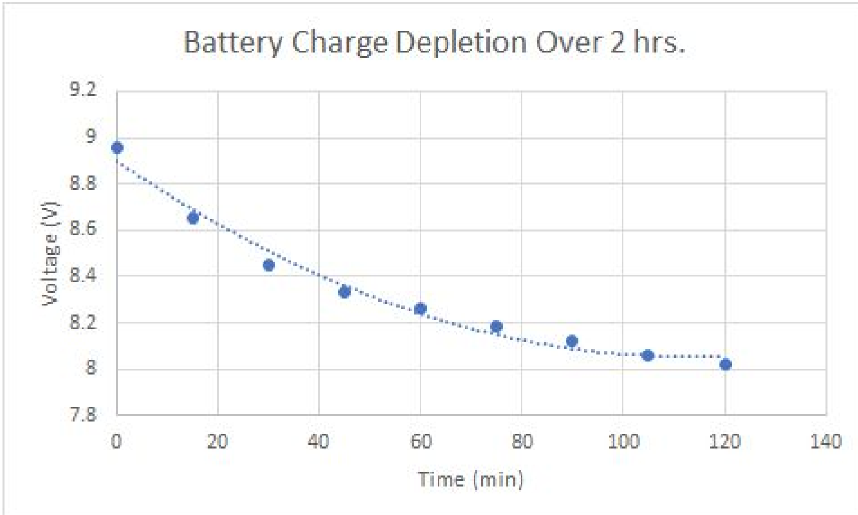

Figure 11 Shown is the data taken for the battery life test. It can be seen that the requirement was met because there was still 8 Volts left in the battery.

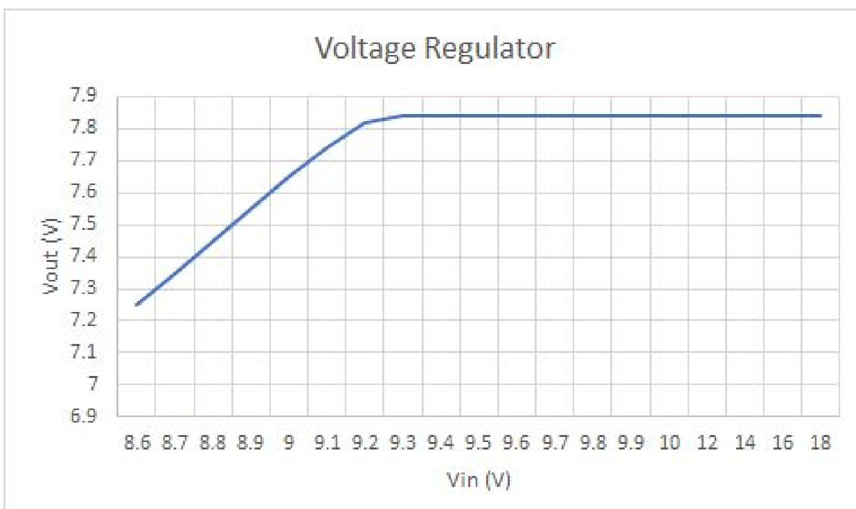

Figure 12 Shown is the data taken for the output voltage of the voltage regulator. It can be seen that the requirement was met for the majority of the range of voltages of commercially available 9 V batteries.

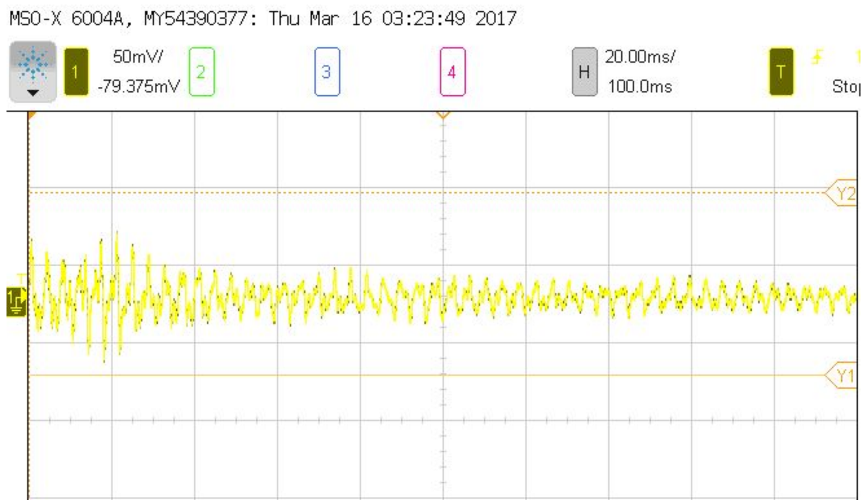

Figure 13 Waveform of the pickup test. The scale can be seen at the top of the capture. The amplitude requirement is met when the string is initially plucked and dies off as time goes on.

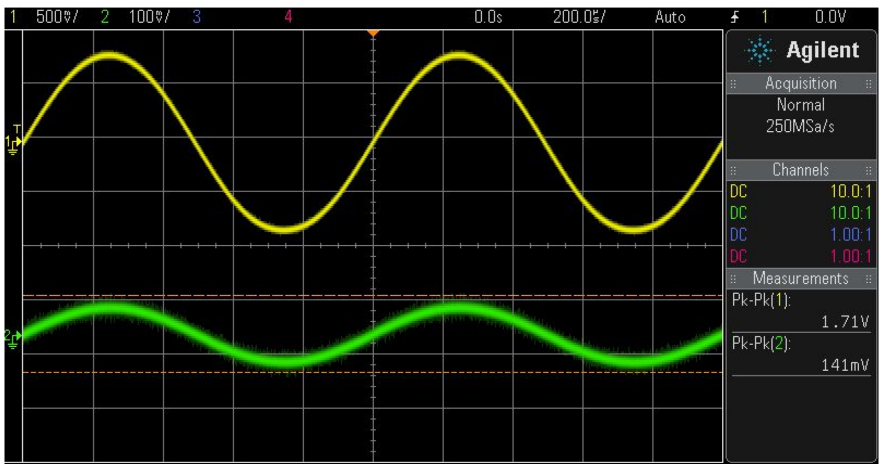

Figure 14 The results of the pre-amplification test are shown above. The input wave is shown in green and has an amplitude of 141 mV. The output is shown in yellow and has an amplitude of 1.71 V. The gain requirement is met and is on the order of 11. The waves are also in phase, and this can be seen because the peaks and valleys are in the same position.

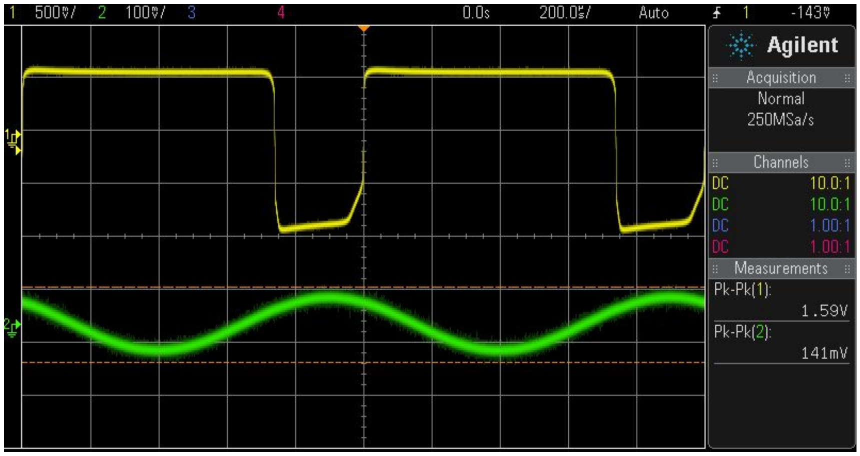

Figure 15 The test results for the distortion effect are shown above. The hard clipping is observed on the output wave, shown in yellow, by the large flat regions on the top of the wave. The input to pre-amplification is shown in green. The original frequency is retained.

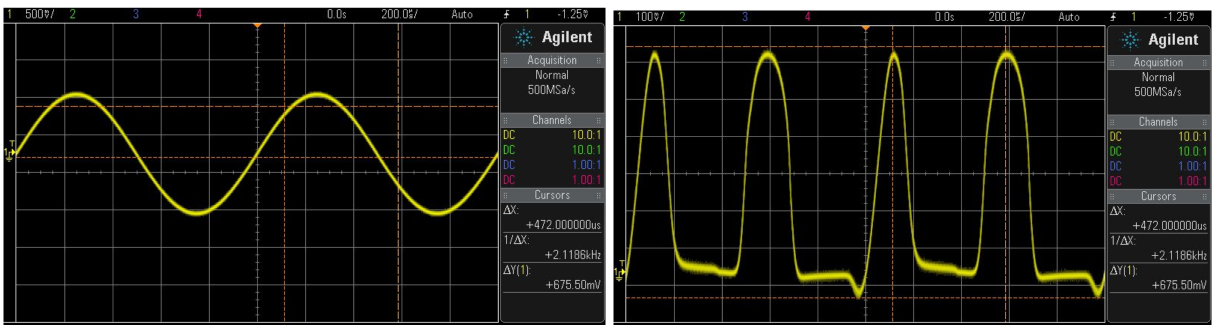

Figure 16 The octave-up test results are shown above. The input wave is shown on the left and the output is shown on the right. Due the grounding issue they could not be shown on the same screen. The frequency in the output is double that of the input.

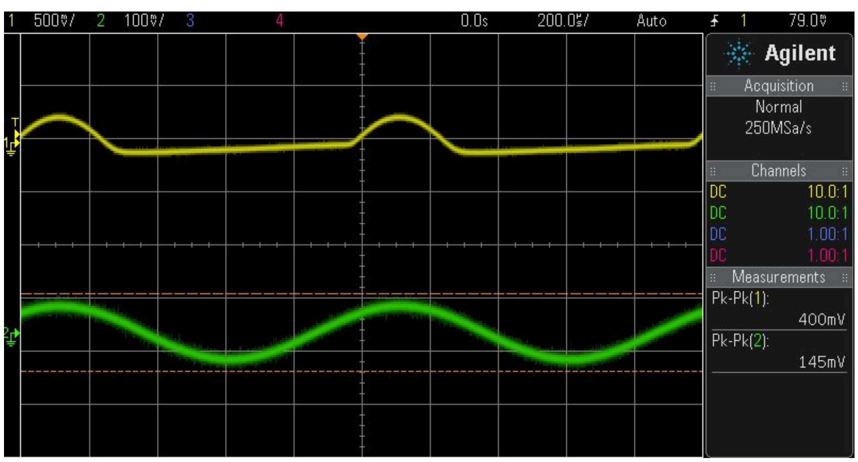

Figure 17 The results of the octave-down test are shown above. The results did not meet the requirements because the frequency was not cut in half.

Appendix C Actual Circuit Photos

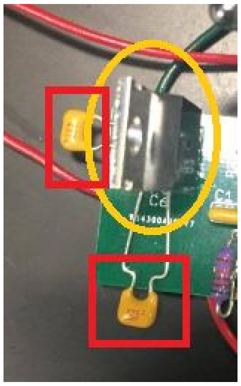

Figure 18 Shown is the power module. The voltage regulator is circled in orange and the filtering capacitors are boxed in red.

Figure 19 Shown is the pcb circuit of the pre-amplification module.

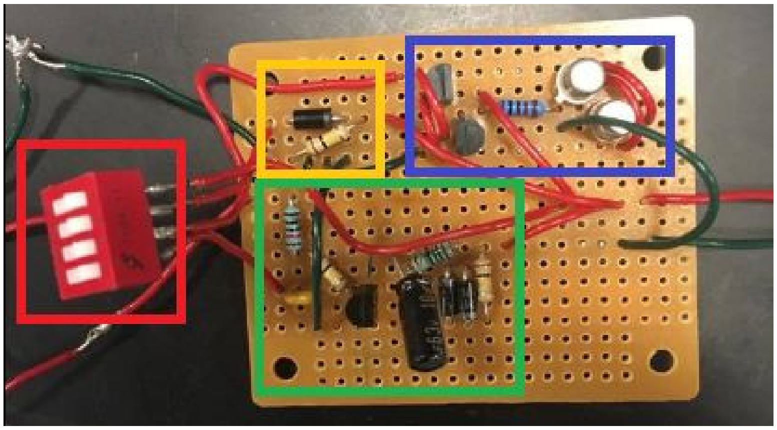

Figure 20 Shown is the perfboard of the effects module. The selection switch is boxed in red, distortion is boxed in green, octave-down is boxed in orange, and octave-up is boxed in blue.

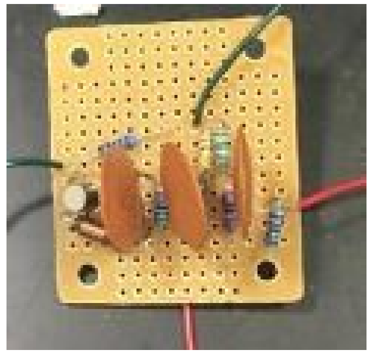

Figure 21 Shown is the perfboard circuit of the FM Transmitter.

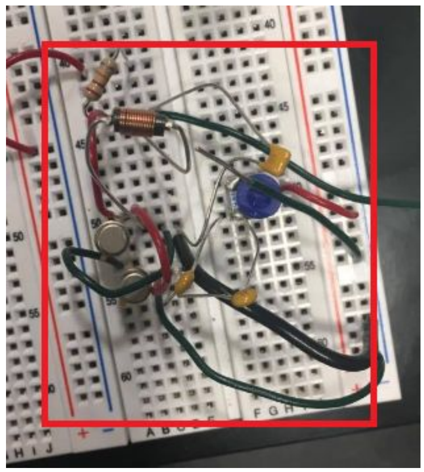

Figure 22 Shown boxed in red is the prototype circuit for the FM receiver.