

Electrifying an Acoustical Guitar



Cody Jones

Final Project Report

Physics 406

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Introduction:

While attempting to find a suitable project for the class, I came upon the idea of an electric guitar. I didn't have one to modify, or the money to buy one to work one. I had heard about acoustical guitars being able to be plugged into an amp, however, I had never heard one actually played. This prompted me to attempt it and see how the electrical frequencies produced compare to the acoustical sounds generated. I had no experience in running measurements, how to go about electrifying an acoustical guitar, the different methods available, or anything else that would be needed to allow me to play my guitar in any amp. As it turned out, this project allowed me to learn more than I thought I would and I feel it has taught me valuable knowledge beyond just the acoustical properties and a desire to continue on building, such as constructing a tube amp or an electric guitar from scratch.

Procedure:

The first thing I bought was the actual guitar I was going to modify. After looking through several stores and pawnshops, I settled upon an Epiphone PR-100. On initial observations, it seemed to produce a rich sound and had a decent feel while playing it.

The next question was how to modify it so that it would produce a signal allowing me to play through an amp. After searching for different methods, I found 3 different methods that would allow me to produce an electrical signal: a soundhole pickup, a condenser microphone, and a piezo transducer.



Sound Hole pickup



Condenser Microphone



Piezo Transducer

With each a signal was produced, but each had different properties and different methods allowing them to translate the signals from a mechanical vibration to an electrical signal. After speaking with Professor Errede and discussing the properties of each and the best suitable for my specific guitar, the decision was made to use the piezo transducer.

A piezo transducer is a crystalline structure that when placed under stress, an electrical signal is generated, thereby allowing it to be used to generate a signal. While piezos are used for musical instruments, the specific model I chose was the Fishman PRO-AG1-125. It is an undersaddle pickup which allows it to pick up the most from the strings of the guitar.

After replacing the strings with new strings made from Martin & Company this allowed me to measure and see how the saddle bridge would have to be modified. After observing that it was a molded plastic, the decision was made to replace it with new material that would not only be able to transfer the mechanical energy generated by the strings better, but would also make the guitar sound a little better overall. The material used for the new saddle bridge is called Tusq made by Graph Tech. The specific saddle bridge needed for my guitar required a fully compensated piece. The measurements for my guitar's saddle bridge were larger than any of the pieces available to purchase premade, so the only course of action I could take was to buy a blank saddle and modify it personally for two weeks on it, with measuring, marking, measuring again, and trimming in small increments allowing me to correctly size the blank unique to my guitar.



The sized saddle bridge installed and strings under tension

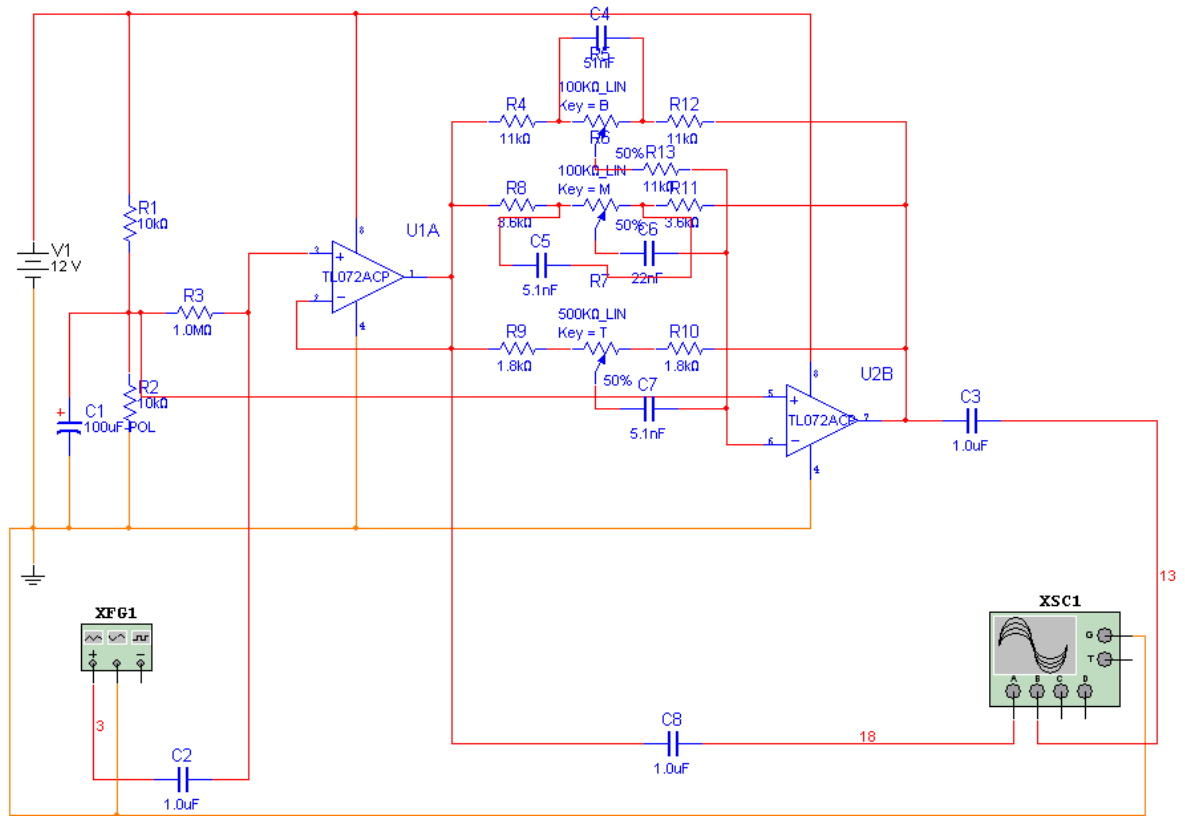
Once the saddle bridge was properly sized, the guitar itself began to undergo its transformation. The first was the hole at the bottom to accommodate the jack that would send the signal to the amp. This required careful drilling so as to not split the external wood or damage any internal supports.



The Endpin Jack installed with no tear out

A hole also had to be drilled to accommodate the wire from the piezo itself. This required me to measure and center the piezo itself to be directly under the strings to allow the maximum absorption. After centered and the hole drilled it turned out the saddle itself was slightly misshapen which prevented the piezo to be properly fitted within. After much filing and fitting, the piezo was carefully placed at the bottom and the new saddle bridge was placed on top of the piezo. The wires from the piezo were connected to the output jack and left outside to test. After the strings were connected and tightened to their correct tension, Professor Errede's preamp was used to see how well the sounds were generated. The sounds produced were beyond anyone's expectation. The piezo produced a clear and rich sound; nothing was damaged during construction which was my worst fear. The final part of construction required me to build a preamp. The piezo produces a high impedance signal which meant the signal itself would not be sent to the amp efficiently, and if the cord is long enough, not at all. It was observed that the sounds produced by the amp were "bright" when the preamp was placed in bypass mode. The bright sounds meant only the higher overtones were being received more than the fundamentals were. The preamp takes the signal and runs it through an op-amp thereby allowing you to either invert it for a gain in voltage

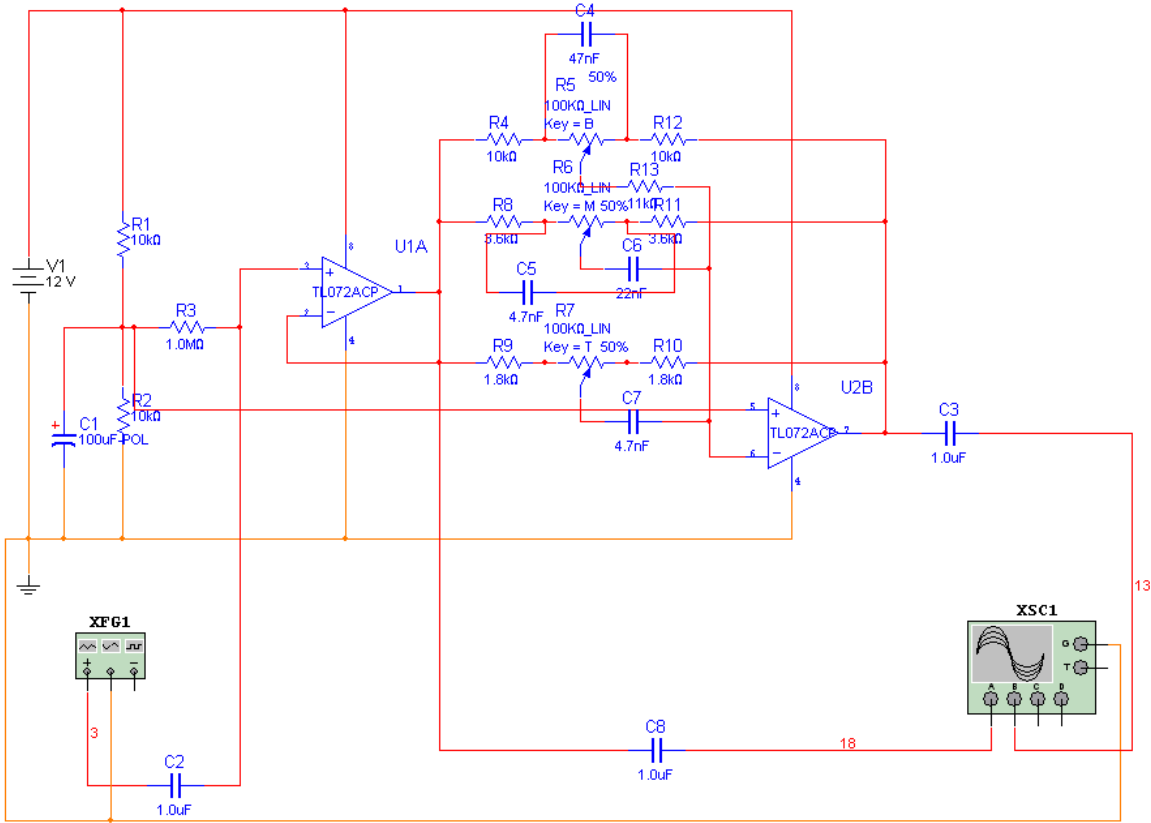
or a non-inverting which is the method I used with mine. The benefits to using a non-inverting op-amp allowed my signal to have a unity gain of 1 and using a modified circuit diagram, I was able to incorporate a 3-band equalizer. The chosen op-amp was the Burr-Brown OPA2134 due to its audio quality and its dual op-amps within one chip. The circuit diagram was drawn into the computer and simulations were run to see the expected results.



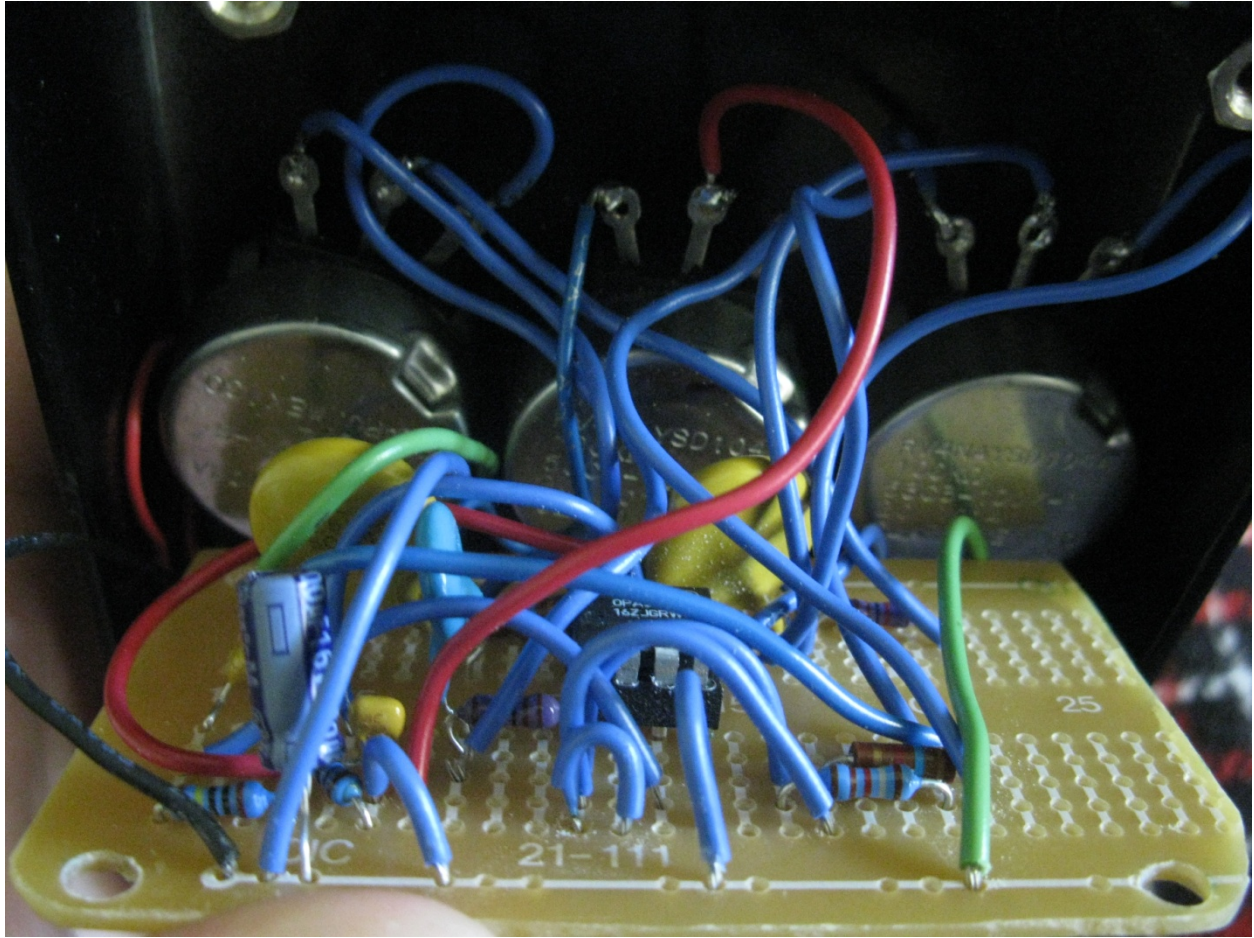
The chosen preamp circuit design with 3 Band Equalizer

My experience constructing electronic circuits was non-existing, however with practice and a little help from both Darby Hewitt and Tom Houlahan I was able to understand how a circuit works physically and how to troubleshoot. The original plans required a 500K Ohm potentiometer, however, after construction the 500K potentiometer was flawed from construction

and was replaced with a 100K potentiometer. The change in resistance also changed the amount of gain for its specific frequencies and cut for the signal within that potentiometer's range. The circuit design was modified to accommodate the change and new simulations ran.

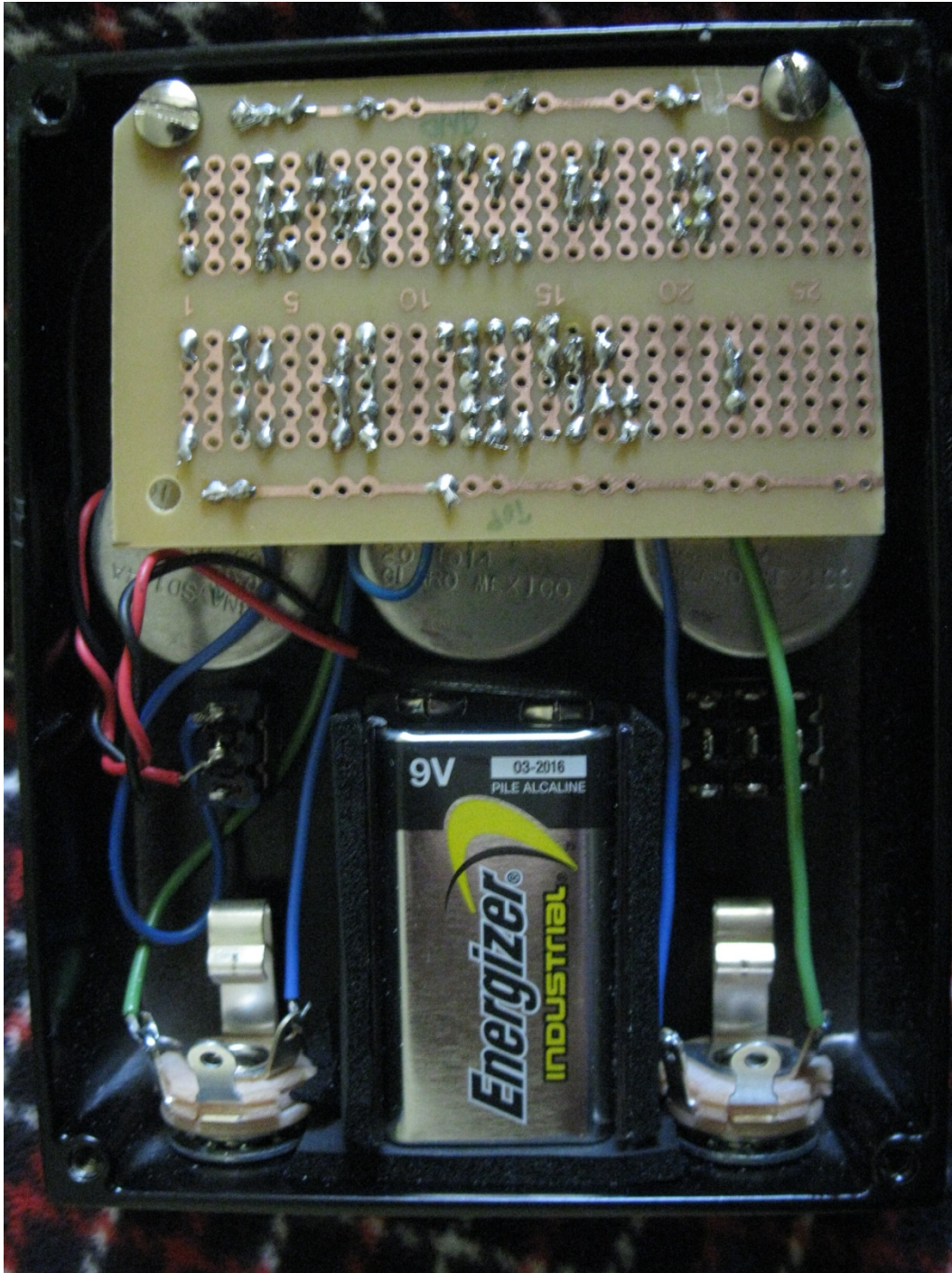


The Modified Circuit Simulated



The completed circuit and installed within the aluminum box

The construction was only half the headaches. After the circuit board was finished, the box layout had to be designed. The potentiometers, the switches, the battery, the circuit board itself, and all the other hardware to hold everything in place had to be designed, modified, and machined to allow them all to fit within the space allotted for them.

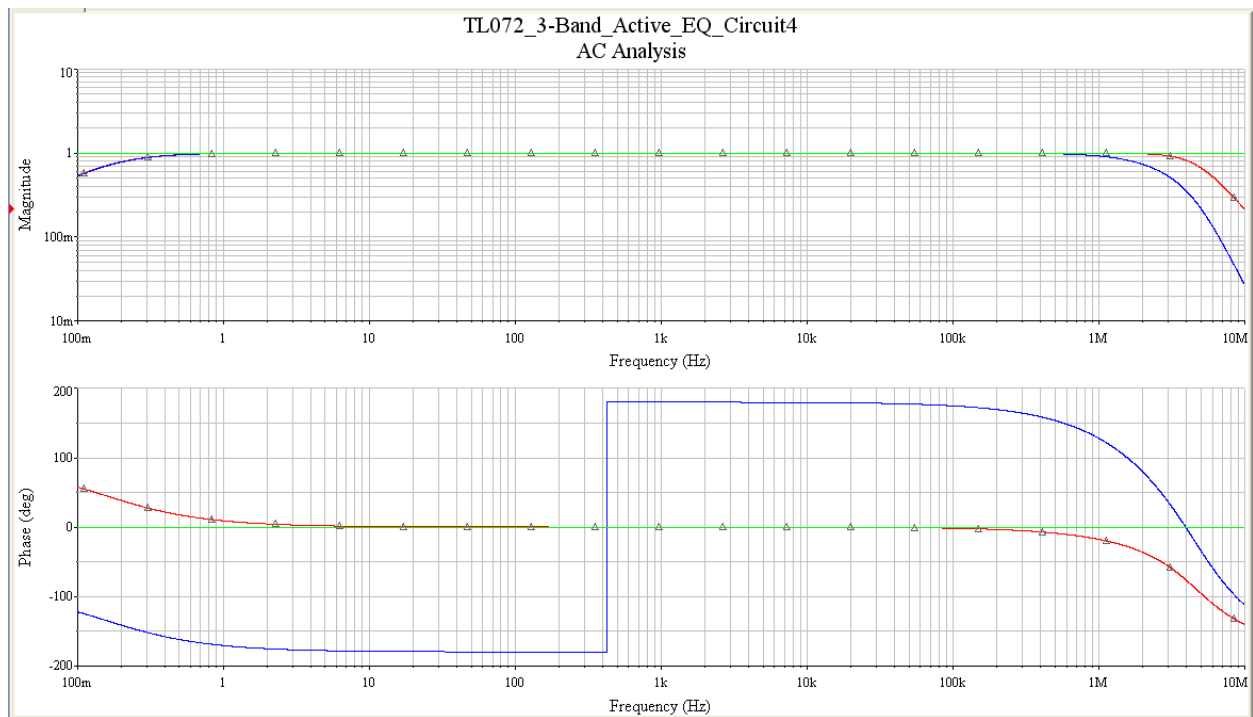


The Completed Preamp 3 Band EQ Box

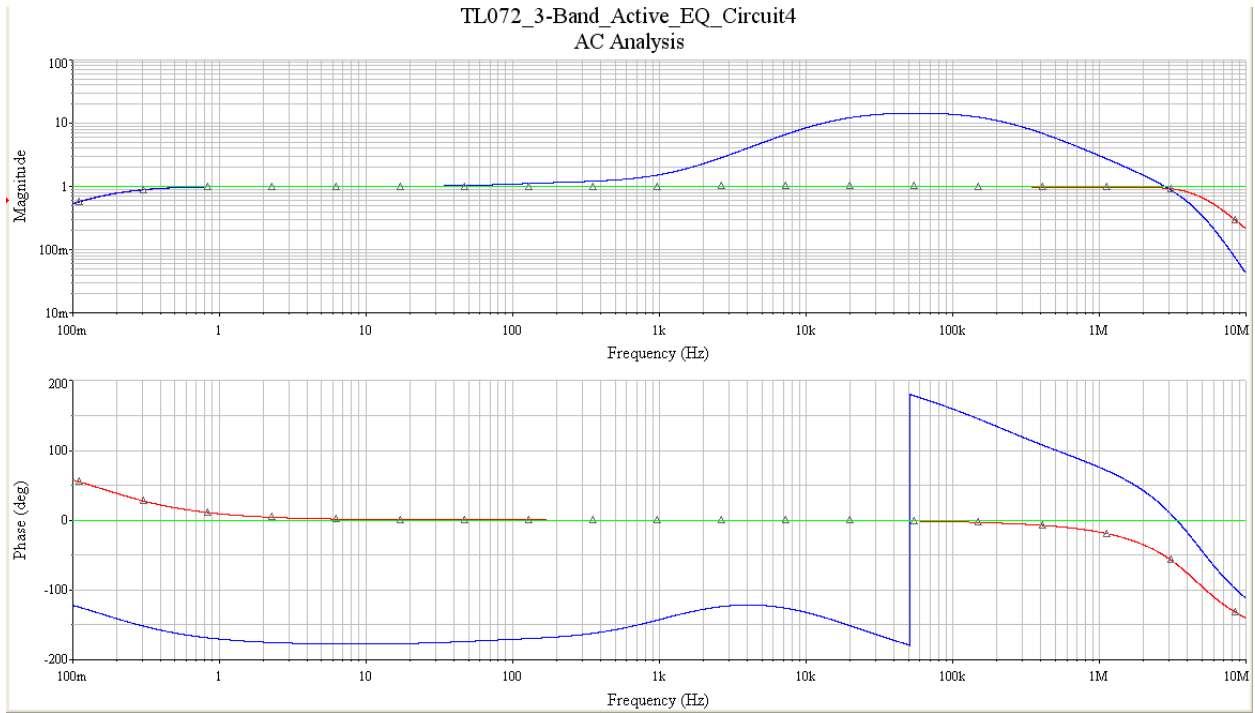
The new potentiometer was installed and placed within a solid aluminum box which help prevent other signals, most notably the 60Hz frequencies produced from the lighting, and a white noise signal was sent

through the circuit. A base line was formed with all potentiometers set at flat. Then one was turned cut fully, measured, then boosted fully and measured again. The procedure was repeated for each potentiometer and graphed to see how it compared with the simulated diagram.

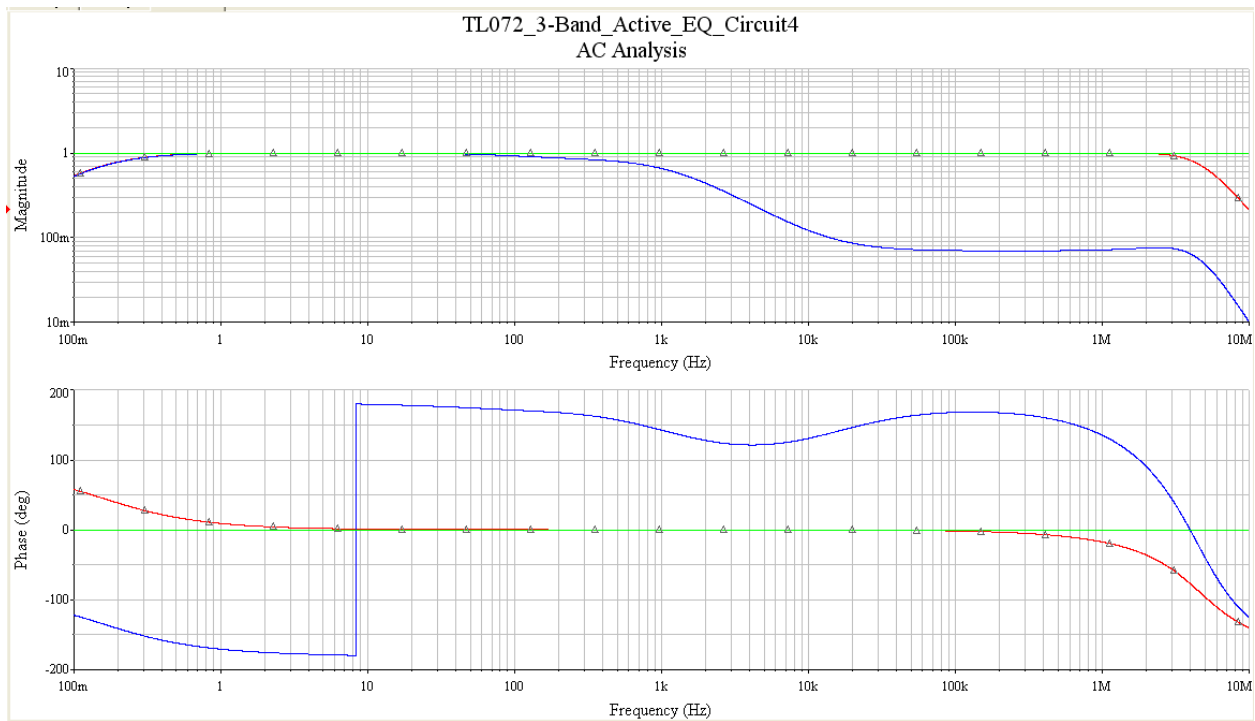
Graphs and Interpretations:



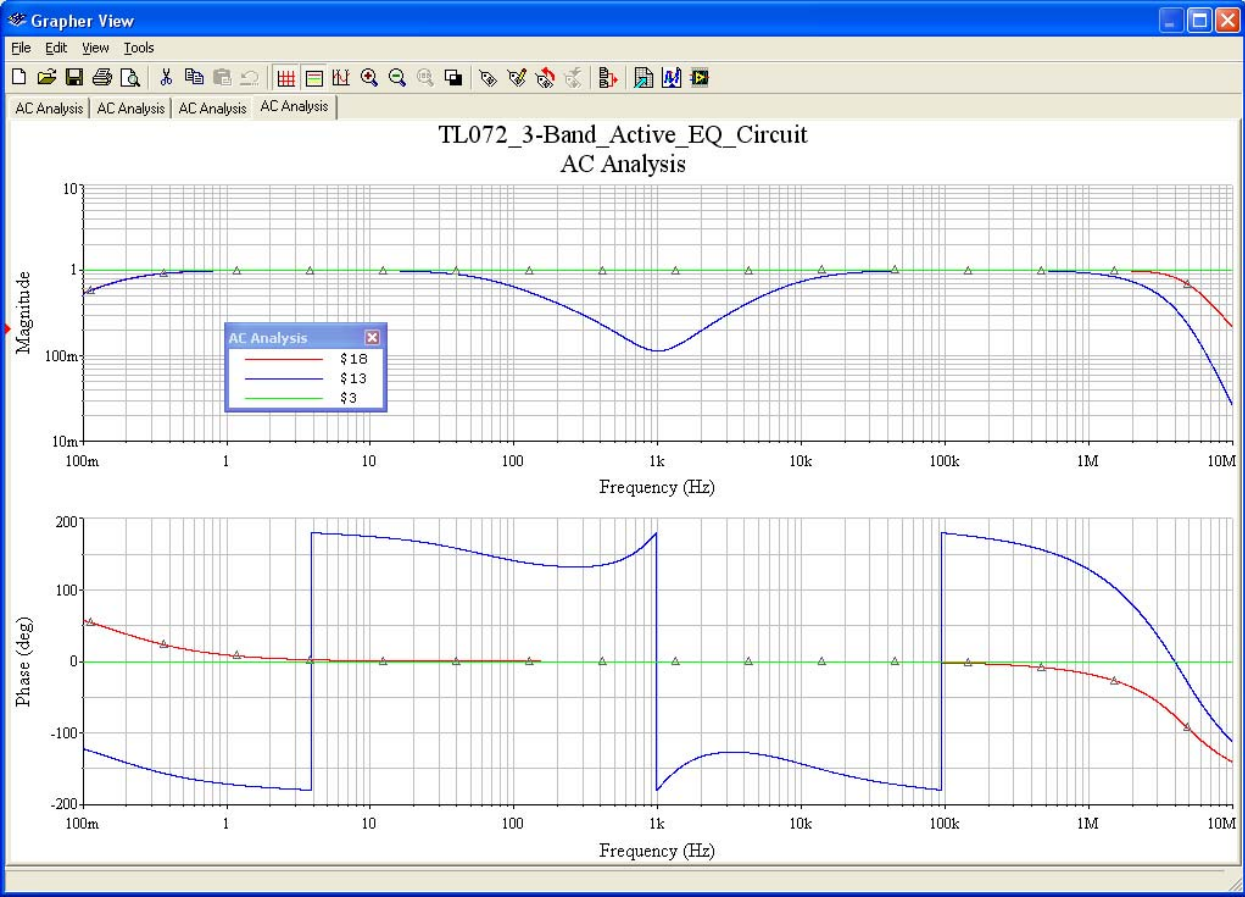
The circuit design was simulated through the computer and was measured for different frequency responses. The graphs are in a log vs log due to the fact that we hear sounds on a logarithmic scale, so therefore the frequencies would be difficult to measure and interpret on a normal linear graph. This first graph is just a sine wave being run through the circuit for a base line. The upper portion is the magnitude of the signal coming out of the circuit measured while the lower is the phase shift of the signal compared to the wave generated.



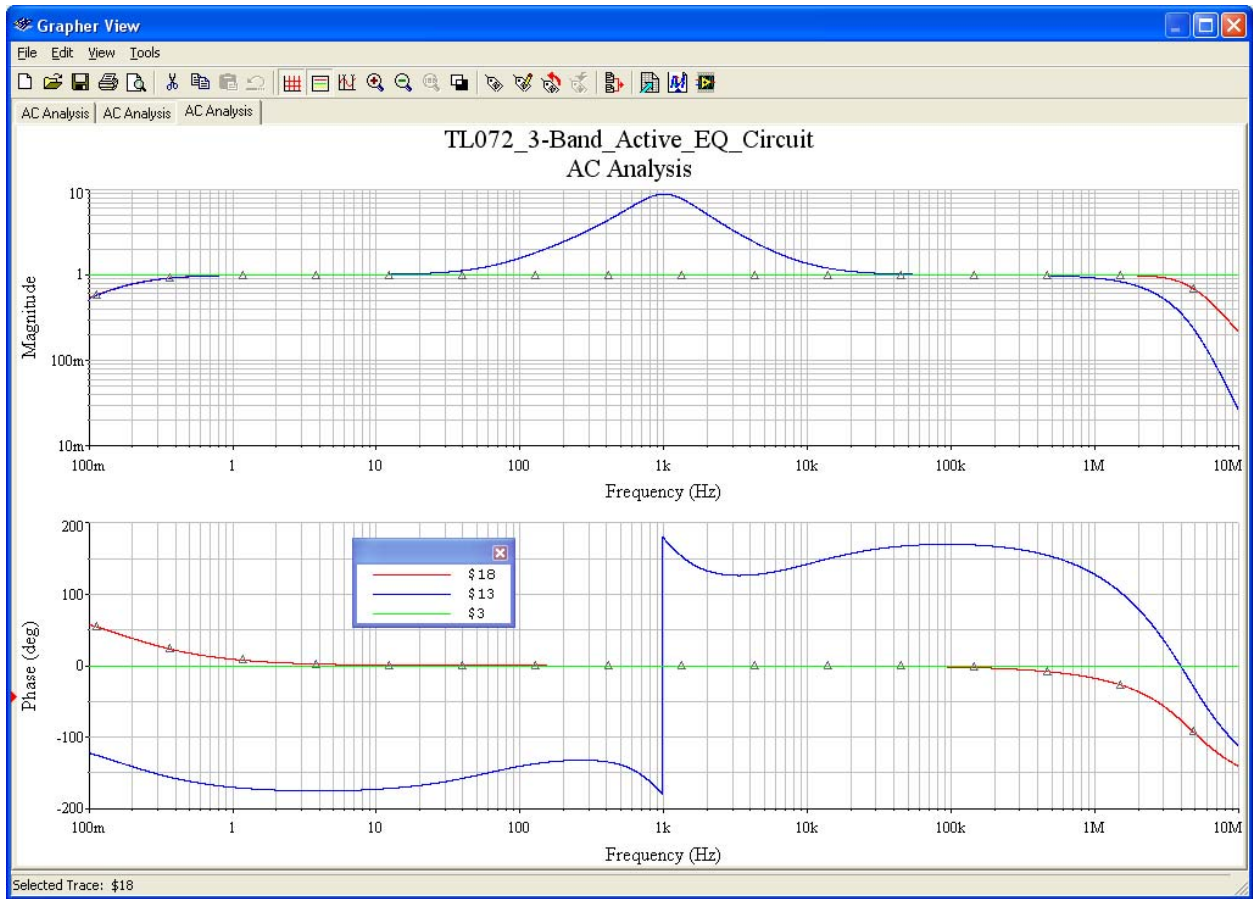
When a base line was obtained, we dialed the treble potentiometer for full boost and measured its frequency response. This graph shows the response with the 100K Ohm potentiometer.



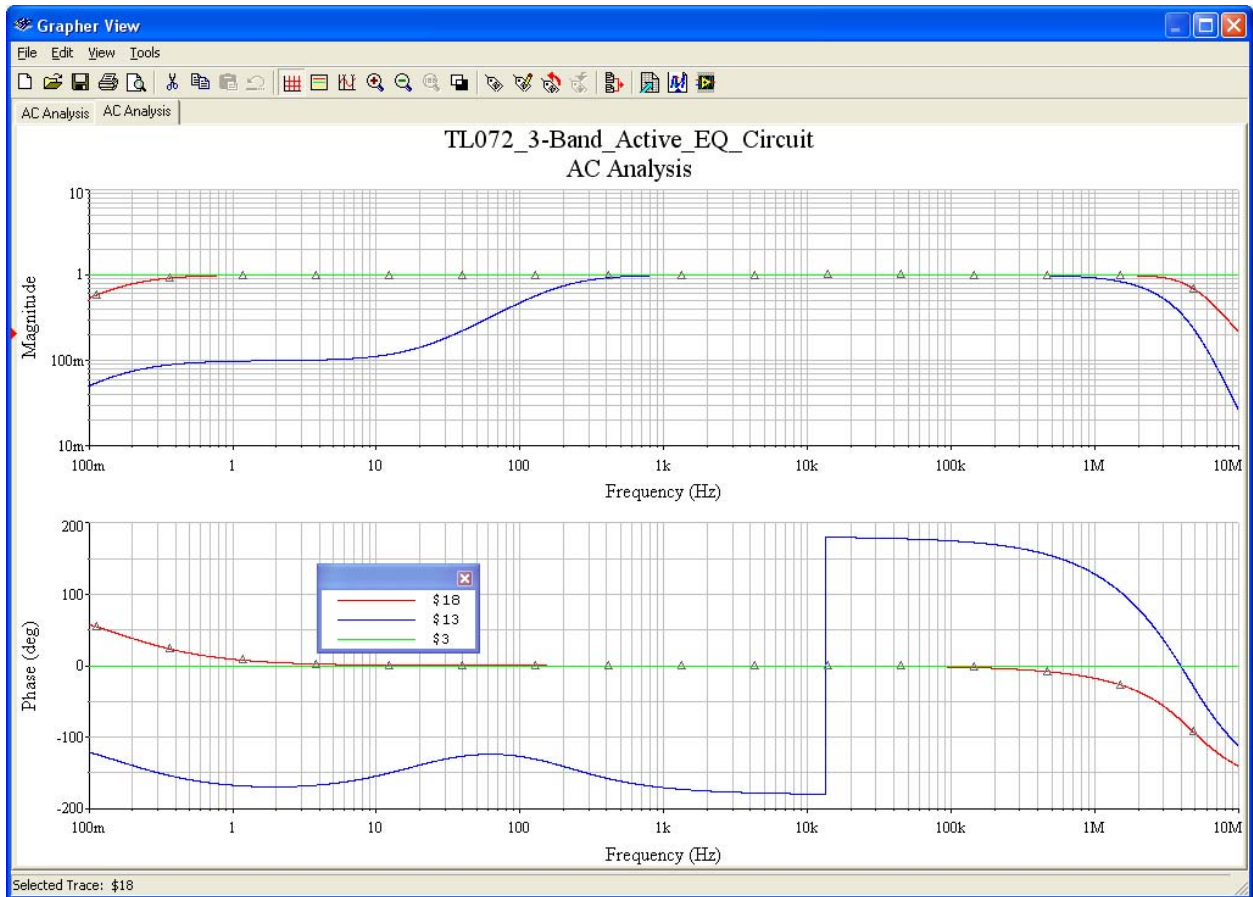
The next graph is with the 100K potentiometer cut fully. The frequency response was reduced to almost an order of magnitude.



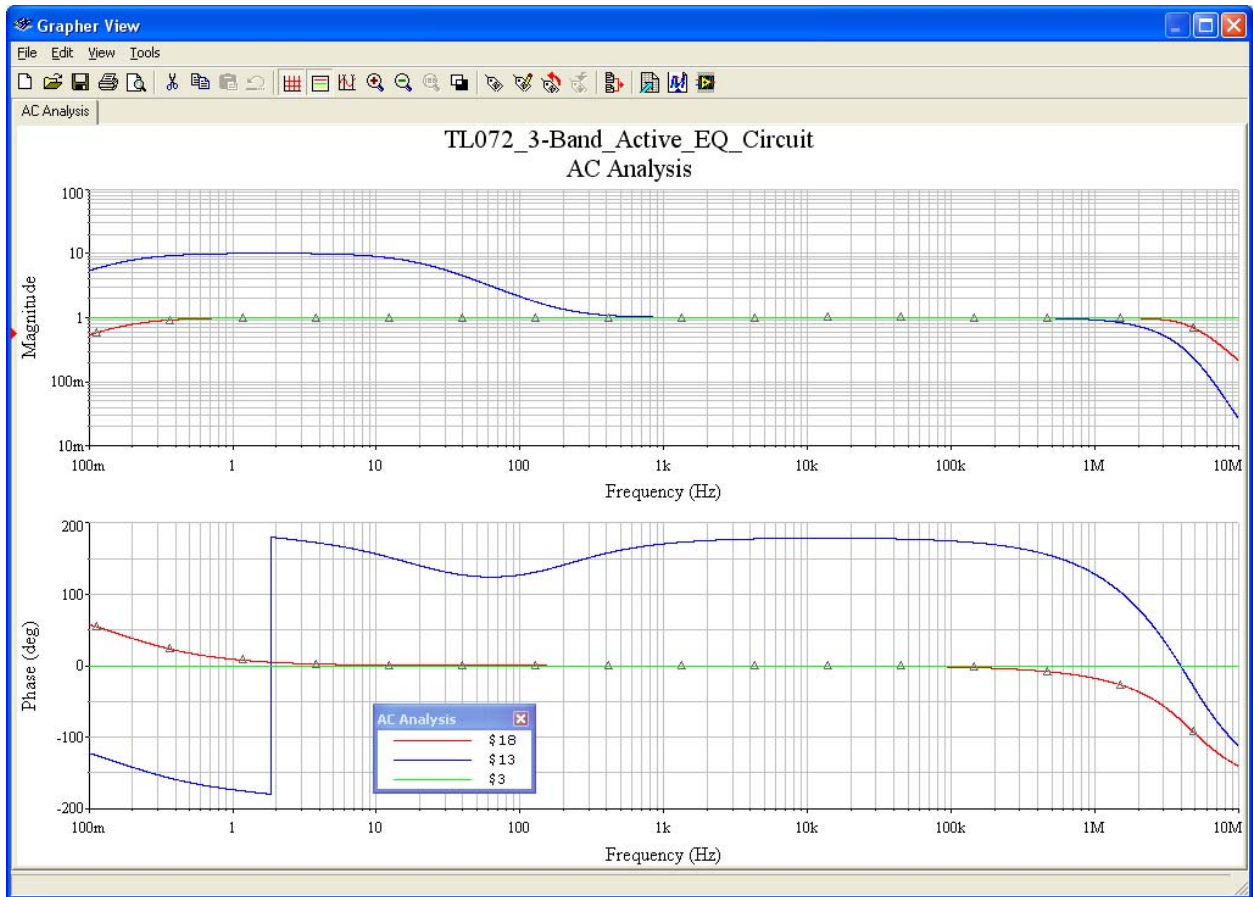
After the Treble was measured, the dial was returned to flat and the Middle dial was rotated to allow full cut and the response was recorded.



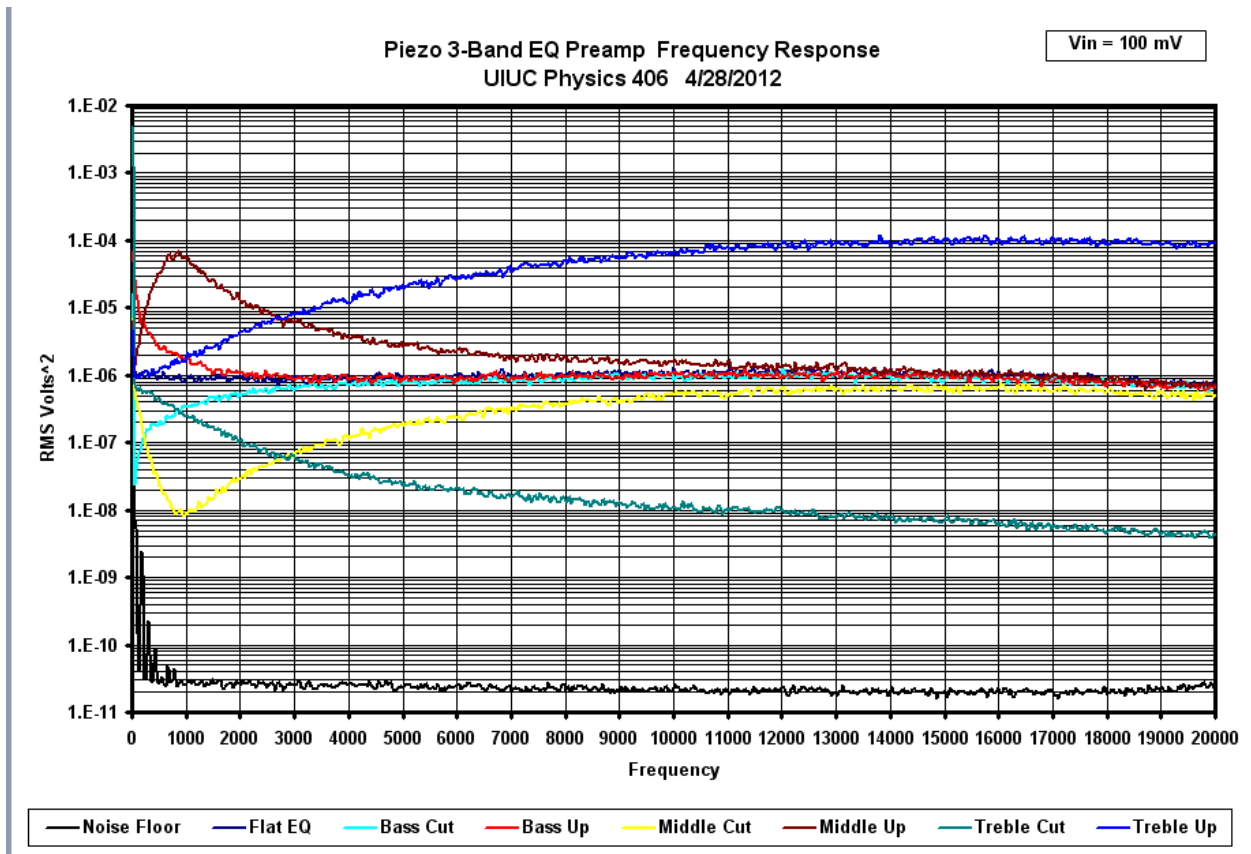
Again the middle was measured, this time with the Middle in full boost.



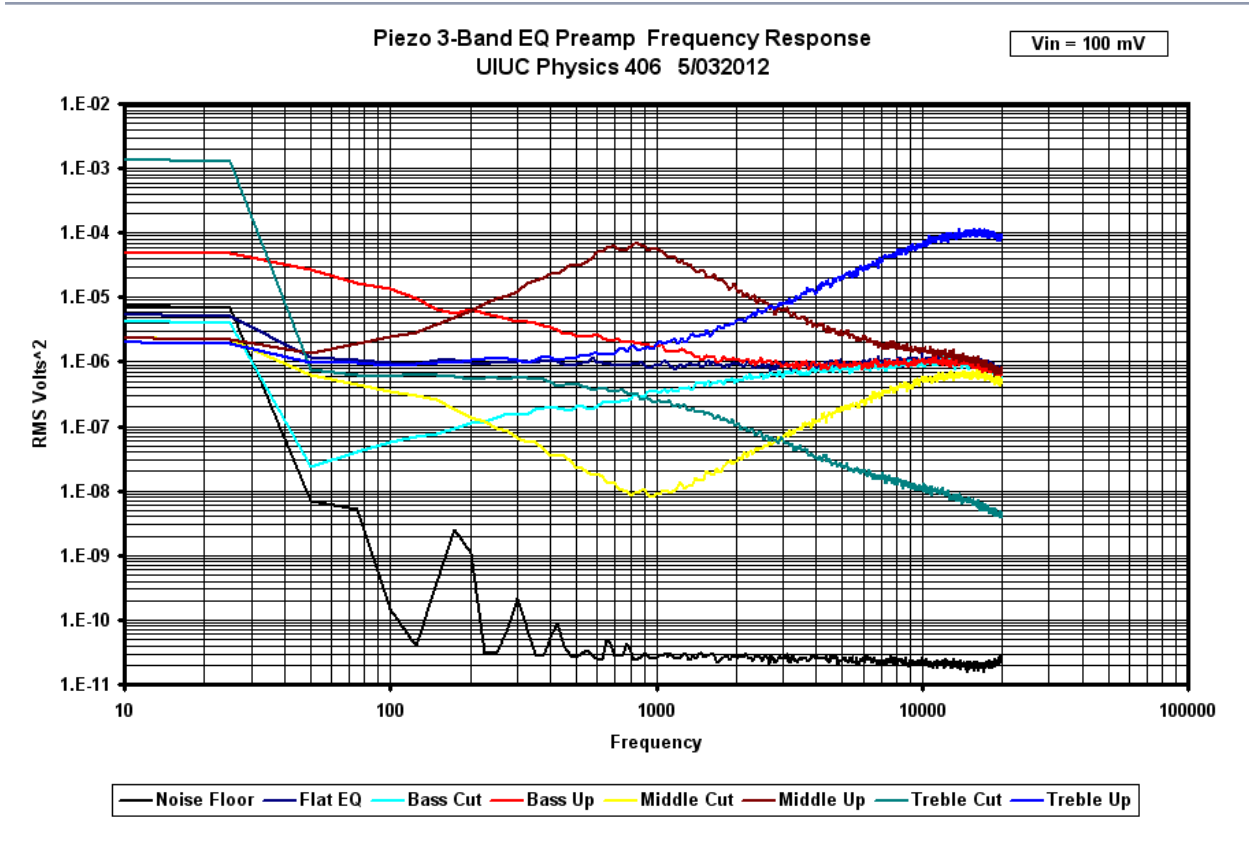
The last potentiometer was measured which controlled the Bass which is the lower frequencies. Again the other potentiometers were turned to flat and the bass was reduced to full cut.



The last measurement simulated was the Bass potentiometer with full boost. With these, I was able to see and expect what my circuit was suppose to behave like.



Once my circuit was completed and debugged, a function wave generator was connected up to the circuit and a sine wave was sent through the circuit. The resulting measurements were averaged over 200 samples, and the above graph is the graph of the responses for each potentiometer's cut and boost. The scale is linear along the x-axis while the y-axis is logarithmic. This data was then scaled again to a log vs log scale, to allow easier interpretation due to the fact that we hear on a log based scale. The responses overall were very close to the simulated.



Conclusion:

This project was really fun because I was able to not only combine my prior knowledge of working with different materials and doing hands on work, but was also able to learn how to take a simple this such as a guitar and use some principles of physics to modify it so that I can amplify what I play, and understand the process itself. The ability to work on this project was not only fun, but was also an enjoyable experience working with new equipment, learning about circuits from no prior knowledge to the construction of my own circuit which works, but most importantly working with people of many different levels of understanding of the principles we all were using. Several understood circuits very well and others, like myself, had no prior knowledge. I wish to thank Professor Errede for all his guidance, patience, and interest that he has given us all. I now have a desire to not only build an electric guitar, but now also a tube amp.

Special Thanks:

A major portion of the information and course of action came from Luthier Paul Breen. Without his help and guidance, my attempt would have ended with a broken piezo, ill constructed components, or an overall failed guitar.