Physics of Music Projects Final Report

John P Alsterda

Prof. Steven Errede

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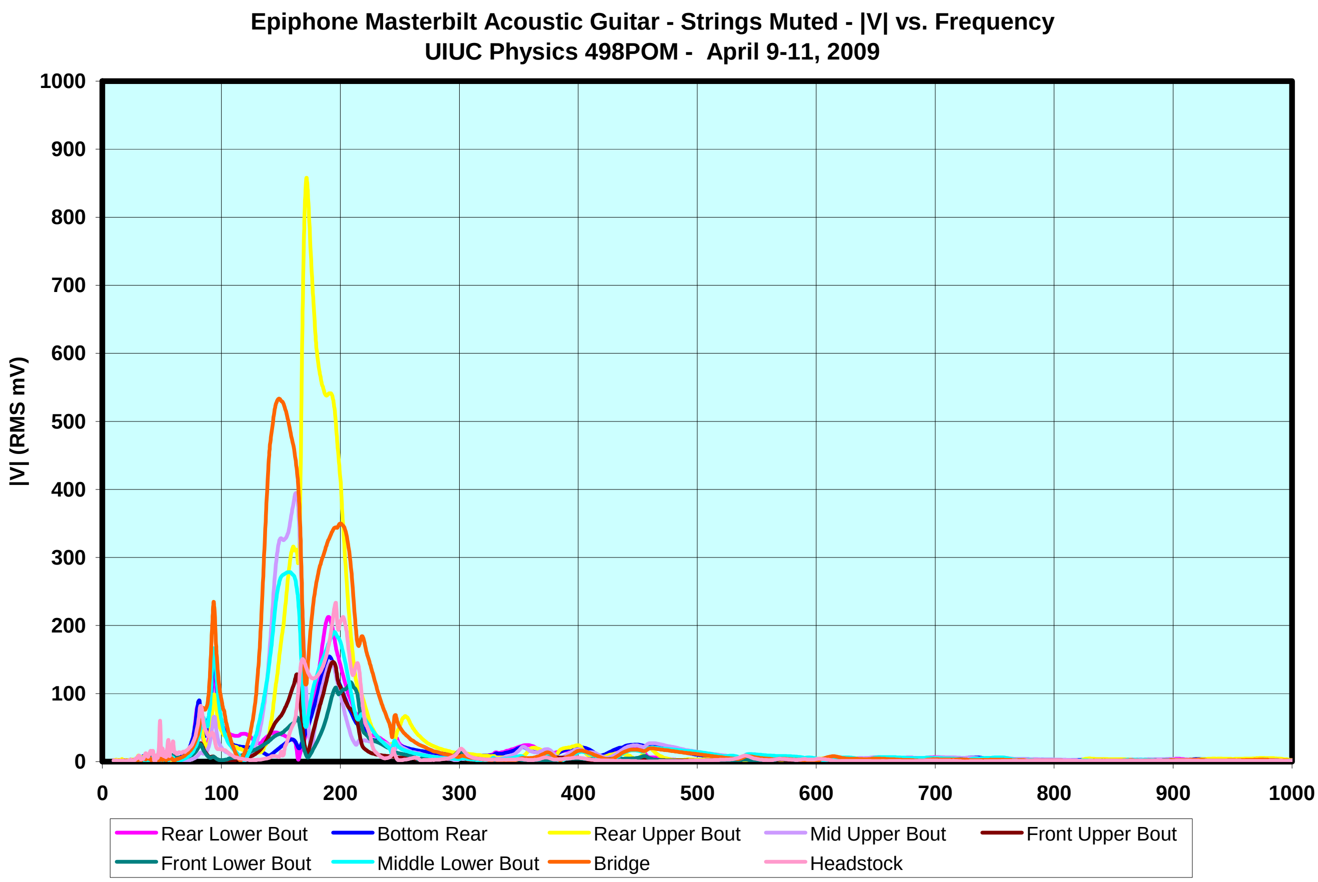
Abstract

The following projects were completed in the spring of 2009 to investigate the physics of my sound signal chain. With several experiments I measured my Epiphone Masterbilt acoustic guitar, Stradivarius student violin, and L.R. Baggs sound hole pick up. Additionally, I fixed and then modified my Fender Blues Deluxe tube amplifier. With a lot of interesting data I have analyzed my tone from its conception through amplification to understand how the mechanical vibrations I create become electrical signals which drive my speaker.

Epiphone Masterbilt Resonance Frequencies

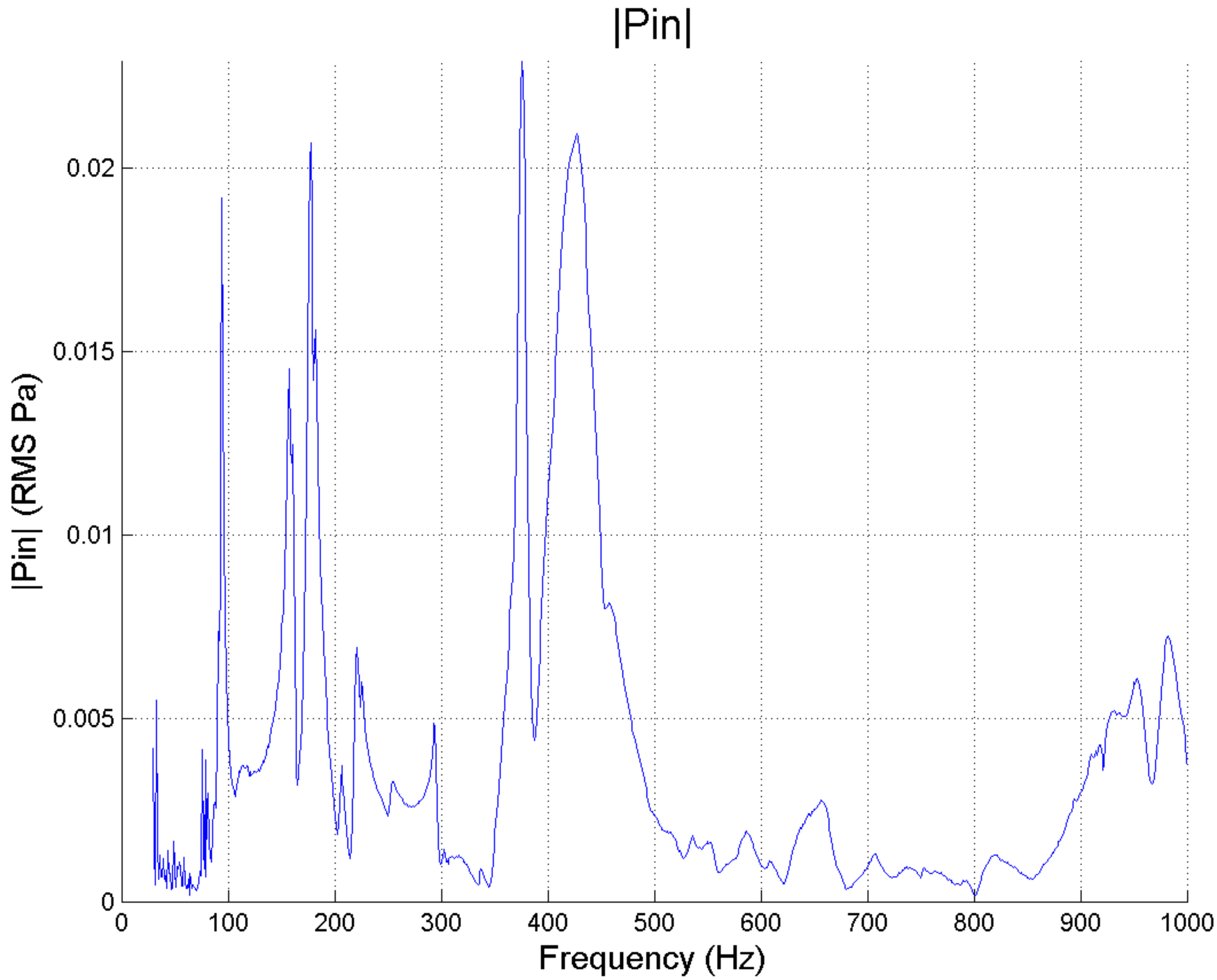
The first step in my signal chain begins with my favorite instrument, the acoustic guitar. When its steel strings are plucked, their intense energy of vibration is absorbed by the wood of the guitar at the bridge and headstock. The frequency of the vibrations is preserved, and the guitar body accepts this energy with a strong frequency response. This means that string vibrations that agree with the structural resonance frequencies of the guitar body make the guitar's wood components also vibrate with the same frequencies. When these special resonance frequencies are excited, the air inside the body cavity undergoes pressure changes and radiates a travelling pressure wave of said frequencies from the guitar's sound hole. Therefore, notes played within the resonant frequency range will be fuller, richer, and louder than notes that do not excite the guitar body.

I conducted two experiments to investigate these resonant frequencies. The first test used a piezoelectric transducer to excite the guitar bridge and then a second piezoelectric to pick up those excitements elsewhere on the face of the guitar. Piezoelectrics have the property that alternating currents cause the material to vibrate with the frequency of those current alternations. This transducer was planted directly onto the sound board beside the bridge with a small weight to attempt to couple the vibration to the sound board. Obeying time reversal, when a piezoelectric vibrates, it creates an AC with voltages comparable to the magnitude of the vibrations. That's where the pick up transducer plays its role. Signals from the pick up transducer told me that the vibrations were successfully transmitted across the guitar face and were therefore resonant frequencies. We drove the primary piezo with alternation frequencies from zero to 1000 Hz to try and capture the full spectrum of possible resonances. The magnitude of the voltage created by the secondary piezo at each frequency is shown below:

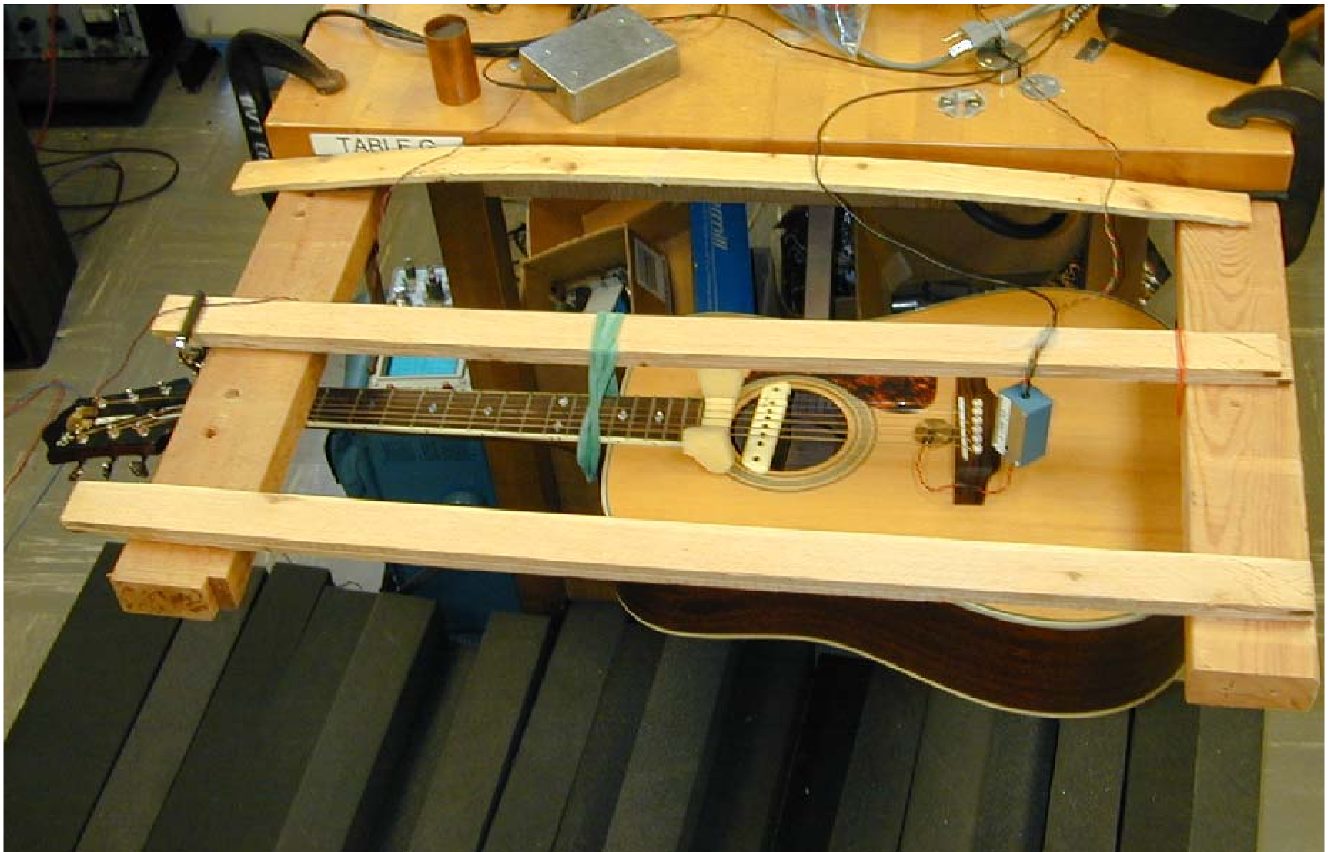


From this plot, it is apparent that my Epiphone resonates strongly in the low end of the frequency spectrum. The first voltage spike is at about $F^{\#}_2$, a whole step above my lowest E note. The second large resonance sweeps from about D_3 to A_3, which covers a great chunk of my lower midrange. Not much interesting happens for frequencies above this point, however. I'm not surprised by these results, as I feel that my guitar has a great low end sound, but thins out as I work up the neck. For this reason I like to play lots of hammer / pull off leads on my D and G strings before I jump to the high notes. The gory complex details can be found as well, in the excel file attached, if the reader is interested. The data provides real and imaginary plots not shown here, which provide insight about the phase difference between the driving and pick up currents.

Wondering if this piezoelectric experiment provided me with the entire picture of my guitars resonance, I set out to measure the wood in a different way. Once again I excited the bridge with a piezoelectric, but picked up data with a pressure and particle velocity microphone instead of a second piezoelectric. The mics were positioned just above the sound hole, to measure the pressure waves emanating from within the body of the guitar. As the primary piezoelectric excites the bridge, the whole body of the guitar can vibrate if driven at the right frequency. As mention afore, these vibrations give rise to pressure waves, and therefore great sounding notes at these frequencies. A plethora of interesting values can be calculated using particle velocity and pressure data, as outlined in Physics 498 POM Lecture Notes 11 through 13 at http://online.physics.uiuc.edu/courses/phys498pom/498pom_lectures.html, and are graphed in the attached excel file. They include the complex impedances, energies, and other useful values, arranged in many different ways. The most relevant data is the magnitude of the pressure waves created, which is exactly what our ears are sensitive to:



For the most part, the data closely follows the curves found in the last experiment, especially throughout the low end range. However, there is an exciting amount of activity between about 360 and 470 Hz, or from about F_4 to B_4, and even a small set of peaks above 900 Hz. This new data is very interesting, and suggests the piezoelectric experiment did not fully capture the resonance range of my guitar. It's possible that the back and side panels of my guitar body play a crucial role in these higher range resonances! These panels were not measured in the previous experiment but this experiment measures the totality of the body creating these pressure waves.



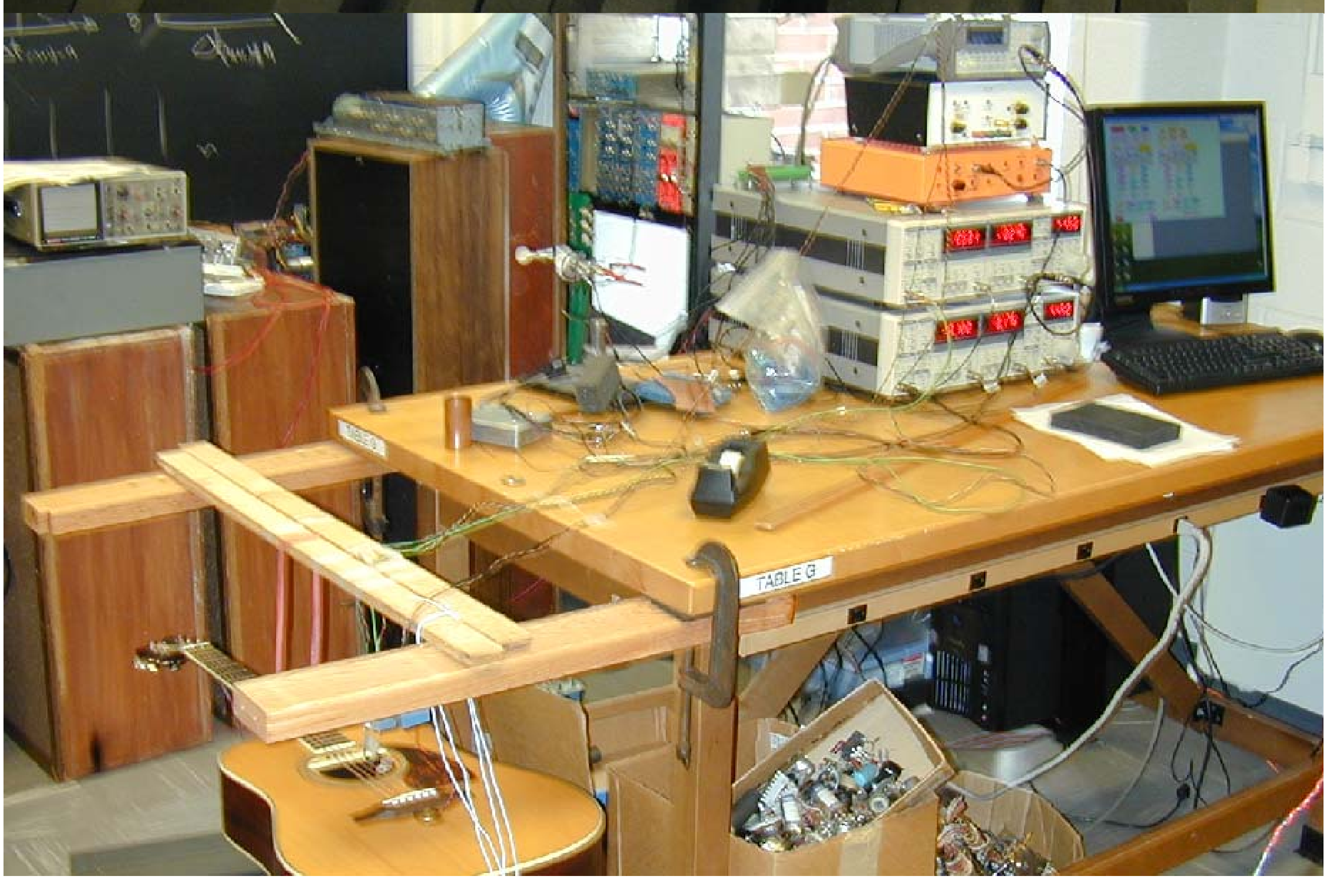
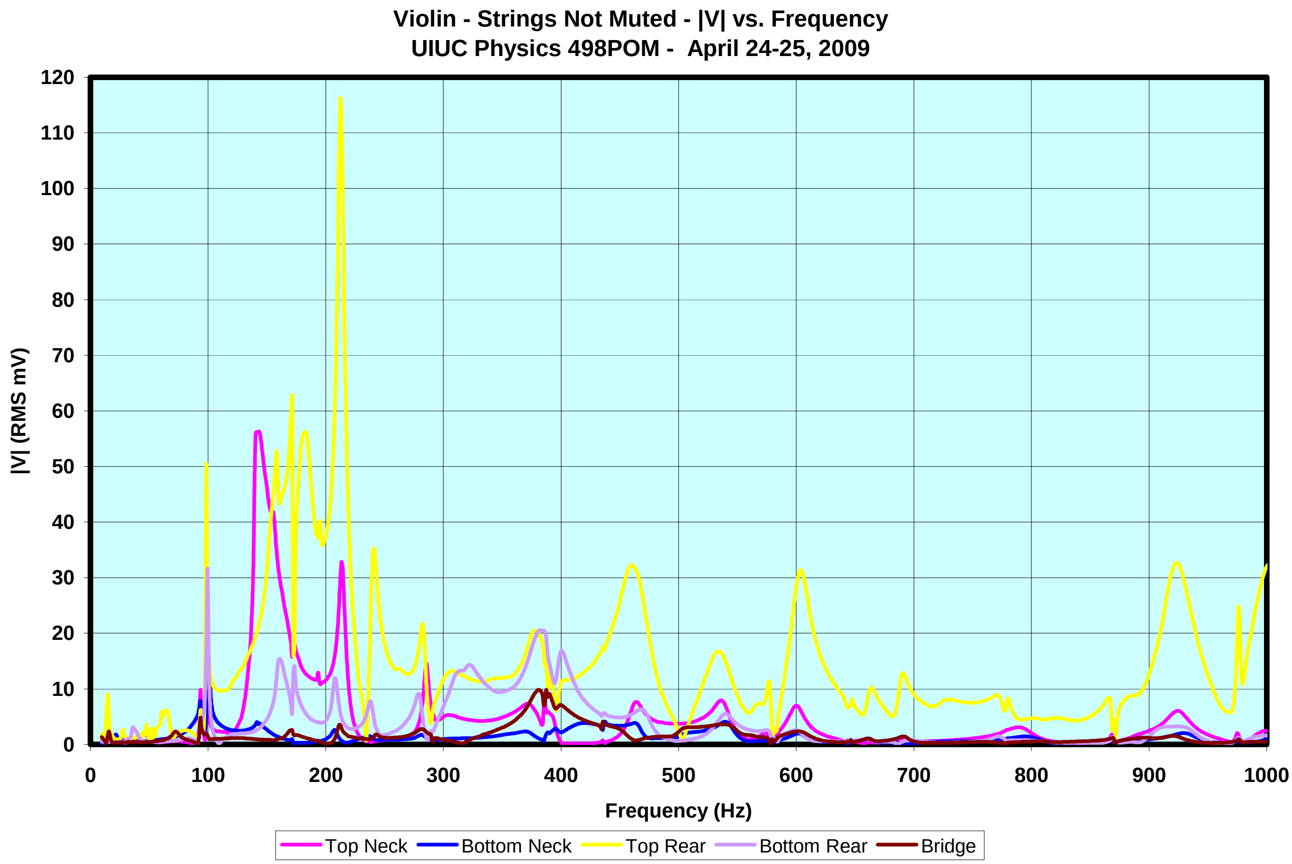


TABLE G

Stradivarius Student Violin Resonance Frequencies

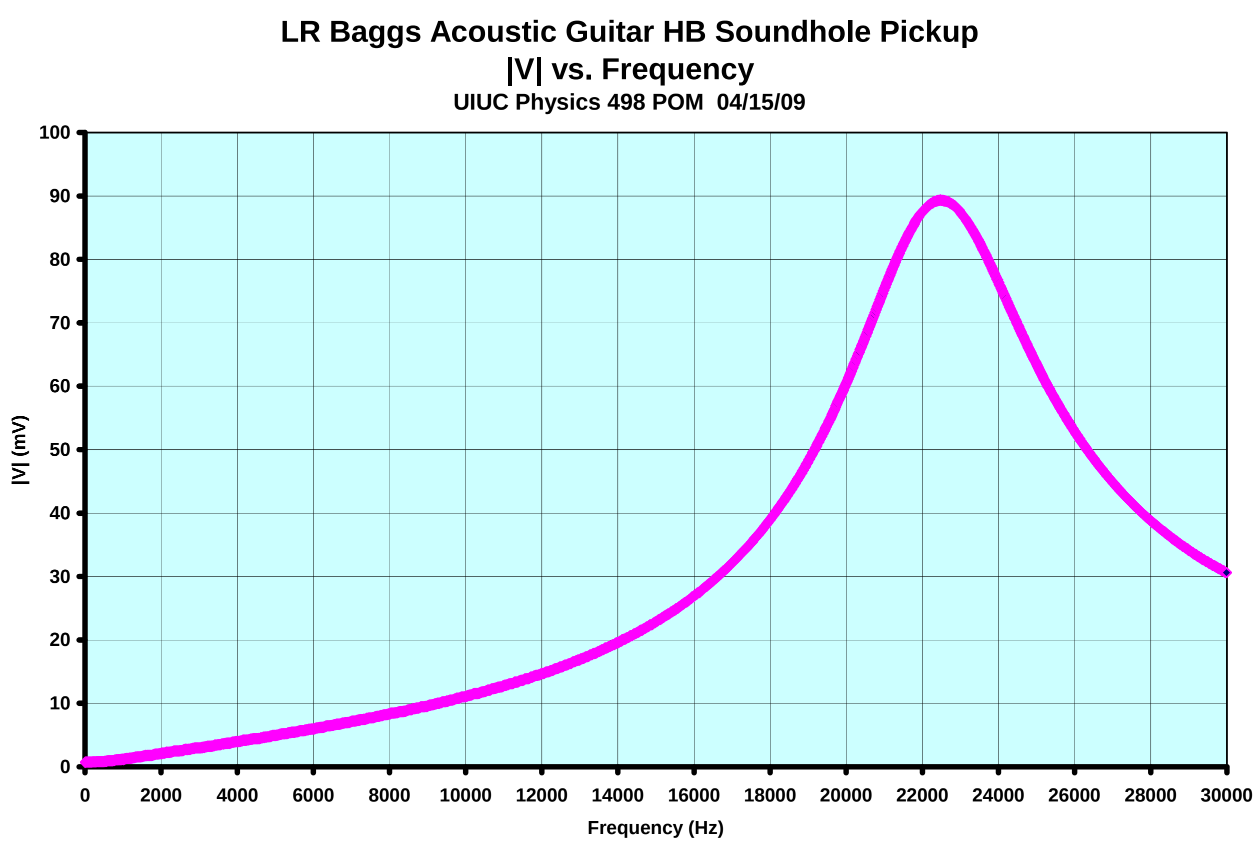
Out of curiosity, I wondered what my violin frequency range might look like and conducted another, purely piezoelectric test. Here is the magnitude of the voltages created by the pick up piezo at different portion of my violin:

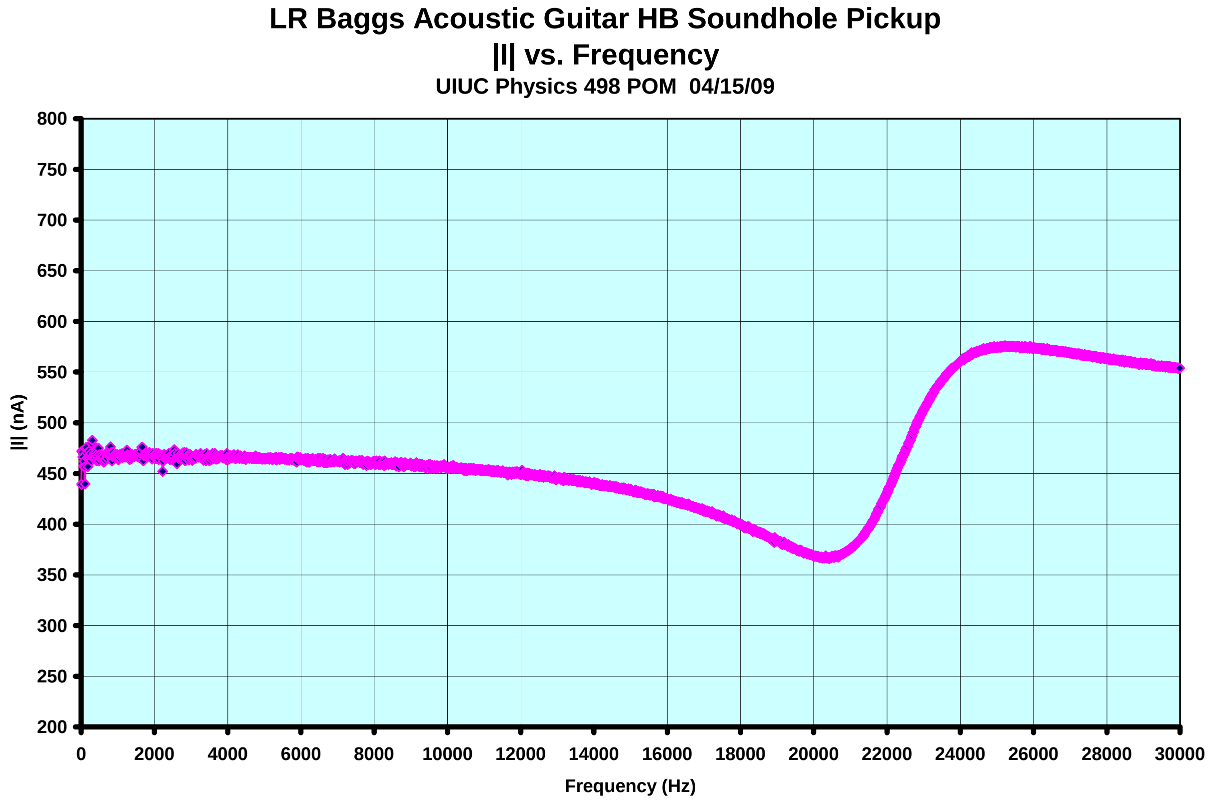


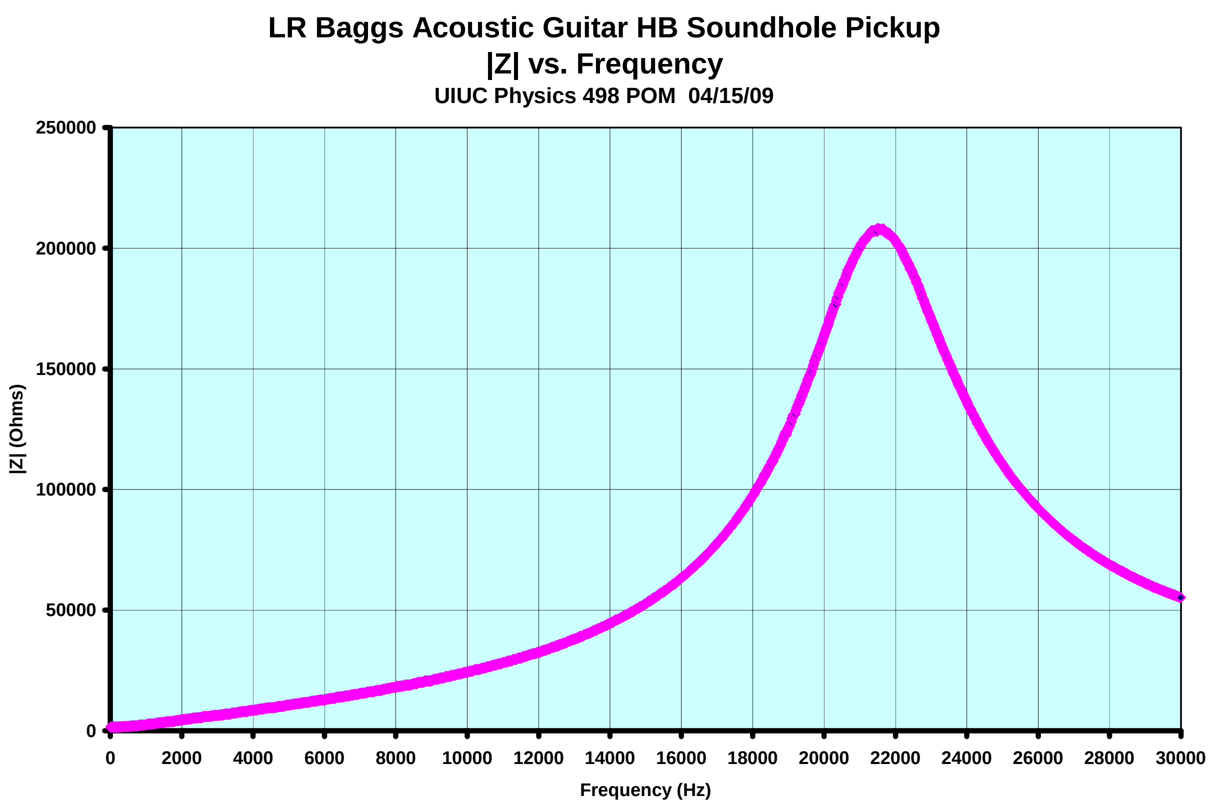
The strongest voltages lie in a similar range as the Epiphone acoustic. However, the violin wood vibrated well into the highest ranges of this experiment, indicating that I should expect a full sound throughout much of the note spectrum. I like the tone of the instrument, but don't have much experience with other violins to really gauge the value of this violin's tone. I'll keep this data in mind when I play and listen for the wood around the A_3, $A^{\#}_4$, $D^{\#}_5$, and $A^{\#}_5$ notes. It's very interesting to me that the most nice notes seem to lie on one fundamental frequency and its harmonics. It seems that the wood reacts much a 1 dimensional harmonic oscillator, even though the material and geometry do not come close to fitting this model.

L.R. Baggs Sound Hole Pick Up

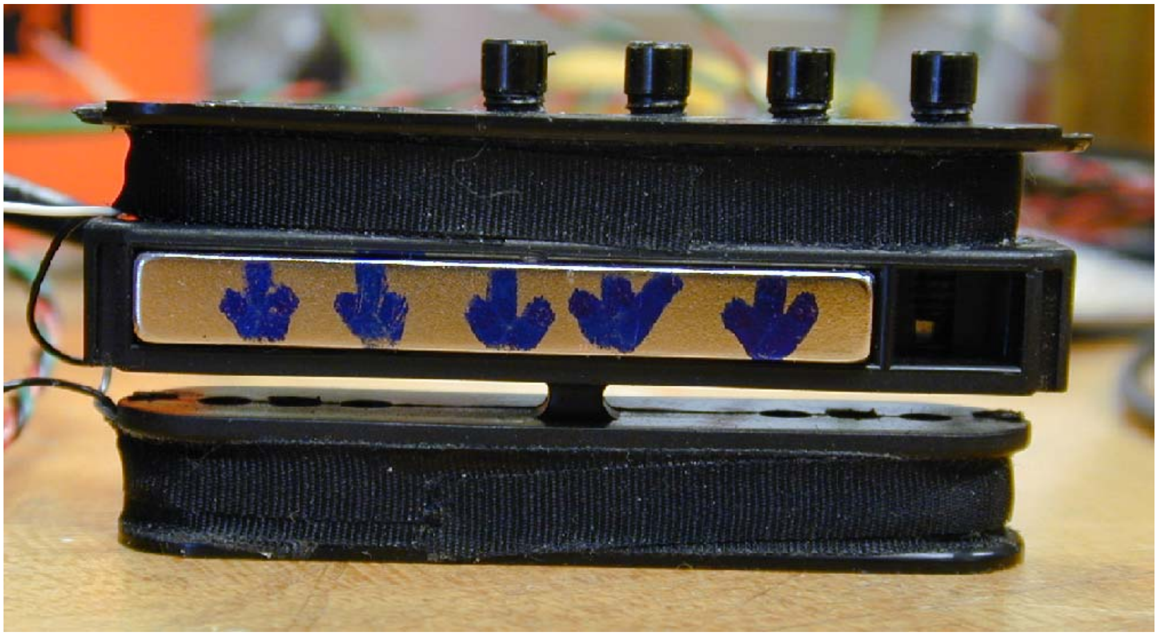
My last set of measurements focused on the magnetic coil pick up that rests in the sound hole of my acoustic guitar. When the steel strings vibrate, they cause magnets inside this pick up to vibrate as well, creating a change in magnetic flux over time through the wire winding coils around the pick up. This change in flux creates currents in the wires that alternate with the frequency of the mechanical vibrations. These line level currents are pre-amped and fed out of the guitar for further amplification, and eventually drive a speaker. Pick ups do not have a flat frequency response however, so the pick up responds with currents of different voltages throughout the frequency spectrum. We swept this pick up with an AC from zero to 30,000 Hz. The voltage, and current, and impedance magnitude curves are as follows:




LR Baggs Acoustic Guitar HB Soundhole Pickup
|I| vs. Frequency
UIUC Physics 498 POM 04/15/09
|I| (nA)
800
750
700
650
600
550
500
450
400
350
300
250
200
0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000 22000 24000 26000 28000 30000
Frequency (Hz)


LR Baggs Acoustic Guitar HB Soundhole Pickup
|Z| vs. Frequency
UIUC Physics 498 POM 04/15/09
|Z| (Ohms)
250000
200000
150000
100000
50000
0
0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000 22000 24000 26000 28000 30000
Frequency (Hz)

With reference to other pick ups, this L.R. Baggs pick up seems to be quite bright, meaning it responds with a strong voltage for high frequency notes. The pre-amplifier data, not shown here, has a flat response, so the above data provides the whole picture for this pick up. I reason that the frequency response is pushed so far into the high range to maintain the fidelity of the acoustic sound this pick up is meant for. The voltage slowly increases with the frequency, to produce the flattest response possible from a magnetic coil pick up.



Fender Blues Deluxe Custom Modifications

Over winter break, I bought a broken Fender tweed tube amplifier for $100 that was supposed to be from the 1970's. Opening the back panel revealed a copyright date of 1993 to dispel the bogus birth date, and few minor fixes that would get this amp back into rocking condition: Over years of pulling quarter inch cables in and out of the input jacks, the jack housing's solder connection to the pc board had been destroyed. I installed two new free hanging inputs to eliminate the possibility of having to fix this problem again and reflowed many pc board connections, including all other input and tube socket ports. A few of other minor jobs brought this amp closer to its mint condition (at least electronically): I lubed up all the potentiometers that had been gunked up with dust over the years. I also reflowed and glued down capacitors and resistors in spots of heavy vibration during play.

Next, I set out to improve the tone of the Blues Deluxe. First, I replaced a bunch of ceramic capacitors with silver mica ones of different values to allow different ranges of frequencies through to portions of my tone chain. I believe I pushed the frequency range up higher for the bright channel, and pulled the range lower for the whole circuit to really bring out the acoustic lows that are important to me.

Second, I worked to correctly bias the power tubes of my amplifier. Upon measurement, I found the two unmatched tubes were pulling a current difference of about 20 milliamps. This leads to a poor sound due to an asymmetric waveform and destroys the life of the tube pulling too much power. Installing two one ohm resistors allowed us to make this measurement, and a new potentiometer allowed us to correctly bias the new pair of power tubes with matching currents.

Lastly, I installed a second speaker output jack to increase the versatility of this amp. I now have the power to switch between a 4 and 8 ohm load, split between up to two outputs. This means I can drive either two 16 or 8 ohm speakers, or one 8 or 4 ohm speaker. This modification will certainly prove handy as I work on my acoustic tone. I will probably end up working towards a new speaker cabinet with backing and different size speakers to really maintain the acoustic tone beginning in my Epiphone.

Conclusion

Overall, I believe these projects allowed me to learn a great deal about the physics behind the instruments and music I play and listen to. I think that this is only the beginning of my musical investigations. I have been shocked this semester by the depth of theory behind acoustics and will continue to research and come up with new project ideas. For example, I intend on attempting to pick up vibrations on the back panel of my acoustic guitar with the piezoelectric. I plan to see how a change in the gauge of string affects the resonance frequencies as more or less tension is pulling on the bridge and headstock. I plan on further modifying my Deluxe amplifier to use the final unused pre-amp tube, which could be used to power a whole new effect on my tone! Thanks for an awesome semester and a lifetime of new material to explore.