Building and Rebuilding

Physics of Musical Instruments

Thomas Satrom

May 12th, 2011

Motivation

When approaching the possibility of a project in the Physics of Musical Instruments class, I had many choices due to my collection of broken musical instruments and electronic devices that I had collected over the years. Since I was young, I have always wanted to play music but had never found the proper motivation or the budget for purchasing anything. I soon found that if one purchased broken or unfinished guitars, amps or violins, which I could get cheaply and try to get them working again. I began with a trip to Ebay to look for broken electric guitars. This resulted in my purchase of an old Japanese copy of a mustang for approximately 20 dollars. This guitar had no parts on it and left room for me to do what I liked with it. After completing this guitar, I soon purchased more guitars to fix up but just adding store bought parts soon became less enjoyable so I decided I was going to build my own pickups. I also had traveled to an antique store in the summer and found a broken tube radio and record player. I purchased it for a low price and decided to try and get the radio working and maybe add a guitar input jack. So the goal for this set of projects is to acquire all the necessary components of a guitar signal chain without the high cost and with personal customization.

1947 Garod Tube Radio and Record Player

After receiving this radio from the antique store, I proceeded to open up the chasis and remove the tube radio. Prof. Errede told me to replace the old paper and wax capacitors, as these would be the likeliest component to fail after 50 years. These capacitors have a tendency to melt from the heat generated by the tubes. This often resulted in the capacitors being the first to break inside an amp. Replacing the capacitors was a simple task after I purchased the tubular polypropylene capacitors at Prof. Errede's suggestion as well as finding an old schematic and user manual on Ebay. From the picture below, it is plain to see that the method for wiring these amps was chaotic and often left openings for shorts across many components. The user manual helped to decipher the values of the capacitors as some had burned off or were hard to find. While replacing the capacitors, I covered the leads in shrink wrap to prevent shorting.

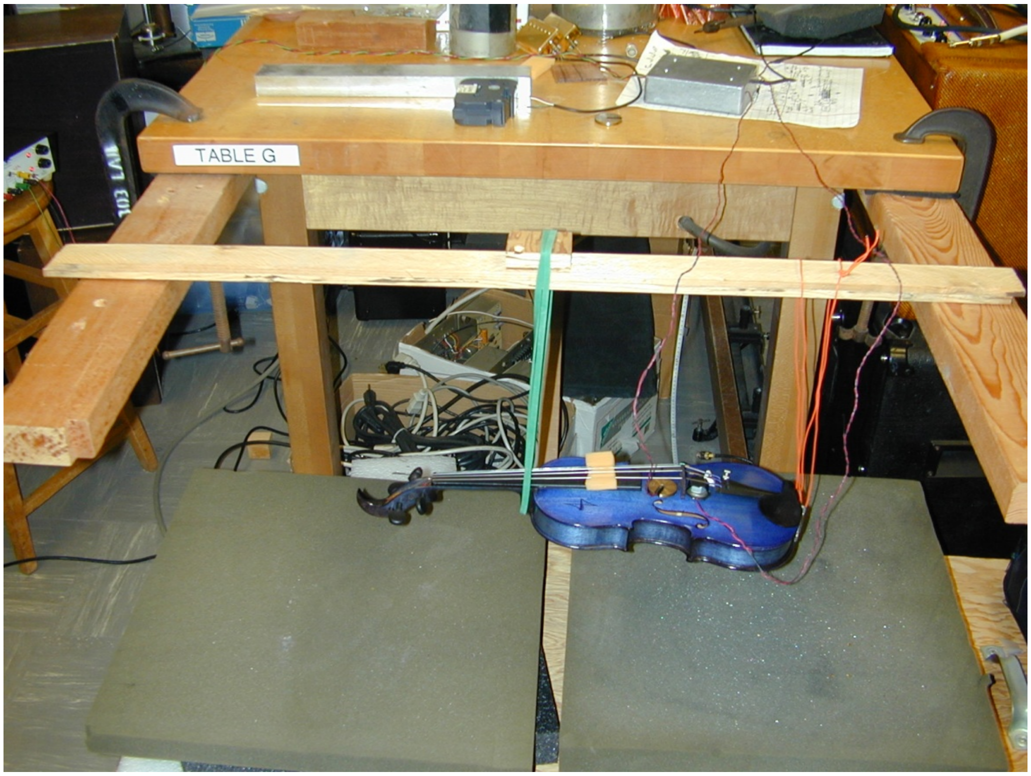
Inside view of 1947 Garod Radio during capacitor replacement

I also changed out the original power cable for a new earth ground power cable. This amp's original power cable was a two pronged cable, meaning the amp had no external grounding and everything was grounded to the chasis. This allowed the chasis voltage to float away from earth ground to anywhere as high as 300V in some cases. This provided a very dangerous situation for anyone. Replacing this cable was a must. Once the capacitors and cable were replaced, it was time to check if the tubes worked. The simplest method for checking the tubes is to turn on the radio and see if the amp works. Luckily, the radio turned on and began to play music from AM radio. I was surprised that all the original tubes worked despite their age. I was pleasantly surprised by the sound of the radio with its large cabinet and electro dynamic speaker.

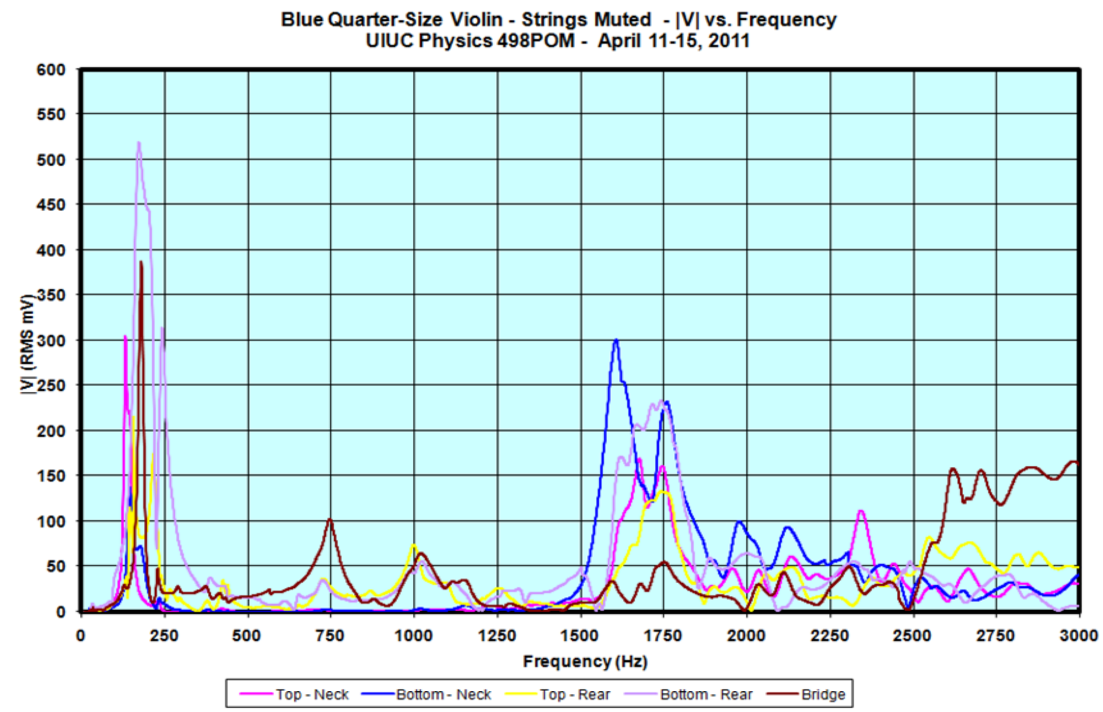
Blue Violin Stradivarius Copy

The previous semester, I had received a Korean Stradivarius copy built for a child with a broken back plate. So I had taken the whole violin apart, removed the varnish, sanded it down despite the all of the violin players I know yelling at me for it. I re-stained it blue and finished it with a simple polyurethane clear coat.

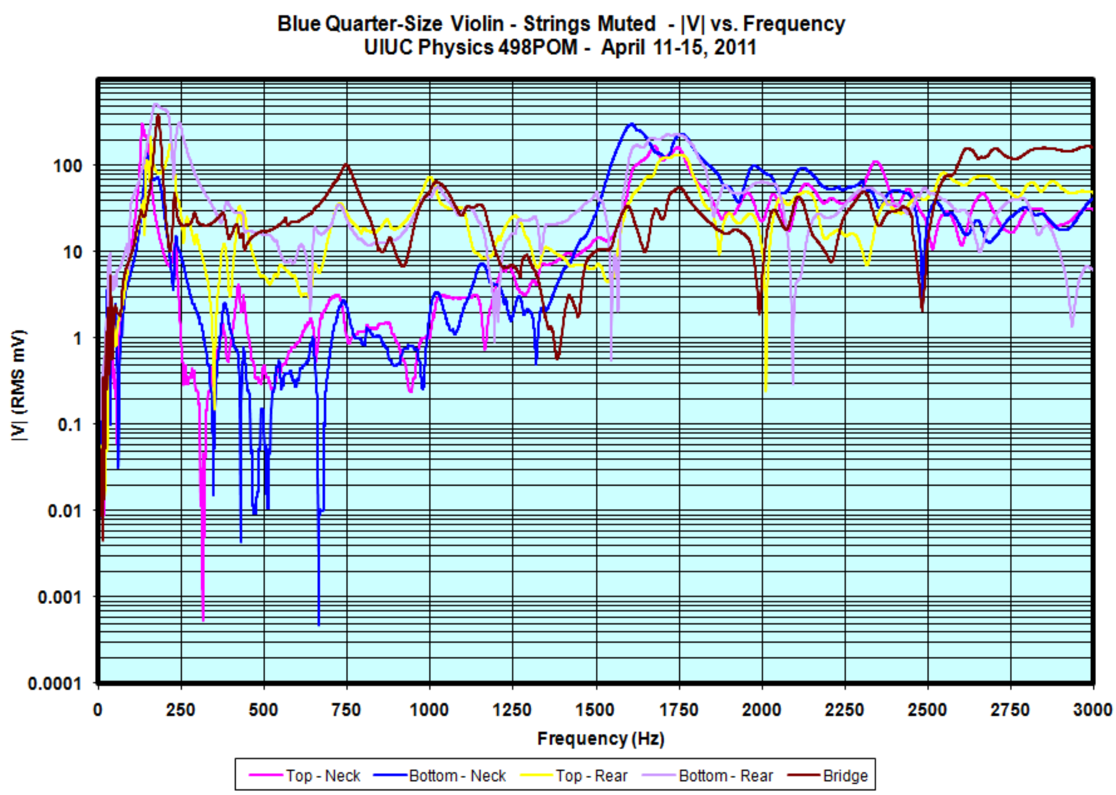
I brought the violin in for testing to generate some correlation between what I was hearing and what could be tested. I also wanted to see how the techniques I had used in its construction may have affected the sound of the violin. To test the violin, a vibrating piezoelectric element is placed at certain positions on the violin, while a receiving piezoelectric element is also placed on the violin. A piezoelectric element distorts under a voltage, so by applying a AC voltage of a certain frequency, the element will also vibrate at that frequency. By using the reverse of this process, we can calculate the resonances of the violin with the second piezo element.



From the data received, the violin has some large resonances between 150 and 250 Hz. These frequencies correspond to the lower end of the violin and this was representative of the sound I heard while others played the violin. Since I am not a violinist, my ability to test the tone of the violin was lacking. From 250 Hz to 1500 Hz, the resonances are rather minimal. This does not confer to the violin sounding terrible at those frequencies, but does imply that the violin will not sound very full or rich. You can also see from the graph of antiresonances that the violin does have a many points where the frequency will actually be suppressed. This will confer a dead sound from the violin and these frequencies should be avoided while playing. Most of the anti-resonances occur around the neck and this is most likely due to the fact that I used wood glue, which forms a strong stiff bond. The neck is an area of the violin with a large amount of wood connections and is a crucial part in the transferrence of vibrations. With the use of wood glue, these vibrations would most likely be suppressed. Most of the repairs applied to the violin occurred around the neck and many craks needed to be filled and glued together which further hampers the sound of the violin.



Blue Violin Resonances

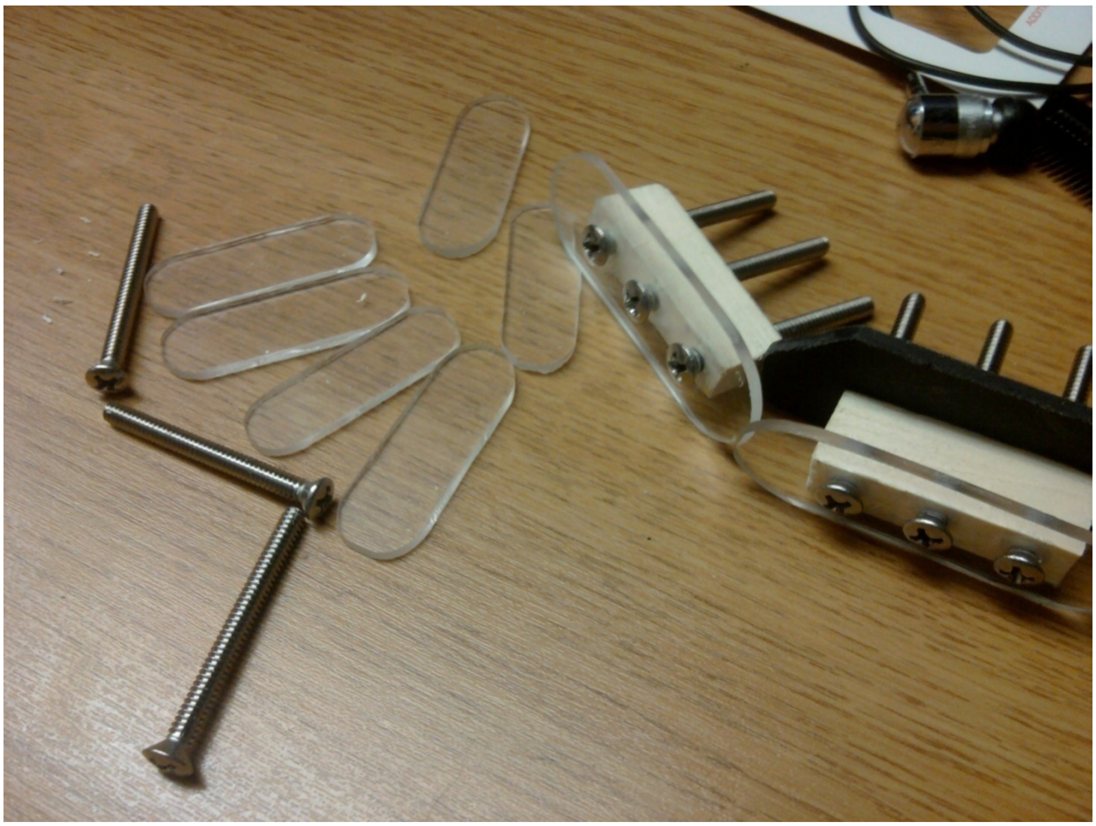


Blue Violin Anti-Resonances

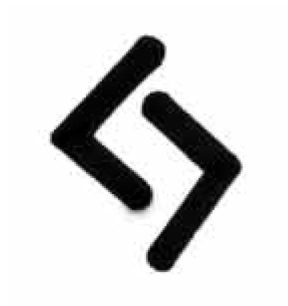
After completing theses measurements, my next goal would be to find a broken full sized violin and use different repair and finishing techniques and compare to this violin. Overall I am happy with my repairing abilities and the compliments I received from violinists that played it. Mainly that it didn't sound as bad as they expected.

X-Pickup & Jera-Pickup

The main project for this semester was to build and test a new set of pickups I designed. This required me to hand build and cut the bobbins as well as designing a way to protect and incorporate the pickups into a guitar. Winding pickups is a tedious endeavor especially when everything is created with parts found at a local hardware store. For my initial design, I planned to create an x shaped pickup made up of 4 smaller pickups that would be selected in different groupings to create different tonal characteristics. I also wanted to create some humbucking capability which required two of the pickups to be wound clockwise and the other two to be wound counterclockwise. The original design specification came from the idea of having a slanted humbucker, much like the slanted bridge pickups of a Stratocaster. After many initial redesigns I stuck with my current design, of four 3-pole pickups splayed out in the shape of an X. I began to cut the pickups with sizes comparable to a single coil pickup cut in half, approximately 18 mm tall by 54 mm long. The center would be a piece of wood cut to approximately half an inch thick with a base of flatwork material bought from Stewart MacDonald.



I used 2mm diameter machine screws as pole pieces. When cutting the initial sizes for each of the four pickups, I realized that it would be impossible to arrange them like the intended design. After realizing this and not wanting to scrap all of the work I put into these pickups, I decided to develop a second pickup much like the X-pickup but with a different arrangement, thus the Jera pickup was created. It was named after the Norse rune which is in the shape of the pickups arrangement.



I also cut new pickups to fit the original intention. These were much smaller, approximately 10mm tall and 25mm long with a blade style core. Due to time restrictions, these have not been constructed yet. The jera pickup was wound over the course of a few weeks. Winding pickup coils is a long, tedious and boring task but creates a unique sound due to scatter winding. Scatter winding creates a more unique sound for each pickup as well as decreases the capacitance of the pickup thus allowing more treble to come through. I followed Dan Carson's approach to winding as written in his guide. For winding I used 42 AWG wire due to 43 AWG being more expensive and fragile than 42. Once each coil was finished I measured their inductance, Damping and Quality Factor at three separate frequencies, 1 kHz, 10 kHz, and 120 kHz.

Bare Coil Pickup Measruements				
Pickup 1	R=3.25 kΩ	1kHz	10 kHz	120kHz
	Inductance (H)	1.094	0.879	0.706
	Dissipation Factor	0.740	0.095	6.10
	Quality Factor	1.351	10.53	0.164
Pickup 2	R= 3.32 kΩ	1kHz	10 kHz	120kHz
	Inductance (H)	1.22	0.938	0.740
	Dissipation Factor	0.717	0.094	5.91
	Quality Factor	1.395	10.64	0.169
Pickup 3	R= 3.51 kΩ	1kHz	10 kHz	120kHz
	Inductance (H)	1.160	0.983	0.742
	Dissipation Factor	0.75	0.103	6.19
	Quality Factor	1.332	9.71	0.162
Pickup 4	R=3.58 kΩ	1kHz	10 kHz	120kHz
	Inductance (H)	1.188	0.933	725
	Dissipation Factor	0.797	0.106	6.57
	Quality Factor	1.255	9.43	0.152

After measuring the values for each pickup, I proceeded to pot the pickups. This process involves dipping the pickup into melted wax and allowing it to become saturated. This prevents the wires within the coil from moving around and thus becoming microphonic. As I created these pickups I wanted to measure the pickups at each stage of their creation. Here are the measurements after potting.

Potted Coil Pickup Measruements				
Pickup 1	R=3.25 kΩ	1kHz	10 kHz	120kHz
	Inductance (H)	1.094	0.981	0.711
	Dissipation Factor	0.731	0.110	6.03
	Quality Factor	1.366	9.09	0.166
Pickup 2	R= 3.32 kΩ	1kHz	10 kHz	120kHz
	Inductance (H)	1.125	1.052	0.745
	Dissipation Factor	0.713	0.109	5.88
	Quality Factor	1.403	9.09	0.170
Pickup 3	R= 3.51 kΩ	1kHz	10 kHz	120kHz
	Inductance (H)	1.169	1.121	0.746
	Dissipation Factor	0.751	0.123	6.19
	Quality Factor	1.332	8.13	0.162
Pickup 4	R=3.58 kΩ	1kHz	10 kHz	120kHz
	Inductance (H)	1.176	1.050	0.730
	Dissipation Factor	0.780	0.121	6.43
	Quality Factor	1.282	8.20	0.156

From this data, it can be seen that the inductances did not consistently change throughout the 4 pickups but the quality factor increased for all three pickups at 1 and 120 kHz but decreased at 10 kHz.

Unfortunately I was not able to complete these pickups by installing them into guitar before the semester came to a close. I intend to install these pickups as well as pursue the creation of the original X-pickup design.

References

-Steve Errede

-Dan Carson's Guide to Winding Pickups