Physics 406
Final Report

Construction of Single Coil Pickups for Fender Stratocaster

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Introduction:

Choosing a project for this class was a little tougher than anticipated. Past projects consisted of a variety of different topics, and I drew a lot of inspiration from there. I narrowed down the choices based on the fact that I wanted a project with my Electric Guitar. This led to me beginning to research different Electric Guitar pickup material, and ordering my own single coil pickup construction kit.

My current guitar is a Made in Mexico Fender Stratocaster that I have owned for the past five years. Traveling across state lines from my home and onto campus, it has endured the wear and tear of a first guitar. I've fallen out of playing my electric guitar for some time, and previously I never gave much thought into modifying my guitar. However, this class provided me the proper inspiration to finally get back into my old hobby.

I ended up replacing all three of the ceramic pickups that came with my original guitar with self constructed Alnico magnet pickups wound with copper wire. The process was a long and arduous one for someone inexperienced like me, but rewarding nonetheless.

Abstract:

This report will walk through the construction process of each of the three pickups. This will include the tools and material that were needed, as well as the measurements taken to thoroughly analyze the electromagnetic properties of both the original factory made ceramic pickups and the self wound Alnico pickups. Attention to small details were always stressed, as the slightest inconsistencies could result in drastic changes in both the physical output and electromagnetic properties of the pickups. The results in data will show that the self wound pickups differed greatly from the original. However, the ultimate test was a subjective, individual sound test after all three pickups were replaced.

Construction:

Luckily, the construction process was very carefully laid out by the experience of Professor Errede, teaching assistant Fanshi Liu, and the instruction manual that came with the Stew-Mac pickup kit. I ordered three Alnico pickup kits. Each kit contained two flatworks, six pole pieces, mounting screws, two wire leads, and rubber tubing for mounting. In addition, I ordered poly-coated 42AWG copper wire for the coiling.

Installing the Pole Pieces

Before starting anything, I smoothed the edges of the flatwork using sandpaper. This was to ensure when winding the coil, the copper wire would not get stuck on a jagged edge of the fiber flatwork and snap. The next step was to carefully arrange the pole pieces based on the height given in the following diagram. The differing heights would make sure the output of each string was consistent based on their different gauges. The Stew-Mac flatwork pieces had predrilled holes, but they needed some work to fit the pole pieces in. Pushing the pole pieces in would punch out any excess fiber out. Using a two pieces of plastic that we measured to be within the suggested 7/16” to 15/32”, I was able to hammer the top flatwork in.

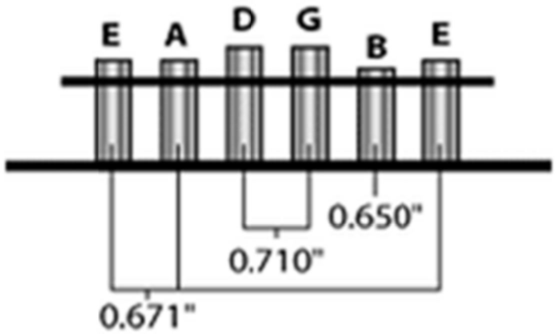

Figure 1. Pole Piece Spacing

Figure 2. Flatwork Construction

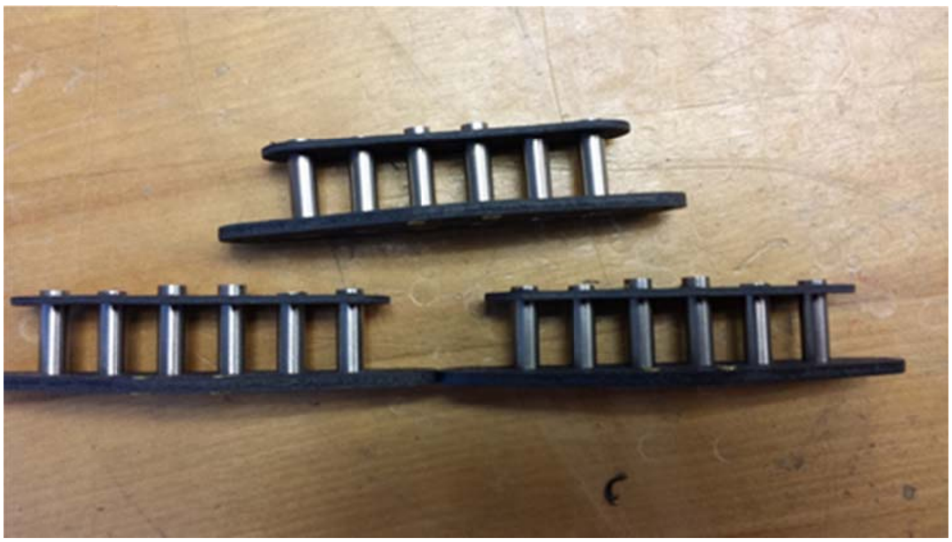

Figure 3. Poles and Flatwork

Winding the Coil

As previously warned by Professor Errede, this was to be the hardest and most tedious part of the construction process. Each pickup would have to be wound 8000 times. However, because of my inexperience, I was not maintaining a high enough tension on the wires while winding, and the 8000 turns on the first pickup made the coil a little too wide to the point where the coils were well outside the frame of the flatworks. This led me to rashly believe I could get away with about 6,000 turns, when it was just getting to the edge of the flatwork.

However, using the same rig and set up as previously used before, the process consisted of the 42AWG polycoated copper wire, a pulley system, and the pickup winding machine.

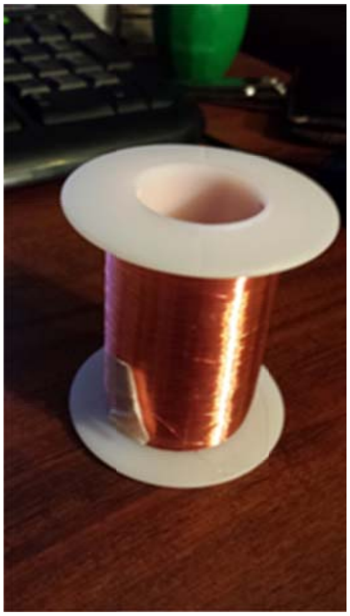

Figure 4. Copper Wire

Figure 5. Pulley Rig

Figure 6. Pickup Winder

The first step was to feed the copper wire through one of the two needle holes in the bottom flatwork around five times, to make sure there was initial tension before winding. Placing the pickup on the right side of the rig allowed me to make counter clockwise rotations, which was needed to make sure I had the right polarity.

I then placed the copper wire spool on a fixed position at the bottom of the pulley rig. At first, i started off lining the copper wire through the wheel, and into the winding machine. however, I had a lot of trouble keeping the wire on the wheel. It would consistently fall off and get stuck on the metal parts of the rig. This led to a few frustrating moments and breakage of the wire. I decided to go directly from the fixed position of the spool to the pickup winder. This strategy proved to be much easier, and I was able to continue the winding process without constantly checking if the copper wire was still on the wheel. Using my hands to keep tension, and carefully moving it back and forth between the two boundary pieces to evenly distribute the wire onto the pickups, I was able to slowly reach my desired coil count based off of the digital counter on the pickup winder.

Figure 7. Winded Pickups

Soldering the Lead Wires

Professor Errede helped me with all of the soldering needed to complete this project. Because each pickup was wound the same way, the only difference in polarity was where we would put the high wire, and where we would put the ground. The Neck and Bridge pickups would have to have opposite polarity from the Middle pickup to allow for hum-canceling. We followed the same foundation as the old pickups, and we were able to determine that the Bridge and Neck both had south polarity, and the Middle had North Polarity. For the Neck and Bridge, the finish was the ground while the high was the start. For the Middle Pickup, it was reversed.

DC Resistance Check

This was not only a test we did to analyze the electromagnetic properties of the pickups, but it was crucial in ensuring that a proper connection was made. These measurements were supposed to be about 5.75K-6.75K Ohms. Though the resistance in two of the pickups was not within that range, we were able to confirm the connection.

Potting the Pickups

The purpose of potting the beeswax was to help eliminate unwanted microphonics and feedback by keeping the copper coils in place. This was done using an old crockpot full of water and a glass jar filled with 80% paraffin wax and 20% beeswax. Professor Errede came up with this mixture to create a balance between the paraffin's harder physical quality to that of the beeswax's softer quality. The wax was to be heated to 180 degrees F before inserting any of the pickups. The pickups were done potted when no more air bubbles emerged, which was a process that took around 7-10 minutes.

Magnetizing the Pickups

The last step before installing the pickups back into my guitar was magnetizing them. This was done using rare earth magnets that Professor Errede had in the lab specifically for pickups. We were careful not to induce too strong of a magnetic field, so we only left the pickups between the rare earth magnets for a few seconds.

Installing the Pickups

The last and final step before being able to finally play the guitar again, was to solder back the pickups after screwing each of them back into their original position. Professor Errede again helped with the soldering, being careful to measure DC resistance making sure proper connections were made. This process took a little longer than expected, because the screw holes needed to be carefully adjusted using a corkscrew. Rubber tubing was used to help adjust height of each pickup.

Figure 8. Underside of Pickup Cover

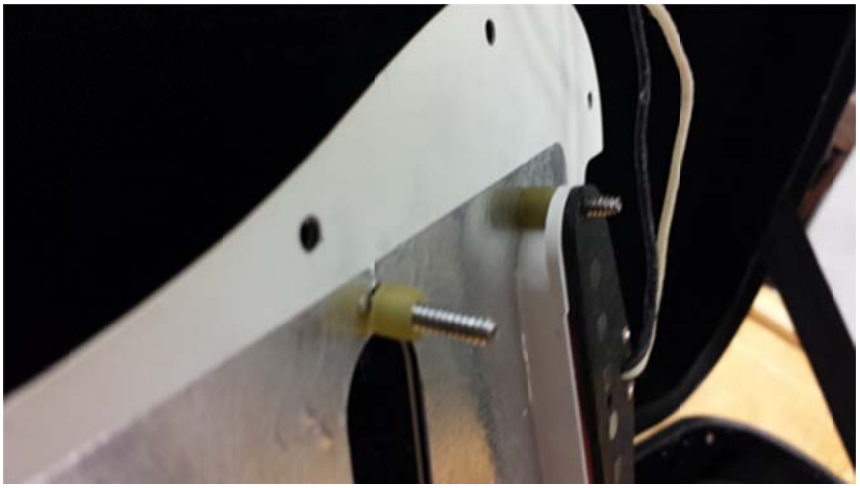

Figure 9. Rubber Tubing and Screws

Figure 10. Finished Product without Strings

Figure 11. Finished Product with Strings

Data Measurements

While constructing the new pickups, Professor Errede helped take measurements of the old ceramic pickups, and eventually ran analysis of the self wound pickups when they were completed. This way, we could compare the quality of the new and old pickups from a quantitative standpoint. Each pickup had to be analyzed separately, and we carried out measurements for all three of the neck, middle, and bridge pickups.

Below are some initial measurements that were made in testing the winding direction, polarity, Resistance, and Magnetic Field Strength. The Magnetic Field Strength was measured for each individual pole, corresponding to the E, A, D, G, B, and e strings.

Original:

	Polarity	Winding Direction	DC Resistance (KOhms)	Pull Off Test	Magnetic Field Strength (G)
Neck	South	CCW	7.32	Negative	E: 395 A: 415 D: 390 G: 388 B: 390 e: 355
Middle	North	CCW	7.08	Negative	E: 414 A: 405 D: 409 G: 387 B: 442 e: 388
Bridge	South	CCW	7.15	Negative	E: 414 A: 431 D: 379 G: 377 B: 421 e: 398

Self Wound:

	Polarity	Winding Direction	DC Resistance (KOhms)	Magnetic Field Strength (G)
Neck	South	CCW	4.26	E: 620 A: 625 D: 660 G: 670 B: 570 e: 1050
Middle	North	CCW	4.26	E: 1085 A: 950 D: 1095 G: 980 B: 970 e: 1100
Bridge	South	CCW	5.81	E: 1090 A: 985 D: 1010 G: 1050 B: 935 e: 1135

As we can easily see, the DC Resistance and Magnetic Field Strength greatly differed.

Important data that was measured were the Complex Voltage, Current, Power, and Impedance, however the total amount of graphs I received go into much more detail. Using the model below, we were able to carry out these measurements. The below graphs show the least square fit complex impedance, which is useful in understanding the actual output the pickup.

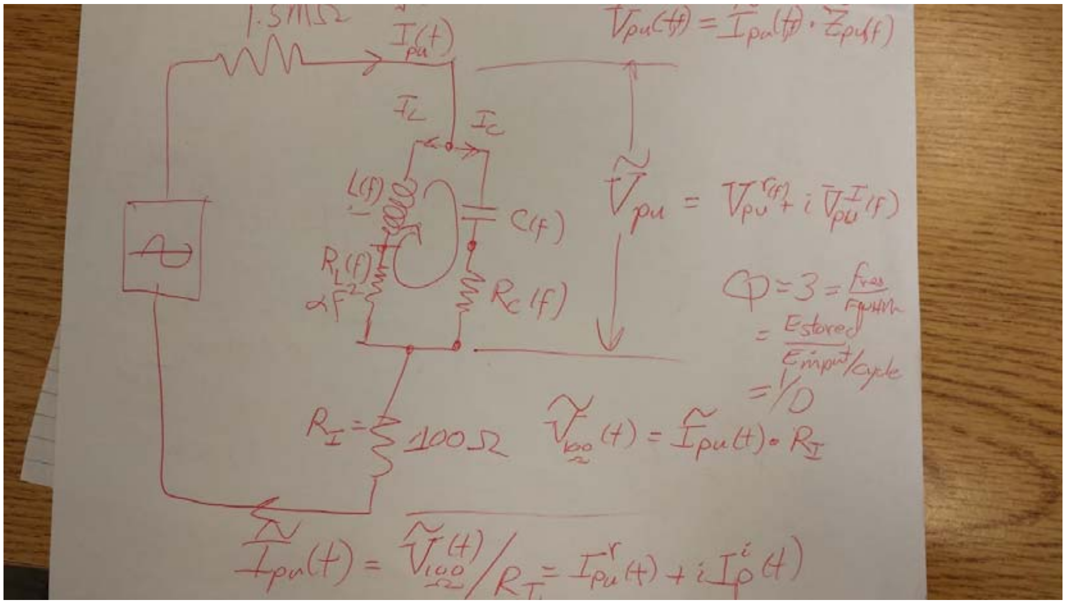

Figure 12. Pickup Model Circuit

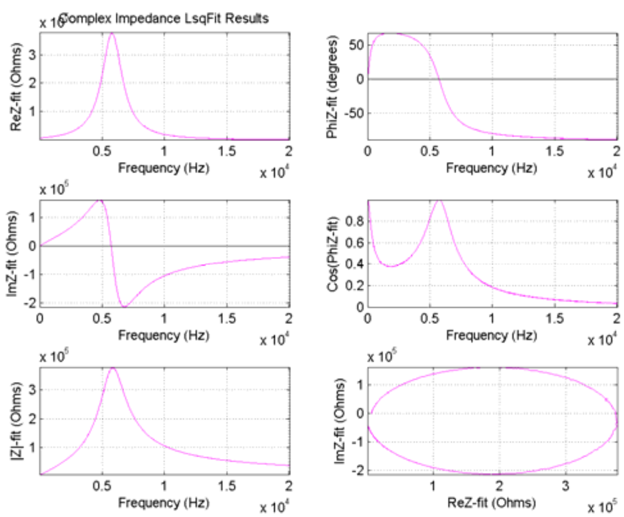

Figure 13. Original Neck LSQ Fit Complex Z

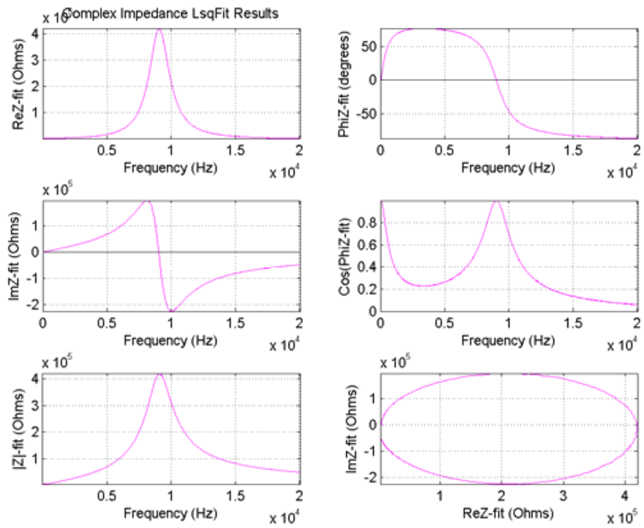

Figure 14. Self Wound Neck LSQ Fit Complex Z

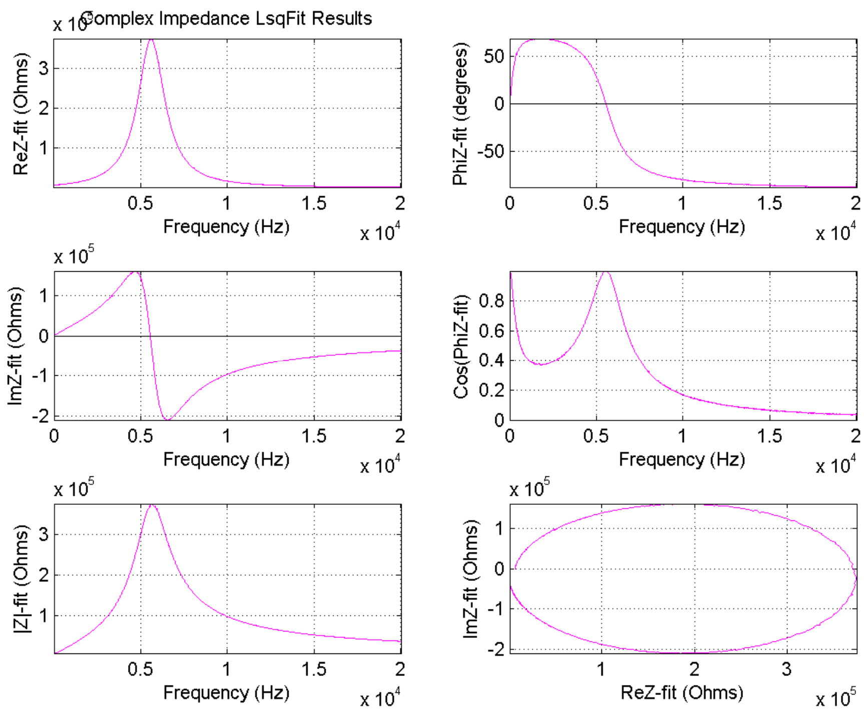

Figure 15. Original Middle LSQ Fit Complex Z

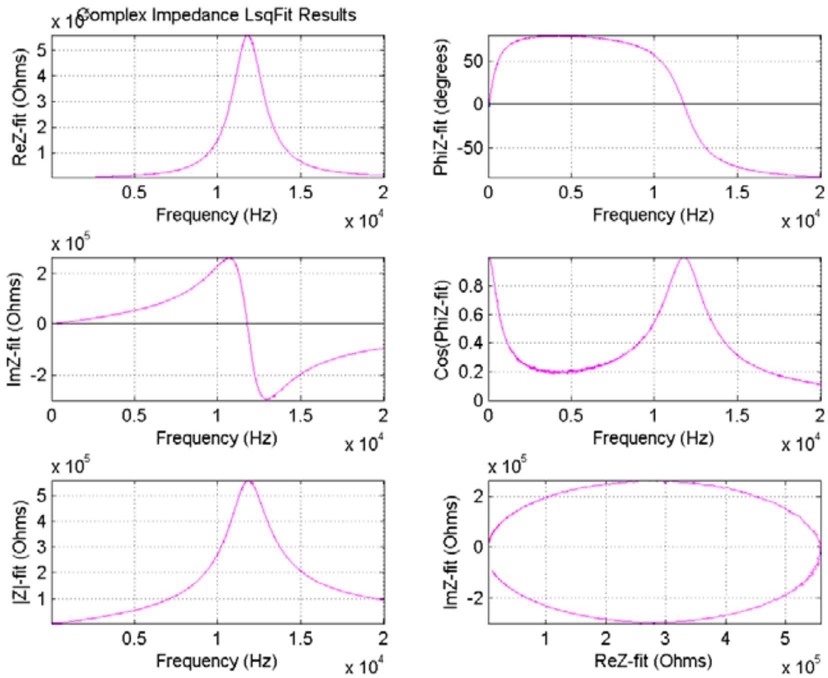

Figure 16. Self Wound Middle LSQ Fit Complex Z

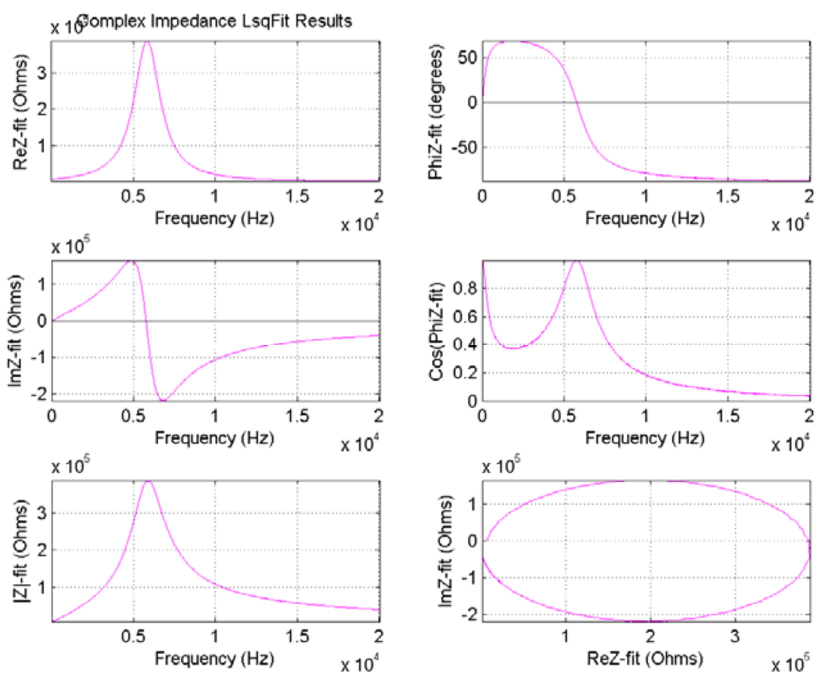

Figure 17. Original Bridge LSQ Fit Complex Z

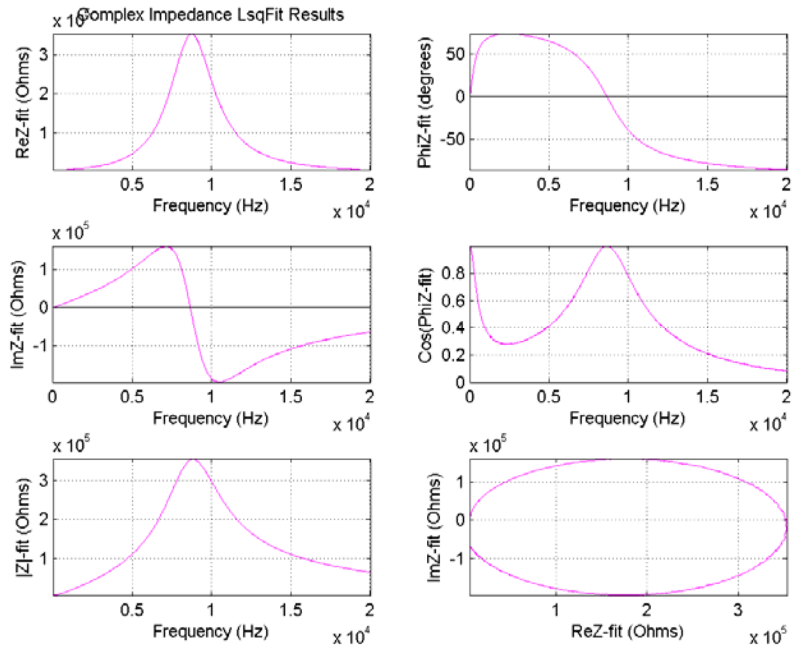

Figure 18. Self Wound Bridge LSQ Fit Complex Z

From these graphs, one could easily tell the inconsistencies between the self wound pickups. However, for the most part, the resonant frequencies are much higher in the new pickups versus the old pickups. The middle pickup has much higher resonance than both the self wound bridge and neck, which I found interesting. This could be attributed to the magnets and the quality of my own winding. The resonance width did not see any drastic differences except for the bridge pickup. We can see the bridge pickup has a much higher width of the resonances, which is something that I was very happy to see. This would result in a warmer sound on the bridge pickup, which is something I wanted to change about the tone of my guitar coming into this project.

Additional Analysis:

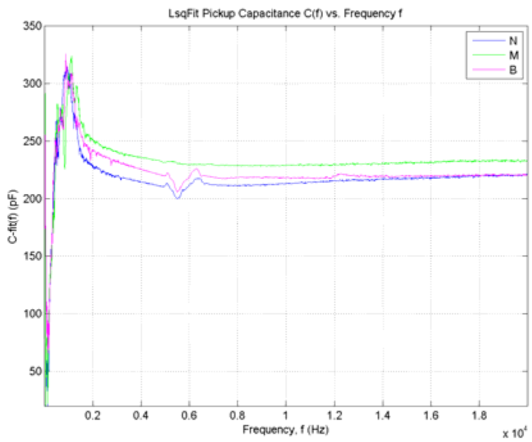

Figure 19. Original Capacitance

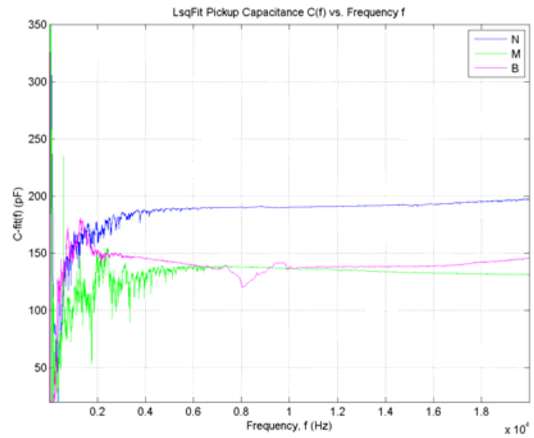

Figure 20. Self Wound Capacitance

One of the more interesting things that Professor Errede pointed out to me was apparent in the above graphs. Figure 19 shows resonances at around 1 KHz, while there are no such peaks in Figure 20. Professor Errede explained to me that the iron crystal structure in the ceramic magnets were the cause of this, something that was not present in the Alnico magnets in the self wound pickups. At the resonant frequency, the crystal structures acted like a loud speaker, propagating and vibrating back and forth much like a loudspeaker, just on a much smaller scale. This is a quality that was inherent in the ceramic magnets.

Conclusion:

This was a very meaningful project to me. It sparked an interest in the material and process that goes into producing quality sound in an electric guitar, something that I haven't given the time to research before. Although I've been playing for five years, I never paid much attention to the hardware, and now that I have some background knowledge, I know that this can be a very meaningful hobby going forward. The final test was playing the guitar through my amp at home, and either it was the excitement of not having played it in quite some time, but when I had adjusted the pickup height accordingly, it sounded great. I'm very pleased to have been able to come away with this project with a working, self-made improvement to my guitar, and I thank this class and Professor Errede for that.