Acoustical Properties of Wooden Solid Body Musical Instruments

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Introduction:

I have been playing solid body instruments for my whole life, and have always had an interest in their many properties. I have also built my own solid body electric guitar and would like to, in the future, build more solid body instruments. In order to further my knowledge on this subject, I conducted some simple acoustical tests on a few solid body instruments. The instruments used were a Zimbabwean Mbira, a Squier Fat Strat, and the solid body guitar that I built.

Instruments:

An Mbira is a “thumb piano” type instrument that is played by plucking the metal keys. The body of the Mbira is made of mubvamaropa (a Zimbabwean hardwood), and is approximately 6 inches wide, 12 inches tall, and 1 inch thick. The metal keys are bolted down using 4 metal bolts and a metal nut and stopper assembly. These bolts travel through the depth of the wood and can be tightened from the back. It also has bottle caps fastened to sheet metal to add a buzzing sound when played. See figure 1 for a picture of this instrument.

Figure 1: Mbira

The Squier Fat Strat is probably an alder body, and is most likely two separate pieces of wood glued together somewhere in the middle of the guitar. It has a maple neck with a 22 fret rosewood fret board. At the headstock, the strings are fastened with standard string tuners and a plastic nut. The bridge is a Fender floating tremolo style bridge with three springs to hold it in equilibrium. The neck is a bolt on type, with 4 screws traveling through the body and into the neck. Like standard Fender Stratocasters, it has three pickups. However, since it is the fat version, it has 2 single coils (neck and middle), and 1 humbucker (bridge). See figure 2 for a picture of this instrument.

Figure 2: Squier Fat Strat

My custom made guitar's body is made from a solid plank of alder. It also has a maple neck but with a 24 fret ebony fret board. As opposed to the bolt on neck of the Strat, it has a through the body neck. This means that the body is actually separated into two pieces and glued to both sides of the neck, with high-grade carpenter's glue. At the headstock, the strings are fastened with standard string tuners and a graphite nut. The bridge is also a Fender floating tremolo style bridge with three springs. Like the Squier, it also has three pickups. The configuration is 1 single coil (neck), 1 single coil sized humbucker (middle), and 1 full sized humbucker (bridge). See figure 3 for a picture of this instrument.

Figure 3: Custom Built Guitar

Method:

To measure the acoustic properties of the instruments, we used piezo-electric transducers. One transducer was used as an acoustic wave transmitter and a second was used as an acoustic wave receiver. The transmitter was connected to a computer controlled function generator which injected a sine wave whose frequency was swept, by the computer, from 10 to 1010 Hz in 1 Hz steps with a step time of 1 sec. The receiver was connected to a lock in amplifier, which determined the fundamental frequency of the signal and sent the complex valued impedance data to the computer. See figure 4 for a diagram of the setup. After the sweep was complete, the impedance data, collected by the computer, was saved to an excel file for interpretation.

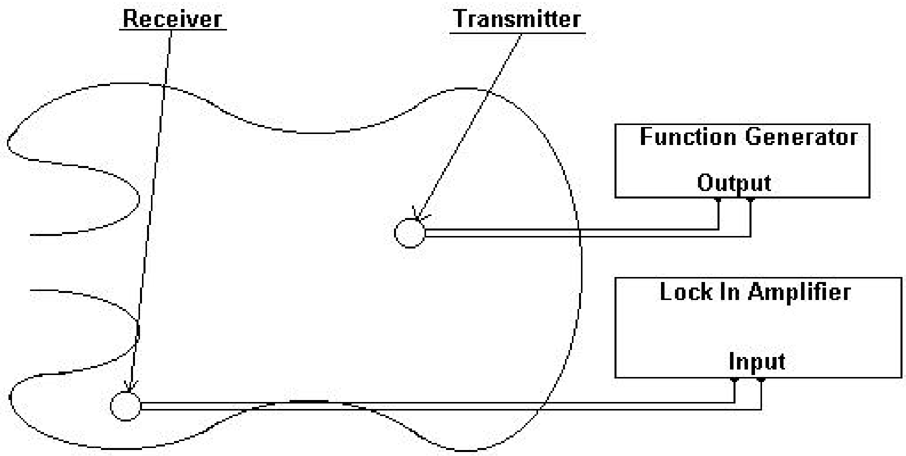


Figure 4: Diagram for Acoustic Test Setup

Results:

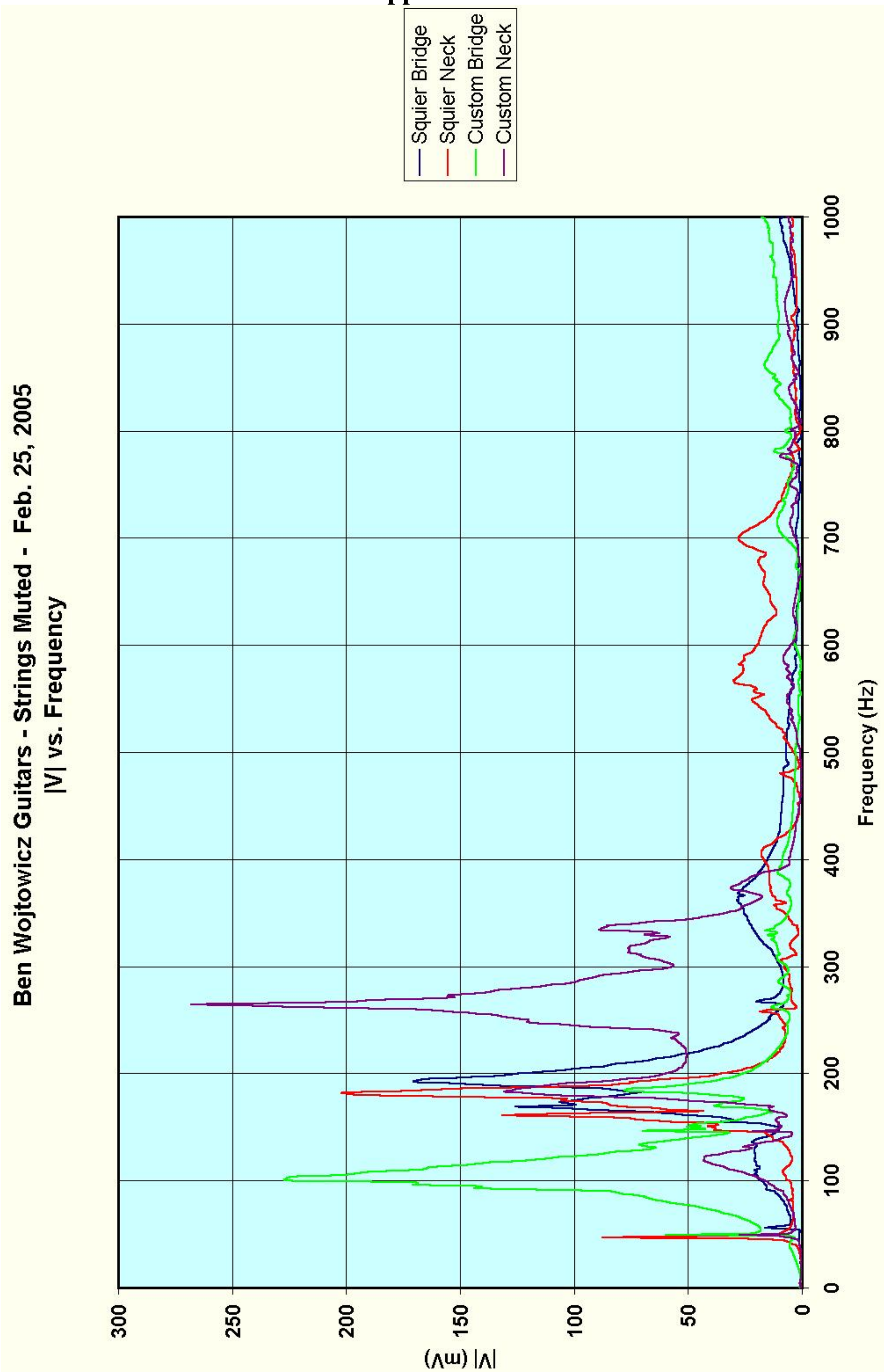
The measurements were performed on both the guitars with the strings muted and in two locations (receiver by the bridge or by the neck, transmitter by the bridge for both). Since I designed the custom built guitar to be similar in appearance to a Strat, the two guitars should show similar results. Overlaying the data, we get A.1 in the appendix. The first thing that is noticed is that the custom guitar, at the resonant peaks, has a higher magnitude than the Squier guitar. However, we must be careful in this comparison, because a 10Vp input was used for the Custom guitars bridge measurement and a 5Vp input was used for all other measurements. Therefore, we can only compare the neck measurements of the two guitars in terms of amplitude. In this comparison, the custom guitar still has larger resonant peaks than the Squier. This might be due to the better acoustical coupling (i.e. sustain) of the through the body neck as opposed to the screw on neck of the Squier. A second observation is that the shapes of the impedance curves are very similar. This is most definitely due to the similar shape of the two instruments. With the same shape, the instruments will have identical Chladni patterns and hence, acoustical standing waves will have nodes and anti-nodes in the exact same places on both instruments. Therefore, the shape of the impedance vs. frequency curves should be similar for the two guitars. The differences that are observed can then be linked to the subtle differences in the two body shapes. Note that this is an approximation of what is observed. In reality many different factors will contribute to the shape of the impedance curve, but the dominant factor is the shape of the body. Another significant factor might be the cavity space for the electronics. The pickup cavity space is larger in the Squier, but the control cavity space slightly bigger in the custom.

In contrast to the guitars, the Mbira had a different impedance curve altogether. The results from this test are given in A.2 of the appendix. Note that the keys were not muted for this test, and hence many resonant peaks are visible. These resonances occur precisely at frequencies corresponding to the pitches of the keys. If we ignore the peaks, the general shape of the waveform gives us information about the instrument body itself and also the location of the transmitter/receiver pair. Since the receiver will measure the no input when it is at an anti-node, moving it to a new location will drastically change the measured data. Two measurements were made at two different voltage output levels with the transmitter/receiver pair in approximately the same location. When compared, we see that the resonances of the first measurement are not identical to the resonances of the second measurement. This is mostly due to the instrument being dropped between measurements and detuning slightly. However as stated above, another reason for the inaccuracy is the location of the transmitter/receiver pair.

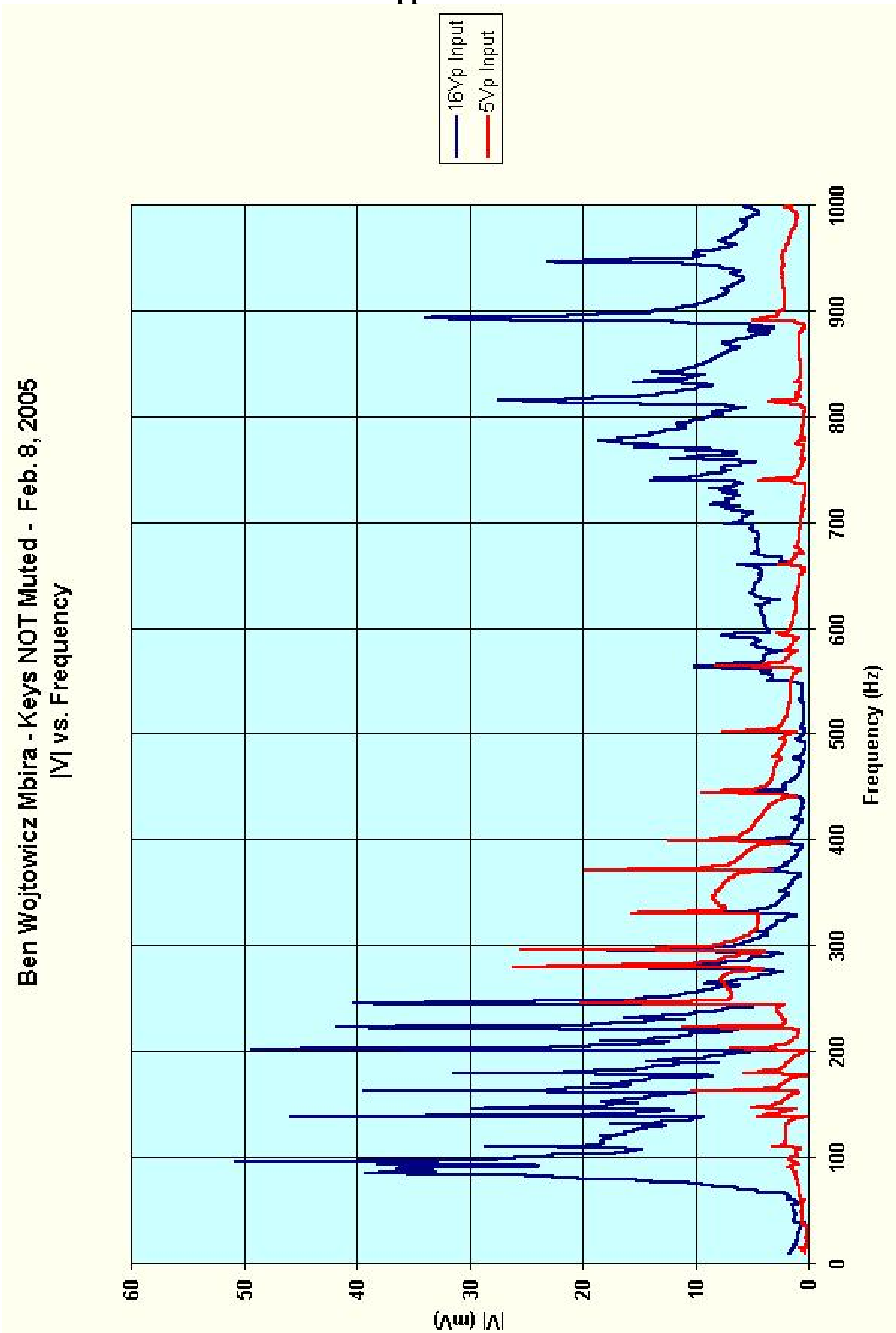
Conclusion:

These tests gave me insight about the general acoustical resonance of solid body instruments. Coupled with the knowledge from class, I was able to determine what some of the results meant. Even though I learned a lot from performing these acoustical tests, I think I could learn more from directly observing the Chladni patterns of the instruments. However, measuring the Chladni patterns would not be nearly as simple as the acoustic property tests performed here.

Appendix A.1


Ben Wojtowicz Guitars - Strings Muted - Feb. 25, 2005
|V| vs. Frequency
|V| (mV)
Frequency (Hz)
Squier Bridge
Squier Neck
Custom Bridge
Custom Neck
0
50
100
150
200
250
300
0
100
200
300
400
500
600
700
800
900
1000

Appendix A.2



Ben Wojtowicz Mbira - Keys NOT Muted - Feb. 8, 2005
|V| vs. Frequency
16Vp Input
5Vp Input
|V| (mV)
Frequency (Hz)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
900
1000