

## Bacon Banjo Analysis

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I have been playing banjo for some time now, so it was only natural to want to understand its unique sound. There are two ways I analyzed my instrument. The first was to record single notes, and to look at the harmonics present using the WAV analysis program developed by the professor. The second is to use a setup with a piezoelectric element to excite the body of the instrument and microphones to record particle velocity and overpressure, and use this to find mechanical resonances. As the banjo has a drum head, I also wanted to use the magnet setup for vibrating a drum head and measuring the change in distance at various points on the head, but the bridge and strings on the banjo made this impossible to do, and taking those off would alter the vibration of the banjo head.

Throughout the semester, I mostly looked at comparisons. This started with me comparing the mechanical resonance of my banjo with that of a ukulele and a mandolin. The fact that the banjo's resonances were more like a mandolin's made me think about comparisons with other bluegrass instruments. There were few files showing the resonances of older instruments, and the analysis I found of a guitar was unsuitable for comparison with the files of the banjo and mandolin. Instead, I used the G3 note, which is present in guitars, banjos, mandolins, and fiddles as an open string.

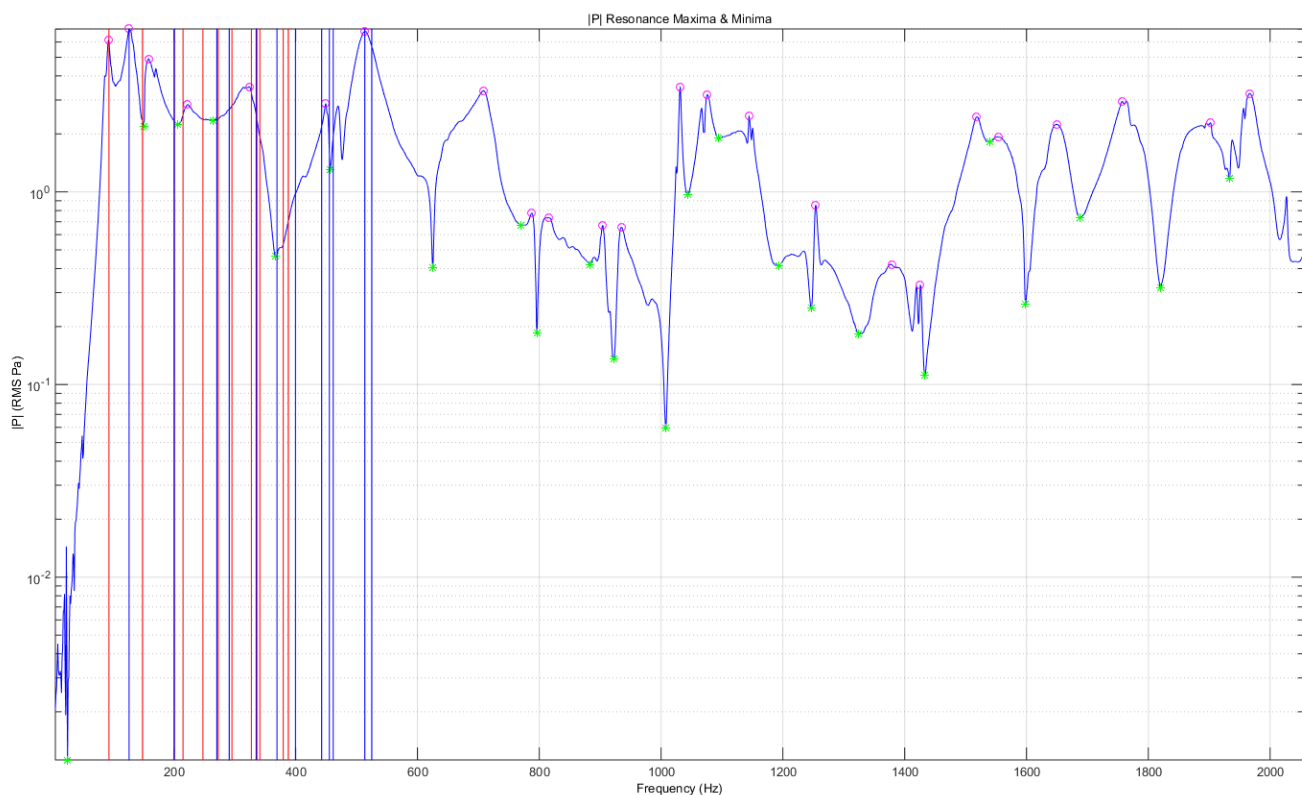
I found recordings of both a nylon strung and steel strung guitar, which showed notable differences. Because my banjo is nylon strung, which is typical of very old banjos but not those used in bluegrass, I found a recording of a steel strung banjo as well. It was interesting to note that the banjos tended to have a higher harmonic that was louder than the fundamental, while the guitar did not. At the same time, the nylon strung instruments had fewer higher harmonics than the steel strung ones.

I also compared notes on the banjo with other notes on the banjo. The first comparison was to

see if retuning the banjo (from gDGBd to gDGCd) made any difference to the notes that were not changed, but I couldn't find a concrete difference. Later in the semester, I looked at the note G4 which can be played on every string on the banjo, one of which is the open string. I wanted to see how string thickness affected the harmonics of the note, and the differences between an open string, a finger, a slide, and a harmonic.

## **Part 1: Mechanical Resonance of a Bacon Banjo**

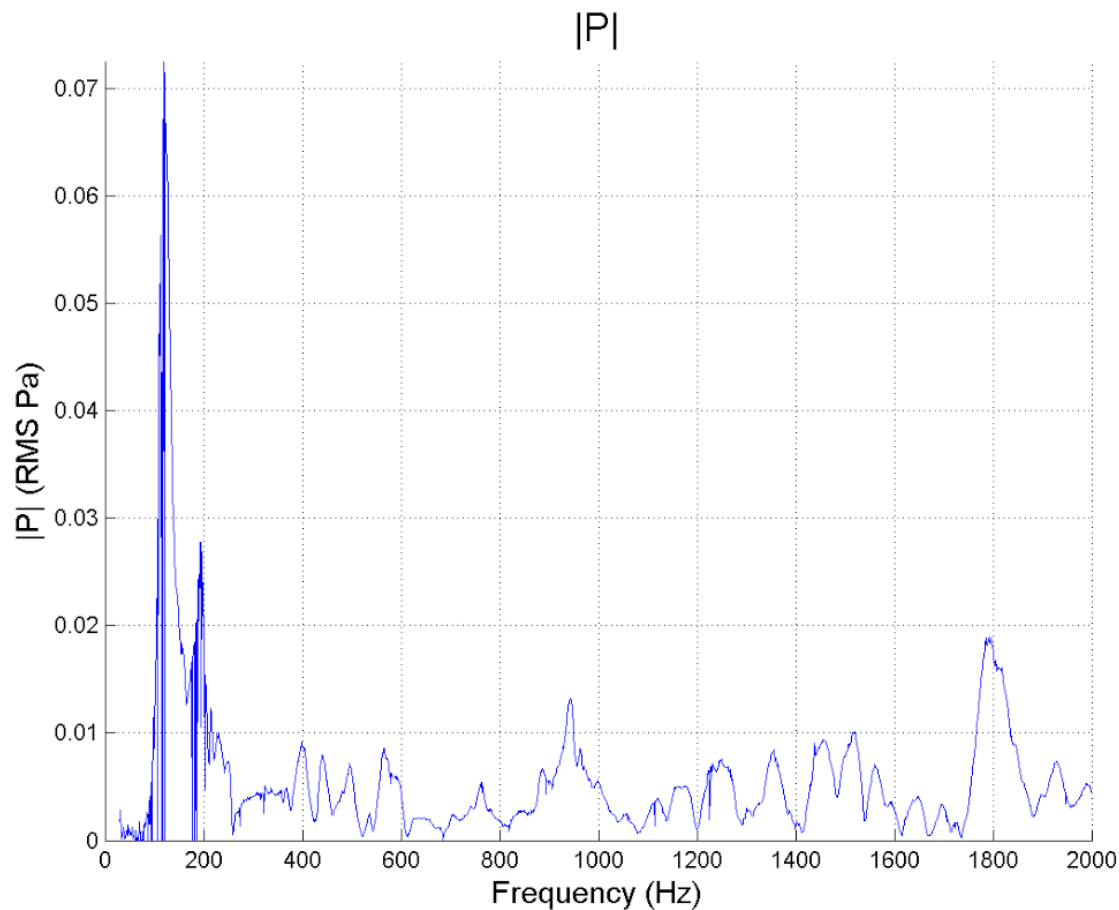
When I look at a banjo, I see a drum head with strings. As such, I thought the mechanical resonances of the banjo would correspond to modes of a circular membrane. The presence of the bridge and strings, however, complicates matters. I had initially thought that the bridge would act as a node, allowing only certain modes of a circular membrane, but the strings don't apply infinite tension and the drum head is not infinitely flexible, so what I found didn't match my predictions. There was also some confusion on my part as to which note to use as a fundamental.



Red lines correspond to modes of a circular membrane if 93.5 Hz is the fundamental frequency, while blue lines correspond to a fundamental of 126.5 Hz. Neither set of lines agree well with the actual maxima.

## Part 2: Comparison of Bluegrass Instruments

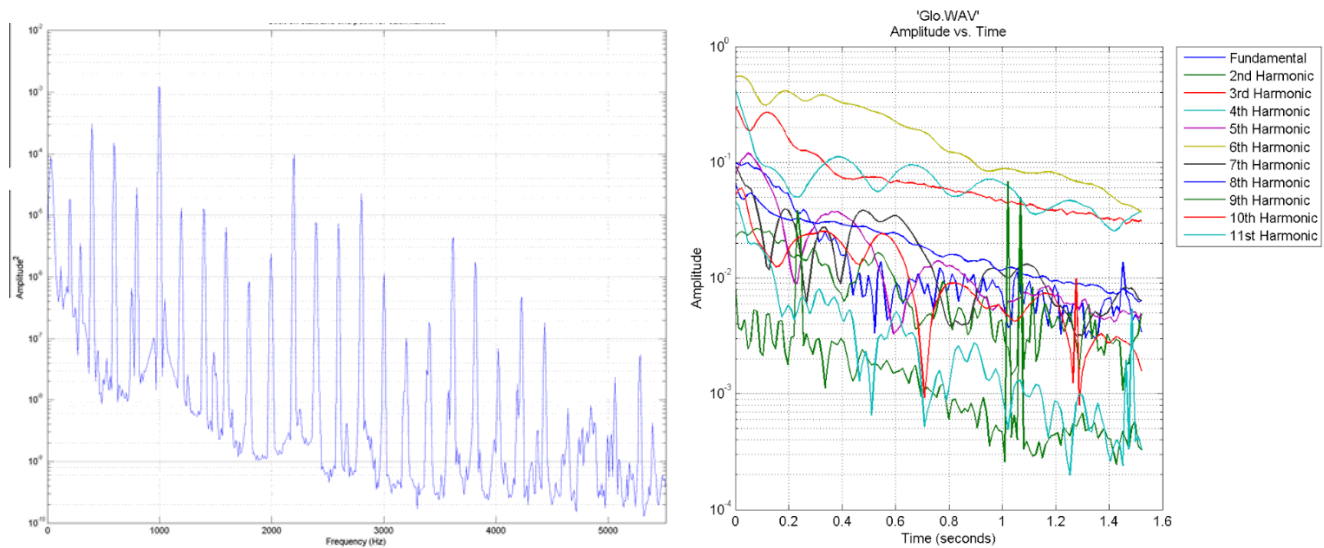
I started looking at bluegrass instruments due to noticing that my banjo's mechanical resonance data was closer to that of a mandolin than a ukulele. This got me thinking about whether the instruments typically used in bluegrass had some shared characteristics that make them sound good when played with each other. I started using mechanical resonance data I had of my banjo, the TA's mandolin, and a guitar someone analyzed in a previous year. There were two main problems. The first was that the guitar's data seemed strange due to one very high resonance peak combined with flatness everywhere else.



## Resonance Data of a Yamaha Guitar

This data is also not useful for making comparisons between instruments as many of the parameters used in the setup, such as driving voltage, change between runs.

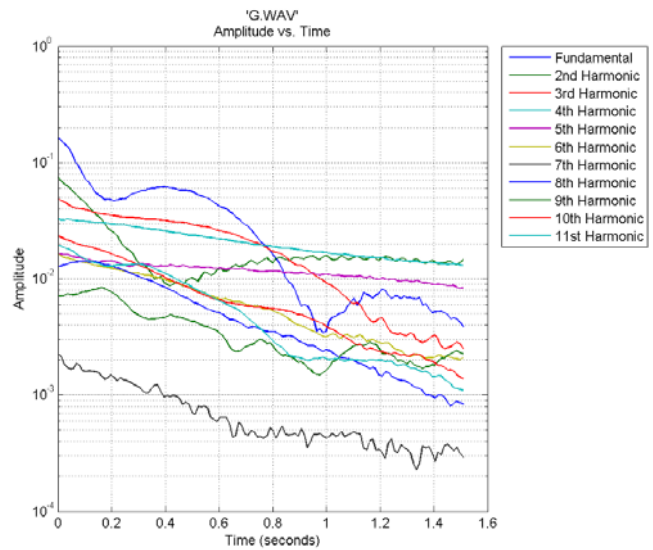
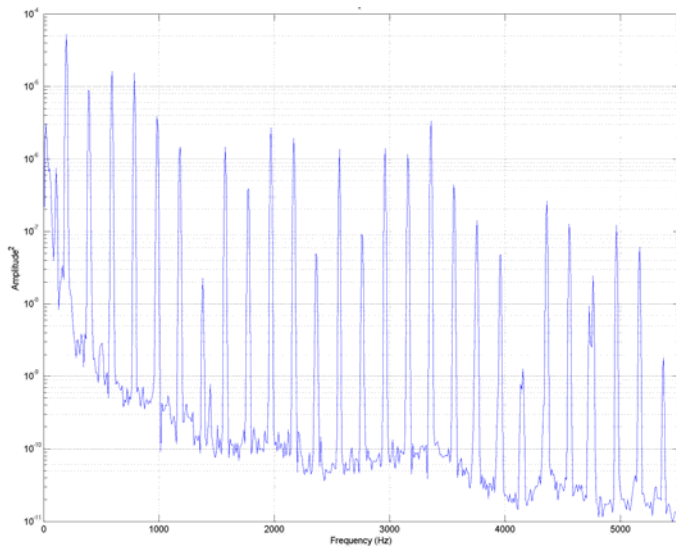
Instead, I decided to use sound recordings, which are also more relevant to the sounds instruments make when they are played. I used the note G3 as it is an open string on every bluegrass instrument except the bass. I also used a recording of a steel string banjo instead of my nylon strung banjo, which is not made for playing bluegrass.



## Harmonic Range and Amplitude vs Time Graphs for an Epiphone Banjo

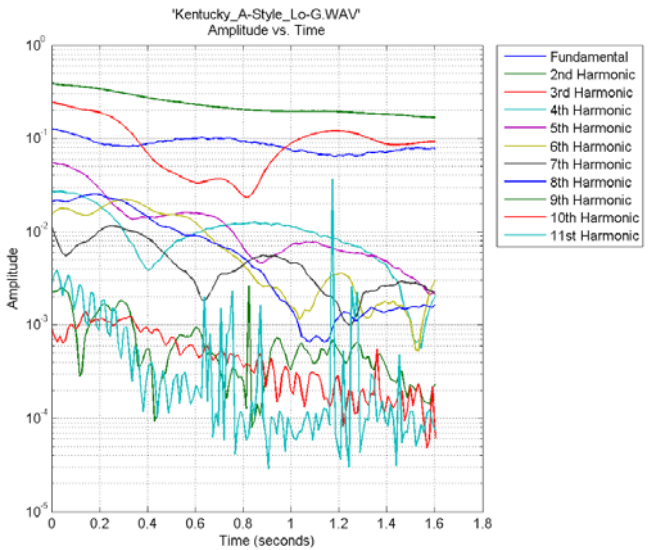
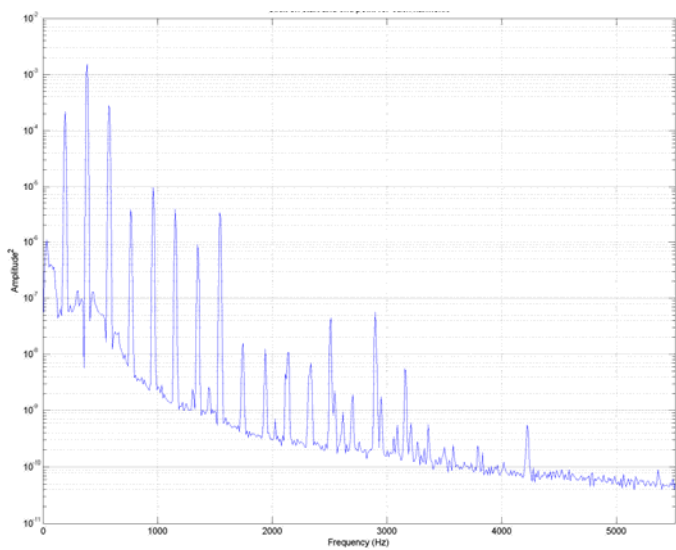
For an Epiphone banjo, the 6<sup>th</sup> harmonic was louder than the fundamental. In fact, the fundamental was quieter than most harmonics until the 6<sup>th</sup>. The harmonic range is somewhat chaotic in that there is no clear repetition of relative peak size, and there are noticeable peaks throughout the range of audible sound. The peaks in the harmonic range fell logarithmically over frequency (the amplitude<sup>2</sup> axis is given in powers of 10). The graph of amplitude of harmonics vs time is very messy. Notes stop dropping in amplitude and become chaotic. My guess is that these notes became quieter than the 1/f noise, which is why notes with lower frequencies tend to exhibit this behavior more

quickly.



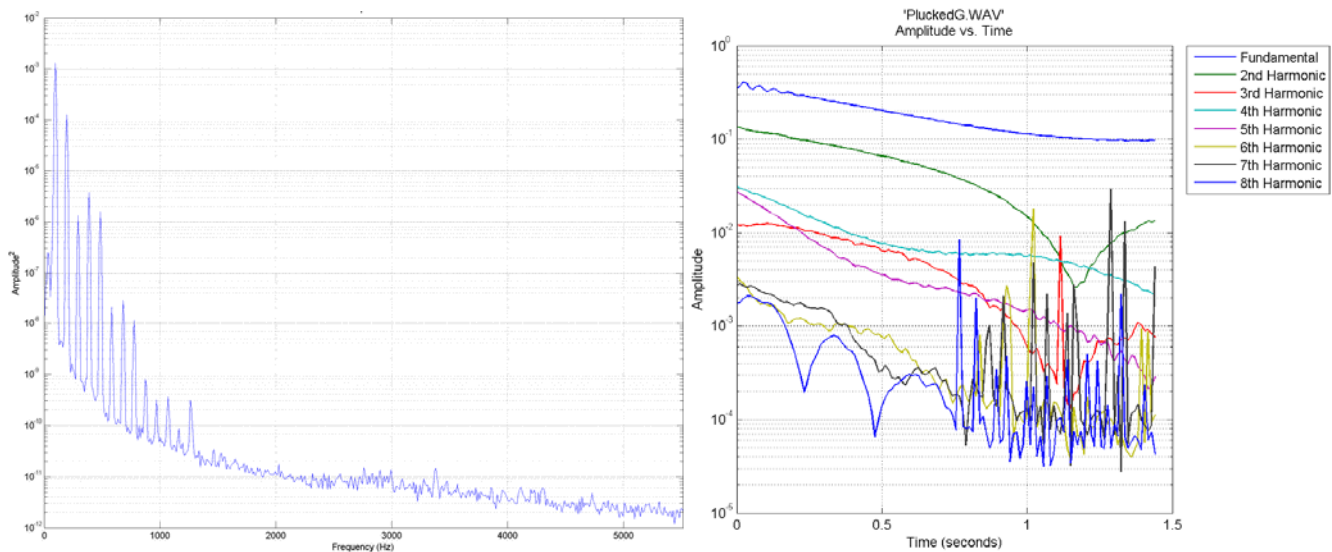
### Harmonic Range and Amplitude vs Time Graphs for an Epiphone Guitar

In contrast to the banjo, the guitar was more orderly. The fundamental was the louder than any harmonic, and the amplitudes all decayed at a relatively constant rate. The chaotic behavior seen with the banjo’s harmonic amplitudes was not seen, which I would attribute to the slower decay of the guitar. Like the banjo, there is no shortage of harmonics at higher frequencies. The guitar has a large range of frequencies where the harmonics are about the same amplitude



### Harmonic Range and Amplitude vs Time Graphs for a Kentucky A Mandolin

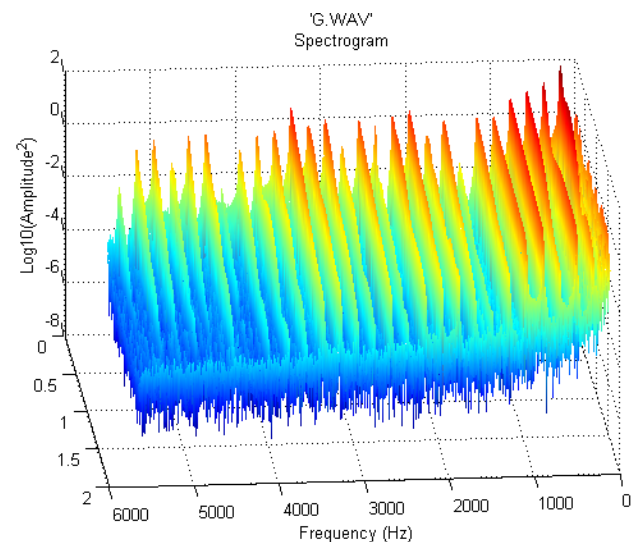
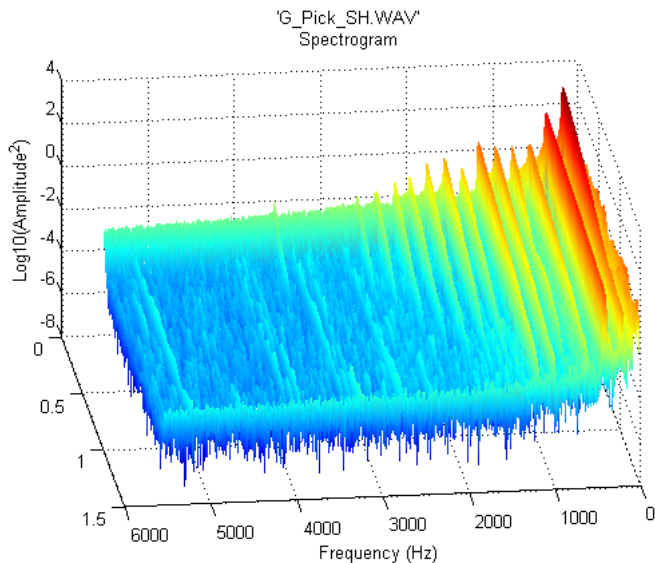
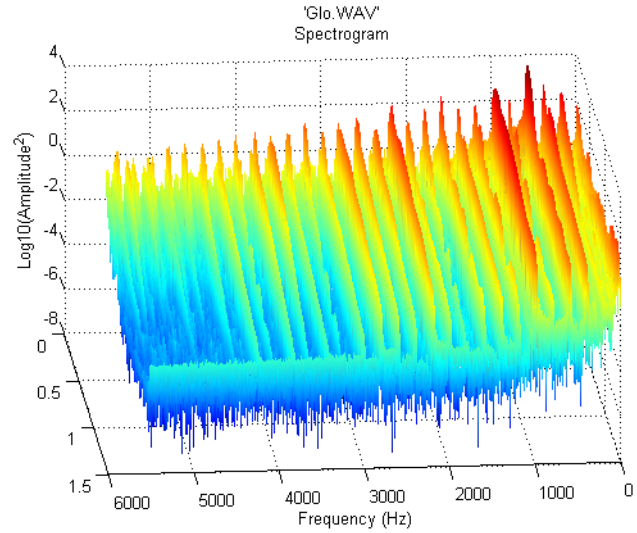
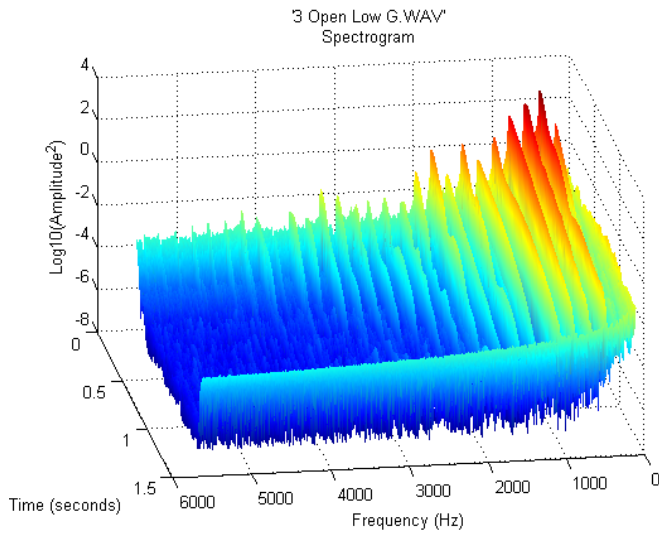
Like the banjo, the fundamental on the mandolin was not as loud as some harmonics. Unlike the banjo, there aren't many harmonics at high frequencies. The amplitude of the harmonics drops suddenly and there aren't any high peaks past 3300 Hz. For some of the higher harmonics looked at in the amplitude vs time graph, you can see chaotic behavior, indicating that those notes died down to below the noise level for that frequency. The lack of harmonics at high frequencies shows that the harmonics of a mandolin have more to do with the strings of a string instrument than the body.



### Harmonic Range and Amplitude vs Time Graphs for a Double Bass

I also decided to look at a double bass. As G3 is not an open string on a bass, I looked at the plucked G2 string. The harmonic range of the bass shared characteristics with those of other instruments: Like a guitar, the fundamental is louder than any of the harmonics. Like a banjo, the harmonics lower in amplitude in relation to frequency. Like a mandolin, there is a lack of higher harmonics. The graph of amplitude vs time was like that of a mandolin; lower harmonics decayed over time while higher harmonics died off and were overtaken by noise.

### Part 3: Nylon Strings vs Steel Strings



**Frequency vs Amplitude vs Time graphs for steel and nylon strung instruments. Nylon strung is on the left while steel strung is on the right. The top is for banjos while the bottom is for guitars.**

While I was looking at data for bluegrass instruments, I grabbed a file for a classical guitar by accident. I realized that it shared many differences from a steel strung guitar with my nylon strung banjo. Both nylon strung instruments had less presence of higher harmonics (in the case of my banjo, the harmonics were quieter, while on the classical guitar they didn't exist). The nylon strung guitar also displayed a drop in harmonic amplitude vs frequency similar to the banjos and not present in the

guitar. Both guitars, however, had a fundamental louder than any harmonic. The banjos did not. The banjos' sound also decayed more quickly than either guitar as shown by the chaotic behavior present in the amplitude vs time graphs of both banjos, but neither of guitars'.

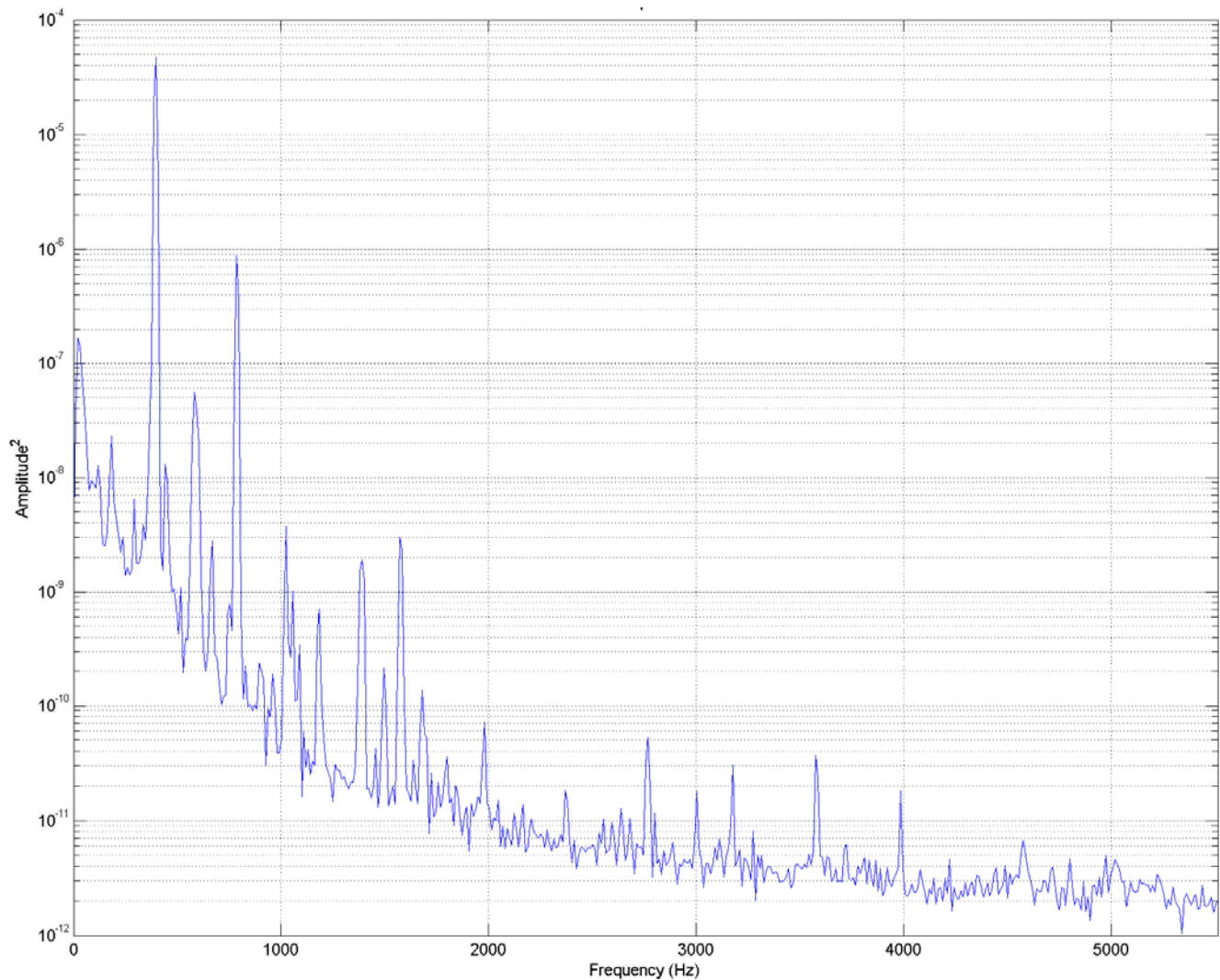
#### **Part 4: Changing Attack and Decay using Matlab**

Inspired by Music Concret, a movement that looked at what happened to sounds of instruments when the attack and decay was cut off and different parts of sounds were put together, I decided to try and make constant volume versions of some of my recordings, which would let me hear harmonic data only. I imported the wav files I recorded into matlab, which converted them into samples over time. To modify the volume, I took a samples of a function equivalent in number to the samples from the wav files. I then multiplied the two sets of samples together. To counteract the decay, I used an exponential function. To counteract the attack, I used a square root function. By playing with the parameters of these, I was able to get a note to sound very different. The result reminded me of an occasion on which I attempted to bow my banjo. For comparison, I multiplied a 196Hz sin wave by the inverse of the functions I used to produce an even note in an attempt to copy the attack and decay of a banjo note. The resulting sound was boring and incomplete to me, as it lacked the harmonic details of the banjo note.

#### **Part 5: Comparisons of G4**

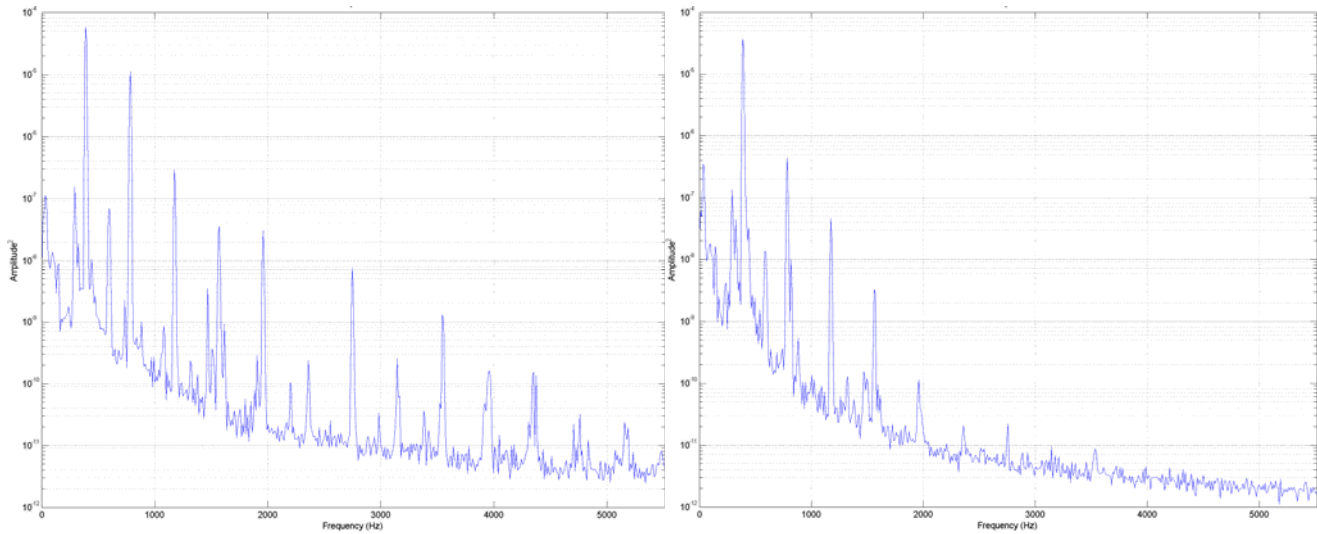
One of the interesting things about playing banjo is that most notes can be played in multiple ways. The most interesting note is G4, the note corresponding to the short 5<sup>th</sup> string of a 5 string banjo. The note can be played on every string on the banjo. As it lies on the octave of the G3 string, it can also be played as a harmonic. I decided to compare every possible way of playing G3 on a banjo, including using a capo or slide in place of a finger.





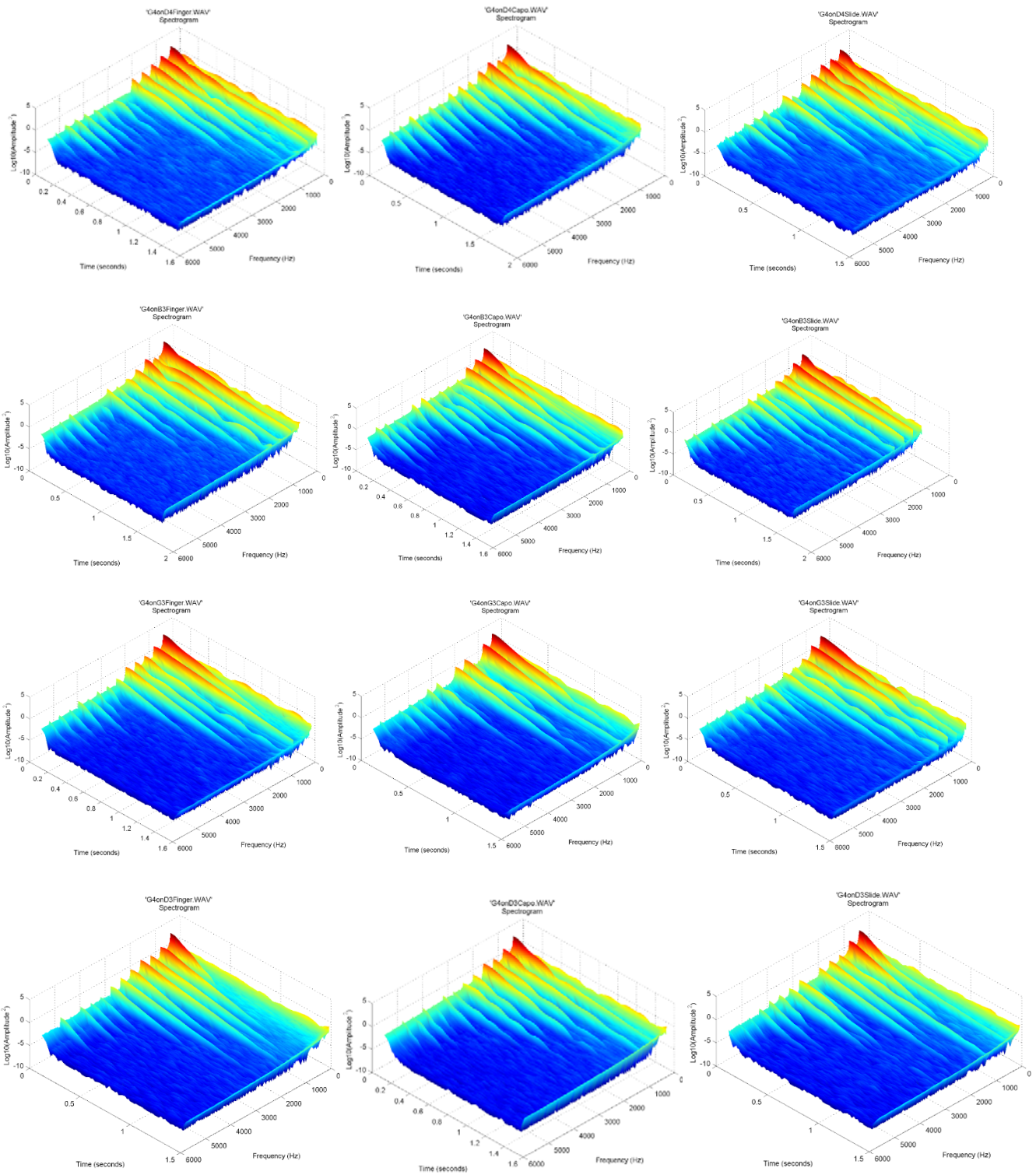
### Harmonic range of G4 as a harmonic on the G3 string.

G4 can be played as a harmonic on the G3 string, where the finger lightly touches the G3 string at its midpoint. When played this way, the note decays much more quickly, and few higher harmonics are present. What I discovered, though, is that the odd harmonics of G3 were still present (the harmonics of G4 correspond with the even harmonics of G3), albeit quiet. This means that playing the note as a harmonic does not create a perfect node at the midpoint. This made me curious about if using a slide would cause the same behavior.



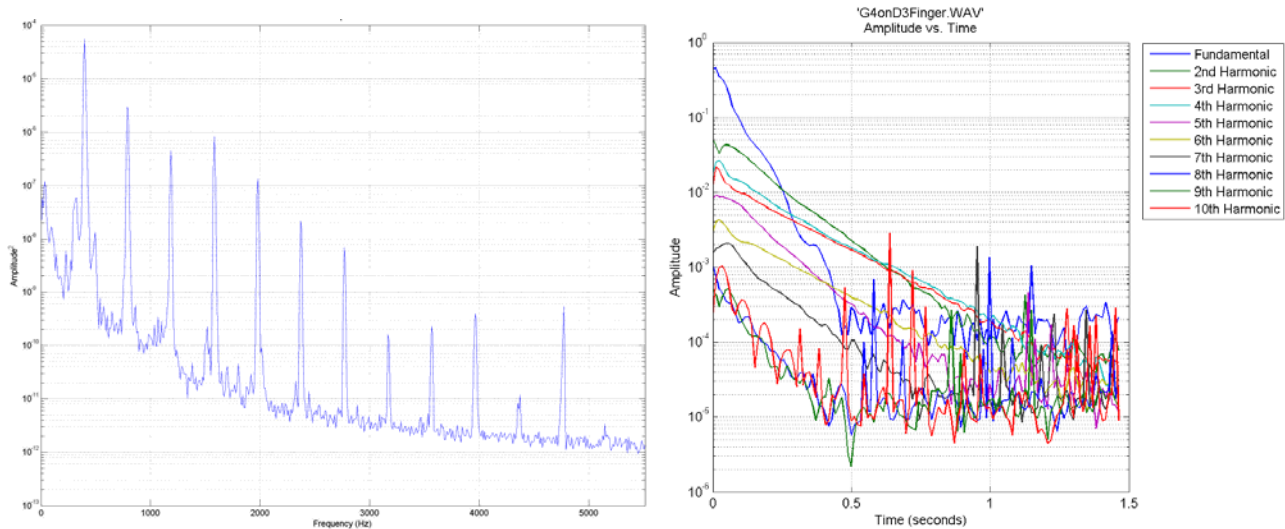
### **Harmonic range of G4 played with a slide on the G3 string compared to a new recording of G4 played as a harmonic**

As I had not recorded with a slide when I started my project, I needed to record again. I also recorded G4 on strings I had not yet played it on (the D3, B3, and D4 strings). This time around, I couldn't find odd harmonics of G3 even when I played G4 as a harmonic. There can be a lot of variance in the sound produced by playing a harmonic, especially by an unskilled player like me. I found the slide to be livelier than the harmonic, which I attribute to the smooth glaze of the slide I used having less friction than my finger.



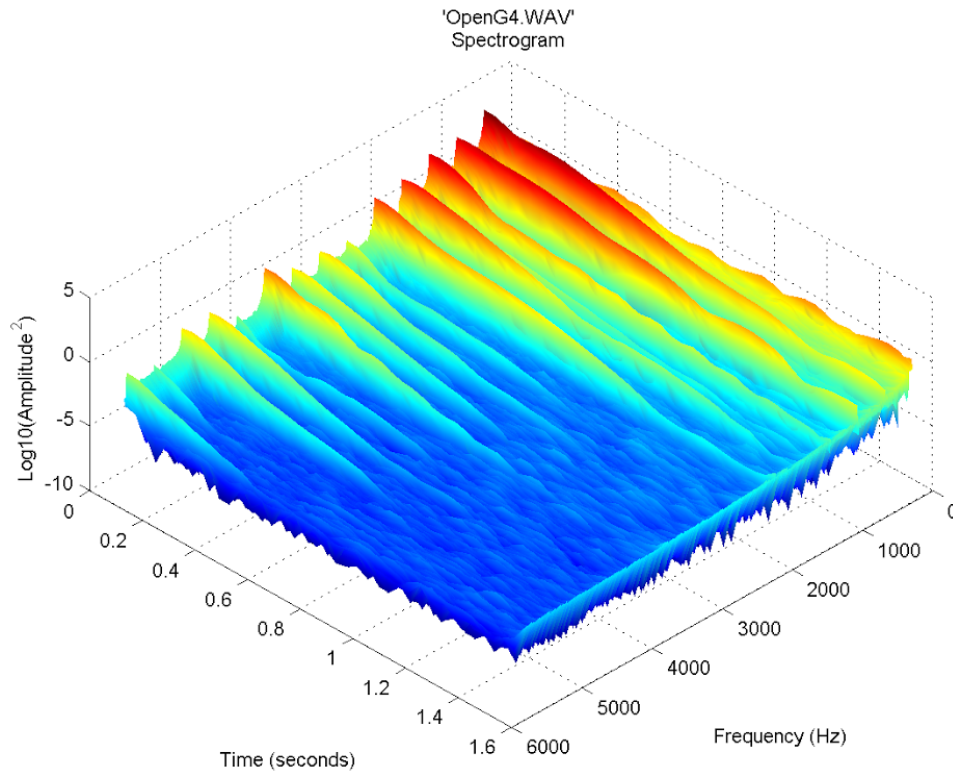
**Comparison of Spectrograms for methods of playing G4 on a banjo. Finger in on the left, capo is in the middle, and slide is on the right. Top row is on D4 string, followed by B3 string, G3 string, and D3 string.**

The differences between using a capo and a finger were minor, and were inconsistent between strings. If I had taken multiple recordings of using a finger or a capo for each note, I suspect that there would be as much variation between the runs as is seen here. The use of the slide was also very similar to a finger or capo.



### Harmonic Range and Amplitude vs Time Graphs of G4 played on D3

The D3 string, which is the thickest string on the banjo and the only string on my banjo which is wound, sustained sound for a much shorter period than other strings. The D3 string is also the only string where the fundamental started louder than any harmonic. On the G3, B3, and D4 strings, the second harmonic starts as the loudest part of the sound.



### Spectrogram of open D4

The open D4 was livelier than any other method of playing the note, producing both more sustain and louder harmonics than other methods of playing the note.

### Conclusion

I learned a lot about the individual oddities that make the banjo sound like it does. Little details I had previously heard from a banjo, such as the low part of the note decaying to leave behind a high pitched sustained sound, I saw on a graph. One of the big lessons I learnt was that musical instruments are complicated, such as the mechanical resonance of the banjo head being affected by the strings. The resonances and sounds of a musical instrument come from many factors. Still, I was able to isolate the difference that nylon strings make. I hope in the future to be able to create experimental setups that let me test one part of a musical instrument at a time, and to see what changing it does.