Electric & Acoustic Guitar Strings:
A Recording of Harmonic Content

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Introduction

The purpose of this study was to analyze the harmonic content and decay of different guitar strings. Testing was done in two parts: 80 electric guitar strings and 145 acoustic guitar strings. The goal was to obtain data for as many different brands, types, and gauges of strings as possible.

Testing

Each string was tested only once, in brand new condition (unless otherwise noted). Once tuned properly, each string was plucked with a bare thumb in two different positions. For the electric guitar, the two positions were at the top of the bridge pickup and at the top of the neck pickup. For the acoustic guitar, the two positions were at the bottom of the sound hole and at the top of the sound hole.

The signal path for the recording of an electric guitar string was as follows:
1994 Gibson SG Standard to ¼" input on a Mark of the Unicorn (MOTU) 896 to a computer (via firewire). Steinberg's Cubase VST 5.0 was the software used to capture the `.wav` files.

The 1999 Taylor 410CE acoustic guitar was recorded in an anechoic chamber. A Bruel & Kjær 4145 condenser microphone was connected directly to a Sony TCD-D8 portable DAT recorder (via its B&K preamp, power supply, and cables). Recording format was mono, 48 kHz, and 16-bit.

Data Entry/Preparation

From the DAT recorder, the data was dumped to a PC via a Sony PCIF-5 interface that performs direct digital-to-digital transfer. Sony PcscanII (version 3.0) was the software used to capture the data and write `.bin` files.

Matlab was used to write a `.wav` file from these `.bin` files. I have included the code for `rock.m` in Appendix I that accomplishes this.

Once I had `.wav` files for each pluck of each string, I used Steinberg's Wavelab v4.0 to generate color graphics of the pluck's harmonic decay with time. These graphics are included in Appendix II and Appendix III for electric and acoustic guitar strings respectively. Figure 1 shows an example of a Martin 80/20 Bronze SP wound string's decay.

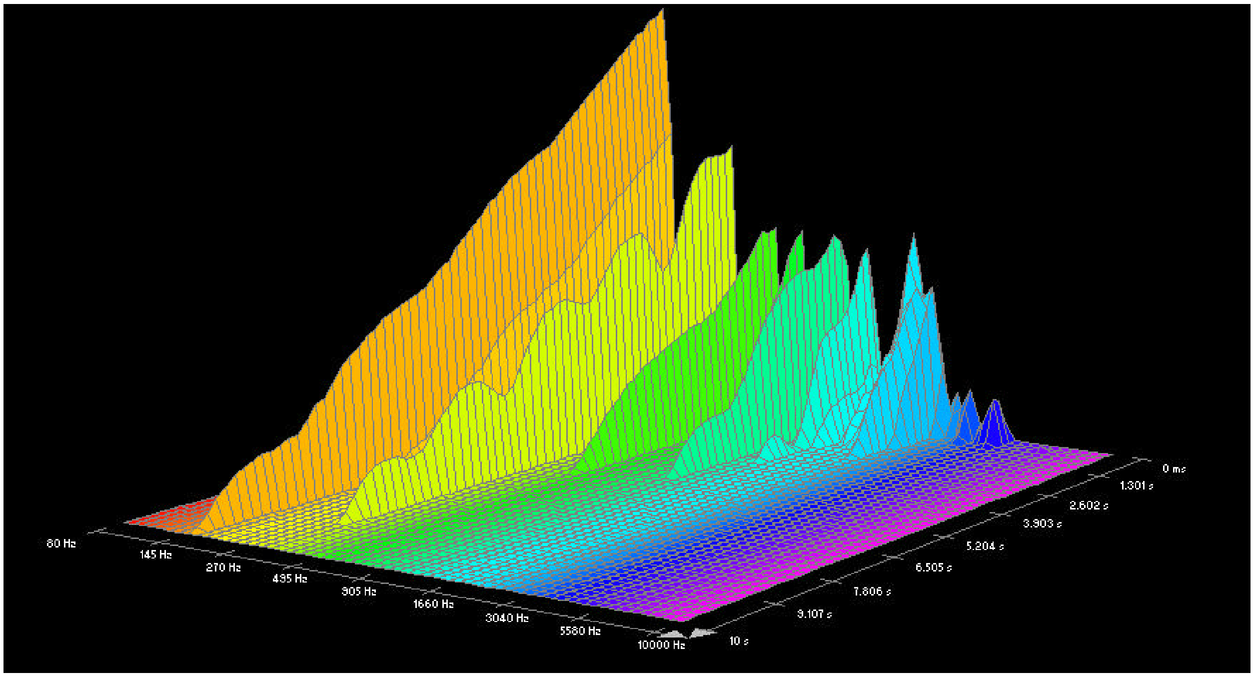

Figure 1 – String's Amplitude versus Frequency and Time

As you can see by following the frequency axis on the lower/left side of the graph, the fundamental is at about 147 Hz, a D-string on a guitar tuned to standard tuning. The second harmonic is in yellow and can be seen to decay as a function of time. The time axis is on the lower right hand side of the figure. Apparently, higher-order harmonics decay more rapidly than lower-order harmonics.

There are some interesting charts. Going into this project, I assumed that all higher-order harmonics would have to have a lower amplitude than the fundamental. This is not necessarily the case, as can be seen in Figure 2 below.

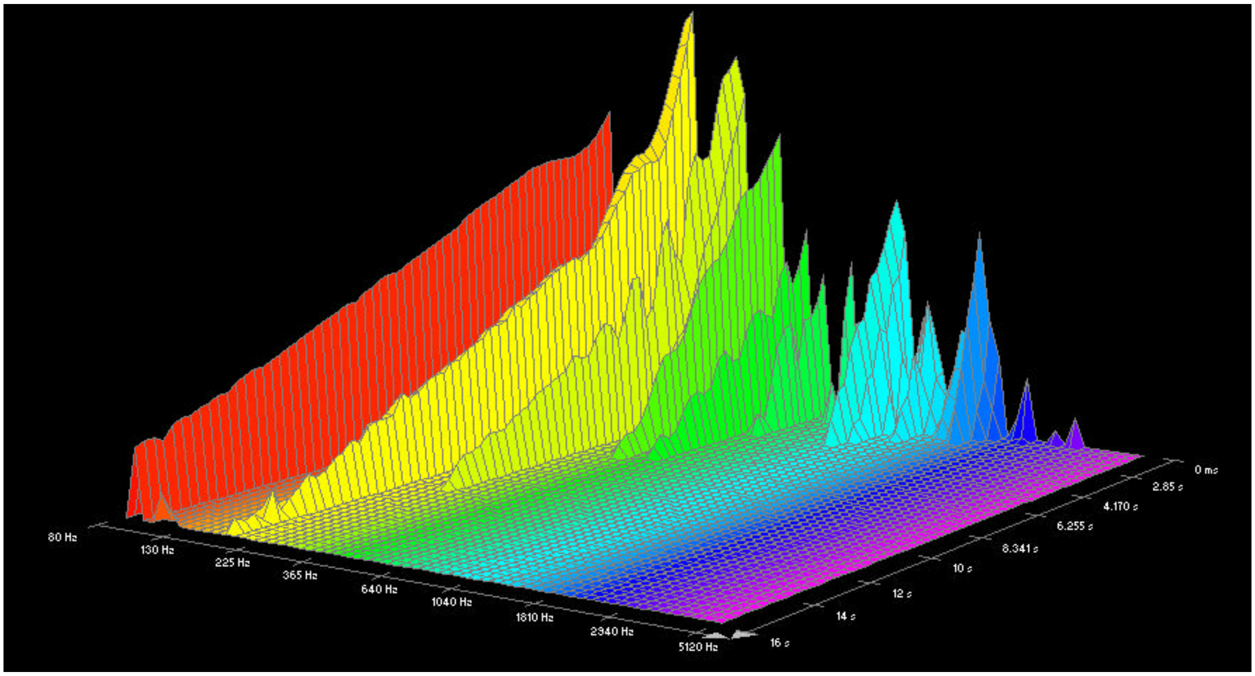

Figure 2 – Dean Markley Phosphor Bronze Acoustic Low E-String, Bridge Position

I also assumed that the fundamental would have to continue oscillating in order for any of the other higher-order harmonics to be in the frequency spectrum. This is not the case either as can be seen in Figure 3.

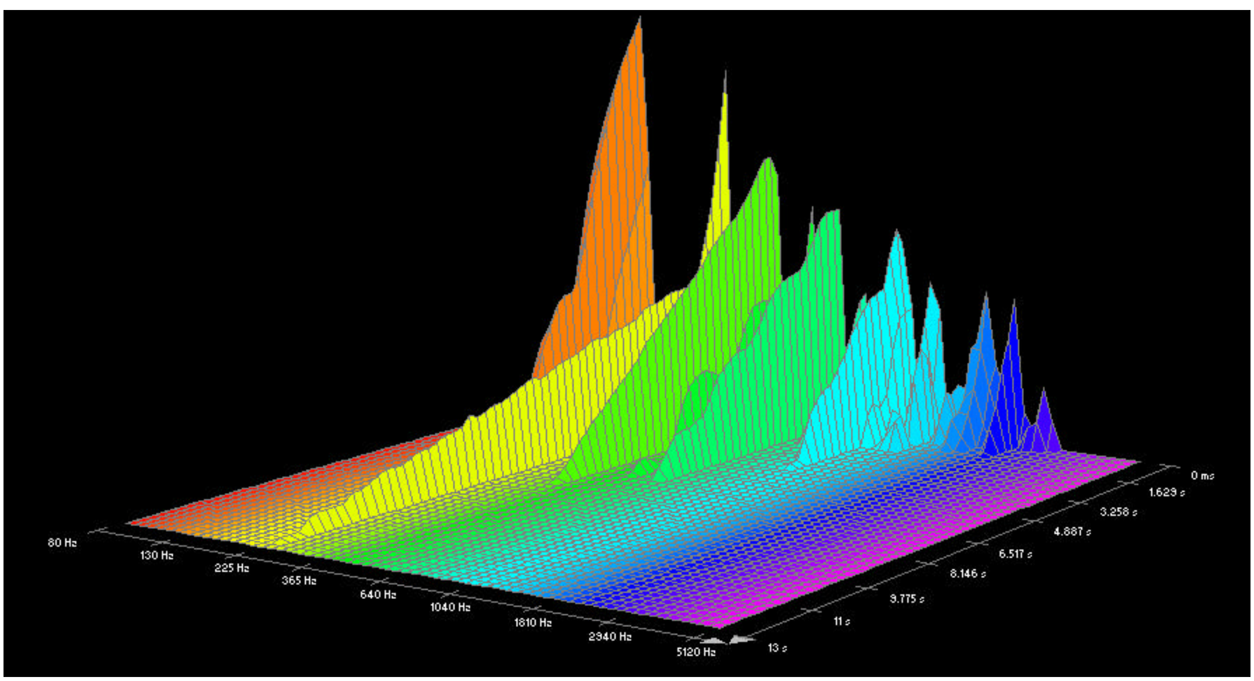

Figure 3 - Dean Markley Phosphor Bronze Acoustic A-String, Neck Position

Data Processing

Using the `.wav` files for each pluck, I wrote a Matlab function called `harmonic_ratios` (also included in Appendix I). This function takes a `.wav` file and, given what note is being plucked, generates 4 different Fast Fourier Transforms (FFTs) over the course of the first 5.46 seconds of the vibration of the string.

By FFT, I mean that the program generates the value of each higher-order harmonic *relative to the fundamental frequency's content* in percent. Therefore, the fundamental's content for the first FFT will always be normalized to 100. These numbers can be seen in Figure 4 and correspond to the peak value of a harmonic's representation in the Fourier spectrum. The units correspond to pressure and voltage, not to decibels.

Brand	**Type**	**Gauge**		**Harmonic**	**0 to 1.37s**	**1.36 to 2.73s**	**2.73 to 4.10s**	**4.10 to 5.46s**
D'addario								
	BPL	0.012	E	1	100	26.451	11.965	6.318
				2	15.410	3.226	2.182	1.063
				3	34.176	4.455	0.705	0.382
				4	30.552	4.706	0.402	0.162
				5	9.196	0.426	0.079	0.029
				6	3.193	0.511	0.076	0.022
				7	8.191	0.794	0.070	0.008
				8	2.902	0.334	0.018	0.006
				9	6.382	0.494	0.037	0.008
				10	4.055	0.497	0.041	0.005

Figure 4 – Matlab-generated numbers as a percentage of the fundamental

There are 4 FFTs for each pluck. Each FFT covers 1.37 seconds (2^16 samples at 48 kHz) in the time domain. I could have calculated many more FFTs for each string, as the sustain often carried on for 20 seconds or more. These initial 4 FFTs, however, cover 5.46 seconds and do a good job of showing the decay of the initial transient. For data after the 5.46 second mark, please see the 3-dimensional graphs in Appendices II and III.

Possible Sources of Error

As with any empirical results, there are always sources of error. The first red flag that I saw in performing the testing was from looking at the `.wav` files of the acoustic guitar strings that were recorded in the anechoic chamber. The DAT recorded had been in the chamber with me, and it made noise that came through on tape. Before `rock.m` (Matlab code referenced earlier and included in Appendix I) writes a `.wav` file, it cleans out this noise and zeroes out frequency content that is below that of the fundamental note being analyzed.

An aside is that these strings were tested in brand-new condition (unless otherwise noted). I did not perform any tests to obtain or predict the performance of a string after days or weeks of playing. This type of test might prove to be more useful than my project, but would take a lot longer to complete.

Conclusion

The results of this test must be very accurate. For example, if you look in Appendix IV and compare the numbers for, say, a D'Addario Brass-Plated Steel B-string, acoustic guitar bridge position, and a D'Addario Plain Steel B-string, acoustic guitar bridge position, the numbers are almost identical. This shows that my method of plucking, recording, and processing was consistent. There is also a great deal of variation amongst other strings' results, so this shows that my method did, in fact, distinguish the strings' differences.

A great way to view the results in Appendix IV and compare any two strings at once is to open up the Excel file and click on `Window` and then `Split`. You can then scroll either of the two windows to any different string.

It is difficult to pinpoint a difference in harmonic decay due to string composition. For example, in comparing phosphor bronze versus 80/20 bronze, the D-string might seem very bright on one set of strings whereas the G-string might seem very bright on the *other* set of strings. The data is still useful, because correlations can be found.

In an attempt to better find these correlations and make use of the results, I have included averages of groups of strings in the lower portion of Appendix IV. In other words, rather than show the data for one pluck of one string, the lower portion of each page of the appendix shows the average of an entire type of string, e.g., all Martin 80/20 Bronze wound strings. The average is shown in the same format as the other data, with 4 FFTs being shown.

If someone wanted more information on a particular string, it is possible to modify some of the Matlab code and spend more time processing that string. One possible improvement is that the length of the FFTs could be shortened. This would allow the user to get more FFTs for one single pluck of a string.

This report presents the data in a way that would allow another researcher to compare specific strings and do further testing if needed. However, a string-by-string commentary is beyond the scope of this project and probably subjective as well. After playing dozens of strings that I would not have played had I not done the project, my favorite strings were *still* the strings I have been playing for years. This tells me that I have consistent ears and that my ears do not lie. The ultimate string is the one that simply sounds the best to you.