**Do guitar strings with an anti-oxidation coating impact your guitar tone?**

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MUS 140-201, Fall 2022

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## Introduction

For the 8 years I've played electric guitar, whenever I needed new strings, I've always bought the same middle of the road D'Addario 10-46 strings. They're a good basic option, and I've not had any issues with them. However, the one inconvenience with them is the rate at which I need to change them. In general, the strings sound noticeably duller towards the end the first month and by the end of the second month or so the strings start to rust, and if I leave them on my guitar for too long, they even become painful to play.

There are countless electric guitar strings on the market, all claiming to sound the best and have the longest life. Generally, strings that claim longevity have some kind of anti-oxidation coating which increases the time it takes for the strings to start rusting. My preliminary research on many online guitar forums has found there is a consensus that this coating makes the strings sound duller, and even Ernie Ball, a string manufacturer, perpetuates this idea [1]. The goal of this experiment is to determine if the anti-oxidation coating significantly impacts the way the guitar sounds, and to provide evidence supporting any conclusion. Additionally, an older, already oxidized string will be recorded and used to highlight the importance of keeping guitar strings from oxidizing.

## Hypothesis and variables

**Hypothesis:** An anti-oxidization coating on a guitar string will act as a damper, changing the way the string vibrates particularly in the higher frequency range.

**Independent:** The coating and type of guitar string.

**Dependent**: The signal produced by the guitar.

## Literature Review

One experiment conducted by faculty at the University of Maribor and University of Ljubljana explored the effect that guitar bodies with different wood species would have on the vibration of the strings. Similar to my approach, they would model the vibration of the strings by capturing the output of the guitar and constructing a frequency spectrum [2]. This study concluded that different types of wood do result in a change in the output signal. In particular, the stiffer ash wood exhibited lower damping when compared to walnut. This research did not convey any findings regarding whether the amplitude of the overtones at particular frequencies changed between wood types, but it does show that damping the vibration of the instrument will change the vibration characteristics of the guitar.

In my research I wanted to learn exactly how string damping works. In an article by Jonathan Christian, the topic of many different sources of damping is explored. I'm interested in his determination that the wrapped strings provided mainly Coulomb damping from the windings rubbing each other [3]. This did raise more questions, such as whether a coating on a wound string would reduce the rubbing between windings resulting in less damping or perhaps more. However, this is admittedly a little outside the scope of this paper given the equipment that I have access to.

A YouTube video by Alex Price titled "Do Uncoated Strings Really Sound Better?" provides an example of how coated and uncoated strings sound compared to each other on an acoustic guitar [4]. Many of the comments were divisive, with some people preferring the sound of coated strings and some people preferring uncoated. Either way, this video is a good reference to exhibit the different sounds.

# Methodology/Experiment design

Three different kinds of strings will be used for this experiment. One set, the D'Addario XL strings, have been out of the package for approximately 4 months and now exhibits oxidation. Not only does oxidation affect the sound of the string but it also makes it difficult or painful to play them. The Ernie Ball Slinky strings are a very middle of the road option for most guitar players, and will be the baseline new string in this comparison. Finally, the Red Devil strings utilize a proprietary "K3" coating, which is on the thicker side of coatings that are available to purchase. Each set of strings are middle-of-the-road .10-.46 gauge with a high-carbon steel core and nickel winding on the lower four strings. These variables have been accounted for, such that the only differences between the strings have to do with the coatings on them, where the D'Addario XL strings have been on my guitar for a few months building a layer of oxidation to be considered the old string in this experiment.


*Figure 1 Packages of the strings used in this experiment*

Each set of strings will be strung on the same guitar, an ESP LTD MH-1000 NT with Seymour Duncan Pegasus and Sentient pickups. In order to avoid an excessive amount of data, I will only be looking at the high and low E strings. During preliminary testing, three different individual recordings were taken of each type of string. To keep comparisons simple, I chose the most consistent sample from each string in terms of signal amplitude, resulting in a total of 6 samples.

In order to eliminate ringing of the other strings and harmonics from the strings above the nut of the guitar I muted the strings with cotton balls, as shown below in Figure 2.

*Figure 2 Muting of strings above the low E*

To record the data, I used a Positive Grid Spark 40 Smart Guitar Amp as an interface to my computer running Studio One, an instrument and track recording software. In an attempt to be able to directly compare waveform amplitudes, each wave was normalized to -3db using Audacity. The normalized audio files were then opened in Python and using the fast FFT function from SciPy, the FFT plots were generated.

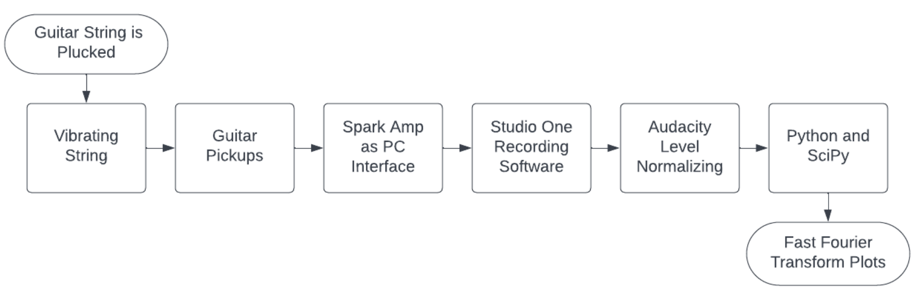


*Figure 3 Schematic of methodology to generate FFT plots*

The way that I will judge the frequency response of each guitar string is by utilizing Python to take a Fast Fourier Transform (FFT) of the signal, and thus represent that data in an amplitude vs. frequency plot. I chose to use the SciPy Python library as it allows me to easily generate an FFT given a .wav file [5]. The Python code used to generate the FFT plots has been attached to this report as Appendix A.

# Data & Data Analysis

## Old, oxidized string vs. new uncoated string

In Figure 4 and Figure 5 below, I can directly compare the FFT plots of an older, oxidized string against a new uncoated string. The overall response is very similar, but there are noticeable amplitude peaks in the 500-750 Hz range with the new string.

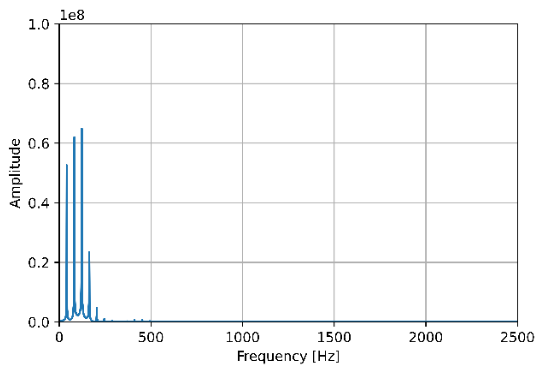

*Figure 4 FFT of oxidized D'Addario XL low E string*

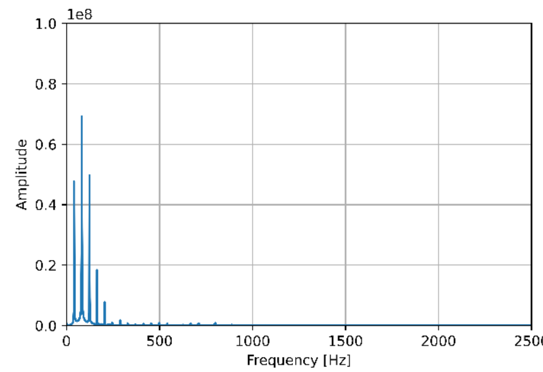

*Figure 5 FFT of new uncoated Ernie Ball Slinky low E string*

For the rest of this report, I will scale the Amplitude (y-axis) such that I will be able to observe the small peaks more easily in high frequencies. This change in scaling can be seen below in Figure 6 and Figure 7 which use the same signal as Figure 4 and Figure 5. The scaling will focus on the higher frequency content which is what we are most interested in.

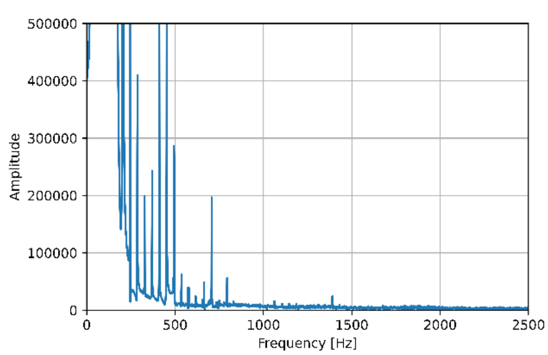

*Figure 6 Magnified FFT of oxidized low E string*

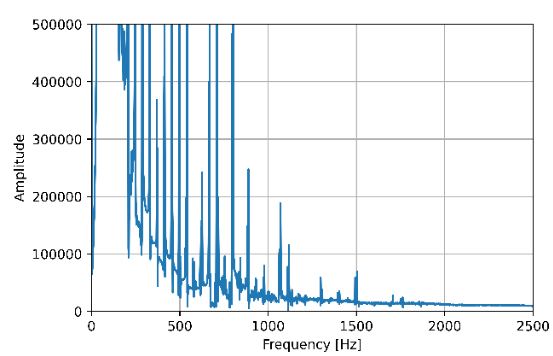

*Figure 7 Magnified FFT of uncoated low E string*

When analyzing Figure 6 and Figure 7, there are a few immediately noticeable details. The first is that the frequency content of the uncoated string is noticeably higher in the 500+ Hz range than the oxidized string. It's also worth mentioning that in the case of the oxidized string, I see a lack of any notable frequency content above the 1500 Hz mark. When looking at the same frequency range but on Figure 7, I can tell there are some higher frequencies that contribute to the sound of the new uncoated string.

To further examine the frequency response that a new string has compared to an older oxidized string, the same process was carried out using the high E strings of each set.

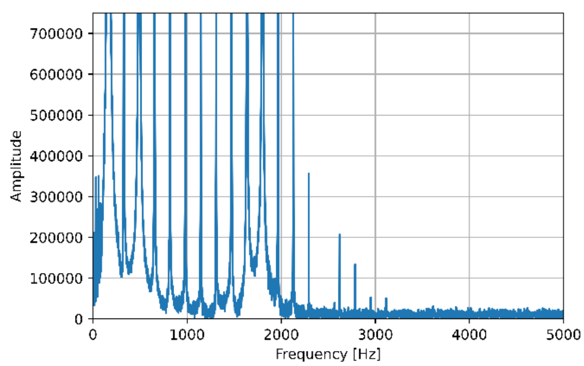


*Figure 8 FFT of oxidized D'Addario XL high E string*

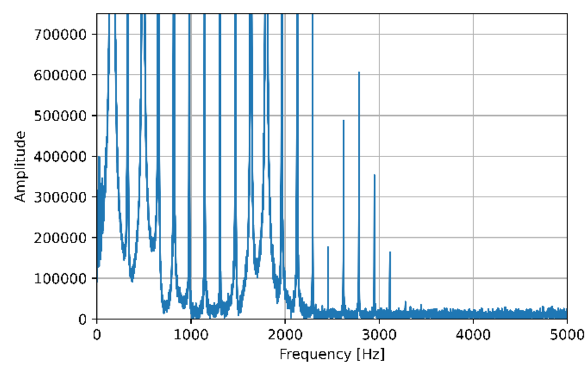


*Figure 9 FFT of new uncoated Ernie Ball Slinky high E string*

Figure 8 and Figure 9 once again show that the old, oxidized string lacks the higher frequency content that the new strings exhibit, particularly in the 2500-3000 Hz range for the high E strings.

## New uncoated string vs. new string with anti-oxidation coating

In order to more easily compare FFT diagrams, some plots will be copied from above. Specifically, this section will compare the uncoated strings to the anti-oxidation coated strings, and Figure 7 and Figure 9 will be copied below as Figure 11 and Figure 13.

*(This section continued next page)*

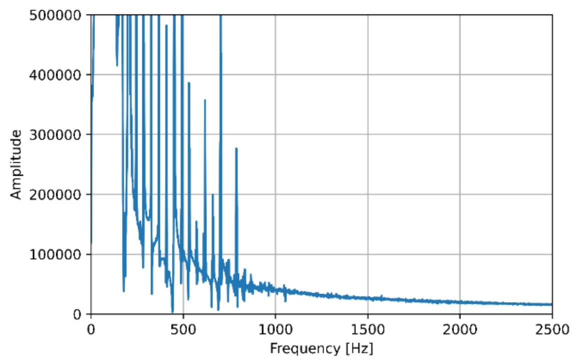


*Figure 10 FFT of low E string with anti-oxidation coating*

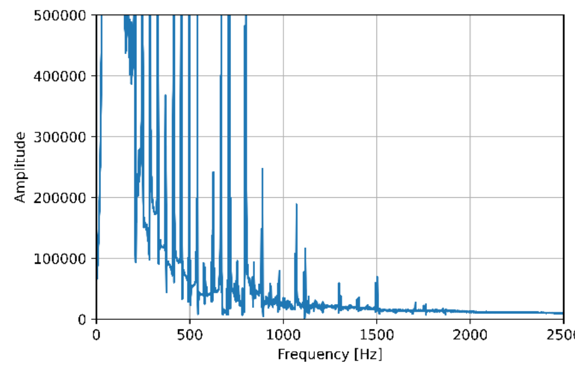


*Figure 11 Copy of Figure 6: FFT of uncoated low E string*

In Figure 10 and Figure 11 I see that the string with the anti-oxidation coating is lacking some frequency content that the uncoated string displays in the 1000-2000 Hz range. The overall response of the coated string bears a resemblance to Figure 6; the FFT of the old and oxidized low E string also appears to lack the frequency content in roughly the same range.

When looking at the high E strings, I don't see the same behavior of the coated string having a similar frequency content to the oxidized string. Instead of appearing to lack frequency content when compared to the new uncoated Ernie Ball Slinky string, Figure 12 and Figure 13 display almost identical amplitudes at matching frequencies.

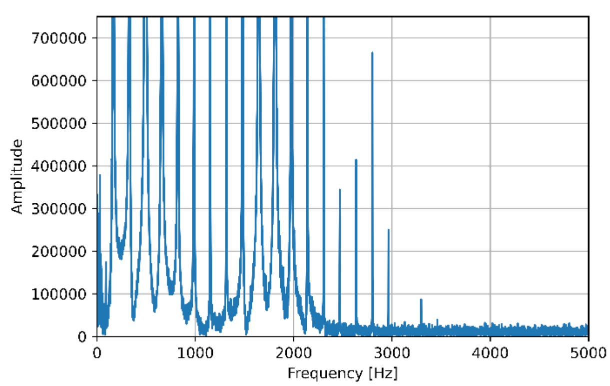


*Figure 12 FFT of high E string with anti-oxidation coating*

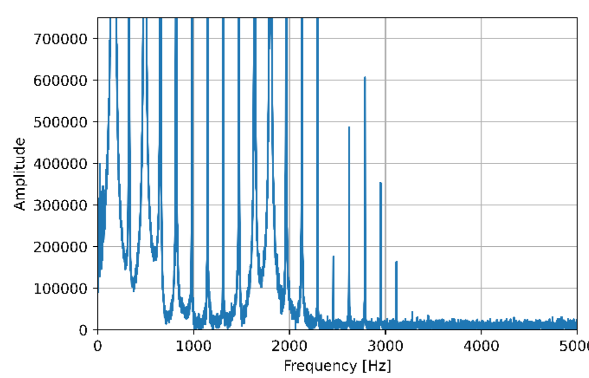


*Figure 13 Copy of Figure 8: FFT of uncoated high E string*

These results are interesting because it suggests that the coating doesn't make a difference when applied to the high E string which is rather unexpected. However, these frequencies stay consistent across multiple retests, so I'm sure it's legitimate data.

## Conclusions

From the data collected, I can confidently say that that new, uncoated strings will have more content in the higher frequency range compared to both old and coated low E strings. New strings are generally described to have a “brighter”, “metallic”, or “jangly” sound, which for the large majority of guitar players, is the more desirable sound [6]. These attributes of new strings are characterized by higher frequency overtones; old guitar strings sound “dull” because over time a thin layer of oils and oxidation is built which acts as a damp. An anti-oxidation coating on a string similarly results in a “dull” sound, though typically not as extreme as an old uncoated string.

In Figure 6, Figure 7, Figure 8, and Figure 9, I can see how the high frequency response differs between the old and new uncoated strings. The frequency spectrum plots for the low and high E strings show a significant difference in the recorded signal and highlight the differences in frequencies that define the “brighter” sound that new strings have, as mentioned earlier. These results fit our expectations and provide a measurable parameter to compare other strings. In this experiment I want to know whether anti-oxidation coatings on guitar strings changes how the string sounds. That is, does the coating act as a damp similar to the layer that builds on an old uncoated string?

Looking at the signal data displayed in Figure 10, Figure 11, Figure 12, and Figure 13 comparing a new string with an anti-oxidation coating with a new uncoating string, I can make a few conclusions. For the low E string, the coated string has a clear lack of higher frequency content compared to the uncoated string, though not quite as significant as the old oxidized string seen in Figure 6. This was expected, as my hypothesis was that the anti-oxidation coating would dampen the vibrations of the string. However, for the high E string, I don’t see the same phenomenon. Rather than seeing a lack of high frequency overtones, I see almost an identical signal compared to the uncoated string. This goes against my hypothesis and is a fascinating contradiction.

Due to the significant difference in behavior between the low E and high E strings, I determined the only difference besides the physical properties such as thickness, mass, and tension was that the low E is wound, and the high E is not. The low E, A, D, and G strings are wound to take advantage of the fact that a larger mass will vibrate at a lower frequency given the same tension, which helps relieve unnecessary stress from the guitar neck. The higher pitch E and B strings don't need to worry about this, because they need to vibrate at a higher frequency and don't need to be weighed down to reach their ideal frequency. As found by J. Christian [3], the friction damping (or Coulomb damping) acting on a string comes "primarily from the windings rubbing on one another". The results of my experiment would imply that while an anti-oxidation coating on the strings increases the friction and therefore damping on wound strings, it has little to no measurable impact on unwound strings.

The next question would be that if an anti-oxidation coating has little impact on the unwound strings, then why does an old oxidized string exhibit such extreme damping compared to the coated string? If the damping cannot be attributed to the increase in friction between windings, then perhaps the added mass of the oxidation layer contributes to the damping. I was unable to find concrete numbers, but generally coated guitar strings are marketed as being ultra-thin, whereas I can visually see places in an oxidized guitar string where it's become thicker. Due to this evidence, my conclusion is that coated guitar strings cause an increase in damping due to increasing the friction in between windings, not because of an increase in mass, and therefore the unwound strings are unaffected.

## Limitations and Implications

This experiment comes with many caveats due to the execution. Due to the limited scope and materials available (read: what I had laying around), there are many possible sources for error and other inaccuracies. I will attempt to address some of the larger more obvious issues that I know about; there are likely many issues with my methodology I don't realize.

Due to the budget of this experiment being my own college-student sized wallet, I only bought one set of each string type. This means that there could be variance between other packs of the same string type that I could not control for. Additionally, only the low and high E strings of each set were used in this experiment. There was variance between these strings; the low E had nickel wrapped around the steel core, whereas the high E had no winding. Another possible source of error related to the strings is the striking/plucking of the string. My initial plans for this experiment involved using an Arduino with a hobby grade servo to pluck the string. However, due to time constraints and not wanting to get tape residue on my guitar, I elected to pluck each string 3 times and to compare the signal amplitude to get the most comparable in terms of loudness. This does assume that comparable amplitude of the signal correlates to a comparable force plucking the strings, which may or may not be an acceptable assumption. Regardless, if I had more time and money, I would like to control the excitation of the string more precisely.

Another consideration is the interface between the guitar string and my recording software. Electric guitar pickups are inherently biased to different parts of the frequency spectrum. The pickups I have in my guitar, Seymour Duncan Pegasus and Sentient humbuckers, have an inherent amplitude bias to mid-range frequencies. Having this kind of bias is typical in electric guitar pickups, but this does mean the effect that the coating has might not be fully realized in this report. Additionally, the Positive Grid Spark 40 Smart Amp may have applied some processing to the signal before passing it to my recording software, but I couldn’t find any information regarding this subject. I could argue that these factors might not matter in a practicality sense, given that when I play guitar, I use the pickups and amps to generate my sound, seeing that there’s some differences in the string in spite of these variances, just shows how impactful the strings can be on the signal output from the guitar. Another consideration is that there may have been important frequency content above the 5000 Hz I chose as my cutoff point, but whether due to my test setup or some other factor, I only saw noise without any identifiable signal and as such excluded those frequencies from this report to make conveying the information easier.

I know that going forward, I want to use coated strings for my guitars. It will depend on how long they last compared to noncoated strings, but I think the longevity of them outweighs the slightly less ideal sound for the first few weeks compared to uncoated strings. Coated strings are more expensive, and this report does show that there are some measurable differences in frequency content for the lower E string (and likely all wound strings), but I had a difficult time hearing a distinct difference and I think the convenience of the longer lifespan is worth those sacrifices.

# Bibliography


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# Appendix A (Python Code)

```
import matplotlib.pyplot as plt
import numpy as np
import wave, struct
from scipy.fftpack import fft

from pathlib import Path
filenames = Path('C:\\Users\\BigE3\\OneDrive - University of Kentucky\\AFall 2022\\MUS 140
Acoustics\\Experiment\\Sound Files\\Mixdown\\filelist.txt').read_text().splitlines()


for x in filenames:
    sound_file = wave.open(x, 'r')
    file_length = 24000 #(sound_file.getnframes()) not necessary
    data = sound_file.readframes(file_length)
    data = struct.unpack('{n}h'.format(n=file_length), data)
    data = np.array(data)
    sound_file.close()

    #x = np.linspace(0.0, 1, 600)
    #y = np.sin(50.0 * 2.0*np.pi*x)
    #yf = fft(y)
    yf = fft(data)

    plt.figure(dpi=1200)
    plt.xlim(0, 15000) #5000 for high E, 2500 for low?
    plt.ylim(0, 7500000)
    plt.plot( np.abs(yf))
    plt.suptitle('Constrained Amplitude to See Frequency Definition'  + x)
    plt.xlabel('Frequency [Hz]')
    plt.ylabel('Amplitude')
    plt.grid()
    plt.show()
```