

Plucking Location and Timbre of a Guitar

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Abstract

A guitar string was plucked at 21 positions spanning the whole string with a consistent plucking method. The sound produced by the pluck was recorded and analyzed under a frequency-amplitude graph. It was shown that the amplitude of a harmonic tone at a point corresponded to the amplitude of the standing wave of the harmonic at the same point. Plucking a string at particular positions is an effective way of influencing the timbre of a guitar to one's preference.

Keywords: guitar, amplitude, harmonic, timbre, standing wave, plucking

I. INTRODUCTION

Guitar strings vibrate with numerous harmonic standing waves when plucked, each standing wave harmonic produces an audible sound wave of the same frequency as the standing wave. The resultant sound of the string is composed of all the harmonic tones. What is perceived by the human ear is the fundamental base harmonic, the additional harmonics only determine the perceived timbre.¹ Timbre refers to the quality that differentiates sounds with the same pitch and amplitude.² The timbre or sound quality depends on the amplitude of the harmonic tones relative to each other.

Different types of terminology are used to describe sound quality, including luminosity, temperature and width. Tones containing predominantly lower harmonic frequencies are described as being warm or dim. Tones containing predominantly upper harmonic frequencies are described as bright.³ Tones with both upper and lower harmonics are described as full or wide, while tones lacking in resonance, containing more middle harmonics, are described as thin. In this paper, I aim to identify where on a guitar one must play in order to achieve a desired timbre. While there are multiple factors that the resultant timbre and musical aesthetic depend on, such as the type of pick used and the force of the pluck, pluck position is one of the most important factors in

determining the harmonic content of the tone.³ Controlling and varying the timbre as one plays the guitar is an important skill and is needed to adapt to certain playing styles, musical environments and the types of songs played.

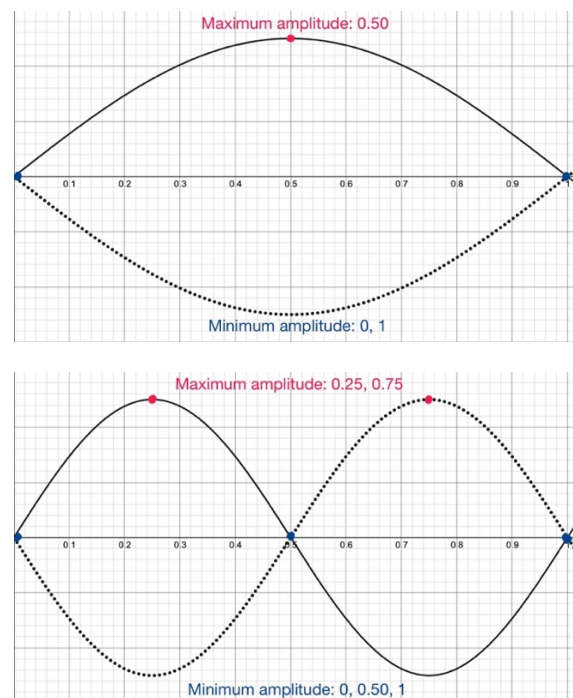


Figure 1. Theoretical Standing Wave Diagrams for harmonic 1 (top) and 2 (bottom).

When plucking a guitar string, the position of the pluck along the string determines the amplitude of each harmonic tone. Plucking the string at the antinode of a standing wave will most efficiently transfer the energy of the pluck as the antinode is the point of highest displacement. Figure 1 shows the shape of the first and second harmonics of a string and where the maximum and minimum amplitude sounds should be when plucked. Sound quality also differs heavily with the mode of picking: finger or pick. Using a pick generally provides more consistency and brighter tones. Fingerpicking is more variable as different fingers and parts of the finger respond differently to the string, however, fingerpicking generally provides warmer tones with less upper harmonics. While this investigation focuses only on the first five harmonics, guitar strings oscillate with many more than five.

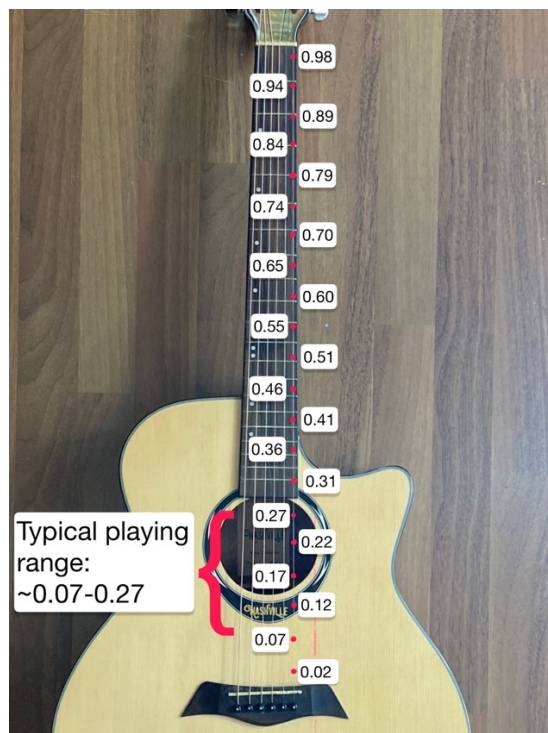


Figure 2. Photograph of the relative positions where the guitar was plucked.

The relative pluck positions are marked out in Figure 2. The value of 0.50 represents the middle of the guitar string, 0 and 1 represent the ends of the string, 0 being the base and 1 being the top of the fretboard. The typical playing range is around 0.07-0.27 of the string, as shown. The loudness of each harmonic tone is expected to correspond proportionally to the

amplitude of the standing wave and follow a sinusoidal pattern as the pluck position goes down the string. This investigation aims to determine how the amplitude of each harmonic varies as the plucking position moves down the string.

II. METHODS

An apparatus was designed to ensure consistent plucking of the string. An electrical motor spun a wheel with an Alice 1.2mm pick attached. The apparatus was positioned at a fixed distance above the string and adjusted so that the wheel stopped spinning once the string was plucked so that only the sound of the string would be measured. The string tested was the first string on the guitar, a bronze grade 10 thickness tuned to E₄, which in standard tuning is 329.63 Hz.

Data was recorded in LoggerPro using a Vernier microphone at a rate of 100,000 samples per second. The string was plucked across 21 positions, each position roughly 3 cm apart, for 21 intervals with 5 trials per interval. The entire string is 65 cm long.

Additional trials at positions 0.02, 0.27, 0.46 were recorded with fingerpicking. Each trial was displayed on an FFT graph to determine the first five harmonics. The average amplitude of the first five harmonics for all 21 positions were calculated and graphed against their position. Absolute sine curves were fitted on each graph.

III. DISCUSSION OF RESULTS

When recording the audio from the guitar onto an Amplitude-Frequency graph, known as an FFT, each harmonic can be viewed as lines, the height of each line showing the relative amplitude. Visually displaying the data in this way can help determine the timbre of the tone and which harmonics are dominant.

From observing the FFTs in Figures 3 and 4, the difference in harmonic amplitude between pluck positions at the base and near the middle of the string becomes apparent. In Figure 4, harmonics 1, 3 and 5 are relatively high compared to Figure 3. This is

because at the position of 0.46, these harmonics are close to the antinode at 0.50. Harmonic 5 in Figure 3 is relatively large as the fifth harmonic is the closest to its first antinode at the position 0.02.

Using the amplitude data of harmonics 1-5 from the FFT graphs of all 21 positions along the string, the relationship between harmonic amplitude and position can be graphed as shown in Figure 5.

As evident from the graphs in Figures 5a-e, the amplitude of each harmonic tone follows the sinusoidal amplitude of the standing wave that the tone is generated by, however the amplitude of the tone never reaches zero. This is likely due to the fact that real guitar strings do not behave like ideal strings. The exciter of the string (plucking object) doesn't have a zero-width plucking point, meaning that the string is not only plucked at the node but also positions approaching the node, where there is a non-zero amplitude of the standing wave. The relative

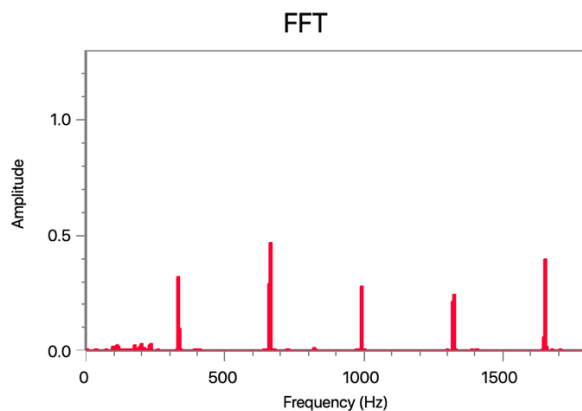


Figure 3. FFT graph at relative position 0.02

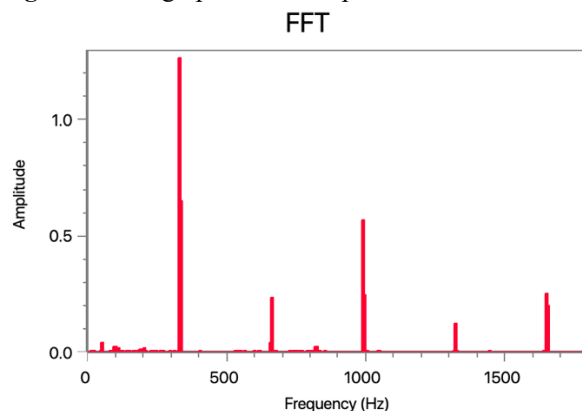
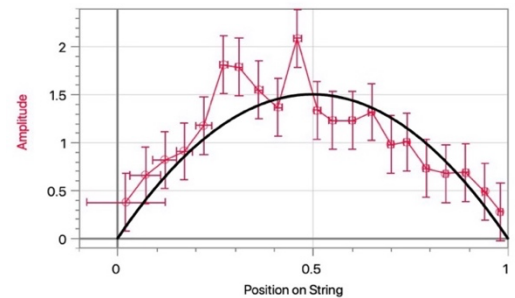
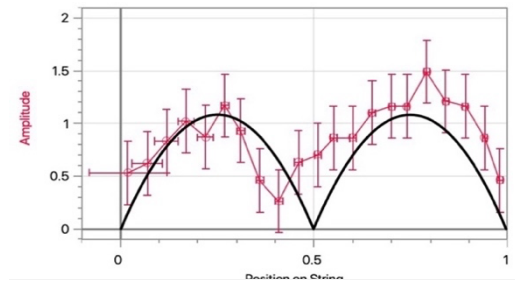


Figure 4. FFT graph at relative position 0.46

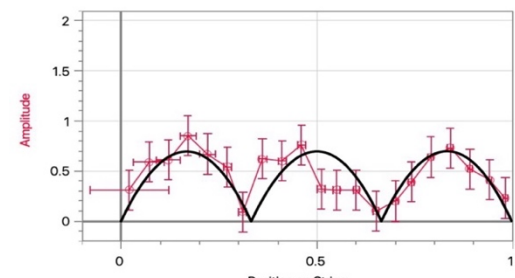
5a



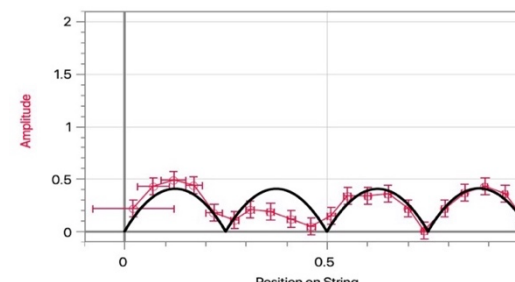
5b



5c



5d



5e

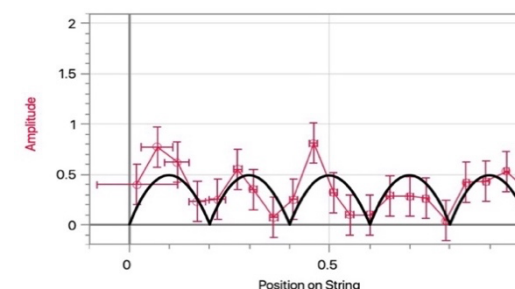


Figure 5. Graphs of amplitude against relative position of harmonics 1-5 (5a-e) with absolute sine trends overlaid.

amplitudes can also be determined from looking at Figures 5a-e, the 4th harmonic having the lowest amplitude on average and the 1st harmonic having the highest amplitude on average out of the harmonics that were analyzed. A trend that can be extrapolated from Figures 5a-e is that plucks near the ends of the string (0-0.1 and 0.9-1) result in thinner and brighter tones, whereas plucks near the middle (0.3-0.7) result in much fuller and warmer tones.

If bright and tinny tones are desired, it would be best to play in the range of 0.07-0.13. If fuller, warmer tones are desired, it is best to play at around 0.3-0.5, where harmonics 1 and 5 are at max amplitude. Harmonic 4 at this range, however, is damped. The typical playing range gives the maximum amplitude for harmonics 2 and 3, however reduced amplitudes for harmonic 1 and is nearly fully damped for harmonics 4 and 5.

It is important to note that, due to the variability of numerous factors of the topic of investigation, such as temperature of the environment, tension of the string and force of the pluck, the results are highly variable, as can be seen from the large error bars.

In the FFTs for both finger and pick plucking in Figures 6b and 7b, it can be observed that the harmonics for the finger pluck drop off significantly more than the pick pluck, which has more mid-upper harmonics. The first five harmonics have minimal differences between the finger and pick pluck. The main difference is in the 2k-5.5k Hz, where the pick pluck's harmonic amplitudes in this range are much higher. This results in the finger pluck sounding dimmer and warmer than the pick pluck and the pick pluck sounding fuller. The audio for a [pick pluck](http://www.isjos.org/assets/Guitarpick.wav) (www.isjos.org/assets/Guitarpick.wav) and a [finger pluck](http://www.isjos.org/assets/Guitarfinger.wav) (www.isjos.org/assets/Guitarfinger.wav) are provided so the reader can hear the difference in timbre.

It is interesting how mainly the upper harmonics differed between pick and finger plucks. The first five harmonics seemed to follow the same relationship as pluck position changed. The reason for the drop off of the upper harmonics could be a subject of future research. The effects of using different exciter objects, such as pick, finger, or fingernail, could also be investigated.

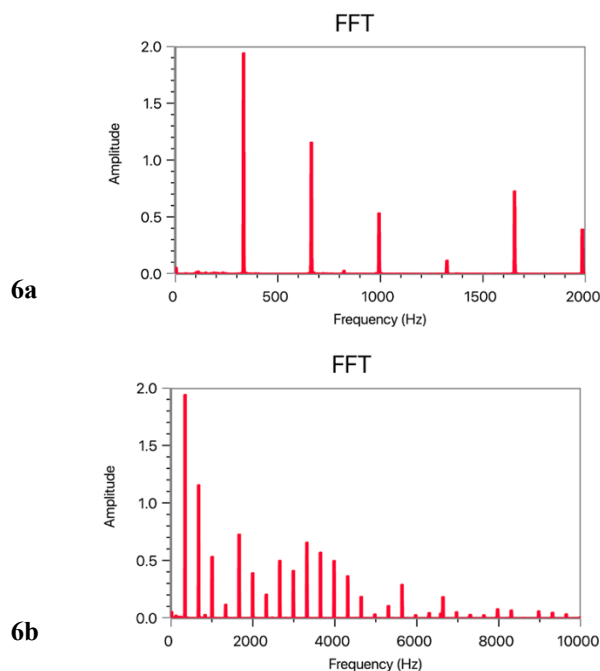


Figure 6. FFT graphs for relative position 0.27 using a pick exciter displayed from 0-2k Hz (6a) and 0-10k Hz (6b)

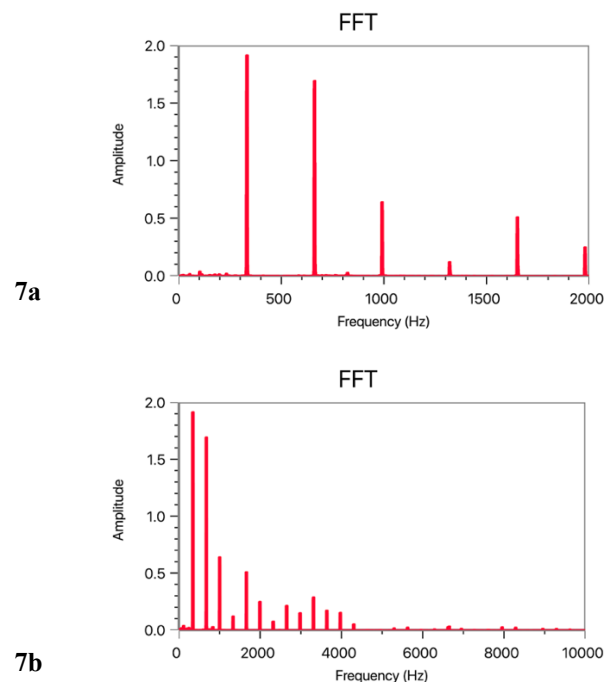


Figure 7. FFT graphs for relative position 0.27 using a finger exciter displayed from 0-2k Hz (7a) and 0-10k Hz (7b)

IV. CONCLUSION

It has been shown that the amplitude of the sound for each harmonic is proportional to the magnitude of the amplitude of the harmonic's standing wave on a string. Plucks towards the ends of the strings produce sounds with higher amplitude upper harmonics, resulting in the listener perceiving brighter sounds while plucks towards the middle of the string result in warmer, fuller sounds with higher amplitude lower harmonics. Plucking with a finger or a pick demonstrates similar harmonic patterns for the initial five, but larger differences in the 2k-5.5k Hz range. The finger pluck has significantly reduced amplitude in this range, resulting in the listener perceiving a thinner sound.

V. REFERENCES

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