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Application Of Fourier Transform In Analyzing Guitar Harmonics

Ahaana Goswamy

Abstract
Humanity has long been enthralled by music, an intangible confluence of creativity and science that serves as a platform for expressing emotions and fostering relationships. This study links musical artistry with scientific research by exploring the realm of guitar harmonics. It focuses on both natural and artificial harmonics, thus aiming to present the effect of the plucking technique on the harmonic strength of the acoustic guitar. Through various meticulous experimentation and spectrogram analyses, the study shows that the mode of plucking plays a significant role in the harmonic content of the guitar sound. Moreover, the natural harmonics produced on the open G-string by hand plucking and the one produced on the 7th fret yield louder excitations of the harmonics as compared to the artificial harmonics produced for the open G-string and that produced on the 7th fret respectively. Whereas, the artificial harmonics produced on the 5th fret of the G-string yield louder excitations of the harmonics as compared to the natural harmonics produced on the same fret. The study also shows, with the use of spectrographs, that practically every experiment conducted deviates from the general rule that the loudness of the harmonics often decreases with the increase in harmonic number. The study also emphasizes the consideration of extraneous factors in analyzing guitar harmonics by revealing the presence of background noise present in the data. This research thus bridges artistic expression with mathematics, linking music to science and thus offering significant insights to the readers by contributing to a more intricate understanding of the copper-stringed acoustic guitar's harmonics.

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I. INTRODUCTION

Music - an avenue for expressing emotions and forging connections- is an intangible fusion of creativity and science that has entranced humanity for centuries. The musical instrument guitar, with its diverse techniques and its limitless capacity for tonal exploration, serves as the most versatile and captivating instrument within this musical realm.

History of Guitar

The exact origin of the guitar is unknown. The term "guitar" is most likely derived from the ancient Greek word Î (kithara). Mythology credits Hermes with inventing the original kithara out of a tortoiseshell, although many depictions of Apollo include this instrument.

This resonator has a wooden soundboard and a box-shaped body. Two hollow arms projected from the resonator, joined by a crossbar. The instrument originally had three strings that ran from the crossbar to the lower end and crossed a bridge on the soundboard; later versions had up to 12 strings. The ancient musician used a plectrum, which was an early version of the current pick, to play the strings. The player would use his or her left-hand fingers to dampen undesirable chords and, on occasion, stop the strings or produce harmony.[1]

Fig. 1 Image of an ancient guitar.

The guitar's history may be traced back to two instruments that preceded written history: the oud and the lute. Many believe that the Arab forerunner to the guitar was developed by Lamech, Noah's grandfather and the sixth grandson of Adam and Eve. Lamech was supposedly inspired to construct the shape of the oud instrument after hanging his dead son's body from a tree. When the Moors invaded Southern Spain in 711 AD, they took the oud with them. By the 1790s, the evolution of Spanish guitars had settled; they had the conventional body form and six courses of strings, similar to the present guitar, but smaller. In the mid-1800s, Spanish musician and guitar manufacturer Antonio de Torres Jurado changed all of that when he invented the style of guitar that gave origin to all guitars that followed. Many regard him as "one of the single most important inventors in the history of the guitar." His guitars had a broader body, a thinner soundboard, and a more pronounced waist curve. In addition, he replaced the wooden tuning pegs with machined heads. His inventive approach to body design and fan bracing, a system of wooden struts inside the instrument, gave his classical guitars their characteristic, rich sound. Andres Segovia, a well-known Spanish guitarist, popularised Torres' classic guitar as a concert instrument. Thus the guitar quickly gained popularity around the world. [1]

According to statistics gathered by Fender, approximately 10% of the world's population knows how to play the guitar. This means that out of almost 7 billion people globally, an estimated 700 million know how to play this instrument or have at least attempted playing it a few times in theirlives. [2]

Harmonics

Among the myriad of approaches that enhance the guitar’s aural pallet, harmonics stand out as a particularly fascinating phenomenon. The guitar stands out as an instrument that can deliberately regulate these harmonics. The plucking of a guitar string forces resonance vibrations at one of its natural frequencies, vibrating in a manner such that a standing wave pattern is formed within the guitar string. Each natural frequency possesses its own characteristical standing wave pattern which is created at specific frequencies of vibration. These frequencies are known as harmonics.

Harmonics in music refer to the frequencies of pitches that vibrate in multiples of whole integers (1f, 2f, 3f and so on) in comparison to the fundamental frequency- which is the first harmonic or This succession of signals with frequencies that are integer multiples of the f frequency may construct a periodic signal with period T and frequency f=1/T.[4] The harmonics enhance the complexity of the guitar’s timbral tapestry. They have a profound significance that spans musical genres, making it crucial for both musicians and scientists to comprehend them. They reveal to us that music is simultaneously keenly mathematical and indescribably mystical. Natural harmonics are the harmonics which are produced on an open string of a stringed musical instrument. Artificial harmonics are the harmonics that are played on a fingered or fretted string. A standing wave pattern is a vibrational pattern that occurs within a medium when the vibrational frequency of the source interferes with reflected waves from one end of the medium. Because of this interference, specific places along the medium appear to be stationary. This

observed wave pattern is commonly referred to as a standing wave pattern.[5] There are some spots along the medium that appear to be stationary. Nodes are these spots, which are frequently described as points of no displacement. Other sites along the medium experience vibrations with significant positive and negative displacements. These are the points that move the most throughout each vibratory cycle of the standing wave. Because these points are the polar opposites of nodes, they are referred to as antinodes. A standing wave pattern is always made up of alternating nodes and antinodes.[6]

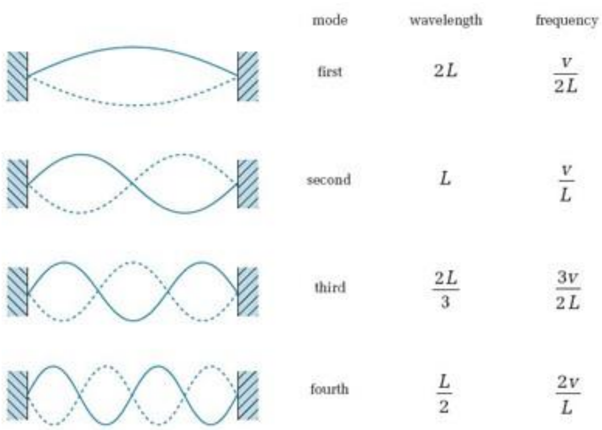


Fig.2 The first four normal modes of vibration of a string are fixed at each end. The solid and dashed lines indicate the positions of the string at opposite phase positions in the cycle.

In the first mode (n = 1), there are nodes at both ends of the string but none elsewhere. This standing-wave pattern will be put up at the frequency f = v/2L. Because the first mode is known as the fundamental mode, the first natural frequency is often referred to as the fundamental frequency.

In the second mode (n = 2), there are nodes at both ends of the string, but there is also a node in the middle. This standing-wave pattern will be put up at the frequency f = v/L. This is double the fundamental frequency value.

The third option (n = 3) has nodes at both ends of the string as well as two more nodes positioned along the string. This standing-wave pattern will be at f = 3v/2L frequency. This is three times the fundamental frequency value.

The anticipated nodes are at either end of the string in the fourth mode (n = 4) and three more are positioned at equal distances down the string. This standing-wave pattern will be put up at f = 2v/L frequency. This is four times the fundamental frequency value. [7]

This study’s objective is to effectively utilise Fourier Transform analysis to thoroughly clarify the different qualities as well as spectral complexities of the various guitar harmonic methods tested. The spectrograms of the various harmonics have been obtained by using the software ‘Audacity’

By aiming to deepen the grasp of the interaction between musical expression and scientific principles and promote a clearer understanding of the complex world of guitar harmonics, this study’s **purpose** is to employ mathematical and analytical methodologies to reveal the underlying harmonic patterns of the various techniques used.

This study's **scope** includes a thorough analysis of numerous harmonic approaches, including both natural and artificial harmonics. Each method adds to the wide range of guitar harmonic possibilities. A copper-string acoustic guitar has been included in the investigation, encompassing forcing nodes at various locations, pick thickness, and the methods utilized to pluck the string, all of which affect the final harmonic content. These harmonics have been analyzed with the help of a mathematical tool known as the Fourier transform which unveils the underlying frequencies of complex signals to achieve a comprehensive analysis.

II. METHODOLOGY

This paper analyzes the harmonic series produced by a guitar string plucked at various positions and determines the frequency ratios and power distribution of harmonics. Through experiments, it aims to determine the strength of the harmonics measured relative to the fundamental change when the pick method changes.

Harmonic Series Analysis

The first experiment was conducted by plucking the open G string on a copper-stringed acousticguitar by

a) Hand
b) Plectrum

For each manner of excitation of string, three trials were taken.

For all the spectrograms plotted, the x-axis denoted the frequency of the peaks in hertz whereas the y-axis denoted their amplitudes in dB.

Range of variations: The range of variations is determined for each harmonic by calculating the ratio of the height (or amplitude) of that harmonic with that of the fundamental frequency (or the first harmonic). Since the vertical scale in the spectrograms is in dB, subtraction gives the ratios in dB.

Strength of the harmonic relative to the fundamental: The strength of the harmonic relative to the fundamental is calculated by subtracting the amplitude of the first harmonic from the amplitude of the harmonic being determined. The lesser the difference, the stronger the peak. The more the difference, the weaker the peak.

Spectrum Analysis Comparison of Data
Plucking of Open G-string by Hand

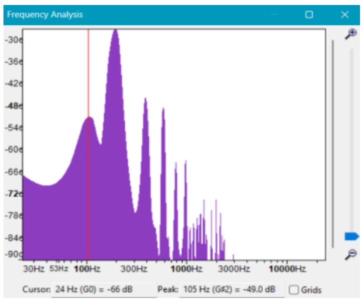


Fig.3 Frequency spectrum of Open G-string plucked by hand.

The fundamental frequency of the open G string of an acoustic guitar is 196.00 Hz (as given in Fig.7). The first peak which was observed at 105 Hz is unexplained. In order to explain this peak, a "blank spot" on the recording is analyzed.

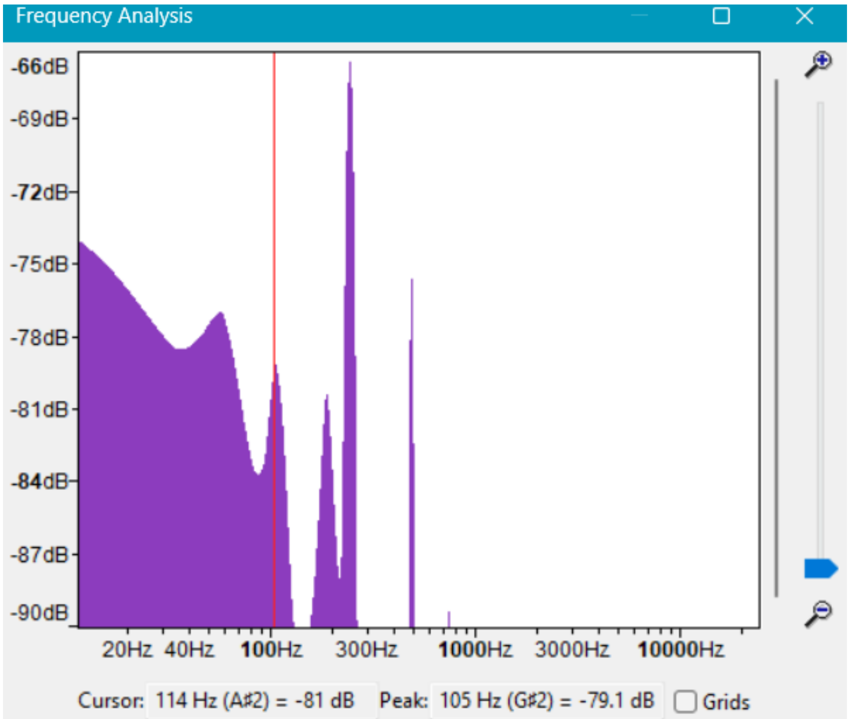


Fig.4 Frequency spectrum of a "blank spot" on the recording

We observe a peak at 105 Hz even when no string is being plucked. This indicates that the peak at 105 Hz is produced due to the background noise that the recorder has recorded.

Harmonics	Frequency (Hz)	Ratio of n harmonic with the first harmonic	Ratio of n harmonic with the ideal fundamental frequency (196Hz)
First Harmonic	195	1.000	0.994
Second Harmonic	389	1.994	1.984
Third Harmonic	588	3.015	3.000
Fourth Harmonic	781	4.005	3.984
Fifth Harmonic	974	4.994	4.969

Table 1: This table shows the frequencies of each harmonic as well as its ratios with the first harmonic and the fundamental frequency

Harmonics	**Amplitude (dB)Trial Number**			**Strength of the harmonic relative to the fundamental (Range of variations)**			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
First Harmonic	-31.7	-30.3	-38.2	0.0	0.0	0.0	0.0
Second Harmonic	-48.0	-47.6	-57.9	16.3	17.3	19.7	17.8
Third Harmonic	-51.3	-51.3	-65.5	19.6	21.0	27.3	22.6
Fourth Harmonic	-72.9	-66.1	-78.9	41.2	35.8	40.7	39.2
Fifth Harmonic	-65.7	-64.7	-65.8	34.0	34.4	27.6	32.0

Table 2: This table gives the height of the peaks i.e. amplitude and their range of variations for each harmonic when plucked by hand.

Plucking of open G string by plectrum

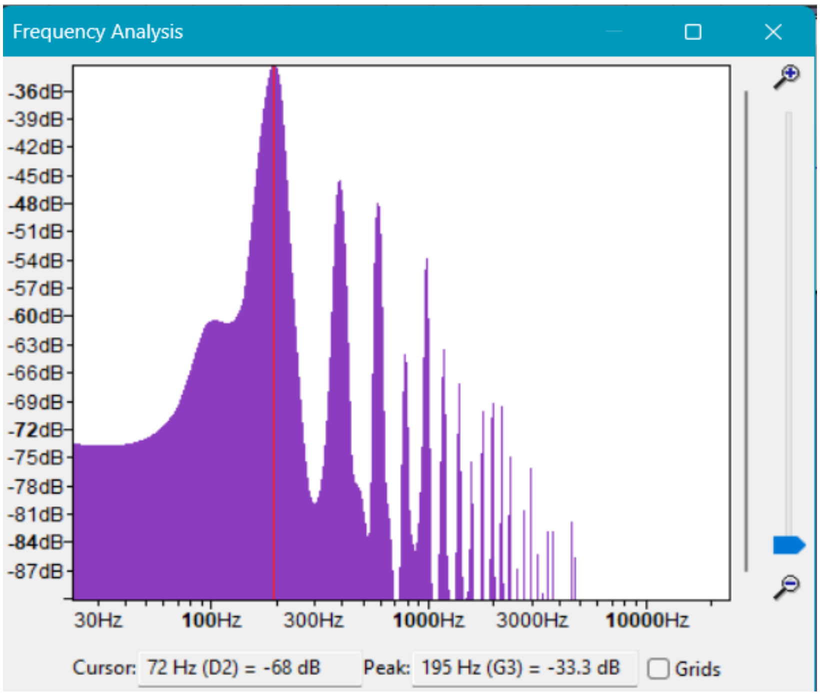


Fig.5 Frequency spectrum of open G string plucked by plectrum

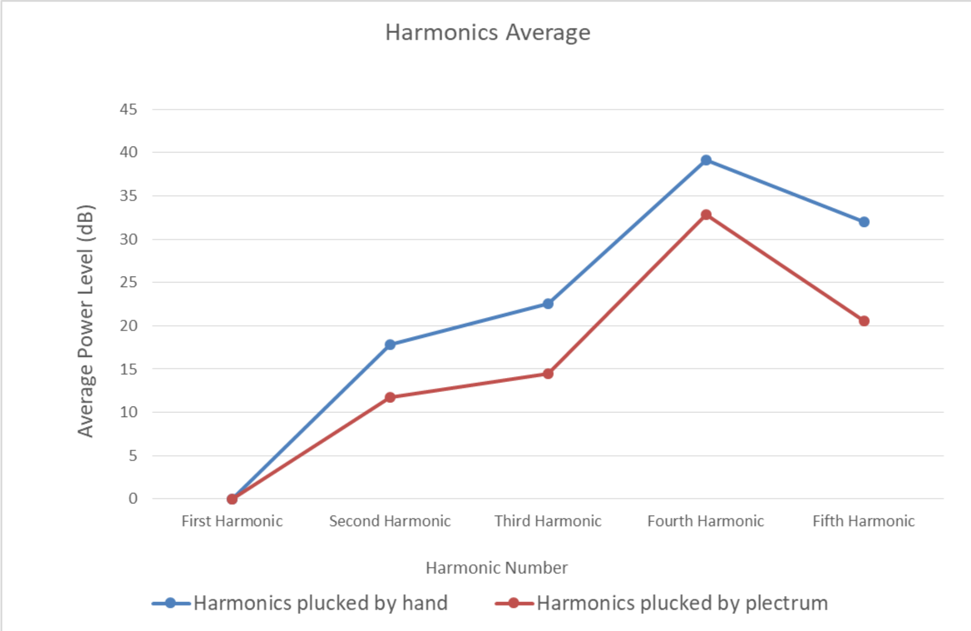
When the open g-string is plucked by the plectrum then the unexplained peak at 105 Hz turns into a broad maximum point. The first peak is now observed at 195 Hz.

Harmonics	Frequency (Hz)	Ratio of n harmonic with the first harmonic	Ratio of n harmonic with the ideal fundamental frequency(196 Hz)
First Harmonic	195 Hz	1.000	0.994
Second Harmonic	389 Hz	1.994	1.984
Third Harmonic	588 Hz	3.015	3.000
Fourth Harmonic	782 Hz	4.010	3.989

Table 3: This table shows the frequencies of each harmonic as well as its ratios with the first harmonic and the fundamental frequency

Harmonics	**Amplitude (dB)Trial Number**			**Strength of the harmonic relative to the fundamental (Range of variations)**			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
First Harmonic	-32.5	-33.3	-34.5	0.0	0.0	0.0	0.0
Second Harmonic	-44.4	-45.3	-45.8	11.9	12.0	11.3	11.7
Third Harmonic	-46.8	-47.9	-49.2	14.3	14.6	14.7	14.5
Fourth Harmonic	-66.1	-63.8	-68.8	33.6	30.5	34.3	32.8
Fifth Harmonic	-52.2	-53.4	-56.6	19.7	20.1	22.1	20.6

Table 4 : This table gives the height of the peaks i.e. amplitude and their range of variations for each harmonic when plucked by the plectrum



Graph 1: Comparative harmonic average of different modes of plucking

III. Observations:

As can be clearly seen from graph 1 and the data given in tables 2 and 4, the range of variations for the harmonics is more when the string is plucked by hand than when it is plucked by a plectrum resulting in a louder excitation of the harmonics when plucked by hand.

The spectrographs of both methods of plucking are consistent with the fact that the fifth harmonic is stronger than the fourth which goes against the general trend that the loudness(i.e. strength) of the harmonics generally decreases with increasing harmonic number.

Artificial vs. natural harmonics analysis:

Natural and artificial harmonics are the two basic forms of harmonics that can be performed on an acoustic guitar. While artificial harmonics are produced when the string is stopped at a specific point with the fretting hand, natural harmonics are produced when the string is plucked at a specific location along the string. In order to produce pitches that are respectively one octave, an octave plus a fifth, and two octaves above the open strings, natural harmonics are most frequently played at the 12th, seventh, and fifth frets..[8]

Therefore in this experiment, the natural harmonics were produced for the 5^{th}, 7^{th} and 12^{th} frets whereas the artificial harmonics were produced for the open g-string and the g-string on the 5^{th} and 7^{th} frets.

How to play Artificial Harmonics:

To play an artificial harmonic, the left-hand frets a note. At the same time, the right hand touches the harmonic node and plucks the string simultaneously. For this reason, it is difficult to play artificial harmonics with a pick. Artificial harmonics are shown using the harmonic node twelve frets (one octave) above the fretted note.

There are many different techniques by which one can produce an artificial harmonic. In this experiment, the open g-string and the 5^{th} and 7^{th} frets of the third string were fretted. Then, the index finger of our right hand was used to lightly touch the node at the 12^{th}, 17^{th}, and 19^{th} frets respectively. While touching the node, the right-hand ring finger was used to pluck the string. The index finger was then quickly lifted from the node.[9]

Fig.6 A technique of plucking used to produce artificial harmonics

6th string	5th String	4th String	3rd string	2nd string	1st string
E open=82	A open=110	D open=147	G open=196	B open=247	E open=330
F 1st fret=87	A# 1st fret=117	D# 1st fret=156	G# 1st fret=208	C 1st fret=262	F 1st fret=349
F# 2nd fret=93	B 2nd fret=124	E 2nd fret=165	A 2nd fret=220	C# 2nd fret=278	F# 2nd fret=370
G 3rd fret=98	C 3rd fret=131	F 3rd fret=175	A# 3rd fret=233	D 3rd fret=294	G 3rd fret=392
G# 4th fret=104	C# 4th fret=139	F# 4th fret=185	B 4th fret=247	D# 4th fret=311	G# 4th fret=415
A 5th fret=110	D 5th fret=147	G 5th fret=196	C 5th fret=262	E 5th fret=330	A 5th fret=440
A# 6th fret=117	D# 6th fret=156	G# 6th fret=208	C# 6th fret=278	F 6th fret=349	A# 6th fret=466
B 7th fret=124	E 7th fret=165	A 7th fret=220	D 7th fret=294	F# 7th fret=370	B 7th fret=494
C 8th fret=131	F 8th fret=175	A# 8th fret=233	D# 8th fret=311	G 8th fret=392	C 8th fret=523
C# 9th fret=139	F# 9th fret=185	B 9th fret=247	E 9th fret=330	G# 9th fret=415	C# 9th fret=554
D 10th fret=147	G 10th fret=196	C 10th fret=262	F 10th fret=349	A 10th fret=440	D 10th fret=587
D# 11th fret=156	G# 11th fret=208	C# 11th fret=278	F# 11th fret=370	A# 11th fret=466	D# 11th fret=622
E 12th fret=165	A 12th fret=220	D 12th fret=294	G 12th fret=392	B 12th fret=494	E 12th fret=659

Fig. 7 Frequency Chart for the notes of the guitar in Table Format

Natural harmonic on the 12th fret:

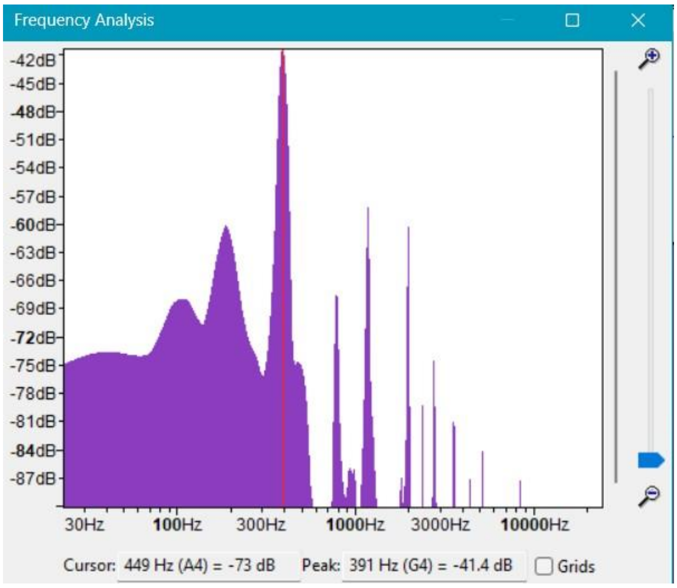


Fig.8 Frequency Spectrum of the natural harmonic produced on the 12th fret

The second harmonic or the first overtone is created when a node is pressed on the 12th fret of the G-string on an acoustic guitar. This is so because the string splits into two equal pieces at the 12th fret, forming a node point that generates a standing wave with a frequency that is double the string's fundamental frequency (i.e. 2*196 = 392 Hz).

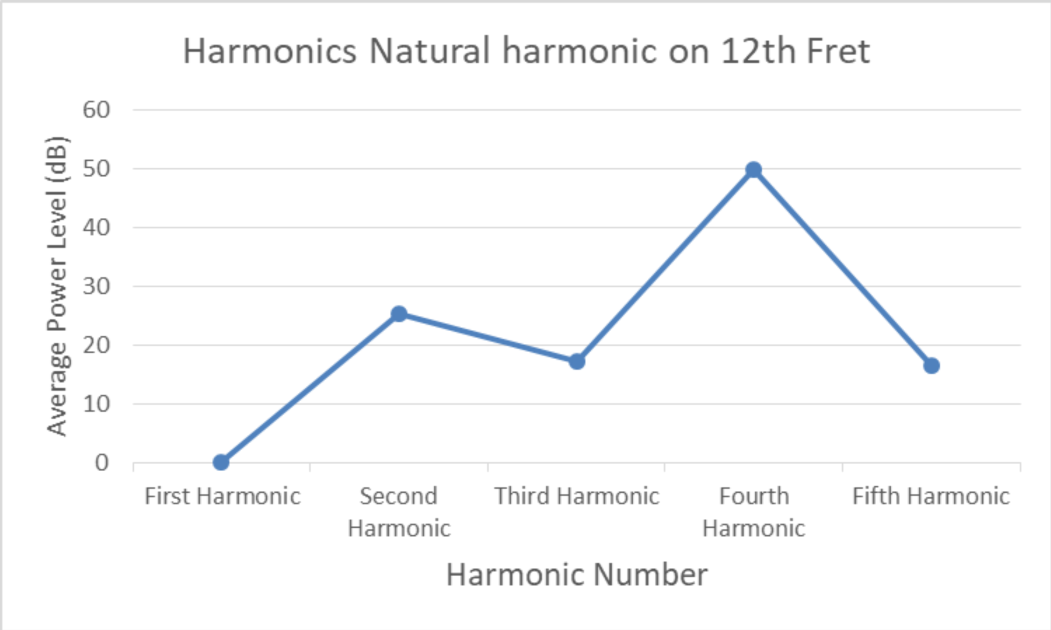
Harmonics	Frequency (Hz)	The ratio of n harmonic with thefirst harmonic	The ratio of n harmonic with the ideal fundamental frequency (392 Hz)
First Harmonic	391	1	0.997
Second Harmonic	784	2.005	2.000
Third Harmonic	1175	3.005	2.997
Fourth Harmonic	1561	3.992	3.982
Fifth Harmonic	1959	5.010	4.997

Table 5: This table shows the frequencies of each harmonic as well as its ratios with the first harmonic and the fundamental frequency

Harmonics	Amplitude (dB)Trial Number			Strength of the harmonic relative to the fundamental (Range of variations)			
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Average
First Harmonic	-41.6	-41.4	-43.4	0.0	0.0	0.0	0.0
Second Harmonic	-66.7	-67.0	-68.6	25.1	25.6	25.2	25.3
Third Harmonic	–58.3	-58.3	-61.0	16.7	16.9	17.6	17.1
Fourth Harmonic	-93.2	-89.8	-92.8	51.6	48.4	49.4	49.8
Fifth Harmonic	-57.6	-56.8	-61.3	16.0	15.4	17.9	16.4

Table 6: This table gives the height of the peaks i.e. amplitude and their range of variations for each harmonic when produced on the 12th fret.

Graph 2: Natural Harmonic on the 12th fret



Observation: The spectrograph of the natural harmonic on the 12th fret does not follow the general harmonic trend that the loudness(i.e. strength) of the harmonics generally decreases with increasing harmonic numbers as in the graph the third harmonic is stronger than the second harmonic and the fifth harmonic is stronger than the fourth harmonic.

Artificial harmonic on the open string

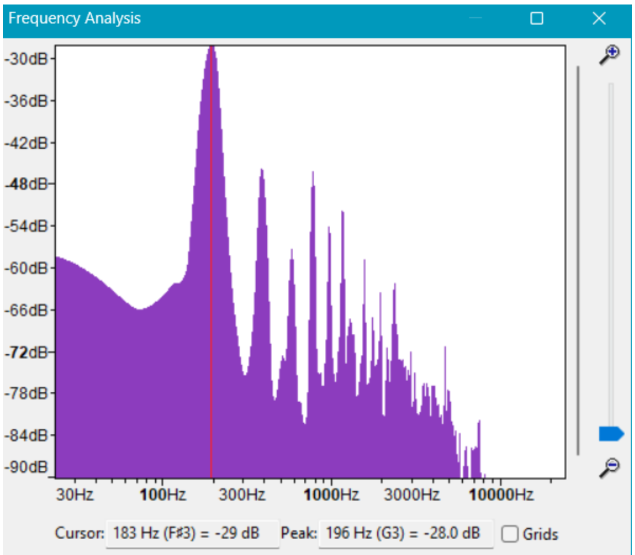


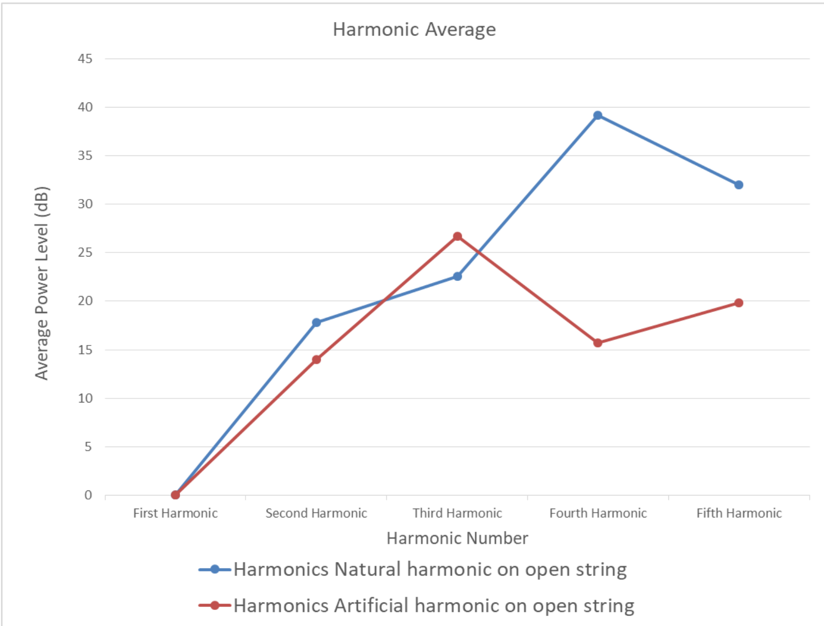
Fig.9 Frequency Spectrum of the artificial harmonic produced on the open g-string

Harmonics	Frequency(Hz)	The ratio of n harmonic to the first harmonic
First Harmonic	196	1.00
Second Harmonic	388	1.979
Third Harmonic	581	2.964
Fourth Harmonic	779	3.974

Table 7: This table shows the frequencies of each harmonic as well as its ratios with the first harmonic

Harmonics	**Amplitude (dB)Trial Number**			**Strength of the harmonic relative to the fundamental (Range of variations)**			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
First Harmonic	-28.0	-30.8	-37.5	0.0	0.0	0.0	0.0
Second Harmonic	-45.4	-46.2	-46.7	17.4	15.4	9.2	14.0
Third Harmonic	-57.1	-58.2	-61.1	29.1	27.4	23.6	26.7
Fourth Harmonic	-46.1	-47.8	-49.5	18.1	17.0	12.0	15.7
Fifth Harmonic	-53.6	-47.0	-55.2	25.6	16.2	17.7	19.8

Table 8: This table gives the height of the peaks i.e. amplitude and their range of variations for each harmonic produced artificially on the open G-string.



Graph 3: Comparative harmonic average of the average and natural harmonics produced on theopen G-string

Observations:

As can clearly be observed from Graph 3 and the data given in Tables 2 and 8, the average range of variations for the open G-string plucked by hand(i.e. natural harmonic on open string) is more for every harmonic except the third indicating that on average, this method of producing harmonics leads to louder excitations of harmonics.

Moreover, the spectrograph of the artificial harmonic of the open G-string breaks the general harmonic trend , that loudness (i.e. strength) of the harmonics generally decreases with increasing harmonic numbers, as , in the graph, the fifth harmonic is stronger than the fourth harmonic which is then stronger than the third harmonic.

Natural harmonic on the 5th fret:

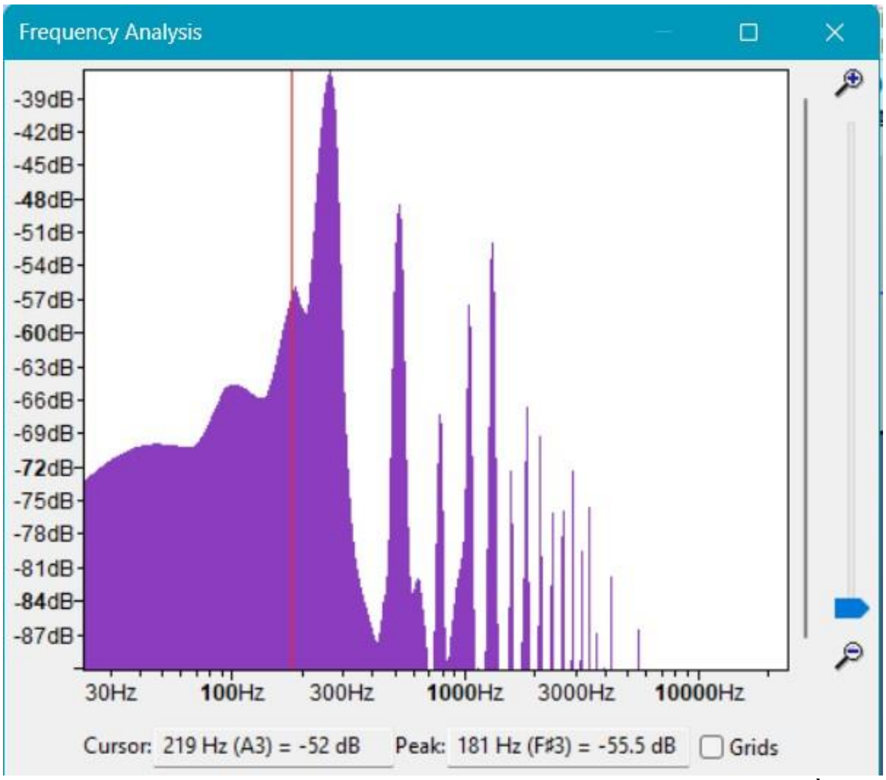


Fig.10 Frequency Spectrum of the natural harmonic produced on the 5th fret

Third Harmonic	782	2.973	2.985
Fourth Harmonic	1043	3.966	3.981
Fifth harmonic	1302	4.950	4.969

Table 9: This table shows the frequencies of each harmonic as well as its ratios with the first harmonic.

Harmonics	Amplitude (dB)Trial Number			Strength of the harmonic relative to the fundamental (Range of variations)			
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Average
First Harmonic	-39.5	-36.8	-38.8	0.0	0.0	0.0	0.0
Second Harmonic	-52.3	-48.6	-50.7	12.8	11.8	11.9	12.2
Third Harmonic	-72.3	-67.0	-70.5	32.8	30.2	31.7	31.6
Fourth Harmonic	-58.6	-57.2	-63.6	19.1	20.4	24.8	21.4
Fifth Harmonic	-52.6	-49.8	-53.6	13.1	13.0	14.8	13.6

Table 10: This table gives the height of the peaks i.e. amplitude and their range of variations for each harmonic produced naturally on the 5th fret.

Artificial harmonic on the 5th fret:

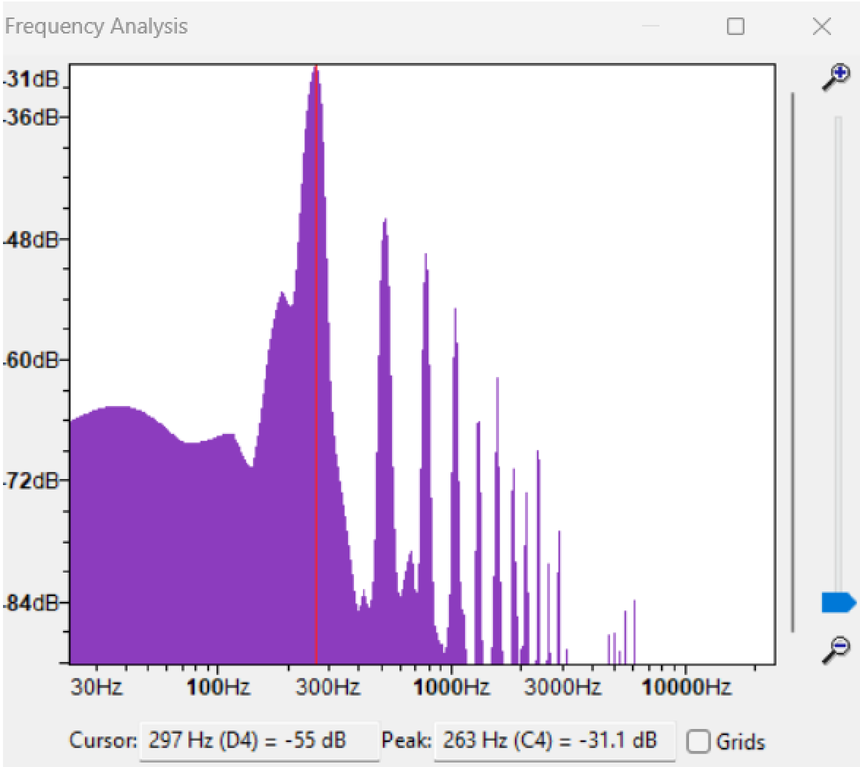


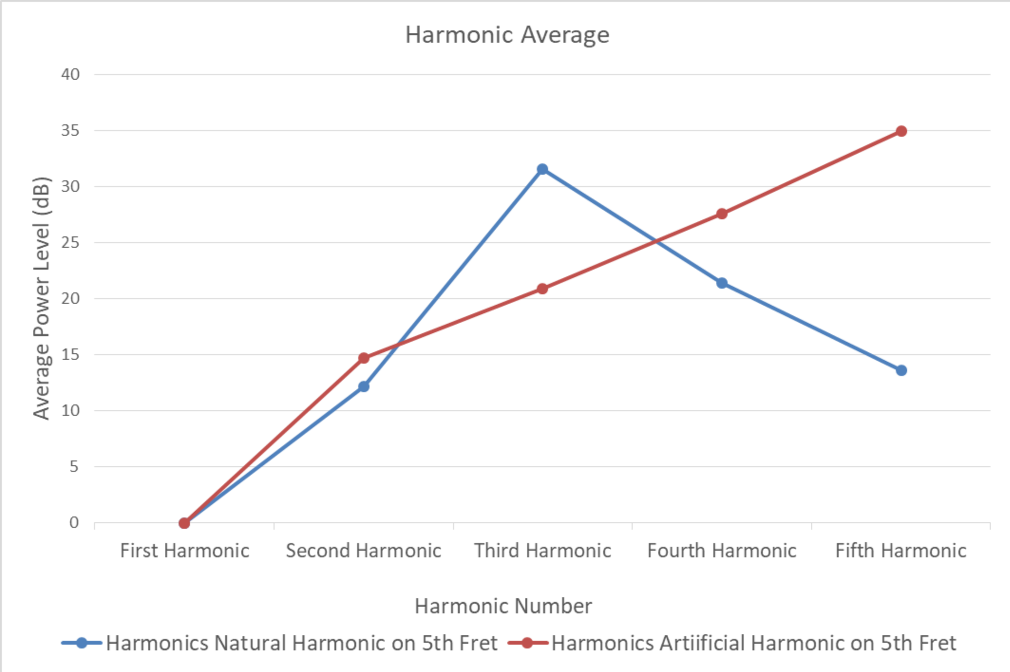
Fig.11 Frequency Spectrum of the artificial harmonic of the 5th fret

Harmonics	Frequency(Hz)	The ratio of n harmonic to the firstharmonic
First Harmonic	263	1
Second Harmonic	521	1.981
Third Harmonic	780	2.966
Fourth Harmonic	1039	3.951
Fifth harmonic	1299	4.939

Table 11: This table shows the frequencies of each harmonic as well as its ratios with the first harmonic.

Harmonics	**Amplitude (dB)Trial Number**			**Strength of the harmonic relative to the fundamental (Range of variations)**			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
First Harmonic	-30.1	-31.7	-30.3	0.0	0.0	0.0	0.0
Second Harmonic	-45.0	-45.6	-45.7	14.9	13.9	15.4	14.7
Third Harmonic	-48.4	-52.2	-54.1	18.3	20.5	23.8	20.9
Fourth Harmonic	-53.8	-61.1	-60.2	23.7	29.4	29.9	27.6
Fifth Harmonic	-63.5	-68.3	-65.4	33.4	36.6	35.1	35.0

Table 12: This table gives the height of the peaks i.e. amplitude and their range of variations for each harmonic produced artificially on the 5th fret.



Graph 4: Comparative harmonic average of the artificial and natural harmonics produced on the5th fret.

Observations: As is clearly evident from graph 4 and the data given in Tables 10 and 12, the range of variations for the artificial harmonics is higher than the range of variations for the natural harmonics for all harmonics except the third. This indicates that on average, the production of artificial harmonics leads to a louder excitation of harmonics on the 5th fret.

Moreover, the spectrographs for the natural harmonics break the general harmonic trend that the loudness (i.e. strength) of the harmonics generally decreases with increasing harmonic numbers as in the graph the fifth harmonic is stronger than the fourth which is stronger than the third harmonic. However, the spectrograph for the artificial harmonics produced on the same fret depicts the general harmonic trend.

Natural harmonic on the 7th fret:

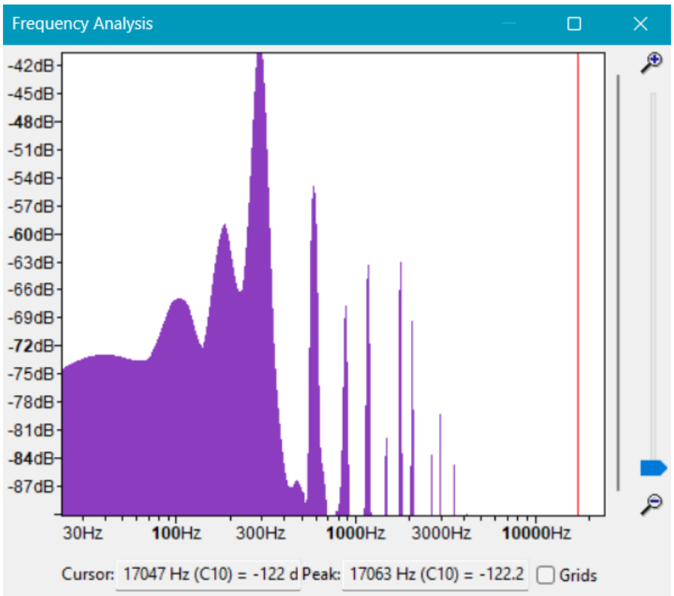


Fig.12 Frequency Spectrum of the natural harmonic produced on the 7th fret

Harmonic	Frequency	The ratio of n harmonic to the first harmonic	The ratio of
First Harmonic	293	1.000	0.996
Second Harmonic	586	2.000	1.993
Third Harmonic	878	2.996	2.986
Fourth Harmonic	1170	3.993	3.979
Fifth Harmonic	1463	4.993	4.976

Table 13: This table shows the frequencies of each harmonic as well as its ratios with the firstharmonic.

Harmonics	**Amplitude (dB)Trial Number**			**Strength of the harmonic relative to the fundamental (Range of variations)**			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
First Harmonic	-38.6	-39.5	-38.6	0.0	0.0	0.0	0.0
Second Harmonic	-55.5	-56.6	-55.2	16.9	17.1	16.6	16.9
Third Harmonic	-63.0	-65.8	-63.4	24.4	26.3	24.8	25.2

Table 14: This table gives the height of the peaks i.e. amplitude and their range of variations for each harmonic produced naturally on the 7th fret.

Artificial harmonics on the 7th fret:

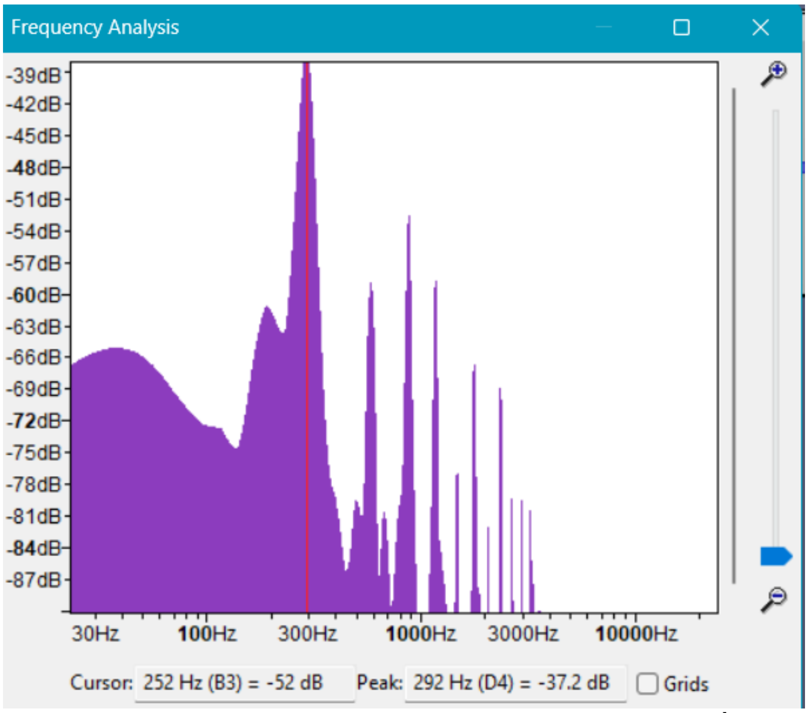


Fig.13 Frequency Spectrum of the artificial harmonic of the 7th fret

Harmonic	Frequency	The ratio of n harmonic to the first harmonic
First Harmonic	292	1.000
Second Harmonic	585	2.003
Third Harmonic	876	3.000
Fourth Harmonic	1167	3.996
Fifth Harmonic	1460	5.000

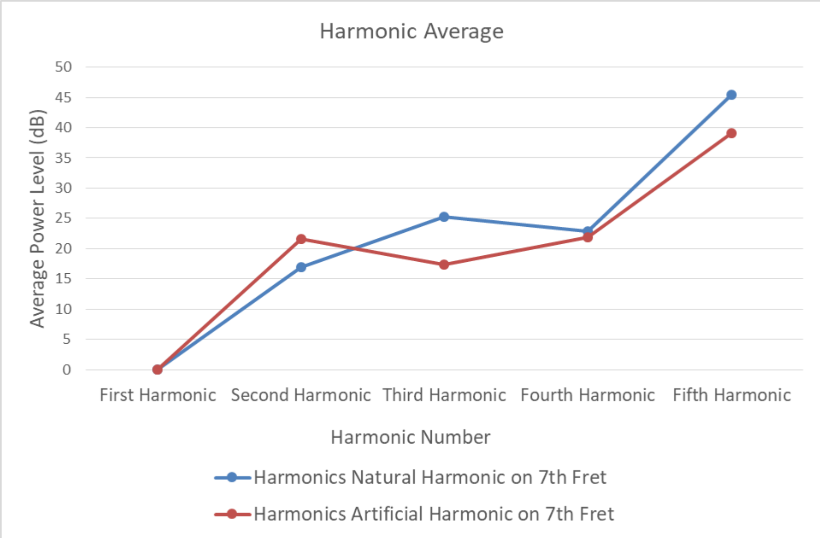
Table 15: This table shows the frequencies of each harmonic as well as its ratios with the firstharmonic.

Harmonics	**Amplitude (dB)Trial Number**			**Strength of the harmonic relative to thefundamental (Range of variations)**			
	Trial 1	**Trial 2**	**Trial 3**	**Trial 1**	**Trial 2**	**Trial 3**	**Average**
First Harmonic	-37.6	-37.7	-36.4	0.0	0.0	0.0	0.0

Second Harmonic	-59.3	-59.3	-58.0	21.7	21.6	21.6	21.6
Third Harmonic	-57.7	-54.8	-51.4	20.1	17.1	15.0	17.4
Fourth Harmonic	-61.1	-59.6	-56.8	23.5	21.9	20.4	21.9
Fifth Harmonic	-73.8	-81.8	-73.4	36.2	44.1	37.0	39.1

Table 16: This table gives the height of the peaks i.e. amplitude and their range of variations for each harmonic produced artificially on the 7th fret.

Graph 5: Comparative harmonic average of the average and natural harmonics produced on the7th fret.



Observations: As is clearly evident from Graph 5 and the data given in Tables 14 and 16 , the range of variations for the natural harmonics is higher than the range of variations for the artificial harmonics for all harmonics except the second harmonic. This indicates that on average, the production of natural harmonics on the 7th fret leads to a louder excitation of the harmonics although the difference is not substantial.

Moreover, the spectrographs of the natural and artificial harmonics on the 7th fret do not follow the general harmonic trend that the loudness (i.e. strength) of the harmonics generally decreases with increasing harmonic numbers as, in the graph, of the natural harmonics the fourth harmonic is stronger than the third harmonic whereas, in the graph of the artificial harmonics, the third harmonic is stronger than the second harmonic.

IV. CONCLUSION

The goal of this study was to understand the intricate connection between musical expression and scientific principles. By careful examination of both natural and artificial harmonics, this study gave important new understandings of the harmonic complexity of the acoustic guitar. The study's findings state that the mode of plucking plays a vital role in influencing the harmonic content of guitar sound. When the harmonics were produced on the open G-string by plucking it by hand, louder excitations of harmonics were consistently produced as compared to plucking the G-string by the plectrum. This emphasizes the complex interactions between the harmonic intensity and plucking techniques. Intriguing questions about the potential impact of extraneous variables on harmonic analysis were also raised by the presence of background noise at 105 Hz, thereby underscoring the importance of rigorous data interpretation in acoustic research. The study's findings further stated that for the open G-string, the natural harmonic plucked by the hand produces louder excitations of harmonics as compared to that produced by the artificial harmonics of the open G-string. Moreover, the artificial harmonics produced on the 5th fret yielded louder excitations of harmonics as compared to the natural harmonics produced on the 5th fret. Whereas, on the 7th fret as a general trend, the natural harmonics produced yielded louder excitations of harmonics as compared to the artificial harmonics produced. The natural harmonic on the 12th fret is presented so that the study covers a wide range of fret positions for the natural harmonics thus helping the readers understand the effect of fret positions on harmonic strength. Additionally, the study uses spectrographs to demonstrate how almost every experiment conducted deviates from the general trend that the loudness of the harmonics frequently decreases with the increase in harmonic number.

This research thus bridges the gap between music and science by highlighting intricate mathematical concepts and the magical properties of the harmonics.