

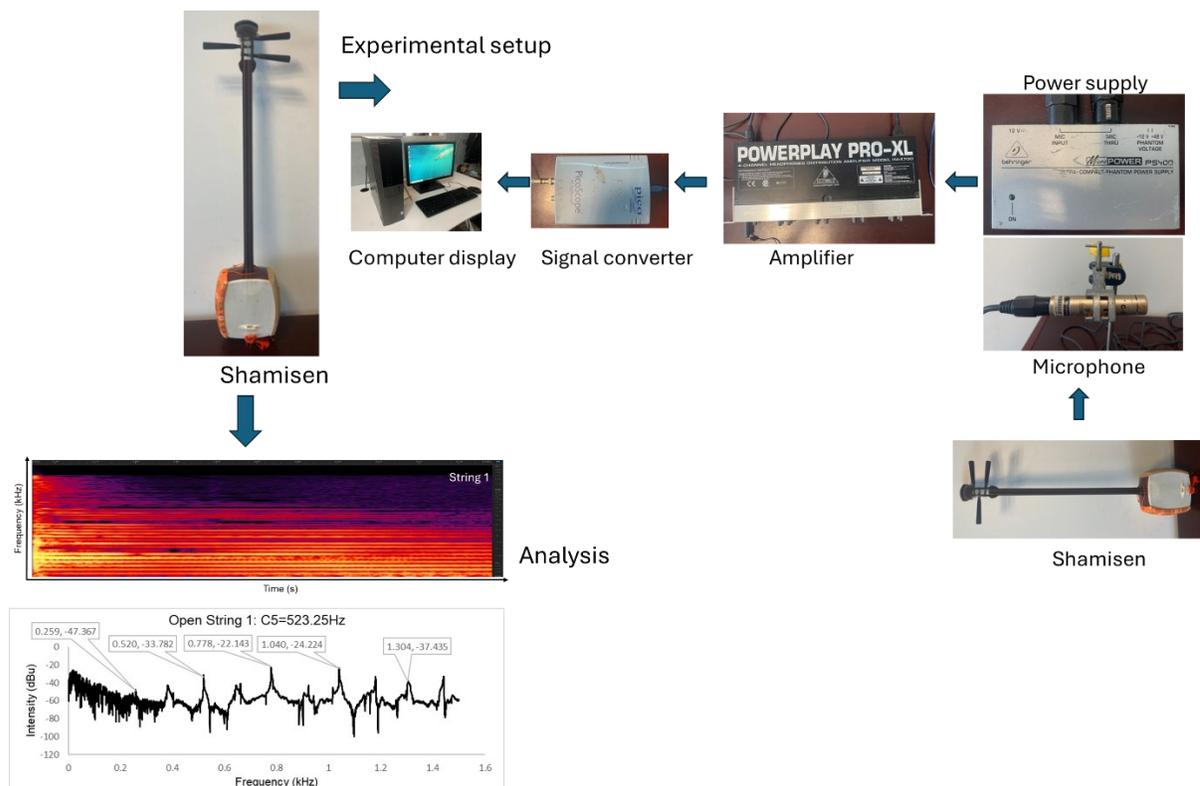
Sound Analyses of a Japanese Traditional Stringed Instrument of Okinawa: The Shamisen

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GRAPHICAL ABSTRACT



Sound Analyses of a Japanese Traditional Stringed Instrument of Okinawa: The Shamisen

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The shamisen is a three-stringed, plucked instrument that is used in a variety of genres, including folk music and kabuki theater. A PicoScope was used to obtain the signals from the shamisen. Open strings 1 and 2 exhibited discontinuities in the sequence of ascending notes. On string 1, B5 at fret 11 unexpectedly drops to C5 (instead of C6) at fret 12. On string 2, C6 at fret 17 drops to C#5 (instead of C#6) at fret 18. String 3 presented a continuous progression, ranging from C4 up to A5. The abrupt shifts from B5 to C5 and C6 to C#5 on string 1 and 2 respectively results from the traditional Japanese approach to tuning (musicians emphasize relative intonation instead of conforming to equal-tempered pitch systems). Certain pitches may not hold functional significance within the melodic or harmonic framework, and their omission or alteration is consistent with historical performance practice. The variations in pitch captured in PicoScope data represent authentic outcomes of the shamisen's culturally rooted tuning system and performance aesthetics. The PicoScope displayed the fundamental frequency one octave higher than the perceived pitch, while the gradient of the plotted partials frequency curves confirmed alignment with the actual sounding pitch.

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Keywords: Shamisen; Sound notes; Fast Fourier Transform (FFT)

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INTRODUCTION

A mainstay of traditional Japanese music, the shamisen is a three-stringed, plucked instrument that is used in a variety of genres, including folk music and kabuki theater. The shamisen is a stringed instrument that is plucked (Alves 2013). Though the use of animal skins was widespread throughout the 20th century, it gradually lost favor starting in the mid-2000s due to social stigma and the decline of workers skilled in preparing these particular skins (Hueston 2016). Traditionally, skins were made from dog or cat skins, with cat skin preferred for finer instruments (Dalby 2000). Modern shamisen skins are frequently made from synthetic materials such as plastic (Miki 2008). The strings likewise are made from synthetic materials such as plastic. The majority of shamisen are designed to be readily disassembled, and the neck, is typically separated into three or four parts that fit and lock together. The shamisen's neck is a single rod that runs across the instrument's drum-like body, partially projecting on the other side and serving as an anchor for the

strings. Even though they were originally made of ivory, many of the long, thin, hexagon-shaped pegs used to wind the strings are now made of other materials including wood and plastic because ivory is scarce, and trading laws restrict its sale. The shamisen's three strings are composed of either nylon or silk, as is customary. The player's skill level will determine the string material. Silk strings are traditionally utilized. However, this is only used for professional performances because silk breaks readily over short periods of time. The nylon strings are less expensive and last longer than silk. Even though the shamisen has ancient roots, its tones are still heard today in Japan and other places. This instrument's versatility and distinctive tone allow it to fit into contemporary visual media and new musical genres.

Figure 1 shows the heike shamisen compared with a medium-sized, or chuzao shamisen and the bachi for min'yo, tsugaru and heike shamisen. Mahogany, Chinese quince, and karin are the main woods used to make shamisen. Chinese quince is frequently used for shamisen practice, while Karin wood is most frequently used for the body and necks of lower-quality instruments. Red sandalwood is usually used to make high-quality necks, although other woods, such as rosewood, or even more costly woods, like kouki, can also be utilized. The heiki shamisen was studied in this work. The standard shamisen tuning, commonly used for niagari, is C-G-C, with the middle string tuned to match the pitch of the fourth fret on the thickest string. In standard tuning (niagari), the most common tuning is C-G-C, where the open strings sound like C, G, and C (from thickest to thinnest).

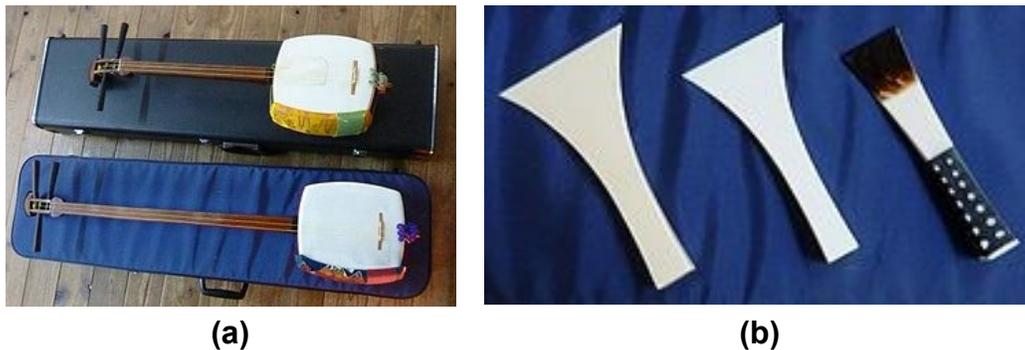


Fig. 1. (a) The heike shamisen compared with a medium-sized, or chuzao shamisen (b) Bachi for min'yo, tsugaru and heike shamisen.

The nomenclature of the notes in an octave varies depending on the genre in which the shamisen is played and tuned. In Western music theory, an octave consists of 12 distinct notes. These notes are evenly spaced and include the 7 diatonic notes (C, D, E, F, G, A, B) plus the 5 chromatic notes (sharps and flats) that fall between them. This is also known as the chromatic scale. There are 21 frets with the marking 1, 2, 3, #, 4, 5, 6, 7, 8, 9, b, 10, 11, 12, 13, #, 14, 15, 16, 17, and 18 on the neck. The tuning is a half-step per position (including the sharps and flats). In niagari tuning it is written as the following: open string is C, fret 1 is C#, fret 2 is D, fret 3 is D#, fret 4 is E, fret 5 is F, and so on. One must ensure that the fret '#' between fret 3 and fret 4, and between fret 13 and fret 14 or the fret 'b' between fret 9 and fret 10 are not being skipped. One first tunes the open string to C, then position 1 is usually right at the bottom of the chibukuro (the flared part of the top of the neck). The corrected tuning should be as the following: open string is C, fret 1 is C#, fret 2 is D, fret 3 is D#, fret # is E, fret 4 is F, and fret 5 is F#.

Frequency spectrum data were captured using a PicoScope oscilloscope and analyzed through Fast Fourier Transform (FFT), while spectrograms from Adobe Audition provided visual insight into overtone distribution. Despite matching the Equal Tempered Scale (ETS) in pitch and harmonic series, the shamisen displayed a markedly different timbre, characterized by reduced radiation and greater damping. Its overtone amplitudes diminished progressively across the spectrum, maintained a clearer, more consistent harmonic presence. Random partials appearing between harmonic peaks in the signal suggest differences in structural resonance.

The shamisen is a traditional Japanese three-stringed instrument distinguished by several standard tunings: honchoushi (C-F-C), niagari (C-G-C), and sansagari (C-F-B \flat). Each tuning supports different vocal registers and expressive needs. For instance, Akita Nikata Bushi exemplifies honchoushi, Tsugaru Jongara Bushi reflects niagari, and Tsugaru Sansagari uses the lowered third tuning. Unlike fixed-pitch instruments such as the guitar (E-A-D-G-B-E) or violin (G-D-A-E), shamisen players freely adjust tunings according to the singer's range or personal preference, provided the intervallic rules are maintained. The middle string is tuned by matching its open pitch to the fourth fret of the thickest string, creating the characteristic C-G-C tuning relationship (<https://en.wikipedia.org/wiki/Shamisen>). Kokubu *et al.* (2012) examined the shamisen's acoustic and vibrational characteristics, focusing on its distinctive sawari mechanism, a buzzing resonance unique among world string instruments. Using FFT and Finite Element Method (FEM) analysis, they identified resonant peaks between 1000 and 5000 Hz and confirmed that sawari increases higher frequency sound pressure, shaping the shamisen's tonal identity. In a different approach, Lasickas (2010) explored the instrument through digital physical modeling, developing a Finite Difference Time Domain (FDTD) simulation of the shamisen for use in digital audio environments. His study highlighted the challenges of reproducing the percussive attack and complex coupling of strings, bridge, and membrane, yet demonstrated the potential for real-time digital synthesis that accurately represents the shamisen's physical behavior. From a perceptual perspective, Chiba *et al.* (2023) conducted a cross-cultural performance evaluation, comparing classical piano and Tsugaru shamisen competitions. Their findings revealed that auditory cues dominate visual ones when performance quality variance is high, underscoring the importance of sound in evaluating shamisen performance artistry within Japanese musical culture. Building upon these earlier works, this study focuses on the acoustic characteristics of the shamisen, employing PicoScope oscilloscope recordings and FFT-based analysis to examine its harmonic behavior and overtone structure. Spectrograms generated in Adobe Audition further visualize overtone distributions. While its pitch and harmonic series may align with the ETS, the shamisen exhibits a distinctive timbre characterized by greater damping, reduced radiation, and irregular partials between harmonic peaks-features that reflect its culturally embedded tuning system and performance aesthetics.

The purpose of this study was to use spectral analysis and scientific documentation to maintain the shamisen's sonic identity. Original tunings and materials run the risk of disappearing due to modernization and deteriorating craftsmanship. This project establishes a digital library that can subsequently facilitate AI-driven sound reconstruction and virtual learning platforms for the preservation of traditional instruments by preserving empirical frequency data and overtone behavior. This research has a substantial impact because it advances both scientific knowledge and cultural preservation. From a scientific perspective, the study offers empirical shamisen acoustic data captured by high-resolution digital equipment. Since historic tuning systems have rarely been examined with the

accuracy of contemporary waveform and FFT tools, this closes a significant gap in ethnomusicological documentation. The information serves as a standard for upcoming comparison research between Japan's traditional and Western tempered systems since it not only illustrates the shamisen's tuning behavior but also maps its overtone patterns. The results have significant cultural and preservation implications for the legacy of traditional music. By documenting the shamisen's spectral properties, the instrument's sound identity can be digitally preserved and recreated in virtual contexts, protecting it against loss resulting from generational discontinuity or material degradation. By using the findings to teach AI-based sound modeling systems, real Japanese tones can be replicated in digital museums, AR/VR cultural simulations, and educational applications. This ensures that the shamisen's acoustic identity will endure in changing digital environments by bridging the gap between traditional workmanship and contemporary technology.

Although ethnomusicological studies have extensively documented the shamisen's cultural role and repertoire (Alves 2013; Dalby 2000; Miki 2008), relatively few have approached its acoustical behavior through quantitative and signal-based analysis. The majority of prior research emphasizes historical development, construction craft, and genre classification, yet seldom connects these to the measurable parameters of sound radiation, harmonic balance, and frequency response. In contrast, studies of the koto and shakuhachi have shown that traditional tuning and performance gestures strongly affect overtone structure and resonance. However, similar acoustic characterization for the shamisen, especially within the Okinawan tradition, remains underrepresented in contemporary literature. In this study, the shamisen's tonal properties were examined using a high-resolution digital oscilloscope (PicoScope) and FFT analysis to identify the relationships between fundamental frequency, harmonic amplitude, and overtone decay. Complementary spectrogram analysis in Adobe Audition was used to visualize timbral behavior and resonance stability across pitches. By correlating acoustical data with traditional performance and tuning practice, this research aimed to bridge the gap between scientific measurement and ethnomusicological interpretation. The findings contribute new insight into how traditional Japanese intonation and construction materials influence the shamisen's acoustic signature, enhancing both the understanding of its sonic identity and the methodological framework for studying non-Western string instruments. For cultural preservation, the measurement data of the shamisen's acoustic behavior provides a scientific record of its traditional tuning and timbral identity, features that are increasingly endangered by modernization and material substitution. By documenting the precise frequency discontinuities and resonance characteristics, this study creates a reproducible reference that supports the safeguarding and digital archiving of Okinawan musical heritage, which align with UNESCO's (2017) framework. For performance practice, it casts light on the recognition of intentional pitch discontinuities and octave-shifted fundamentals clarification on how traditional performers manipulate tuning and articulation to achieve expressive nuance. It can contribute to pedagogical and interpretive awareness of musicians.

EXPERIMENTAL

In this study, a heike shamisen with body, neck, and head constructed from rosewood as the primary material was used. The dimensions and features of the shamisen included an overall length measured at approximately 65 cm, the body length around 20

cm, and the neck extending 33 cm, whereas the head was approximately 12 cm. Figure 2 shows the shamisen and the marking: 1, 2, 3, ♯, 4, 5, 6, 7, 8, 9, ♭, 10, 11, 12, 13, ♯, 14, 15, 16, 17, and 18 on the neck. Figure 3 illustrates the front, back of shamisen body and the long, thin, hexagon-shaped pegs at the instrument's head. Figure 4 shows the bachi (or the plectrum) used for playing the shamisen in this work.



Fig. 2. (a) The shamisen and (b) the marking: 1, 2, 3, ♯, 4, 5, 6, 7, 8, 9, ♭, 10, 11, 12, 13, ♯, 14, 15, 16, 17, and 18 on the neck

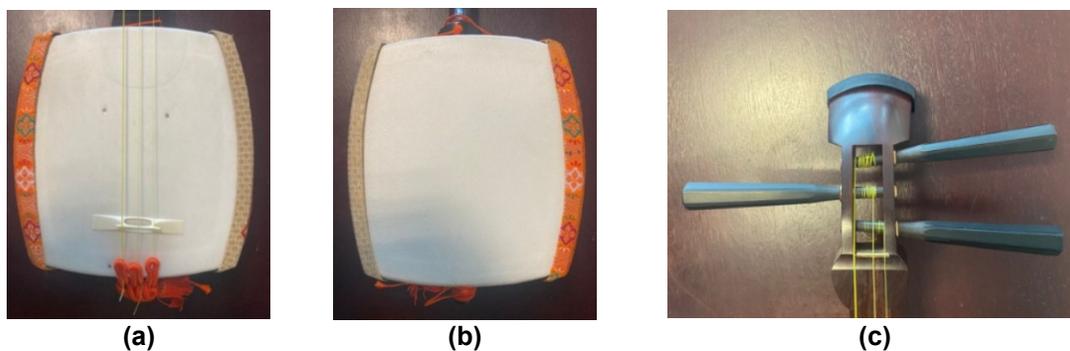


Fig. 3. (a) The front (b) back of shamisen body (c) the long, thin, hexagon-shaped pegs at the instrument's head are used to wound the strings

An omnidirectional polar pattern microphone was positioned 20 cm in front the shamisen to capture the radiated sound. It was plucked in a conventional seated position to replicate typical playing conditions and ensure optimal sound resonance. The sound signals were captured in real time using a PicoScope 3000 series oscilloscope and accompanying data recorder (Pico Technology, Eaton Socon, UK). The PicoScope software enabled

waveform viewing, FFT analysis, spectrum visualization, and voltage-based triggering. The apparatus used in the experimental setup is provided in Fig. 5.



Fig. 4. Bachi, or the plectrum used for playing the shamisen



Fig. 5. The apparatus used in the experimental setup

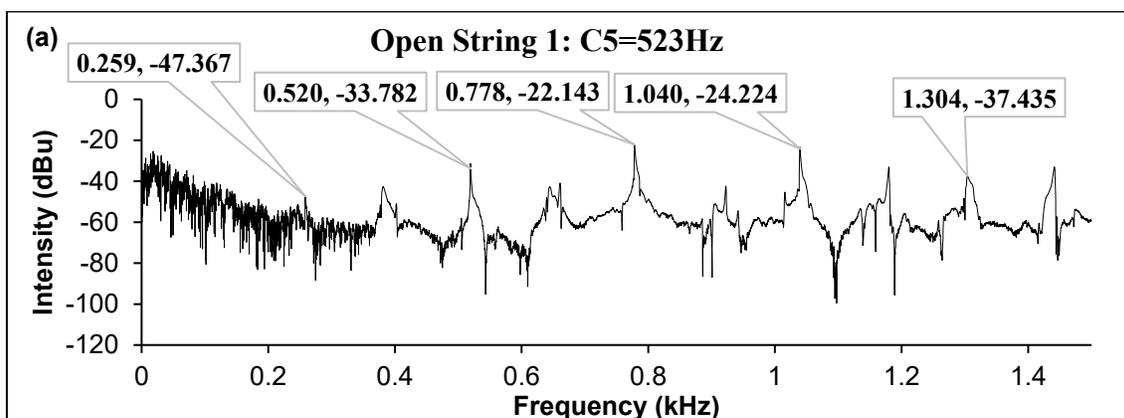
A sample frequency of 48 kHz was used to record the audio. The experiment was conducted in an anechoic chamber in the music department of Universiti Malaysia Sarawak (UNIMAS) at room temperature (27°C) and relative humidity at 64%. Using measurements in seconds, the Time Frequency Analysis (TFA) was carried out using Adobe Audition, focusing on the precise intensity in hertz to differentiate the power of partial frequencies. Using this paradigm, tone systems are frequently investigated in sound analysis and re-synthesis. The notes heard in music are produced by the sound waves created by the vibrations. The audio signals were captured in monaural format using a sampling rate of 48 kHz and a 24-bit resolution. For additional processing, the audio profile was saved in ".wav" format. To ensure correct settings, a calibration was done before the session. In accordance with the European Broadcasting Union's (EBU) protocol, the calibration test tone was limited to a sine wave at 1.0 kHz. A digital recording level of 0 VU at either +4 dBu or -18 dBFS in analog or digital format is required by the EBU. During the calibration process, the signal amplitude might not have been impacted by any other neighboring

devices. The Audio-Technica AT4050 microphone, Behringer Powerplay Pro XL amplifier, Steinberg UR22mkII audio interface, and XLR cable made up the recording apparatus. A low-cut filter was applied to the microphone's recording settings.

To prevent distortion or bias, the shamisen was recorded many times under identical conditions, including fixed microphone position and orientation. The signal was amplified using a Behringer Powerplay Pro XL amplifier (Zhongshan, Guangdong, China) before being processed by the PicoScope. The resulting sound spectra were analyzed in Adobe Audition, where FFT analysis was used to extract dominant frequencies and evaluate tonal characteristics. The sample rate was 48000 Hz, with mono channel, bit depth 32-bit (float) and format as imported quick time compressed. The Fourier Transform technique enabled identification of fundamentals, harmonics, and subharmonics in the recorded waveforms. Sound data from the shamisen were collected in multiple trials. Each iteration is recorded under the same conditions, and the resulting waveforms were averaged to reduce variability and noise. This approach ensured a robust and meaningful acoustic comparison. By employing controlled plucking, consistent recording parameters, and multiple rounds of measurement with averaged data, the methodology ensures a clear, accurate, and scientifically valid comparison of the acoustic performance of the shamisen. To ensure accurate and repeatable sound production, a skilled player performed the plucking on the shamisen. Consistency was ensured by maintaining the same technique, plucking angle, and force for each attempt. Prior to recording, the player rehearsed the precise motions multiple times to minimize human variability and enhance the reliability of the sound comparison. The plucked notes were C5 (523 Hz), G4 (392 Hz), and C4 (261 Hz), corresponding to strings 1 through 3. In niagari tuning, the open string corresponds to C, with subsequent frets ascending chromatically to F \sharp at the fifth fret. The middle string is tuned by matching its open pitch to the fourth fret of the thickest string, creating the characteristic C-G-C tuning relationship (<https://en.wikipedia.org/wiki/Shamisen>).

RESULTS AND DISCUSSION

Figure 6 shows the typical signals obtained from (a) open string 1, (b) open string 2, and (c) open string 3. The Picoscope accuracy reads up to 3 decimal points (where the unit is kHz). Therefore, in the unit of Hz the accuracy does not give any decimal point. From Fig. 6, Table 1 is generated to display the fundamental (f_0), partials (f_n) and f_n/f_0 for open strings 1, 2, and 3. The presented plots represent a single best recording. The f_n/f_0 are computed by normalizing partial frequency f_n with the fundamental frequency f_0 .



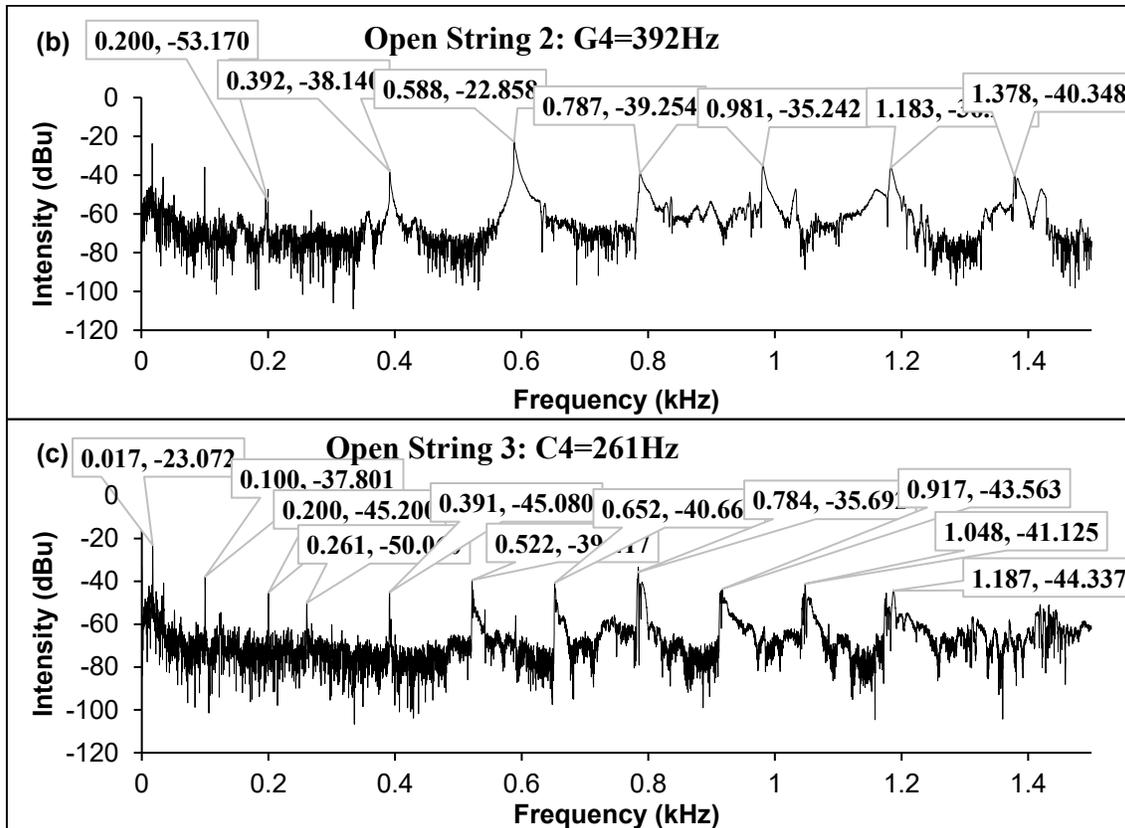


Fig. 6. A typical signal obtained from open (a) string 1, (b) string 2, and (c) string 3

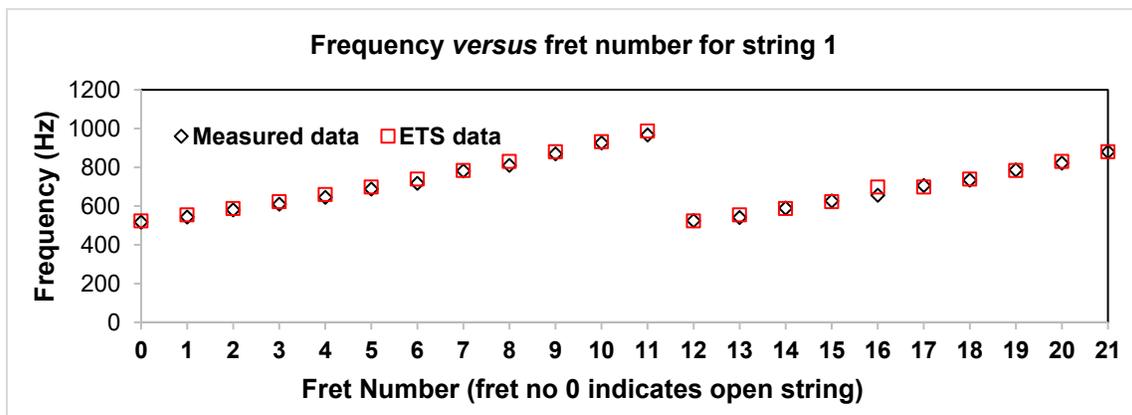
Table 1. The Fundamental (f0), Partial (fn) and fn/f0 for Open String 1 (C5), Open String 2 (G4), and Open String 3 (C4)

Partial	String 1 (C5) (Hz)	fn/f0	String 2 (G4) (Hz)	fn/f0	String 3 (C4) (Hz)	fn/f0
fundamental	520	1	392	1	261	1
2 nd partial	778	1.49	588	1.5	391	1.49
3 rd partial	1040	2	787	2	522	2
4 th partial	1304	2.50	981	2.50	652	2.49
5 th partial	-	-	1183	3	784	3
6 th partial	-	-	1378	3.51	917	3.51
7 th partial	-	-	-	-	1048	4
8 th partial	-	-	-	-	1187	4.54

All the open strings had the harmonics (1, 2, 3, 4) and in-harmonics (1.5, 2.5, 3.5, 4.5) with the partials decreasing with pitch (less partials at high pitch string 1 (C5) compared to low pitch string 3 (C4)). Based on the signals obtained from open string and fret 1 to 21 for strings 1 through 3 (only string 3 is attached here in Fig. 10), Table 2 is generated to display the fret number and frequency for strings 1 through 3. From Table 2, Figs. 7, 8, and 9 are plotted for the frequency *versus* fret number for string 1, 2, and 3 respectively.

Table 2. Fret Number and Frequency for String 1, String 2, and String 3

Fret Number	Marking on the Neck	String 1 (Hz)	String 2 (Hz)	String 3 (Hz)
0 (open string)	0 (open string)	517 (C5=523)	392(G4=392)	261 (C4=261)
1	1	543 (C5#=554)	406 (G4#=415)	269 (C4#=277)
2	2	580 (D5=587)	437 (A4=440)	290 (D4=293)
3	3	610 (D5#=622)	458 (A4#=466)	306 (D4#=311)
4	#	645 (E5=659)	482 (B4=493)	329 (E4=329)
5	4	688 (F5=698)	512 (C5=523)	348 (F4=349)
6	5	717 (F5#=739)	532 (C5#=554)	363 (F4#=369)
7	6	781 (G5=783)	573 (D5=587)	399 (G4=392)
8	7	810 (G5#=830)	598 (D5#=622)	408 (G4#=415)
9	8	869 (A5=880)	636 (E5=659)	429 (A4=440)
10	9	926 (A5#=932)	685 (F5=698)	463 (A4#=466)
11	b	967 (B5=987)	720 (F5#=739)	480 (B4=493)
12	10	524 (C5=523)	780 (G5=783)	518 (C5=523)
13	11	541 (C5#=554)	808 (G5#=830)	546(C5#=554)
14	12	589 (D5=587)	868 (A5=880)	588(D5=587)
15	13	626 (D5#=622)	932 (A5#=923)	624(D5#=622)
16	#	656 (E5=698)	965 (B5=987)	649(E5=659)
17	14	706 (F5=698)	1041(C6=1046)	696(F5=698)
18	15	734 (F5#=739)	543 (C5#=554)	739(F5#=739)
19	16	786 (G5=783)	579 (D5=587)	793(G5=783)
20	17	822 (G5#=830)	607 (D5#=622)	813(G5#=830)
21	18	890 (A5=880)	661 (E5=659)	876(A5=880)

**Fig. 7.** The frequency versus fret number for string 1. ETS is equal tempered scale

From Fig. 7, fret 11 from string 1 shows the note B5, whereas fret 12 displays the note C5 (instead of C6). Similar to Fig. 8, fret 17 from string 2 shows the note C6, whereas fret 18 displays the note C5# (instead of C6#). From Fig. 9, open string 3 displays the note C4 and increases gradually up to A5 for fret 21. The ETS in the figures is for comparison purposes. Open strings 1 and 2 exhibited discontinuities in the sequence of ascending notes. On string 1, B5 at fret 11 unexpectedly drops to C5 (instead of C6) at fret 12. On string 2, C6 at fret 17 drops to C#5 (instead of C#6) at fret 18. String 3 presents a continuous progression, ranging from C4 up to A5. This abrupt shifts from B5 to C5 and C6 to C#5 on string 1 and 2 respectively results from the traditional Japanese approach to tuning (musicians emphasize relative intonation instead of conforming to equal-tempered pitch systems).

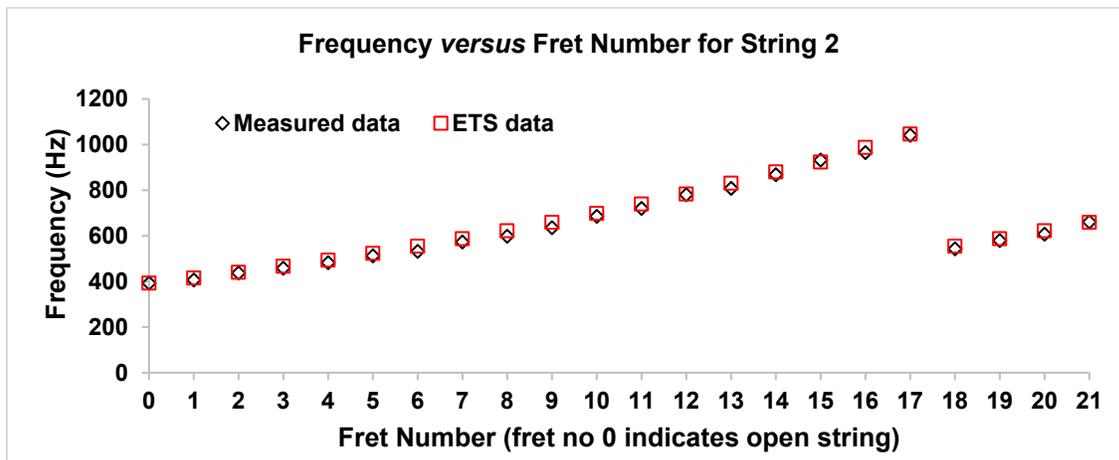


Fig. 8. The frequency *versus* fret number for string 2. ETS is equal tempered scale

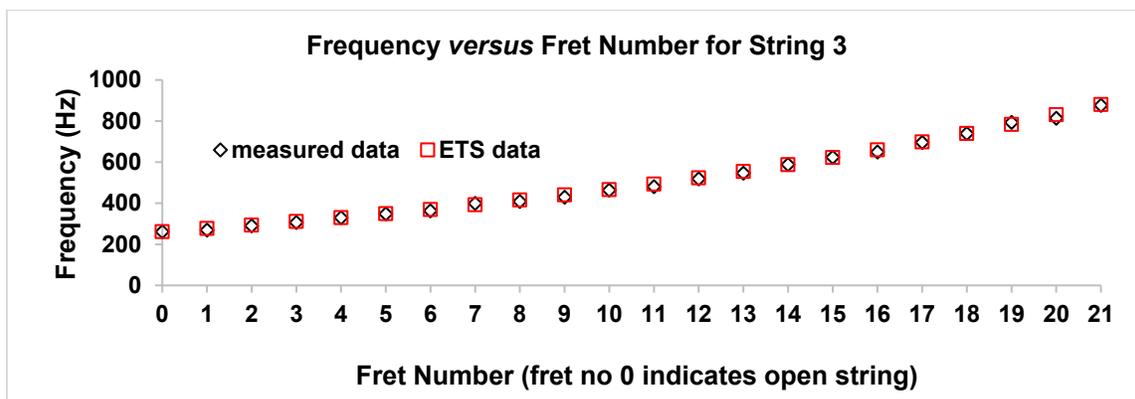
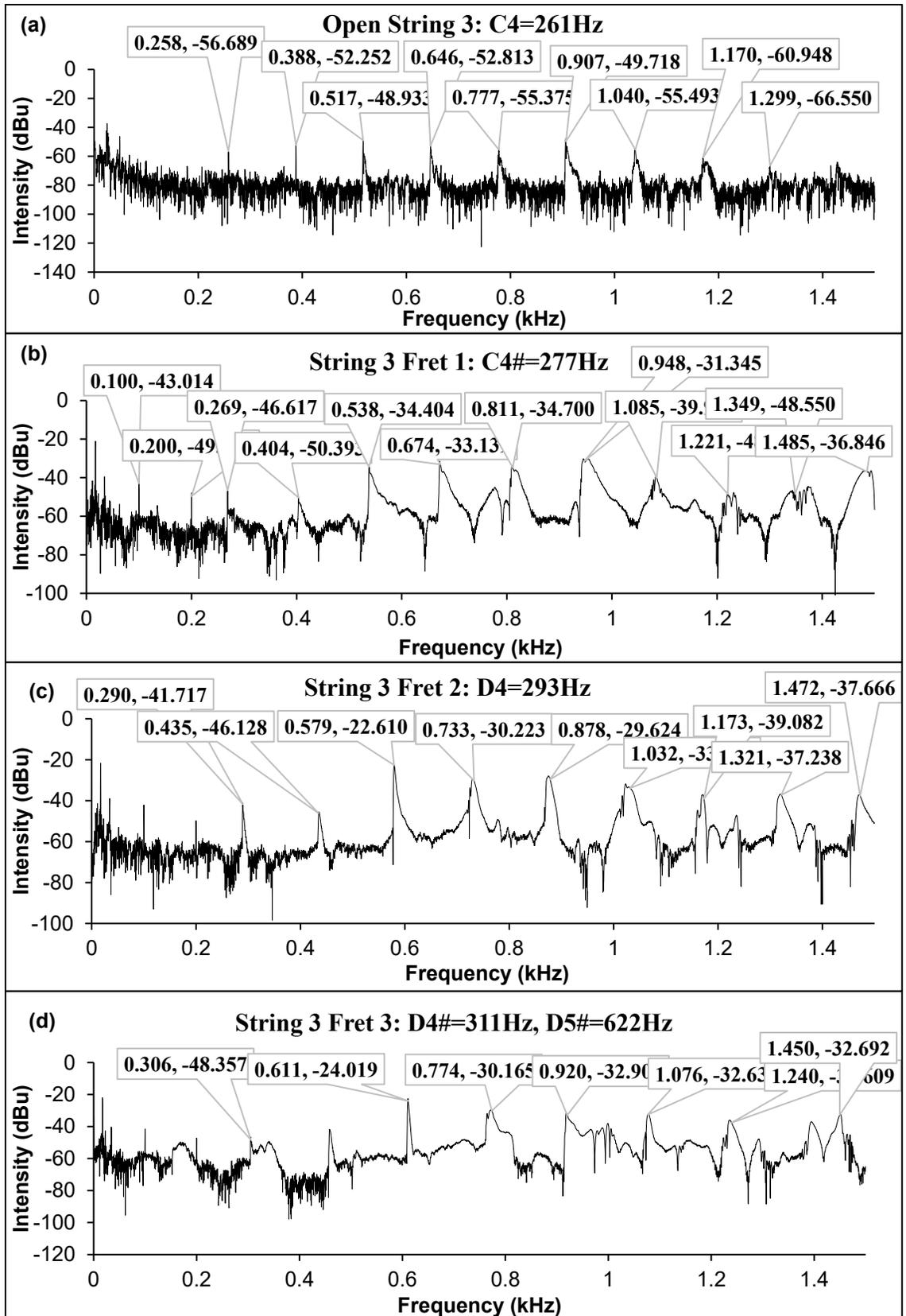
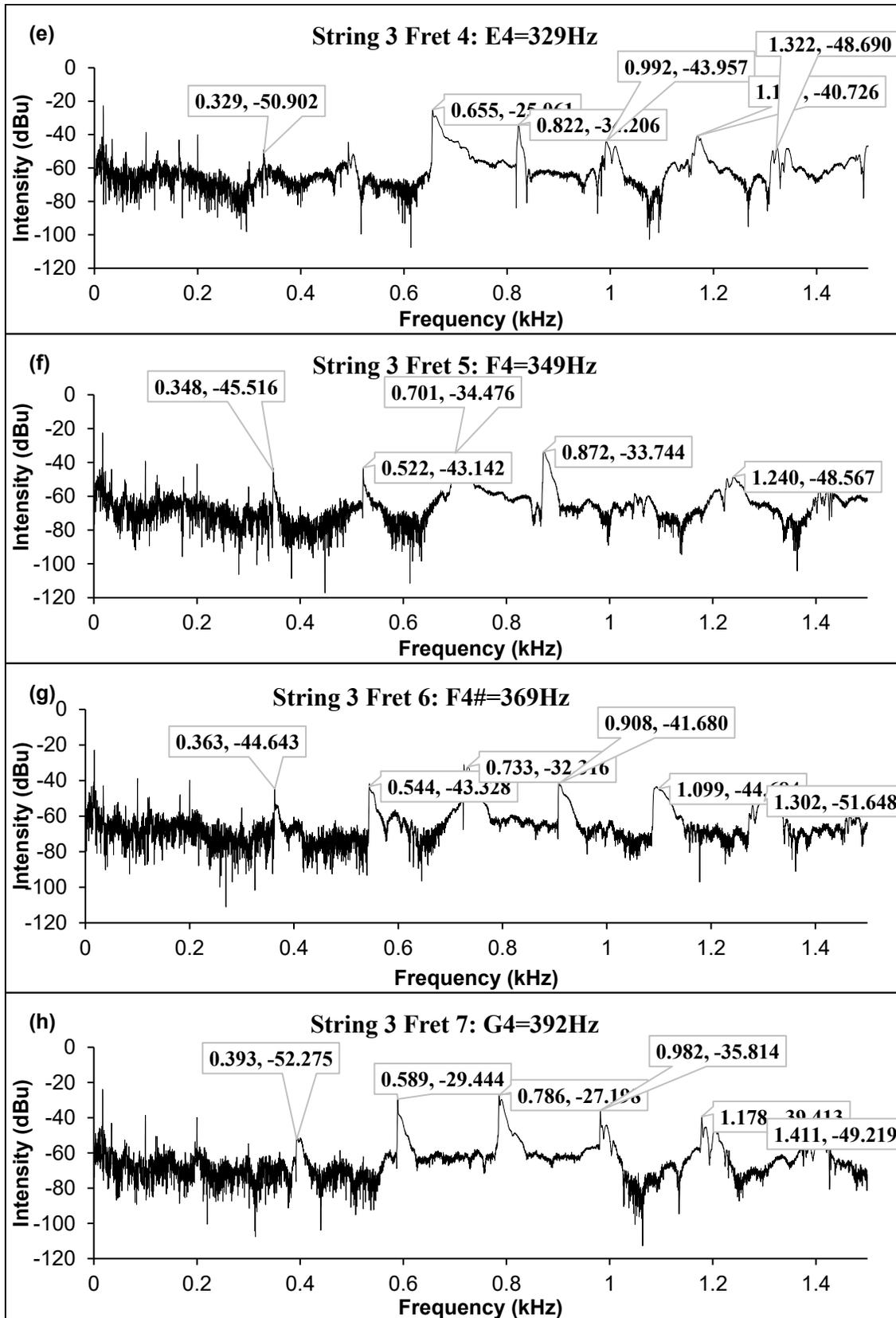


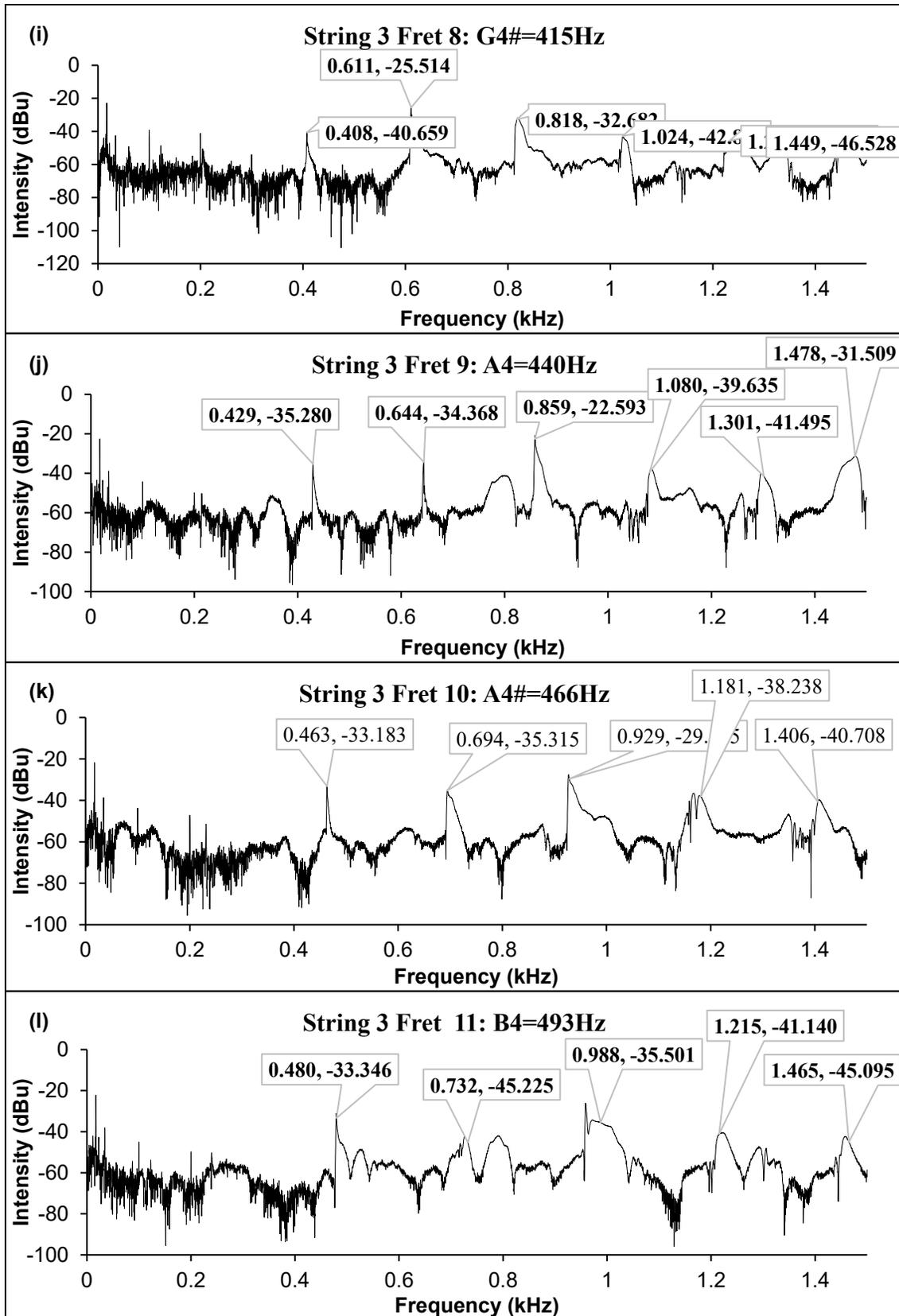
Fig. 9. The frequency *versus* fret number for string 3. ETS is equal tempered scale

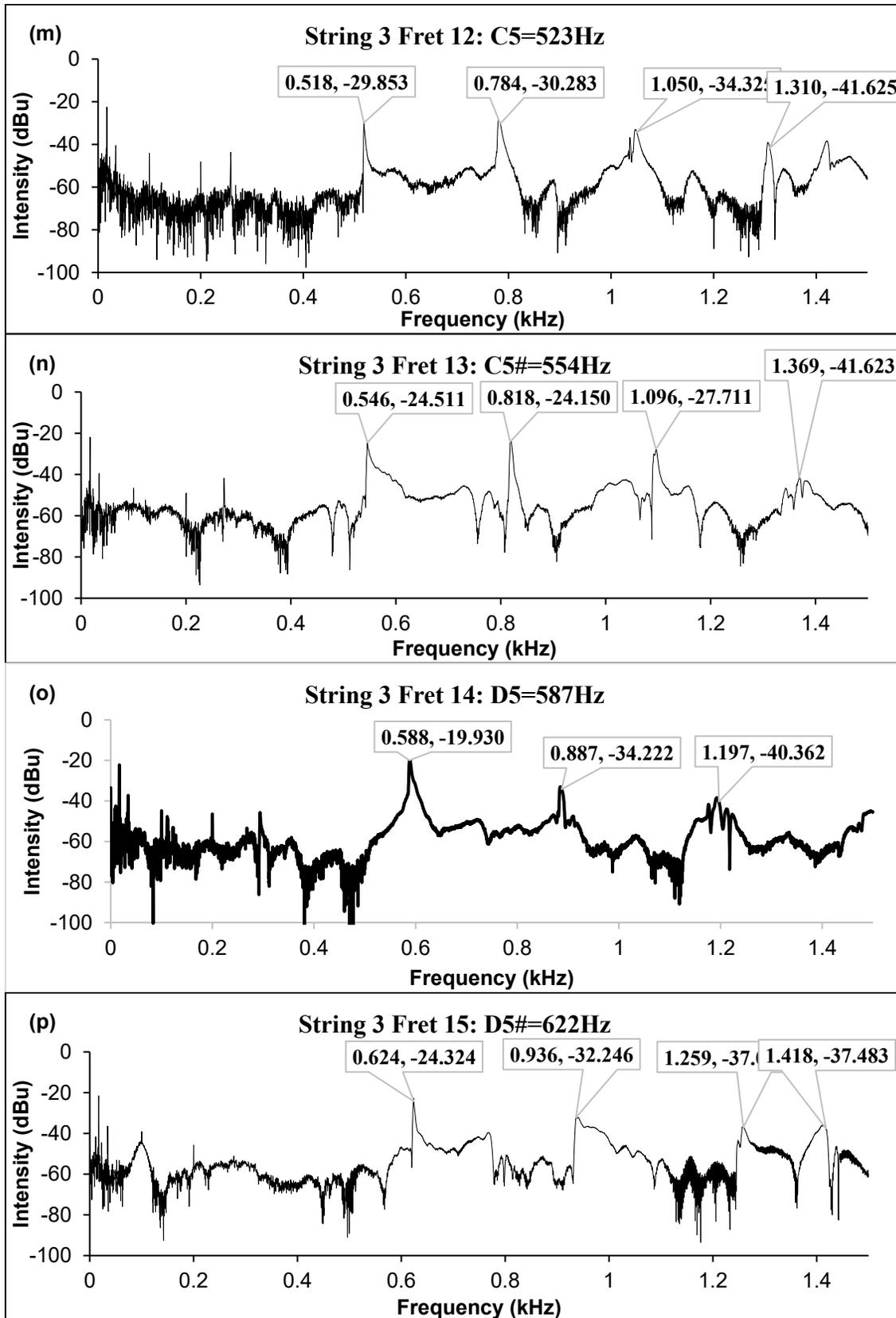
Acoustic observations of pitch discontinuities in shamisen performance can be understood not as tuning inaccuracies, but as a reflection of traditional performance practice and the cultural logic of tuning. As Tokita (1996) explains, shamisen pitch organization is not governed by Western equal temperament; instead, tuning choices are shaped by the singer's repertoire, modal framework, and narrative expression. This relational tuning practice produces intervals that align with the tonal and linguistic contours of the song rather than fixed scale divisions. Groemer's (1999) ethnographic research further demonstrates that shamisen players tune by ear and adapt intonation dynamically in response to voice and ensemble context, resulting in subtle variations that enhance expressive authenticity. Johnson (2006) also notes that contemporary shamisen pedagogy continues to value these flexible tunings, viewing them as an essential part of the instrument's aesthetic identity rather than as deviations requiring standardization. Taken together, these studies provide ethnographic and theoretical support for interpreting the measured pitch discontinuities as culturally embedded phenomena within the shamisen tradition, rather than as performance or measurement errors.

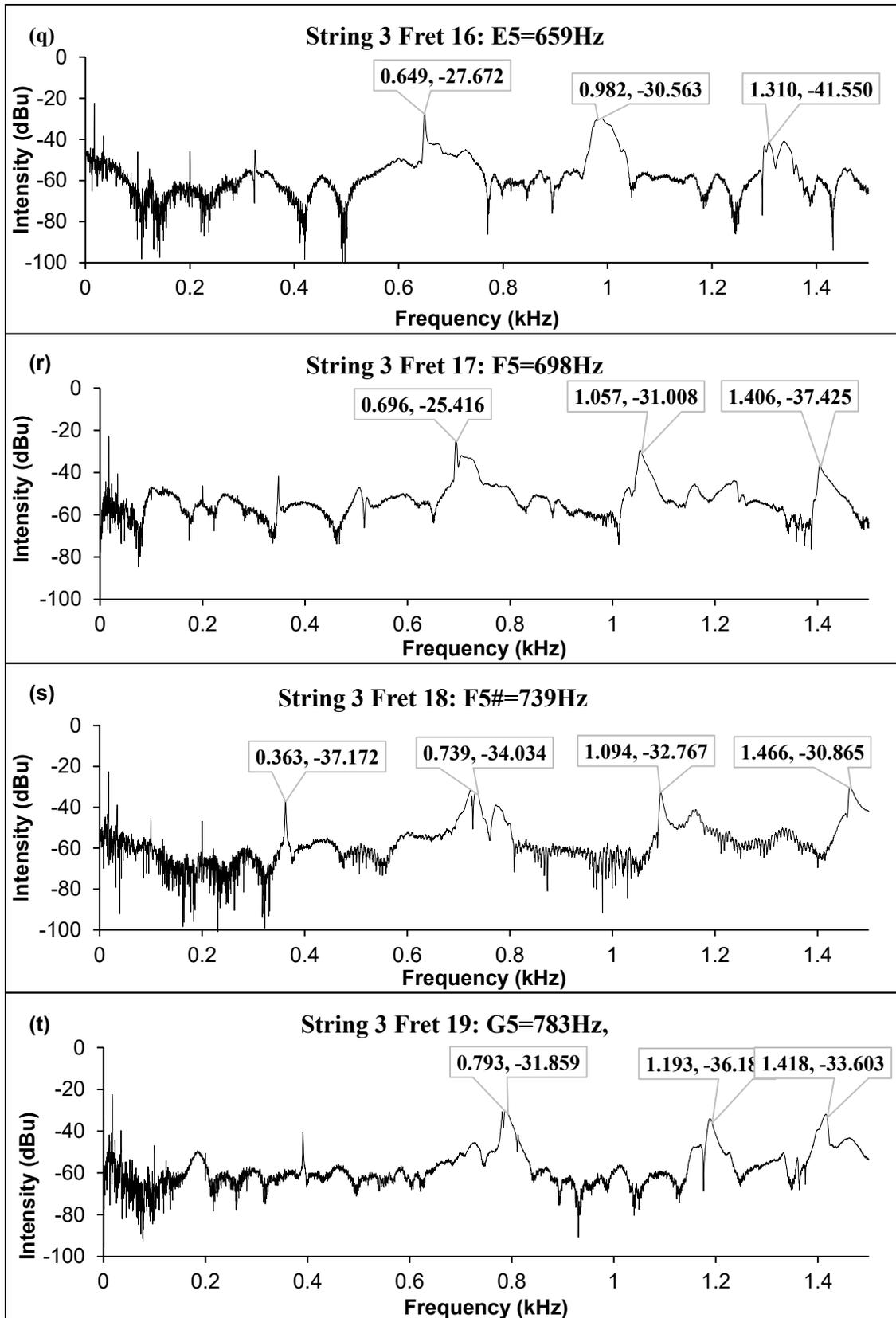
Figure 10 shows the frequency spectrum of the open string 3 and fret 1 to 21. Tables 3 and 4 shows the frequency of every partial for open string 3, fret 1 to 10 and fret 11 to 21, respectively.











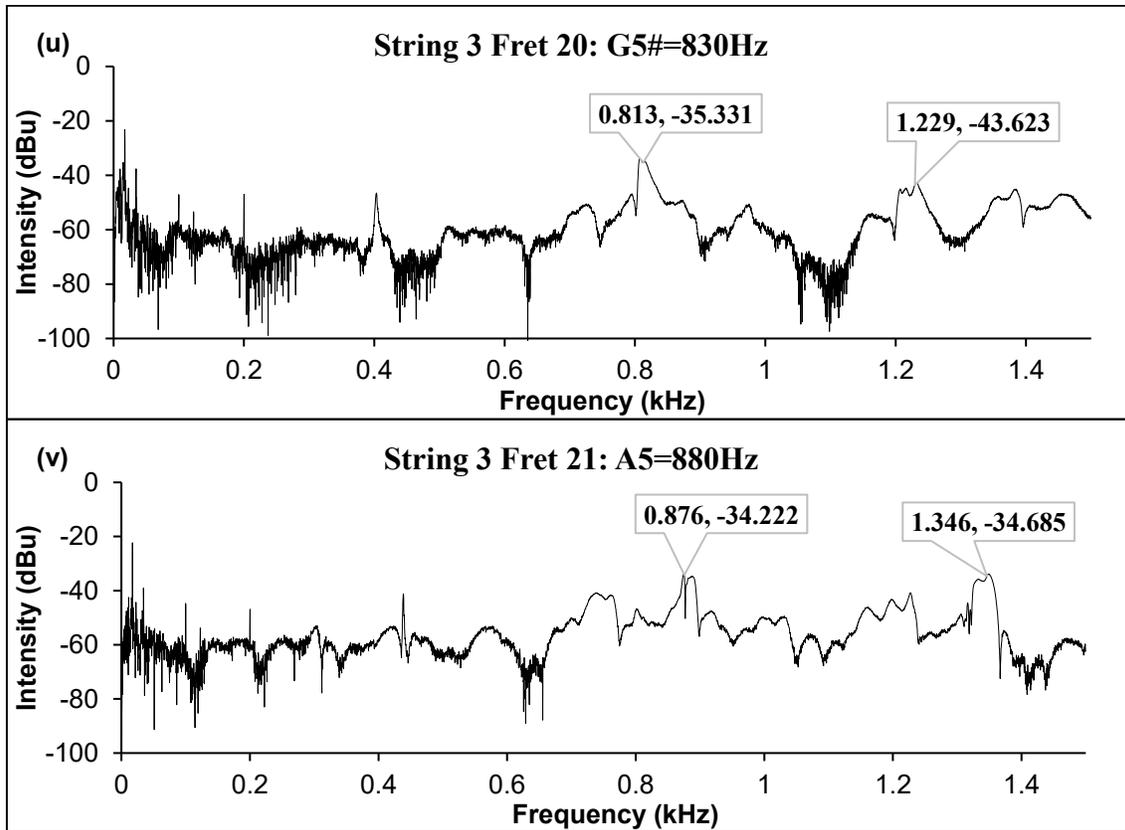


Fig. 10. The frequency spectrum of the open string 3 and fret 1 to 21

Table 3. The Frequency of Every Partial for Open String 3 and Frets 1 to 10

Partials	Open string (Hz)	Fret 1 (Hz)	Fret 2 (Hz)	Fret 3 (Hz)	Fret 4 (Hz)	Fret 5 (Hz)	Fret 6 (Hz)	Fret 7 (Hz)	Fret 8 (Hz)	Fret 9 (Hz)	Fret 10 (Hz)
1	258	269	290	306	329	348	363	393	408	429	463
2	388	404	435	611	655	522	544	589	611	644	698
3	517	538	579	774	822	701	733	786	818	859	929
4	646	674	733	920	992	872	908	982	1024	1080	1181
5	777	811	878	1076	1169	1240	1099	1178	1232	1301	1406
6		948	1032	1240	1322		1302	1411	1449	1478	
7		1085	1173	1450							
8		1221	1321								
9		1349	1472								
10		1485									

Table 4. The Frequency of Every Partial for Fret 11 to 21

partials	Fret 11 (Hz)	Fret 12 (Hz)	Fret 13 (Hz)	Fret 14 (Hz)	Fret 15 (Hz)	Fret 16 (Hz)	Fret 17 (Hz)	Fret 18 (Hz)	Fret 19 (Hz)	Fret 20 (Hz)	Fret 21 (Hz)
1	480	518	546	588	624	649	696	363	793	813	876
2	732	784	818	887	936	982	1057	739	1193	1229	1346
3	988	1050	1096	1197	1259	1310	1406	1094	1418		
4	1215	1310	1369		1418			1466			
5	1465										

Figures 11 and 12 show the frequency of every partial *versus* the partial number for open string 3, fret 1 to 10 and fret 11 to 21 respectively.

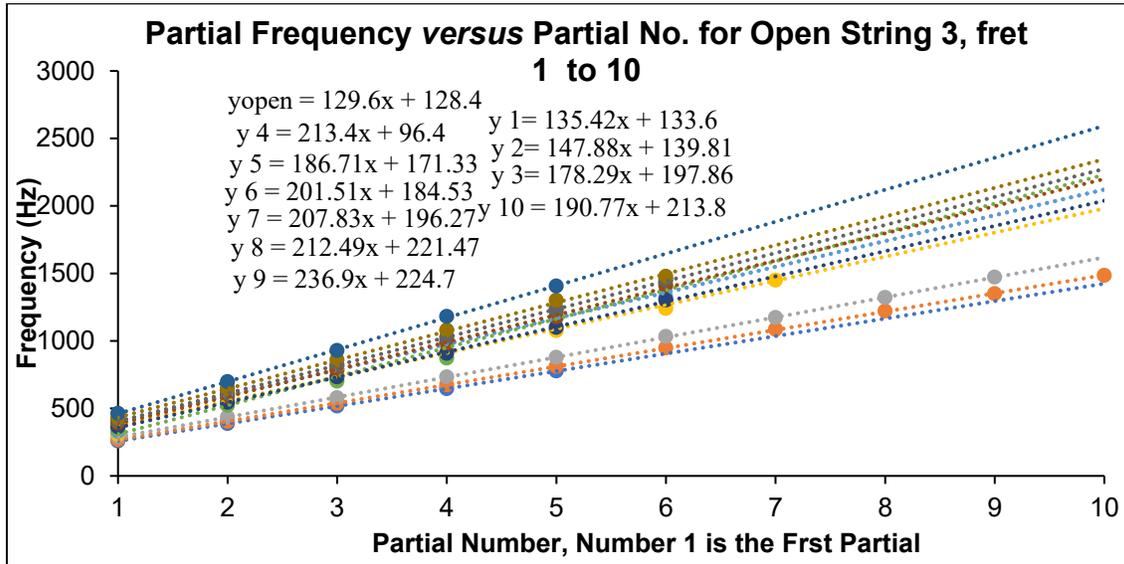


Fig. 11. The frequency of every partial *versus* the partial number for open string 3 and fret 1 to 9

From Fig. 11, the equation for the frequency *versus* the partial number for open string 3 is given by $y_{\text{open}}=129.6x+128.4$. The open string 3 was tuned (using a tuner) to C3 (130 Hz), but the PicoScope spectrum displayed only 258 Hz (*i.e.* C4 (261 Hz)). The slope from the frequency *versus* partials number indicated that the gradient obtained from the open string 3 was 129 Hz (equivalent to C3 (1301 Hz)). The equation for the frequency *versus* the partial number for string 3 fret 1 was given by $y_1=135.42x+133.6$. The PicoScope spectrum displayed only 269 Hz (*i.e.* C#4 (277 Hz)). The slope from the frequency *versus* partials number indicated that the gradient obtained from the open string 3 fret 1 was 135 Hz (equivalent to C#3 (138 Hz)). The following fret 2 ($y_2=147.88x+139.81$), demonstrated that the gradient was 147 Hz (*i.e.* equivalent to D3 (146 Hz)), although the PicoScope displayed $F_0=290$ Hz (*i.e.*, D4=293 Hz). The following finding occurs to fret 3 to fret 9:

1. Fret 3 ($y_3=178.29x+197.86$) is equivalent to D#3=155 Hz, while PicoScope display $F_0=306$ Hz (*i.e.*, D#4 311 Hz)
2. Fret 4 ($y_4=190.77x+213.8$), is equivalent to E3=164 Hz, while PicoScope display $F_0=329$ Hz (*i.e.*, E4=329 Hz)
3. Fret 5 ($y_5=213.4x+96.4$), is equivalent to F3=164 Hz, while PicoScope display $F_0=348$ Hz (*i.e.*, F4=349 Hz)
4. Fret 6 ($y_6=186.71x+171.33$), is equivalent to F#3=185 Hz, while PicoScope display $F_0=363$ Hz (*i.e.* F#4=369 Hz)
5. Fret 7 ($y_7=201.51x+184.53$), is equivalent to G3=196 Hz, while PicoScope display $F_0=399$ Hz (*i.e.* G4=392 Hz)
6. Fret 8 ($y_8=207.83x+196.27$), is equivalent to G#3=207 Hz, while PicoScope display $F_0=408$ Hz (*i.e.* G#4=415 Hz)
7. Fret 9 ($y_9=212.49x+221.47$), is equivalent to A3=220 Hz, while PicoScope display $F_0=429$ Hz (*i.e.* A4=440 Hz)

8. Fret 10 ($y_{10}=236.9x+224.7$), is equivalent to A \sharp 3=233Hz, while PicoScope display F0=463 Hz (*i.e.* A \sharp 4=466Hz)

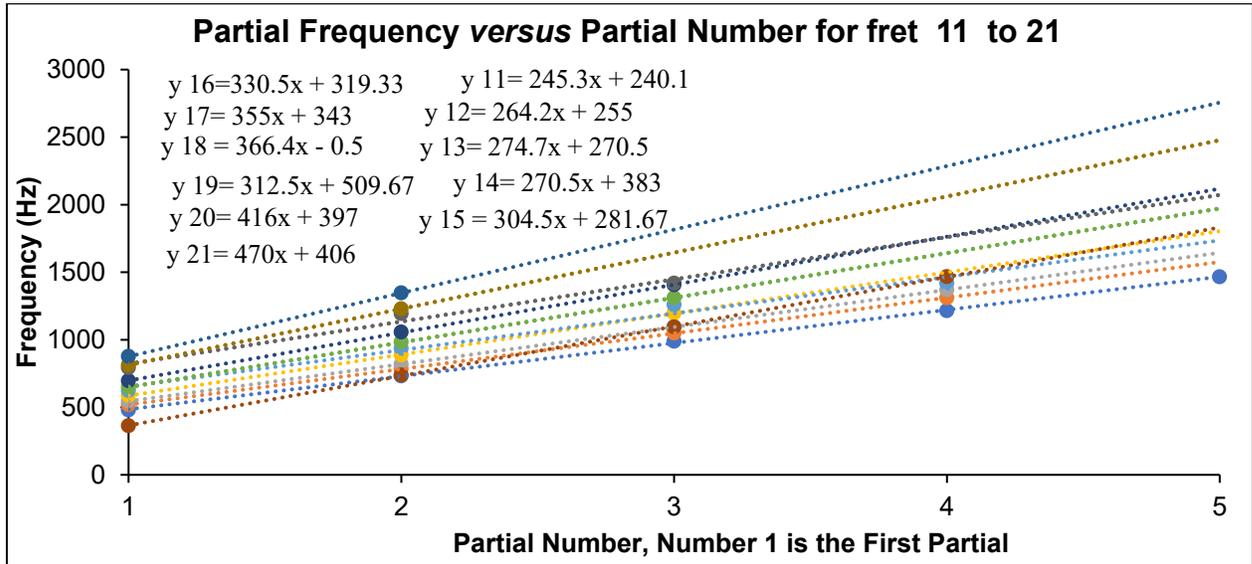


Fig. 12. The frequency of every partial *versus* the partial number for fret 11 to 21

From Fig. 12, the equation for the frequency *versus* the partial number for fret 11 is given by $y_{11}=245.3x+240.1$. The fret 11 was tuned (using a tuner) to B3 (246 Hz), but the PicoScope spectrum displayed only 480 Hz (*i.e.*, B4 (493 Hz)). The slope from the frequency *versus* partials number showed that the gradient obtained from the fret 11 was 245 Hz (equivalent to B3 (246 Hz)). The equation for the frequency *versus* the partial number for string 3 fret 12 was given by $y_{10}=264.2x+255$. The PicoScope spectrum displayed only 518 Hz (*i.e.*, C5 (523)). The slope from the frequency *versus* partials number indicated that the gradient obtained from the open string 3 fret 12 was 264Hz (equivalent to C4 (261 Hz)). The following fret 13 ($y_{13}=274.7x+270.5$), showed that the gradient was 27 4Hz (*i.e.* equivalent to C \sharp 4 (277 Hz)) although the PicoScope display F0=546 Hz (*i.e.*, C \sharp 5=554Hz). The following finding occurred to fret 14 to fret 21:

1. Fret 14 ($y_{14}=270.5x+383$), is equivalent to D4=293 Hz, while PicoScope display F0=588Hz (*i.e.* D5=587Hz)
2. Fret 15 ($y_{15}=304.5x+281.67$), is equivalent to D \sharp 4=311 Hz, while PicoScope display F0=624Hz (*i.e.* D \sharp 5=622Hz)
3. Fret 16 ($y_{16}=330.5x+319.33$), is equivalent to E4=329 Hz, while PicoScope display F0=649 Hz (*i.e.* E5=659Hz)
4. Fret 17 ($y_{17}=355x+343$), is equivalent to F4=349 Hz, while PicoScope display F0=696 Hz (*i.e.* F5=698Hz)
5. Fret 18 ($y_{18}=366.4x-0.5$), is equivalent to F \sharp 4=369 Hz, while PicoScope display F0=739 Hz (*i.e.*, F \sharp 5=739Hz)
6. Fret 19 ($y_{19}=312.5x+509.67$), is equivalent to G4=392 Hz, while PicoScope display F0=793 Hz (*i.e.*, G5=783Hz)
7. Fret 20 ($y_{20}=416x+397$), is equivalent to G \sharp 4=415 Hz, while PicoScope display F0=813 Hz (*i.e.*, G \sharp 5=830Hz)
8. Fret 21 ($y_{21}=470x+406$), is equivalent to A4=440 Hz, while PicoScope display F0=876 Hz (*i.e.*, A5=880Hz)

Figure 13 shows a spectrogram of the three strings being excited from highest (C5) to the lowest (C4) pitch. String 1 (C5) showed the most dense of frequency distribution due to the high pitch compared to string 3 (C4) with the lowest pitch. Recording conditions were as follows: The input from the microphone and amplifier was connected to a computer and analyzed with Adobe Audition under multitrack function. Yellow indicates the low frequency spectrum, red indicates the medium frequency spectrum and violet indicates the high frequency spectrum.

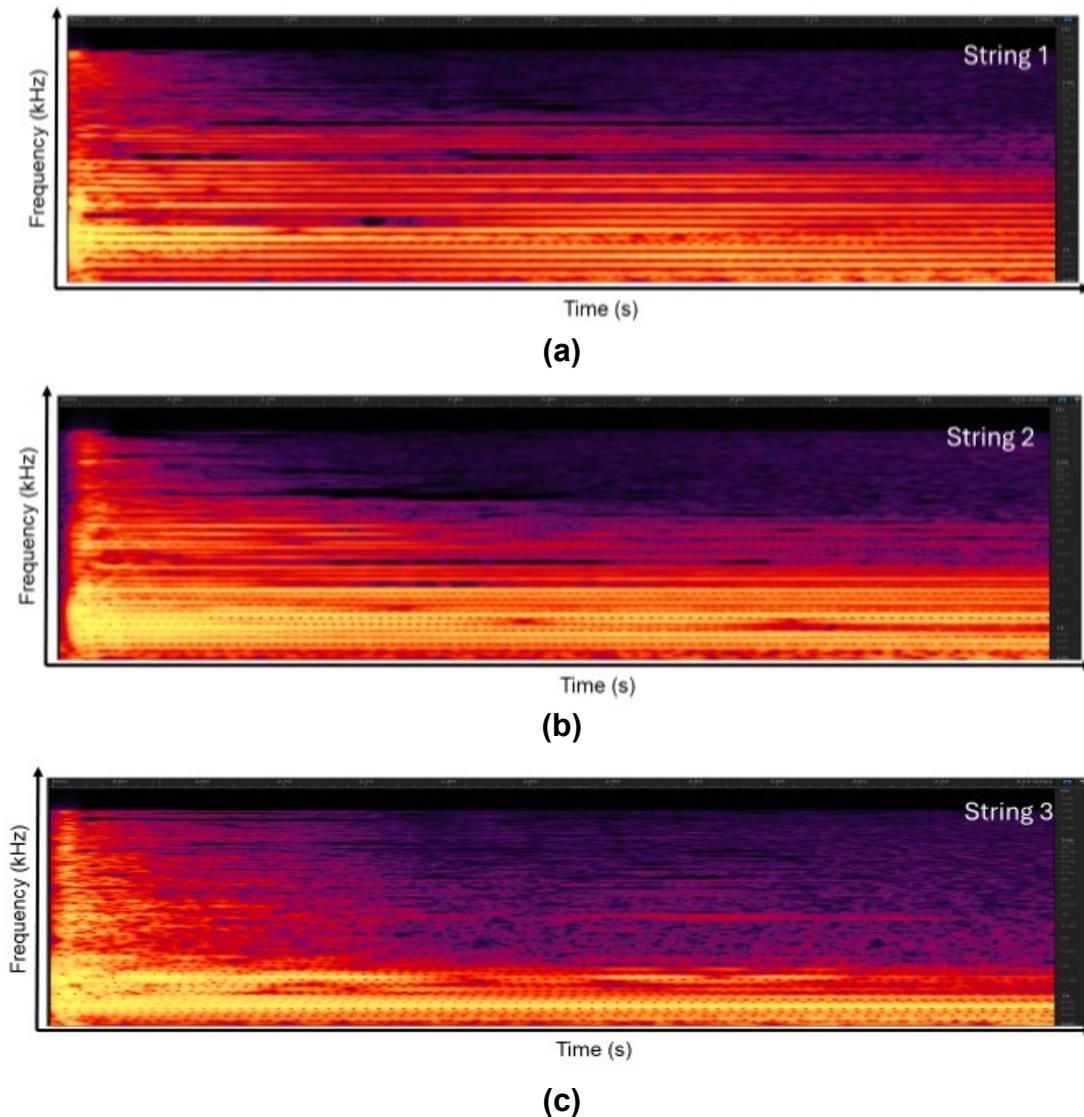


Fig. 13. A spectrogram of the three shamisen strings being excited in a succession from (a) the highest string 1 (C5) (b) intermediate string 2 (G4), and (c) the lowest string 3 (C4)

The primary findings center on how the shamisen acoustic and tuning properties deviate from equal temperament systems in the West. The shamisen cultural tuning identity rather than conformity to Western tonal frameworks was confirmed by the FFT analysis, which showed that each string and fret generates a unique frequency spectrum. In particular, when investigating eco-material innovations such as plant-based resonators for sustainable instrument design, these findings are important for audio preservation because

they provide a quantitative reference for recreating the shamisen authentic tuning in AI-assisted audio modeling, AR-based instrument visualization, and VR heritage exhibitions. Future research directions or practical applications of the findings will carry out an analysis in which selected aspects of such an instrument are systematically changed. The skin might be removed or it might be replaced with materials having known viscoelastic properties. In this way, the authors could in future work test a hypothesis that the sound quality is strongly influenced by the resonating body of the instrument.

CONCLUSIONS

1. All the open string had the harmonic (1, 2, 3...) and inharmonic (1.5, 2.5, 3.5...) with the partials decreasing with pitch (less partial at string 1 (C5) compared to string 3 (C4)).
2. Open string 1 and open string 2 showed a discontinuity in the progressing note. Strings 1 fret 11 shows the note B5, whereas fret 12 shows the note C5 (instead of C6). String 2 fret 17 shows the note C6, whereas fret 18 shows the note C5# (instead of C6#). Open string 3 shows the note C4 progress up to A5 for fret 21. The changes of frequencies such as C6 to C5 (string 1) and C6# to C#5 (string 2) in the acoustic analysis of the shamisen can be attributed to the traditional Japanese approach to tuning, which emphasizes relative intonation rather than adherence to fixed, equal-tempered pitch standards.
3. In this practice, strings are tuned based on their relational function and auditory perception rather than absolute frequency values in hertz. The shamisen, being a fretless instrument or sometimes fitted with non-standard frets, does not follow the chromatic pitch arrangement typical of Western instruments. As such, the semitone intervals are utilized or even physically accessible in performance.
4. Additionally, certain pitches such as C6 and C6# may not play a functional role in the melodic or harmonic language of traditional shamisen repertoire and thus are neither emphasized in playing techniques nor reinforced by the instrument's natural resonance. Therefore, the changing pitch in the spectral data should not be interpreted as an error or deficiency but rather as an authentic reflection of shamisen's culturally rooted tuning system and performance aesthetics.
5. Although all of the PicoScope data display the fundamental frequency one octave higher than the frequency as heard (tuner frequency), the gradient of the plotted figures showed that the frequency of the string was similar to the frequency as heard (tuner frequency).
6. For future recommendation, the authors will collaborate with music program in Universiti Malaysia Sarawak for performance practice, instrument making and acoustic modelling.

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