Instrument Testing via Structural Acoustics

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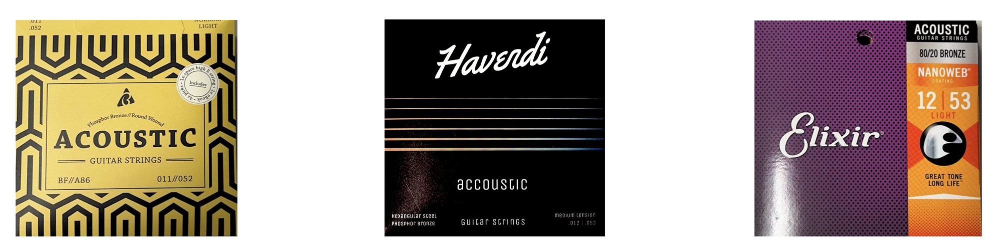
Introduction & Motivation

- What makes a good sounding guitar sound good?
- Many guitarists assume expensive strings yield better tones, but this belief is rarely backed by data.
- Sellers often justify high prices with “brand name” and “craftsmanship,” influencing players to overspend on strings with minimal acoustic benefit.
- This project tests whether string type or guitar body has a greater impact on sound.
- Using modal analysis, we aim to isolate each factor and determine if the cost truly reflects quality, or if tone is in the wood.

According to statistics gathered by Fender, approximately 10% of the world population knows how to play the guitar. That means ~806 million know how to play/attempted to play this instrument a few times in their life.

The global guitar market is valued at approximately $19.9 billion, with entry-level guitars starting at around $100. On the other end of the spectrum, high-end, non-custom retail guitars can cost up to $20,000, depending on craftsmanship, materials, and brand.

Strings Used



Bronze: $10.99 | $14.90 | $17.99

Nylon: $9.99 | $14.90 | $22.00

Figure [1]: For this experiment, we tested two different string materials at three separate price points to determine whether the strings significantly impacted the acoustic quality of a guitar.

What is Modal

What is Modal Analysis?
Modal analysis is a way to figure out how a structure vibrates. It tells us the structure’s natural frequencies, damping, and mode shapes. We excite the structure and measure how it responds. That response, which can be hard to interpret on its own, gets turned into a set of simpler vibration properties called modal parameters.

How Are the Structures Excited?
We use two methods: impact hammer and modal shaker.
- The impact hammer gives a short, controlled hit and is good for simple structures.
- The modal shaker applies continuous force through a thin metal rod called a “stinger”. It can run different signal types like random, burst random, pseudo-random, or chirp to excite a range of frequencies.

How Is the Response Measured?
We attach a force sensor and an accelerometer to the structure to record the input and output signals. A Dynamic Signal Analyzer collects this data and converts it into the frequency domain.
From this, we get two important results:
- FRF (Frequency Response Function): compares response to input across all frequencies.
- Coherence: shows how much of the vibration is directly caused by the excitation, values near 1 mean clean data.

We also average multiple hits or runs to reduce noise and get smoother, more reliable results.

What Happens to the Data?
The signals are processed in MATLAB using functions like pwelch to estimate the Power Spectral Density (PSD). This lets us clearly see the frequency peaks and extract the important modal parameters.

Testing the Guitar Body

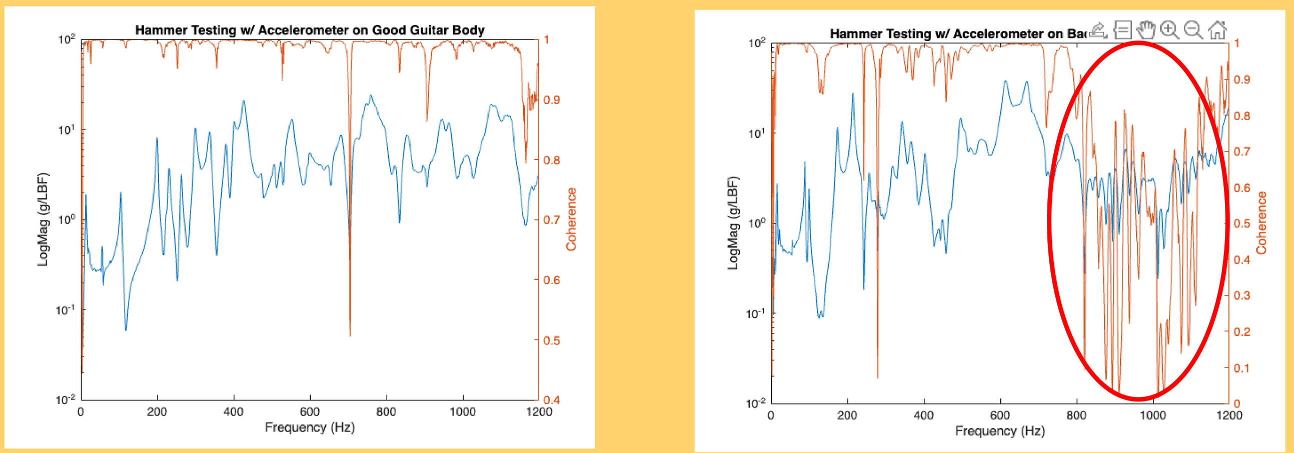
Hammer Impact Method

Figure [2a]: Experimental setup for the impact test.

Figure [2b]: Modal Hammer for the experiment

- Both guitars were suspended in a free-free boundary condition.
- Four accelerometers were mounted on the back plate.
- The soundboard was excited with an impact hammer between the bridge and sound hole.
- Data was collected using Crystal Instruments and analyzed in MATLAB.
- We aimed to identify natural frequencies and evaluate whether the body’s material and construction affect tone more than strings.

Results



Figure(s) [3]: The coherence spectrum for the low-end guitar showed considerably more noise than the high-end guitar, indicating potential vibrational leakage due to cracks or structural flaws.

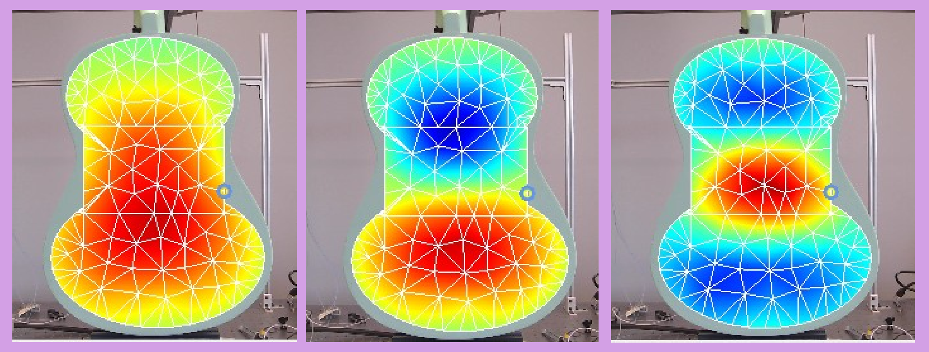
Laser Doppler Vibrometer Method

Figure [4a]: LDV setup for the experiment

Figure [4b]: Shaker setup to the sound board for modal testing

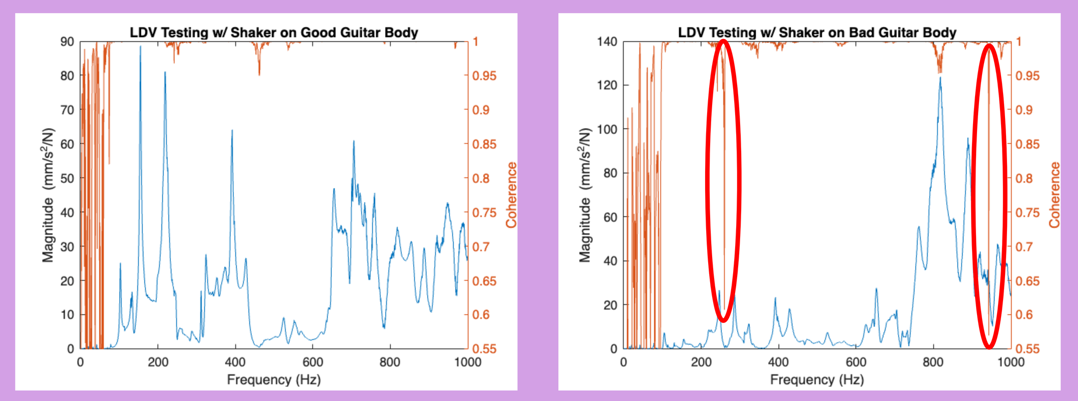
- Used a clamped endpin boundary condition and tied the guitar neck for stability.
- Measured vibrations on the guitar back using a PSV-500 Scanning Vibrometer.
- Low-end guitar had 140 scan points; high-end guitar had 155.
- Glossy finish on the high-end guitar improved LDV signal compared to the matte surface.
- Setup was used to observe mode shapes and their relation to perceived sound quality.

Results



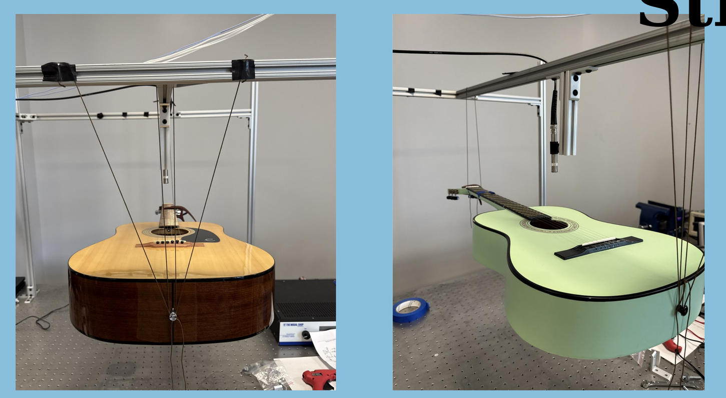
Figure(s) [5a]: Shows three mode shapes of the guitar body:
- 126.9 Hz (left)
- 211.9 Hz (middle)
- 326.9 Hz (right).

They visualize how the guitar vibrates at different frequencies, illustrating the nodal and anti-nodal regions at each frequency.



Figure(s) [5b]: Once again, the coherence for the low-end guitar appeared far noisier than for the high-end guitar, suggesting leakage or inconsistencies in structure, possibly due to cracks or construction defects.

Testing the Strings



Figure(s) [6]: The high-end guitar (left) and low-end guitar (right) were suspended using string in a free-free boundary condition to reduce damping.
- Acoustic testing was done using Crystal Instruments software, with each string plucked 12 times and averaged.
- Signals were sampled at 51.2 kHz with an 18.5 kHz frequency range.
- A microphone was placed 10 cm from the soundboard, which gave the most consistent results.
- This setup tested how string material and price affect the guitar’s harmonic profile.

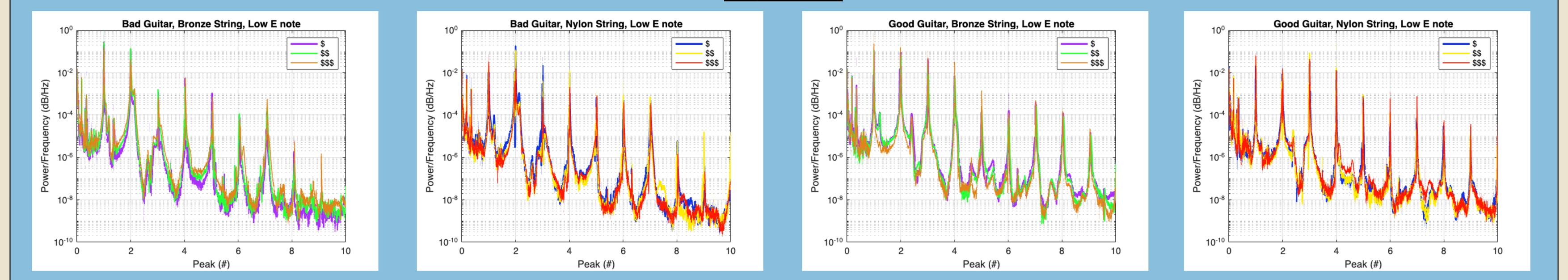
Figure [8]: We tested the guitars with non-standard string setups.
- On the left guitar, we used two bronze D strings: the left one was taped, and the right one was untaped as a control.
- On the right guitar, we used a fishing line on the left side and a nylon string of similar thickness on the right, tuned to an A note.

We wanted to see if any string could be used to play the guitar and whether the guitar is designed specifically for acoustic strings or if other materials can work.

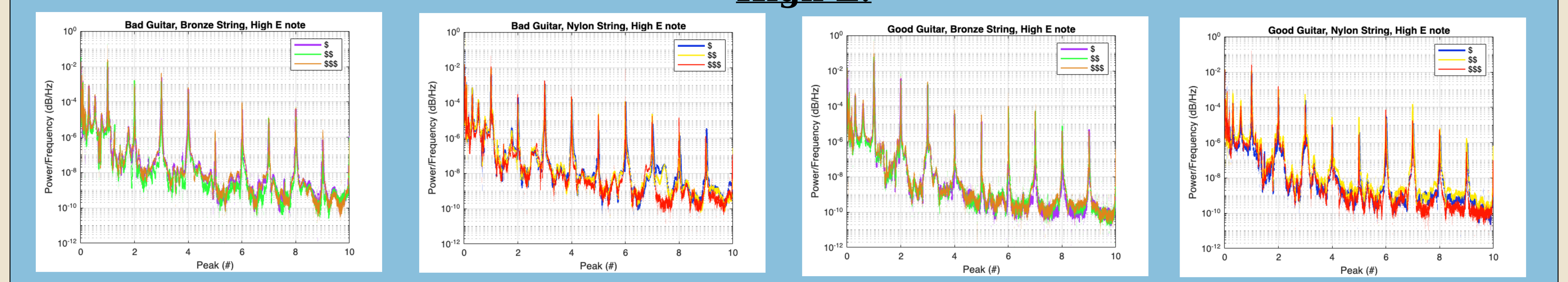
Results

= $ Bronze String
= $$ Bronze String
= $$$ Bronze String
= $ Nylon String
= $$ Nylon String
= $$$ Nylon String

Low E:



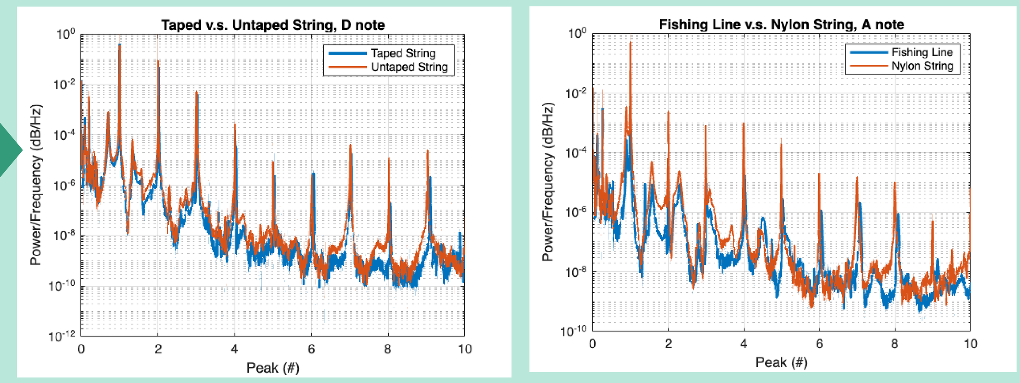
High E:



Figure(s) [7]: Frequency spectra from 1/2" pre-polarized free-field condenser microphone after 12 averages when excited by the string. A standard tuned guitar vibrates at a frequency of ~330 Hz for a high E string, and ~82.4 Hz for a low E string. Then we utilized the pwelch function on MATLAB to calculate the PSD, and compute the FFT of each windowed segment

Results

= Regular Guitar String
= Tampered String



Figure(s) [9]: The frequency spectra obtained from using the pwelch function on MATLAB
- Regular guitar strings show stronger and more defined harmonic peaks.
- Taped strings and fishing line produce weaker, less distinct peaks.
- The decay time is longer in regular strings, resulting in greater sustain.
- These characteristics create more resonance and tonal clarity.
- These qualities are what makes the guitar sound more “pleasing to the ear”

Conclusion

- Different-cost strings of the same material have a subtle, often negligible impact on acoustic modal quality.
- The guitar body’s quality, size, material, and construction have a greater influence on sound.
- Sound quality is subjective, shaped by spectral balance, materials, build quality, and the player’s intent.
- No single acoustic metric reliably predicts guitar quality, and individual judgment often outweighs objective data.

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