

A Comparison of the Resonant Properties of

Three Acoustic Guitars

And

A Comparison of the Resonant Properties of

An Acoustic Guitar

With Muted vs. Un-Muted Strings

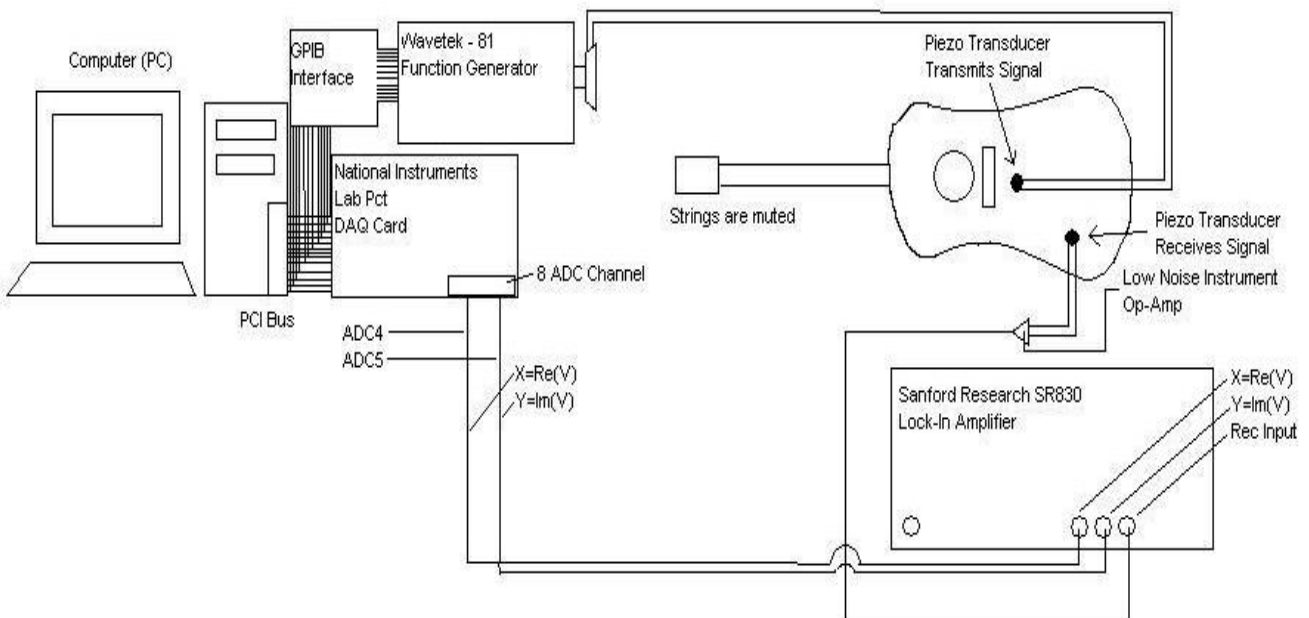
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## Part I: Introduction:

A PC-based data-acquisition system designed to measure the mechanical vibrational properties of musical instruments as a function of frequency was used to investigate the properties of three different kinds of acoustic guitars – an Ibanez PF15CE, a Gibson J-45 and Washburn D10. What Professor Errede and I did was to send a sine-wave signal at a certain voltage into three separate acoustic guitars to make them resonate. To do this we used a piezoelectric transducer. Then another transducer picked up the resonance response of the guitar. Using the data we found we can make the following graphs and judge at what frequencies the guitars resonate the most.

## The Experimental Setup:



As you can see, we have a GPIB card in the computer, which sends commands to the Wavetek 81 function generator. The computer can set the function generator's frequency and voltage amplitude of the sine wave via GPIB commands. The sine wave output from this function generator is applied to a piezoelectric transducer. A sinusoidal AC voltage applied to a piezoelectric material causes the piezoelectric material to vibrate mechanically – producing a mechanical sine wave at the same frequency! The Wavetek 81 function generator nominally applied a voltage amplitude of 3.0 Volts to the piezoelectric transducer. The frequency of this sine wave signal applied to the piezo transducer was varied from 10 to 1010 Hz in 10 Hz steps under computer control.

This sine wave, at different frequencies makes a guitar resonate. This wave is detected via a second piezoelectric transducer. If the guitar resonates, and it should, the second piezo transducer, acting like a pick-up, sends its response signal to a low noise instrumentation op-amp, which has a voltage gain of 5x. This amplifies the resonance signal of the guitar so we can read the data. The now-amplified signal travels to the input of a Stanford Research Systems SRS-830 DSP lock-in amplifier. Settings for the lock-in include a time constant of one second, signal input = channel A, as well as DC coupling

and float. The lock-in input sensitivity was set at 1.0 V, the reserve was set at normal, and we didn't use any of the lock-in's filters. The sine wave output from the Wavetek 81 function generator was also used as the reference signal to the lock-in amplifier, for the purpose of obtaining phase information. Thus, we set the lock-in amplifier's Ref. In = Sine, Ref. Phase = 0.0, and Ref. Harm # = 1. The SRS 830 DSP lock-in amplifier outputs *two* DC voltage signals associated with the AC signal coming from the 2<sup>nd</sup> piezoelectric transducer – one DC voltage signal output from the lock-in amplifier (the X-channel) is proportional to the component of the AC amplitude from the 2<sup>nd</sup> piezo transducer that is either in-phase – i.e. zero degrees phase, or 180 degrees out of phase with the reference sine wave signal output from the Wavetek 81 function generator at a given frequency, f. The second DC voltage signal output from the lock-in amplifier (the Y-channel) is proportional to the component of the AC amplitude that either +90 or –90 degrees out of phase with the reference sine wave signal output from the Wavetek function generator at that same frequency, f. At each frequency, the in-phase (X-axis, also known as the Real axis) and 90-degree out-of-phase (Y-axis, also known as the Imaginary axis) DC voltage components output from the SRS 830 DSP lock-in amplifier were separately digitized by two Analog-to-Digital Converters (ADC's) associated with a National Instruments LabPC+ Data Acquisition Card. We had these as ADC 4 (X=Re(V)) and ADC 4 (X=Im(V)). The Sonic-1 Data Acquisition Program, written by Prof. Errede was used to take this data.

## **The Guitars:**

We used three separate acoustic guitars to acquire data. For these measurements, we damped the strings – using a wide piece of foam rubber underneath the fretboard around the 12<sup>th</sup> fret. This way we can compare them to each other. We tested a 1968 Gibson J-45 that belongs to Professor Deborah Errede, as well as a Washburn D10 that belongs to Professor Mats Selen. The third guitar is my own, an Ibanez PF-15. The Ibanez and the Washburn are acoustic/electric.

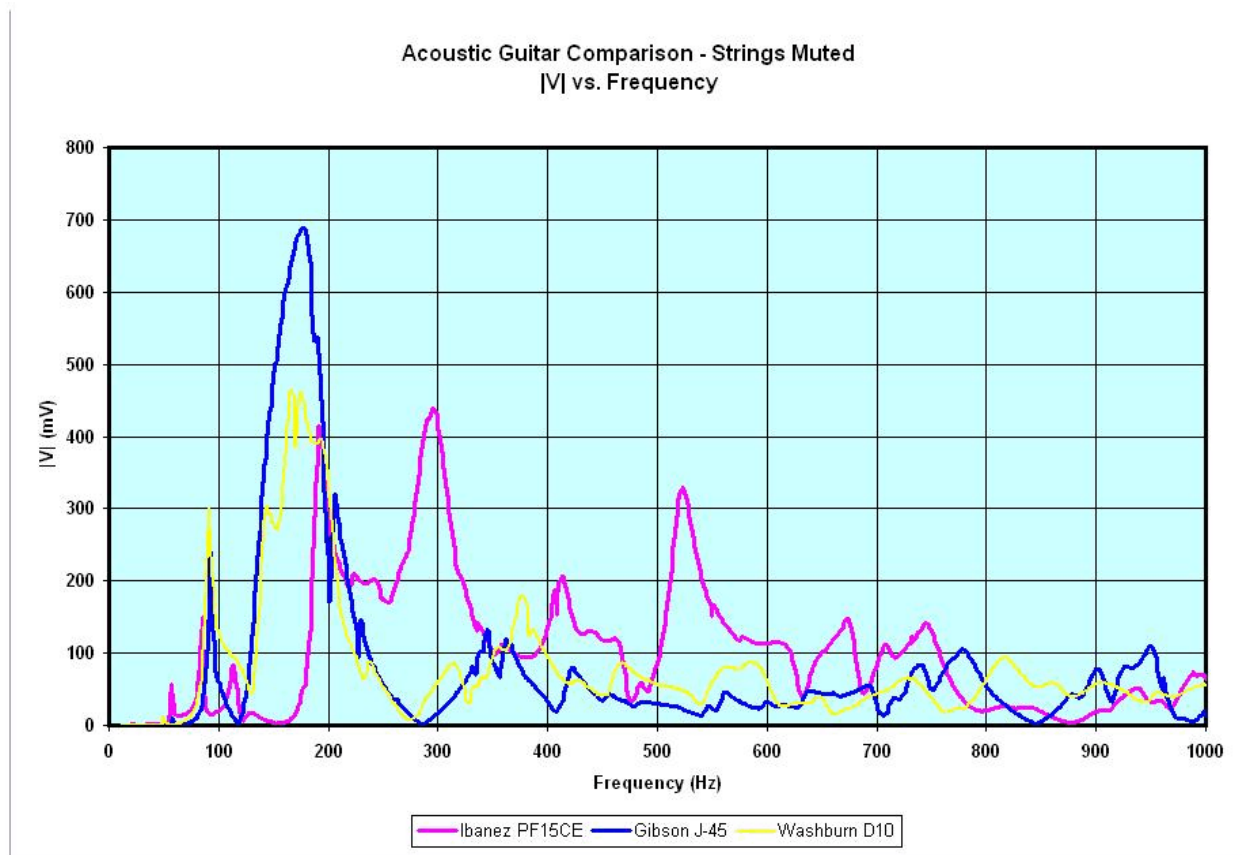
## **The Results:**

We have acquired several graphs for each guitar, and comparison/overlay plots with results from all three guitars that show:

- a.) In-phase,  $\text{Re}(V(f))$  vs. frequency, f
- b.) 90-degrees out-of-phase,  $\text{Im}(V(f))$  vs. frequency, f
- c.) Voltage magnitude,  $|V(f)| \equiv \text{SQRT}[\text{Re}(V^2(f)) + \text{Im}(V^2(f))]$  vs. frequency, f
- d.) Phase  $(V(f)) \equiv \tan^{-1} \{ \text{Im}(V(f)) / \text{Re}(V(f)) \}$  vs. frequency
- e.) and the so-called complex plane:  $\text{Im}(V)$  vs.  $\text{Re}(V)$ .  
 {  $\text{Im}(V)$  stands for Imaginary (V) while  $\text{Re}(V)$  stands for Real(V). }

The graph of most interest would probably be the  $|V(f)|$  versus frequency graph. This graph shows where the guitars resonate the most. As you will see all three guitars resonate quite well at just under 200Hz. This may correspond with the note of G3, which is located around 196 Hz. This is the same frequency as that for the open G string on the guitar. Another possibility is the F3 note which is one step down from the G3. After this resonance at 200 Hz the Gibson and the Washburn experience a large drop off. While these two obviously resonate in other places, nothing is comparably to the first resonance.

The Ibanez acoustic has more resonances as the frequency increases. One possible explanation is the type of bracing used in the Ibanez. It uses cross bracing as opposed to scalloped bracing used by the J-45. It would make sense that this variation in resonance would be due to differences in the bracing used for the two guitars, because the same kind of wood used by the Ibanez is used in the J-45. The woods used are Sitka Spruce tops, and mahogany sides and backs. The other large resonant spots for the Ibanez are just under 300Hz, possibly a D4, and about 520Hz, which would be around a C5.



## **Part II: Introduction:**

For this experiment Professor Errede and I studied one guitar, my Ibanez PF15CE acoustic with the strings un-muted vs. muted.

### **The Setup:**

The setup is the same as last time except for two things. First we only used one guitar. Second, we changed the amplitude to 5V. This was the highest possible voltage we could have had the function generator set at without having the Sonic-1 program restart itself.

### **The Results:**

As the graph on the following page shows, the results for (V) versus Frequency the two lines nearly mirror each other. The pink line, un-muted, wavers much more than the blue, which is muted. This is because of the strings resonating with the body at those particular frequencies associated with the fundamental(s) and harmonic(s) associated with each of the open strings!

### **Thanks:**

I would like to thank Professor Steve Errede for his infinite amounts of help as well as much of the direction and motivation for this work. Also, Professor Errede provided the equipment and the workspace and without him this project would not have started. I would also like to thank his wife, Deborah Errede, for the use of her guitar, the '68 Gibson J-45. I would also like to thank professor Mats Selen for use of his Washburn D10 acoustic guitar.

Phil Byrne Ibanez PF15CE Acoustic Guitar - Strings Not Muted vs. Muted - Oct. 7, 2004  
|V| vs. Frequency

