Pickups and Wood in Solid Body Electric Guitar – Part 1

by Butch Iafelice - Calaveras Fretworks Custom Guitars - May 2011

Introduction:

Well here you go – this is the first in a series of papers where I will try to give the reader a comprehensive overview of how different pickups and wood interact and produce the sounds in solid body electric guitars. Trying to understand these effects and interactions was actually the motivation for why I started building guitars in the first place and the beginning of Calaveras Fretworks Custom Guitars. A few years back I put a Maple Tele neck on the first CFCG mahogany body and was floored by the new sounds I heard – especially from pickups like the Fender Texas Specials and Gibson 57 Classics that I was already familiar with but had only played in instruments using different body and neck woods. Why did these pickups play so much better? So much more sustain along with a fuller or "fatter" tone. You all know what sustain is – there is so much more hang time to the note or chord that the guitar seems to play itself. A fatter sound to me means that there's more meat or gain in portions of the audible spectra – more on this later.

First let me establish a few definitions on how the data will be presented here – some of which will be my own loose interpretations without taking too much away from the technical accuracy of my statements or conclusions. The audible frequency range is 20 Hz to 20,000 Hz (or 20 kHz). I will be concerned here with frequencies between 250 Hz and 10 kHz and will refer to low frequencies as 250 Hz up to 1 kHz, mid frequencies as 1 to 3 kHz, and high frequencies as 3 to 10 kHz. The amplitudes of measured data are presented in dB's (decibels) and a way I put common sense to this unit of measure is that to your ears if you think the volume of sound is "half as loud" you would measure a -10 db loss in amplitude. Half of half as loud is -20 db, etc.

Now for the guitars and guitar setup – I have designed the CF guitar to be completely modular and all of the parts are easily interchangeable. All of the electronic and hardware components (pots, switches, caps, bridge, nut, tuners, screws…) are identical. The pickups and all electronics are mounted on an interchangeable pickguard assembly and can be swapped out between guitars in a matter of minutes. Geometrical parameters of all wood cuts are identical on all guitars. The necks are 21 fret bolt-on necks that were based on the 50's Fender Telecaster design. I have used the same neck profile (medium C) and frets (6105) on all instruments unless noted otherwise. The set up of all guitars is identical. The string bottom to fret top distance is measured at the 17th fret and is set to 5/64" for the two fat strings and 4/64" for the other four. The pickup heights are set by depressing the appropriate string at the 21st fret and, for single coil pickups, by adjusting the pole piece to string bottom distance to 6/64" for the high "e" and 8/64" for the low "E" strings. For humbucker pickups this distance is set to 2mm for the e string and 2.5 mm for E string. D'Addario EXL110 strings are used on all the guitars.

Great care has been taken to pick the guitar strings the same way each time a test was performed because picking differences would have a huge impact on the results. First I chose to restrict my tests to the open low E and high e strings only. This gives me representative data from both the bass end and treble end of the instrument, respectively. This also allowed me to easily mute the other strings so they would not contribute to the sound after a pick. Another reason I choose to restrict my measurements to open E strings only was to eliminate any effect that fingering a note or slight differences between fretting might add to the measurement variation.

I used a medium-hard picking stroke similar to what I would use on a moderate lead passage. To guarantee identical repeat picking over the course of the test work I created "calibration" sound bites where I recorded the same attack for each type of pickup used. I could then refer back to the appropriate calibration file whenever I was using a particular pickup and match amplitudes during the measurements. Here is an example of a typical calibration file – this one for the Fender Texas Special bridge pickup and the low E string.

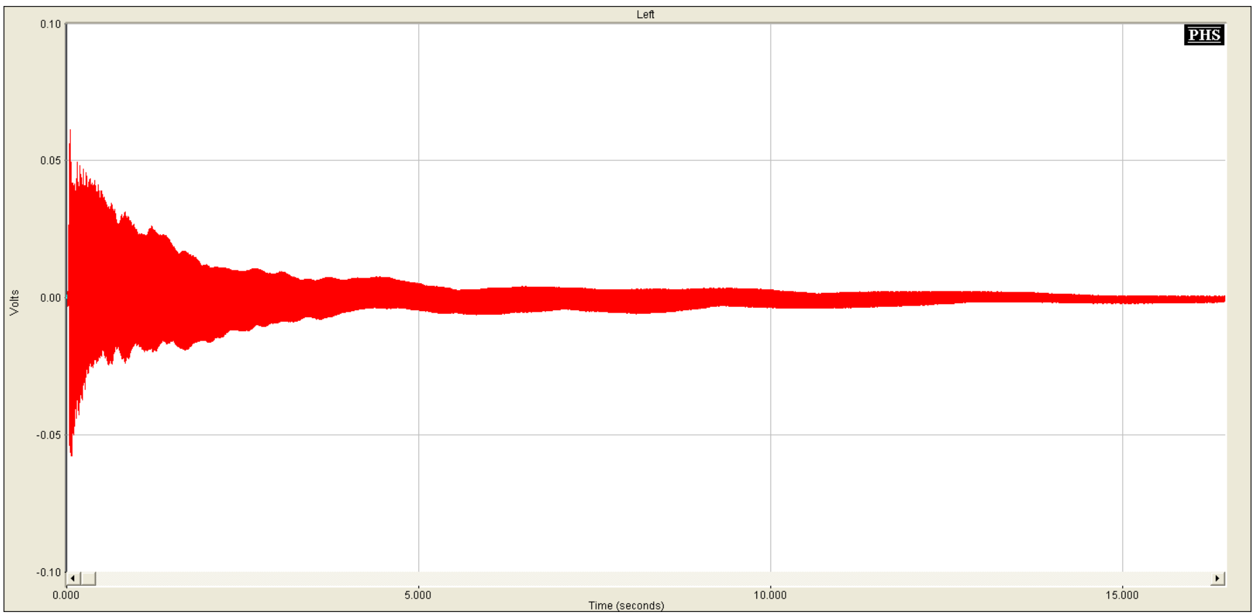

Figure 1: Amplitude spectra (Volts vs. time) low E calibration file for Fender Texas Special pickup.

Picking the string impacts the data in a huge way and by duplicating the stroke method as best as I could and matching the calibration file amplitude for each particular pickup I feel I have done as good a job as is possible at reducing repeatability errors between tests that were performed at different times. Repeatability tests that I performed showed that this method was able to obtain better than 2% repeatability error, that is, if I were to repeat the measurement many times the variation between measurements would be less than 2%. I even used the same pick (Gretsch Thin) throughout the test work.

A note about the notes. The open E note is composed of many harmonics and many additional resonant vibrations which appear as spikes or peaks in the measurement spectra. The random data that occurs between peaks I call the "grass" for obvious reasons. Table 1 below gives you the natural frequency peaks for the E note up to the 9^{th} harmonic.

Note	E_0	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9
Frequency (Hz)	20.6	41.2	82.4	164.8	329.6	659.3	1318.5	2637.0	5274.0	10548.0

The actual spectrometer measurements display all harmonics E1 and higher for the low E note and all harmonics E4 and higher for the high e note. For the open low E string measurements I will also be concerned with E4 and for the open high e string measurements I may also be concerned with both E4 and E5. These are the harmonics that have better that 5% repeatability and at the same time have the most significant duration time or sustain.

A note about the notation. I will sometimes refer to the low and high open "e" strings as E and e, respectively. For the guitar wood combinations I will use as shorthand for the "body wood-neck wood-fingerboard wood". For example, AMM is shorthand for a Swamp Ash body-Rock Maple neck-Rock Maple fingerboard. MMM is shorthand for an African Mahogany body-Rock Maple neck-Rock Maple fingerboard. The same MM neck was used in both guitar configurations – just the bodies were changed for this test work.

Part 1 of this study will investigate the bridge pickup responses for the Fender Texas Special, Gibson 57 Classic Plus, and Seymour Duncan JB model pickups. Neck pickup responses are also important and may be described in a later publication.

<u>The Data Description</u>:

Taking a look at the differences between pickups mounted into the same guitar configuration (same wood and hardware) would be the obvious place to begin this investigation. By far the pickups make the most significant contribution to the sound of the solid body electric guitar - you buy the pickup and you buy the sound. The ability to easily swap out pickups is what makes the Calaveras Fretworks Custom Guitars simply the most versatile guitars on the market today. CFCG players can in effect own multiple guitars at a fraction of the cost by collecting custom pickguard assemblies in order to change both the sound and look of their instrument!

The contributions of the various woods that make up the guitar body are much more subtle and as you will see are much more difficult to quantify.

1a) Effect of the pickups on the frequency response – Low E string:

In order to compare pickup low E string responses I will look at the AMM guitar data graphically. Here is a plot of the Fender Texas Special response in the AMM guitar in gray.

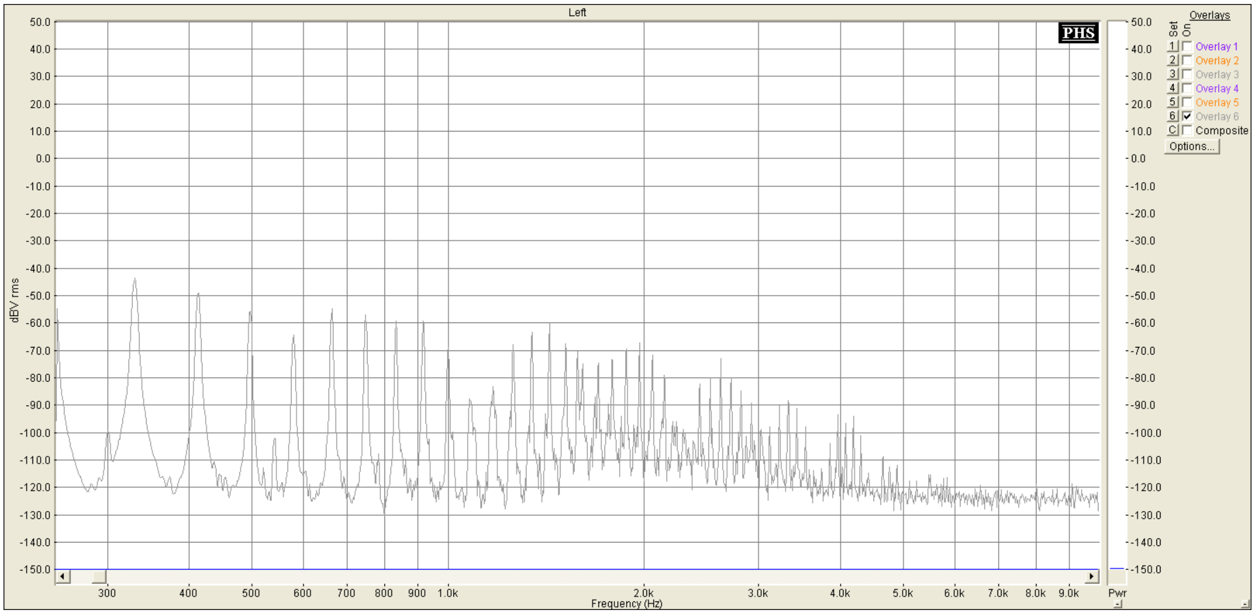

Figure 2: Low E string frequency spectra (dB vs. Hz) for Ash-MapleMaple guitar. Texas Special pickups in gray.

Figure 3 below shows the Gibson 57 Classic Plus in the AMM guitar added in purple.

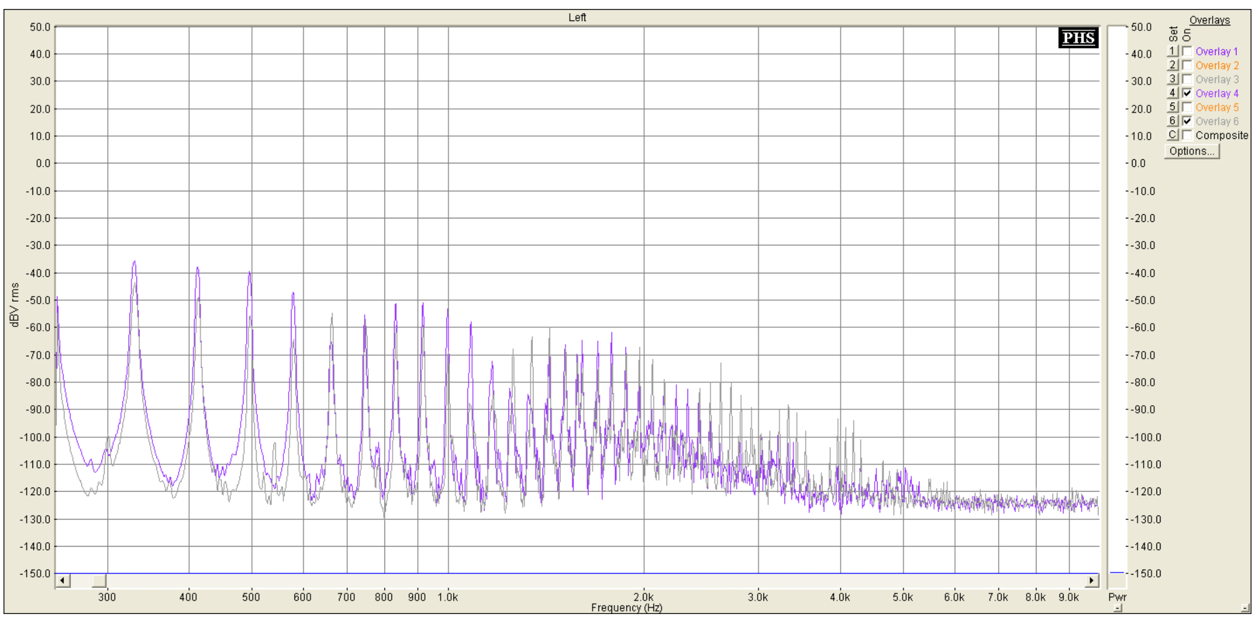

Figure 3: Low E string frequency spectra (dB vs. Hz) for Ash-MapleMaple guitar. Texas Special in gray, Gibson 57 in purple.

Note the Gibson 57 has higher low frequency amplitudes for frequencies up to 1.2 kHz and the Texas Special shows higher amplitudes thereafter. The Gibson has the louder bottom end while the Fender dominates the mid and high end response albeit with an overall lower output (volume).

Next I compare the Gibson 57 to the Seymour Duncan JB model in the AMM guitar shown in orange.

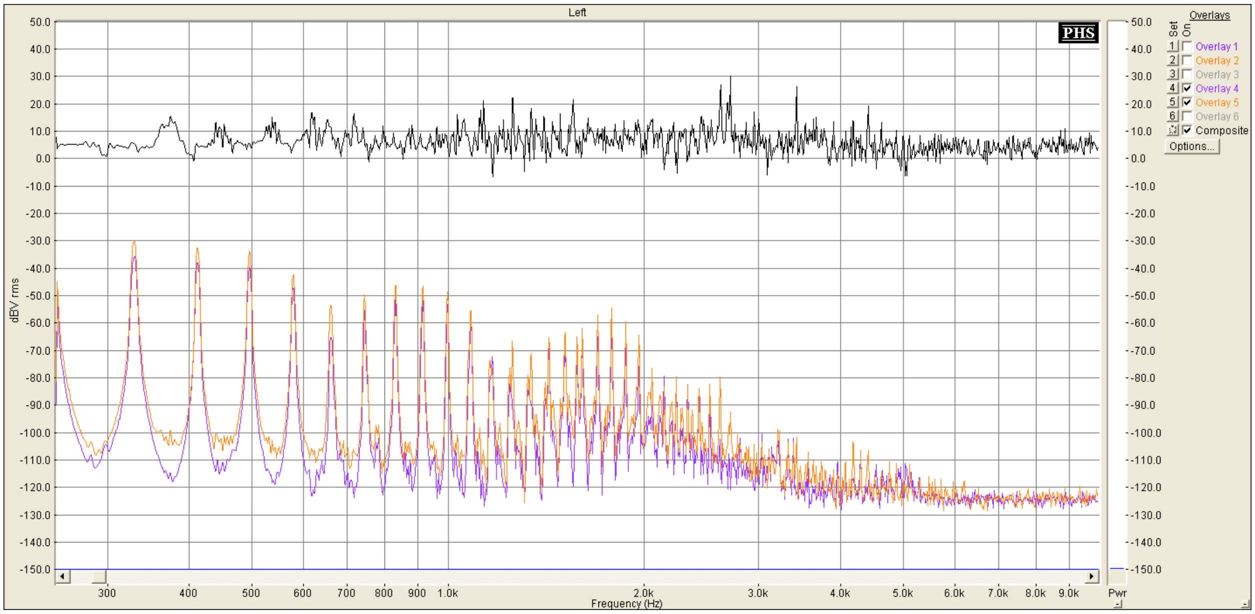

Figure 4: Low E string frequency spectra (dB vs. Hz) for Ash-MapleMaple guitar. Gibson 57 in purple, JB in orange.

Note that there is a somewhat uniform amplitude increase of approximately 5 to 10 dB for the JB as indicated by the difference data in black. The JB offers a similar tone to the Gibson in ash with a much higher output.

1b) Effect of pickups on frequency response – High e string:

For the high e string comparisons I chose to look at the MMM configuration. The Texas Special pickup response in the MMM guitar is shown below in gray.

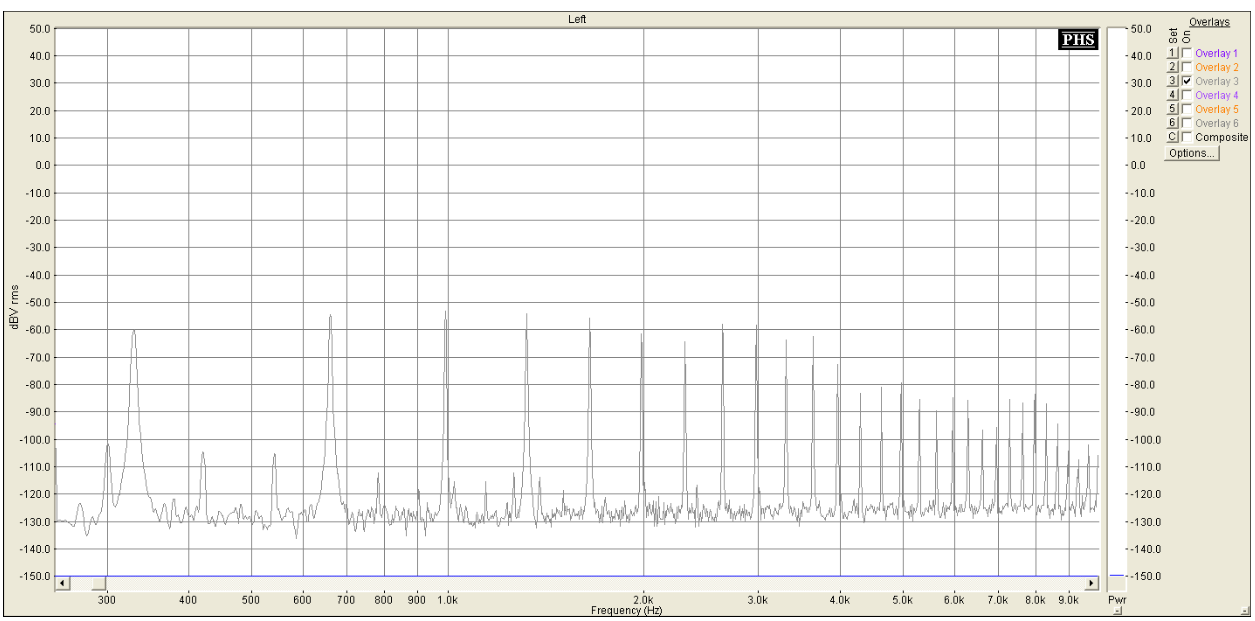

Figure 5: High e string frequency spectra (dB vs. Hz) for Mahogany-MapleMaple guitar. Texas Specials pickup in gray.

The Gibson 57 in the MMM guitar is added in purple in Figure 6. Note the Gibson 57 has higher amplitude for frequencies up to approximately 5 kHz. The Fender shows slightly higher gains in the region above 5 kHz. The high e string is louder and has more bottom end in mahogany for the Gibson while the Fender is brighter, again with overall less output.

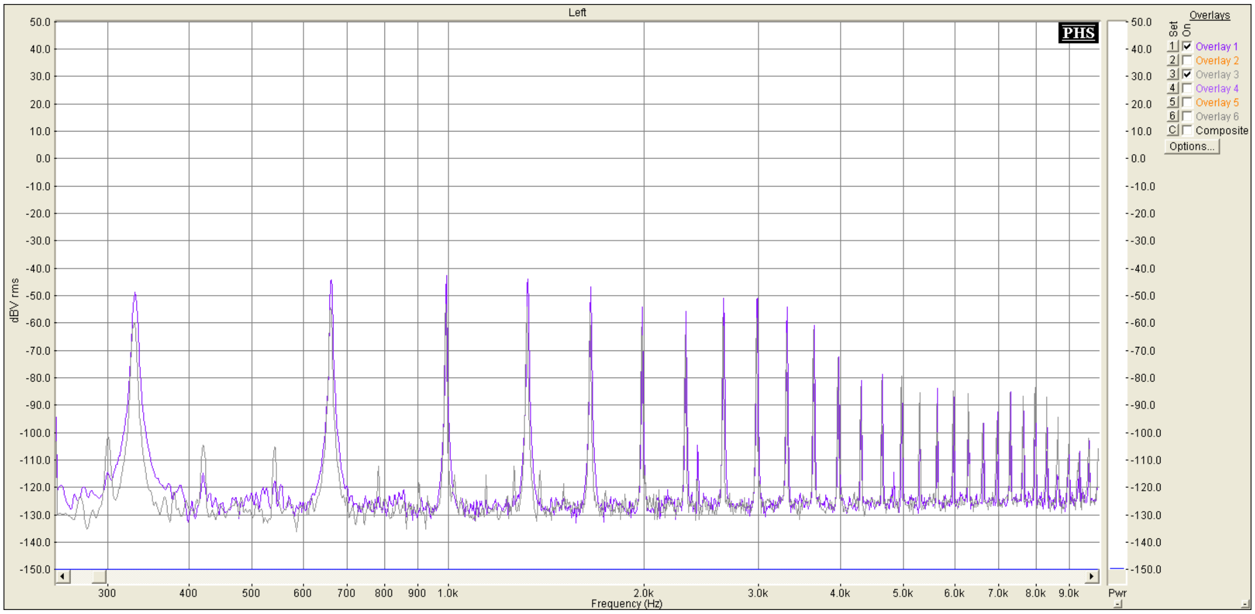

Figure 6: High e string frequency spectra (dB vs. Hz) for Mahogany-MapleMaple guitar. Texas Special in gray, Gibson 57 in purple.

The JB in the MMM guitar is shown in orange and compared to the Gibson 57 in the Figure 7 below. Note the overall increase in amplitudes of 5 to 10 dB across the entire frequency range.

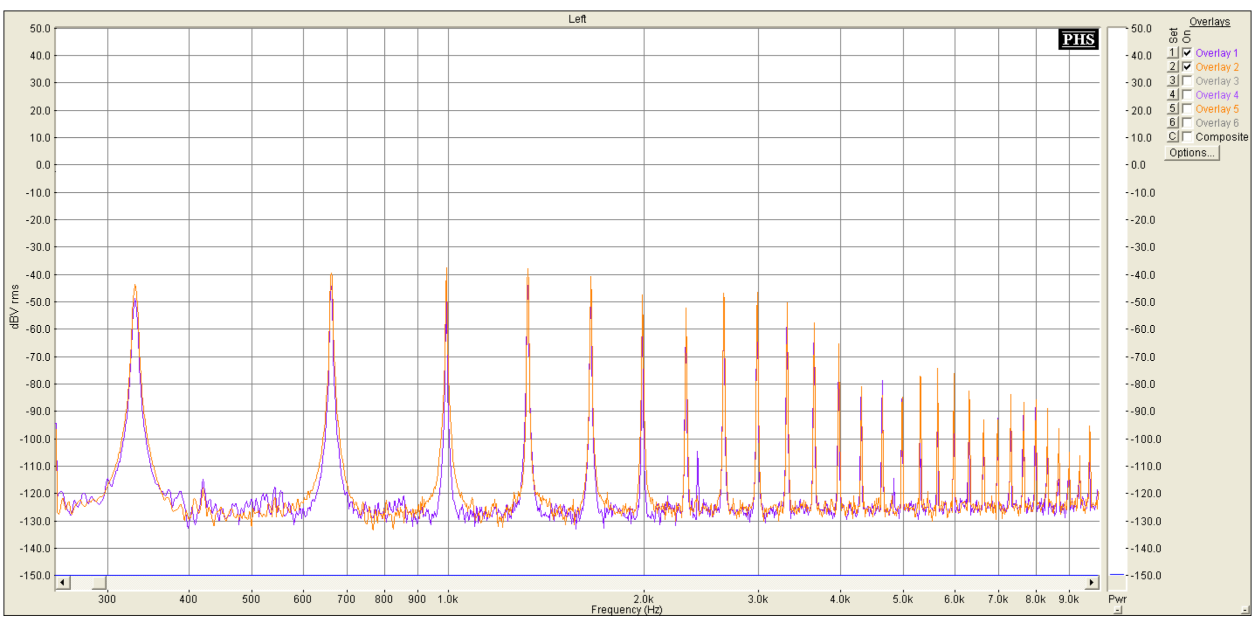

Figure 7: High e string frequency spectra (dB vs. Hz) for Mahogany-MapleMaple guitar. Gibson 57 in purple, JB in orange.

The JB cranks the output up across the board for the high e string in the mahogany body.

2a) Effect of body wood on the frequency response – Low E string:

Now I will compare the same pickup in the two different guitar body woods to see if we can notice any of the subtle differences in the spectra. Remember the only component that changes during these tests is the guitar body wood – all other guitar parts are identical.

The Gibson 57 Classic Plus pickup in the MMM guitar shows a 20 dB increase for E5 (660 Hz) when compared to the AMM data. In general, the MMM data also shows a 5 to 20 dB increase at harmonic intervals and resonance peaks for frequencies greater than E5. This indicates that the bass end of the instrument is brighter with slightly more bottom end for the Gibson 57 in the mahogany body.

The Seymour Duncan JB Model pickup shows only a 5 dB increase in E5 for the MMM guitar. In general, the AMM data shows a 5 to 10 dB increase at harmonic intervals and resonance peaks for frequencies greater than 1 kHz when compared to the MMM data. Two things are going on here. The JB pickup shows a small increase in the E5 response in the MMM guitar and at the same time the JB seems to have an enhanced mid to high frequency response in the AMM compared to the MMM guitar. This indicates that the bass end of the instrument is brighter with slightly less bottom end for the JB in the ash body.

The Fender Texas Special shows essentially no difference in E5 between the MMM and AMM guitars. In general, the AMM guitar shows an increase of 5 to 10 dB at frequencies greater than 1.2 kHz. Much like the JB model, the Texas Special pickup seems to have an enhanced mid to high frequency response in the AMM compared to the MMM guitar. This indicates that the bass end of the instrument is brighter in the ash body for the Texas Special which is also the traditional Fender wood construction and sound.

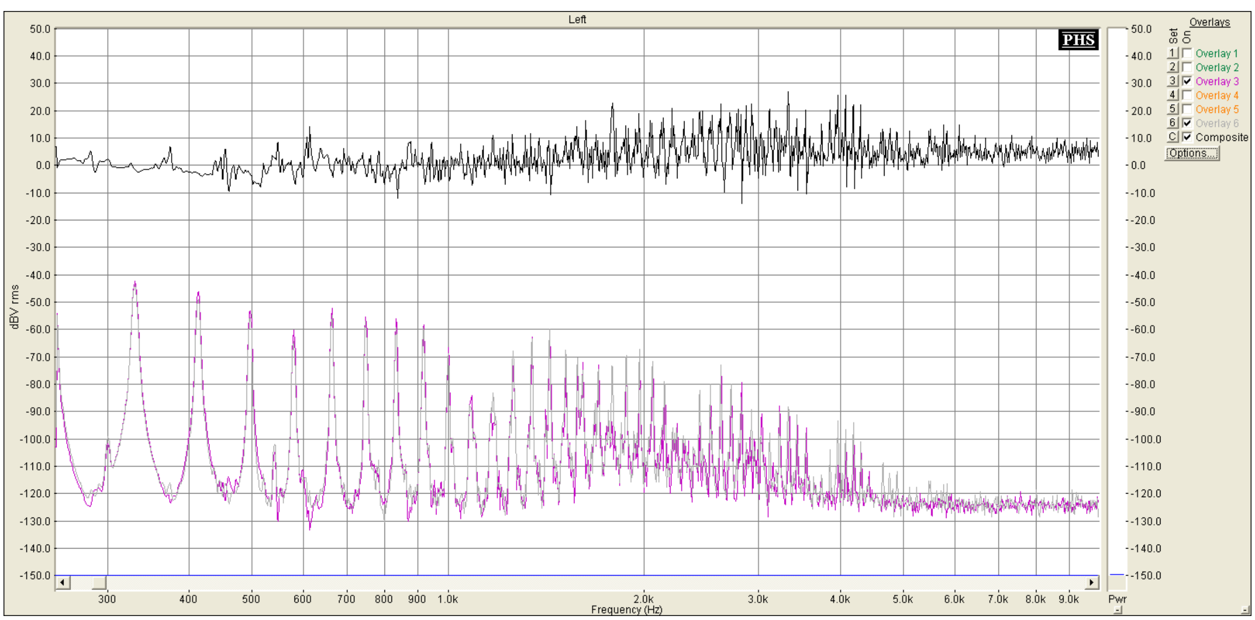

Figure 8: Low E string frequency spectra (dB vs. Hz) for Texas Special bridge pickup. MMM in purple, AMM in gray, difference in black.

Figure 8 above shows the Texas Special data to give you a better idea of what the comparison data looks like. The gray data is from the AMM and the purple data is from the MMM. The black data at the top is the difference between the two measurements. You can see here there is essentially a zero difference between the two guitar bodies up to 1.2 kHz and a 5 to 10 dB gain for the AMM thereafter.

2b) Effect of body wood on frequency response – High e string:

The only significant difference in the high e string measurements was observed from the Gibson 57 pickup. The AMM guitar shows the larger amplitudes (gain) for frequencies over 1 kHz (see Figure 9). This indicates that the treble end of the instrument is brighter for the Gibson 57 in the ash body.

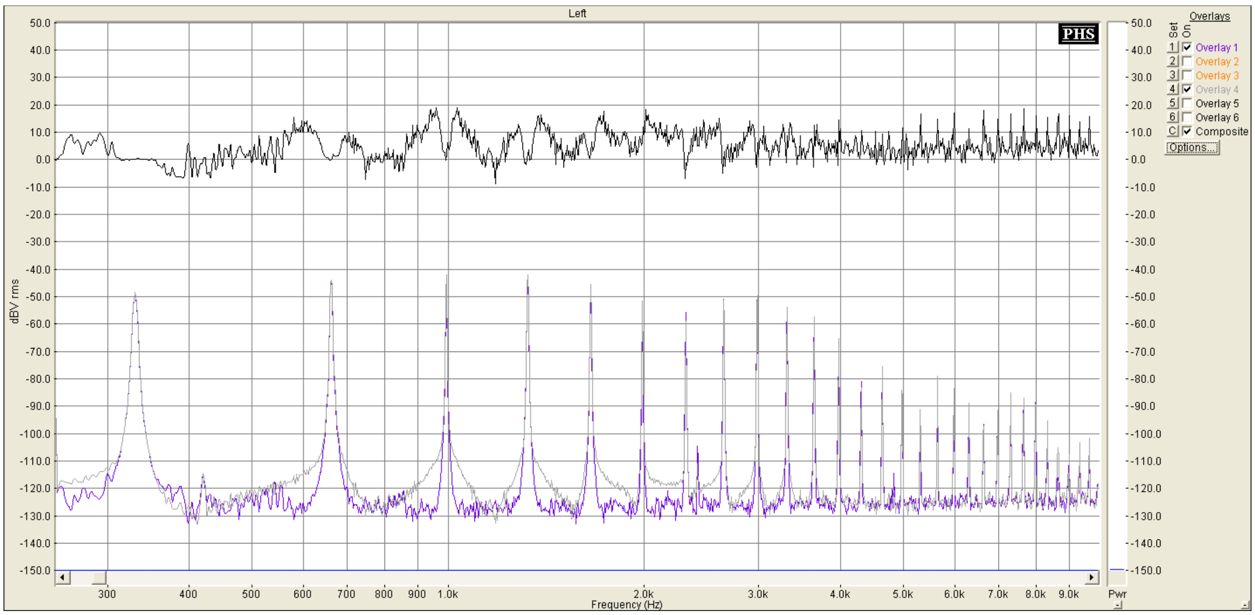

Figure 9: High e string frequency spectra (db vs. Hz) for Gibson 57 pickup. MMM in purple, AMM in gray, difference in black.

The JB model shows only slight gains for MMM at frequencies over 4 kHz. Likewise the Texas Special shows only slight gains for the MMM at frequencies over 3 kHz. These differences are so small that it is hard to say from this data alone whether the JB and/or the Texas Specials have a body wood preference for the treble end of the instrument. We will need to consider the sustain data for additional insight.

The Data Discussion:

Well the data is the data but the discussion section is where I will try to make some sense out of it for the reader. The data is quantitative and my analysis will be guided by my experience and education as an experimental physicist, but I will also offer qualitative interpretations that will fold in my 45 years of experience as a musician and electric guitar player.

When you look at the frequency spectrum data presented in this paper you can easily pick out the natural harmonic frequencies of the E note that are listed in Table 1. There is also a lot of other complicated information outside of the natural harmonics of the E note that I will not discuss here in any detail. By looking at things as simply as possible I believe I can extract enough information to validate what I believe I hear with my ears when I play these instruments – quantitative + qualitative + simplicity seems to work here.

I mentioned in the introduction the ideas of gain and sustain. By just looking at the frequency spectra we can get a good idea of what if any gain (amplitude) changes have occurred during a particular test. We can deduce a change in the overall sound by comparing two guitar configurations and noting any differences in the gain across the frequency spectra. All frequency spectra that I have presented in this paper are called "peak frequency" spectra, that is, the spectra that occurred immediately after the note was picked. As time progresses that peak frequency spectra changes shape and all of the frequency components eventually collapse into the background noise of the electronics. The time it takes for any of these peak frequency components to degrade by a certain amount (specified in units of -dB) can be measured. This length of time is what I will call the sustain time or more simply sustain of the note. Sustain will be the focus of Part 2 in this series of articles.

Let's consider a comparative set of measurements between two guitars that have identical frequency spectra. We now compare sustain measurements and find that there is a difference in sustain time over some portion of the frequency spectrum. The guitar configuration with the greater sustain will be a more responsive and dynamic guitar to play and the way the tone will change as a function of time as the frequency spectrum changes will be different. Since the interaction between the pickups and the different woods are so subtle, it will become important to consider comparative differences in both gain and sustain and how each of them contribute to the overall sound and playability of the instrument.

Section 1: The contribution from the pickups – both Low and High e notes:

In Section 1 I presented data from three types of bridge pickups and two different types of body woods. Differences between the pickups follow an overall trend, that is, in going from the Texas Special to the Gibson 57 to the JB there is a significant overall increase in output (volume) across the spectra. The JB is louder than the Gibson which is louder than the Fender. This is true when each of these pickups is mounted in either AMM or MMM guitars and for both the bass and treble ends of the instrument. What I found to be unique to a particular body wood type is the subtle amplitude (gain) variations that occur in different regions of the frequency spectrum and therefore in the way a particular note sounds for a given pickup.

Section 2: The contribution from the woods – both Low E and High e notes:

I have summarized the results of Section 2 in Table 2 below. The x indicates higher gain in that region of the frequency spectra for a given wood type. A blank space indicates that there was no significant difference between body woods in that region of the spectrum. This does not mean that there is no measureable difference between the two body types – it just means that we will need to consider the contribution introduced by changes in sustain to fully characterize any differences. This analysis will be continued in Part 2 of this article.

Gibson 57	Low E			High e		
	Bottom	Mid	High	Bottom	Mid	High
MMM	x	x	x			
AMM					x	x
Texas Special	Low E			High e		
	Bottom	Mid	High	Bottom	Mid	High
MMM						
AMM		x	x			
JB	Low E			High e		
	Bottom	Mid	High	Bottom	Mid	High
MMM	x					
AMM		x	x			

Table 2: Summary of the body wood measurement data. The x indicates the wood type and frequency region that shows the overall higher gain for each of the three pickups.