A Series of Projects:

Repairing an Entire Rig
From Pedal to Guitar to Amp

Drew Beeson
POM 498-Spring '10
Professor Steve Errede

As I began to think about projects for this semester, I first thought about constructing something from scratch. Possibly building a tube amp from beginning to end, or maybe a custom-made tremolo effect pedal for my guitar would be a worthy project. But as I dug deeper into project plans and estimated costs, I realized that I already had a whole pile of gear at home that needed repair. And why let that go to waste when I have an opportunity to bring them back into good working condition (and learn how to revive them if they ever fell out of commission a second or third time around).

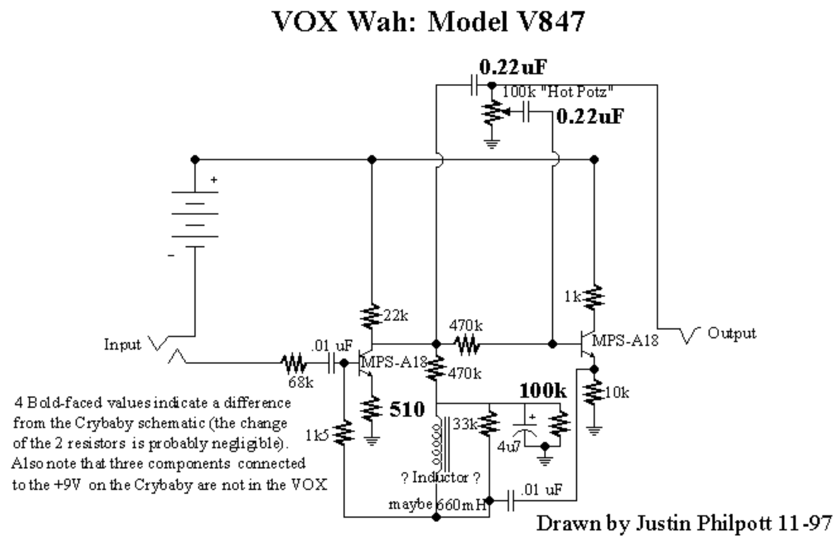
I chose three individual projects to work on this semester. The first was repairing an old Vox Wah-Wah pedal: Model V847, which I had purchased from a garage sale a few years back for $5 dollars and barely worked when I bought it. It always sounded dirty and whenever you opened the pedal from the closed position it would make a "swooshing" sound; something not many guitarist look for in their ideal tone. My second project was to revisit a custom-built solid body electric guitar I made my senior year of high school. This guitar I had built from scratch; from plans to cutting to construction. And in being the first guitar I had built, there was bound to be some mistakes. However, after getting the guitar to a point where it was in playable condition (barely), I never returned to the project to fix my mistakes. I had left the neck with no back-angle, which made the string-action a considerable amount higher as you traveled up the fretboard. I also did not wiring my pickups correctly. There were many cold joints, bad grounds, and even unconnected output wires from the pickups. It wasn't until the end of this year that I could really play my custom guitar properly with the help of this class.

My third project was something new to me. I brought in my Fender Hot Rod Deluxe with the hopes of modifying the circuitry to help satisfy my sonic tastes in a more pleasing way. Luckily, Professor Errede had much experience with reissue Fender amps and was able to give some very helpful advice in replacing/removing various parts in the amp's schematic to create a more appealing tone (at least to my hears).

"Don't Need No Wah-Wah"

The wah-pedal is a very common effect choice for many guitarists nowadays. It was originally built to mimic the sound trumpet players made when using mutes/plungers with their trumpets, like that of Louis Armstrong. The wah-pedal has a relatively simple design, where the pedal acts as a sweepable bandpass filter. In the case of my Vox pedal, the carbon trace on the potentiometer (variable resistor) had been worn down so much that there was barely any contact for the output, which helped explain the "dirtiness" of the pedal when I first bough it. The original pot was a Hot Potz-I 100K-Ohm resistor, and I replaced it with a Hot Potz-II 100K-Ohm resistor, which was the closest, relatively priced pot that this circuit requires.

Here is the schematic:



This was a relatively easy fix. I simply unsoldered the old contacts of the pot, and then removed the old one. I aligned the new potentiometer's adjustment gear with the teeth attached to the foot pedal. This is important that they line up with each other; i.e. when pedal is all the way down, the pot is almost all the way closed. This is to ensure that you don't accidentally break your pot when you stomp on the pedal. Once the pot was set and soldered back together, the wah was back in action and ready to be played. Not bad for a $25 dollar investment.

Parts:
1 x Hot Potz II Crybaby, 100k-Ohm = $19.95 (at antique electric supply online store)

Custom-Built Guitar

For my second project, I revisited my custom-made electric guitar with hopes of making it actually playable. The body of the guitar is mahogany, as is the bolt-on neck. The body top is flamed maple with a sunburst stain finish. I chose a 25" scale length (length from nut to bridge) because it was a rounded, middle point between a standard Gibson and Fender scale length (24 3/4" and 25 1/2" respectively) giving a nice blend of Gibson playability and Fender fret space. The two pickups I chose were a Seymour Duncan '59 Reissue Humbucker (Neck) and a Seymour Duncan JB Humbucker (Bridge).

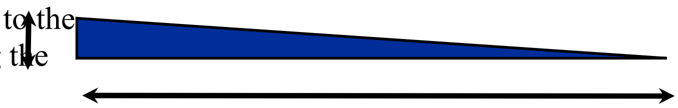
The first problem I decided to tackle was the very low output I was getting from my pickups. After a few years away from this guitar I forgot how I had wired it together. As I began taking the parts out, I revealed a lot of the flaws I had made. First, I had used cheap, non-shielded wire and had not grounded everything efficiently. This in turn led to the excess noise and buzzing characteristics which my guitar was outputting. I also took note of two outputs from the pickups themselves, the red and white leads (the south magnet's finish lead and the north magnet's finish lead) that were not properly connected. This also helps explain the large loss of output from the pickups.

After redrawing the wiring diagram, I took out all old wires and replaced them with braided coaxial wire. I also removed the tone caps that came with the Gibson Alpha pots I used for my tone controls, and replaced them with higher quality, more sonically pleasing caps per suggestion by Professor Errede. Fellow student, Dan Carson, and Professor Errede then tested the resonances of my Seymour Duncan pickups; a continuation of their study of the electromagnetic properties of pickups. After data was collected, I rewired the pickups back into the guitar. I tested the output of the pickups and was very pleased to hear more than just white noise, but the actual string vibrations. I then moved on to my next problem; no neck angle.

While building this guitar, I did not take into account the height differences between the bridge and nut. When the neck of the guitar is parallel with the surface of the guitar top, and you are using a bridge that is mounted on studs, the height difference makes the string-action much higher on the upper frets which then slants down to the nut height. I used a Gotoh 510 bridge and tailpiece on my guitar.

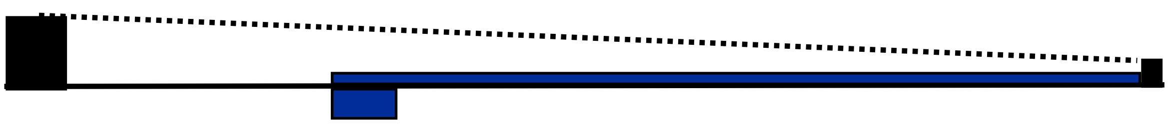
To solve this problem I needed to create a wooden shim and mount it in the neck pocket of the guitar, which would angle the neck back, i.e., evening the string height along the fretboard. I first used trail and error to find the shim thickness by placing different materials under the shoe of the neck. I assumed at first, that the thickness would simply be the amount that I needed to lower the strings, however, that was certainly not the case. After adjusting the neck with a piece of 0.39 cm thick wood (the amount the stings needed to get lowered to have playable action at the 23rd fret), I bolted the neck back on and brought the stings under tension. The strings now had absolutely no action whatsoever and rested firmly on the frets. I decided a little geometry would help with this.

When looking at the neck pocket, I noticed that this problem was similar to that of a lever problem. The small additional height added at the neck pocket was doing much more work to the end of the neck (first fret), i.e. changing the height more drastically. I found the simple ratio, $(d_s/x_p)=(h_b/x_b)$, to find a closer estimated thickness.



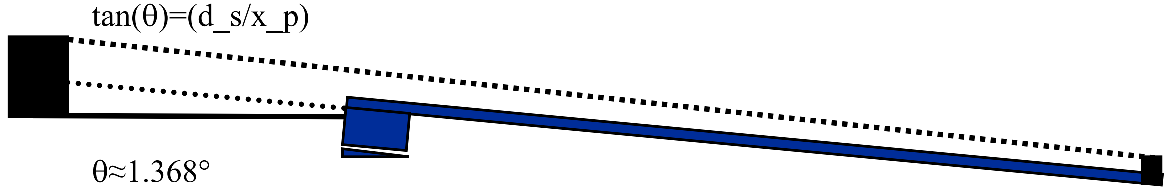
Picture of wooden shim:

$d_s \approx 0.16$cm



$x_p \approx 6.7$cm

$\tan(\theta)=(d_s/x_p)$



$\theta \approx 1.368°$

Picture of neck profile without shim:
(not to scale)

Picture of neck profile with shim:

d_s=shim thickness, x_p=neck pocket length, h_n=height of nut (ideal action height)
x_b=distance from bridge to neck pocket, h_B=height of bridge, d_f=fretboard thickness
h_b=height from guitar top to imaginary point extended from fretboard
$h_b=(h_B)-(h_n)-(d_f)\approx 0.42095$ cm
$x_p\approx 6.7$ cm, $x_b\approx 16.98$ cm,
$h_B\approx 1.42875$ cm, $h_n\approx 0.2778$ cm, $d_f=0.73$ cm

A few other items used for trail and error:

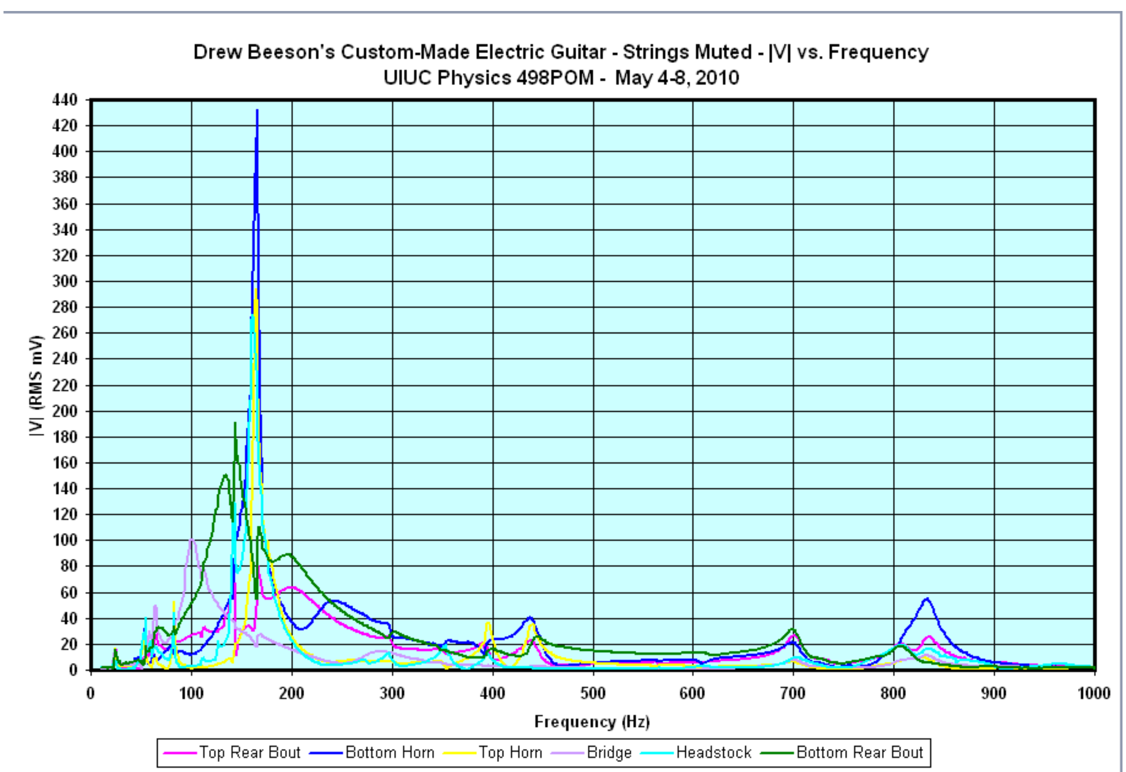
Material	Thickness	Action
Wood	0.39 cm	Too low
Circuit board	0.13 cm	A little high
Metal Strip	0.25 cm	A little low (fret buzzing)
Metal Strip	0.17 cm	Good

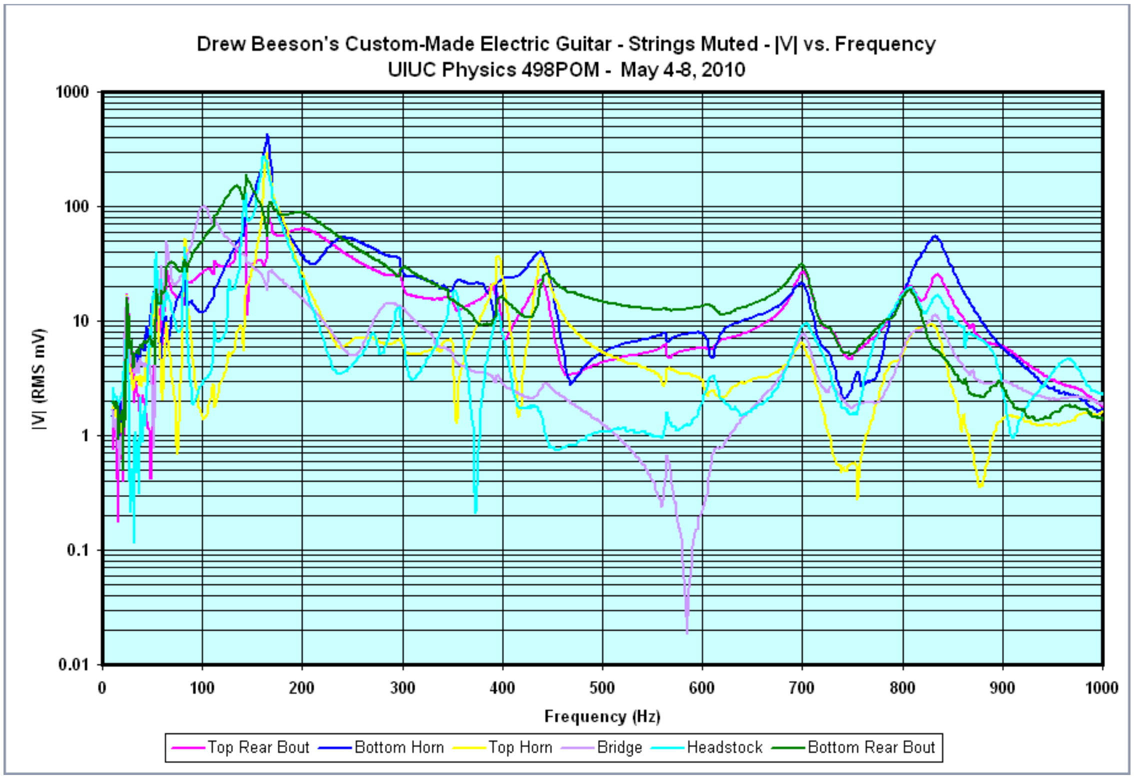
The wooden shim I created was from a piece of hard mahogany to match the body and neck of the guitar. After sanding the shim down, its thickest point was approximately 0.172 cm. The theoretical thickness I obtained from my ratio was $(d_s)=(h_b/x_b)*(x_p)\approx 0.1661$ cm, which was very close to my actual thickness. Though the shim was slightly different (3.43% error) it works very well and makes the guitar much more playable.

After revisiting this guitar and fixing a few problems, we took some data on the mechanical resonances of the guitar's body. Using a piezoelectric transducer to excite the solid mahogany body and using another transducer as a stethoscope, we found the resonances of the guitar at various points.

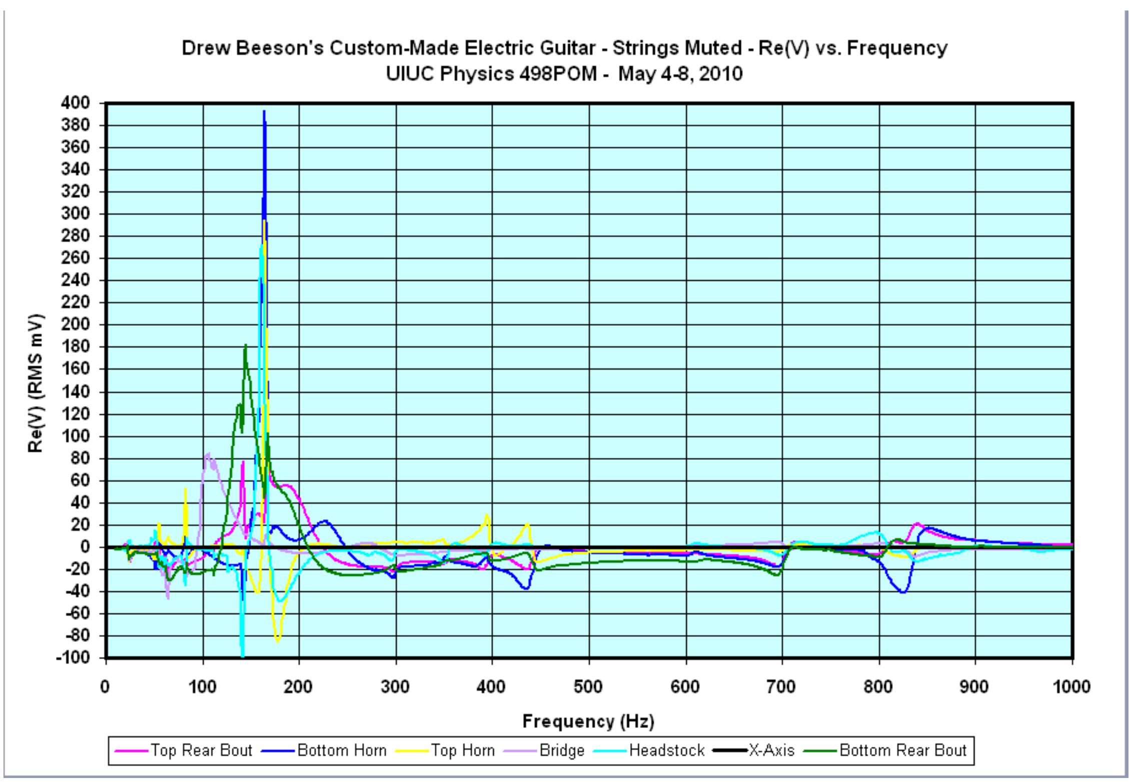
Here the guitar is hanging from elastic bands to minimize outside vibrations.

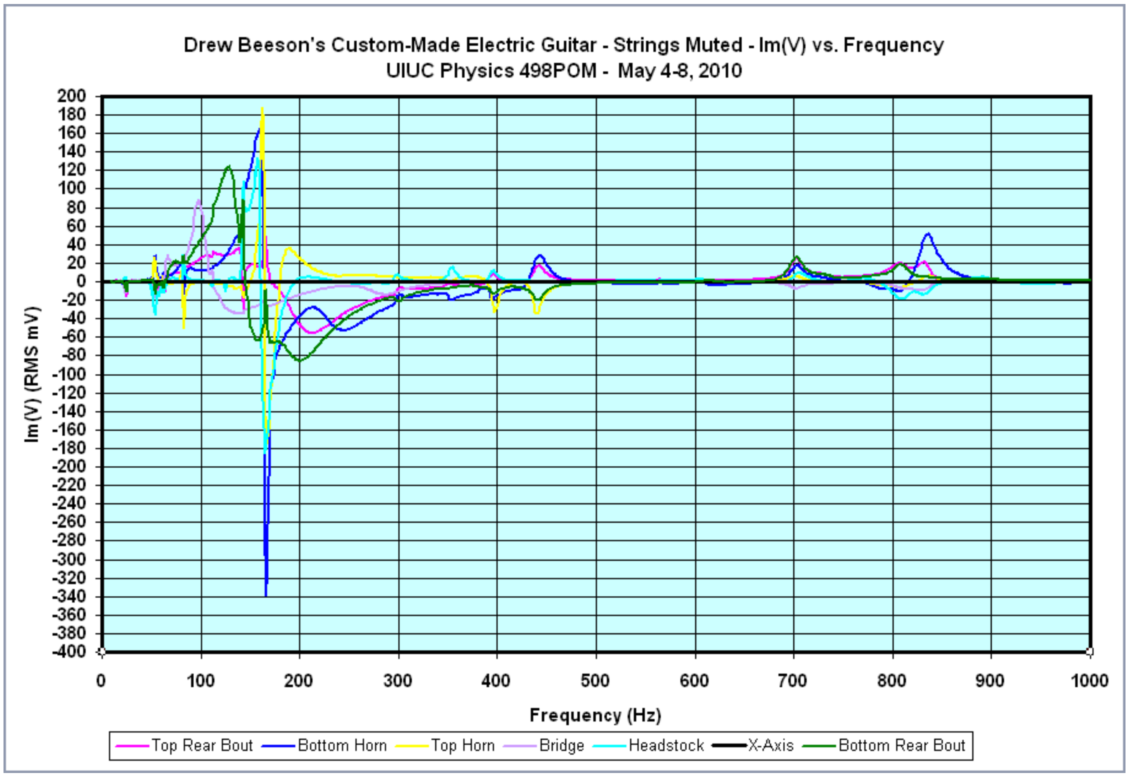
Here are some graphs displaying the mechanical resonances. Looking at the frequency vs. amplitude graph, we can see a peak at approximately f≈164 Hz, near E3 (as reference, Lo-E≈82 Hz and Hi-E≈330 Hz). The second peak is at f≈143 Hz, near D3.



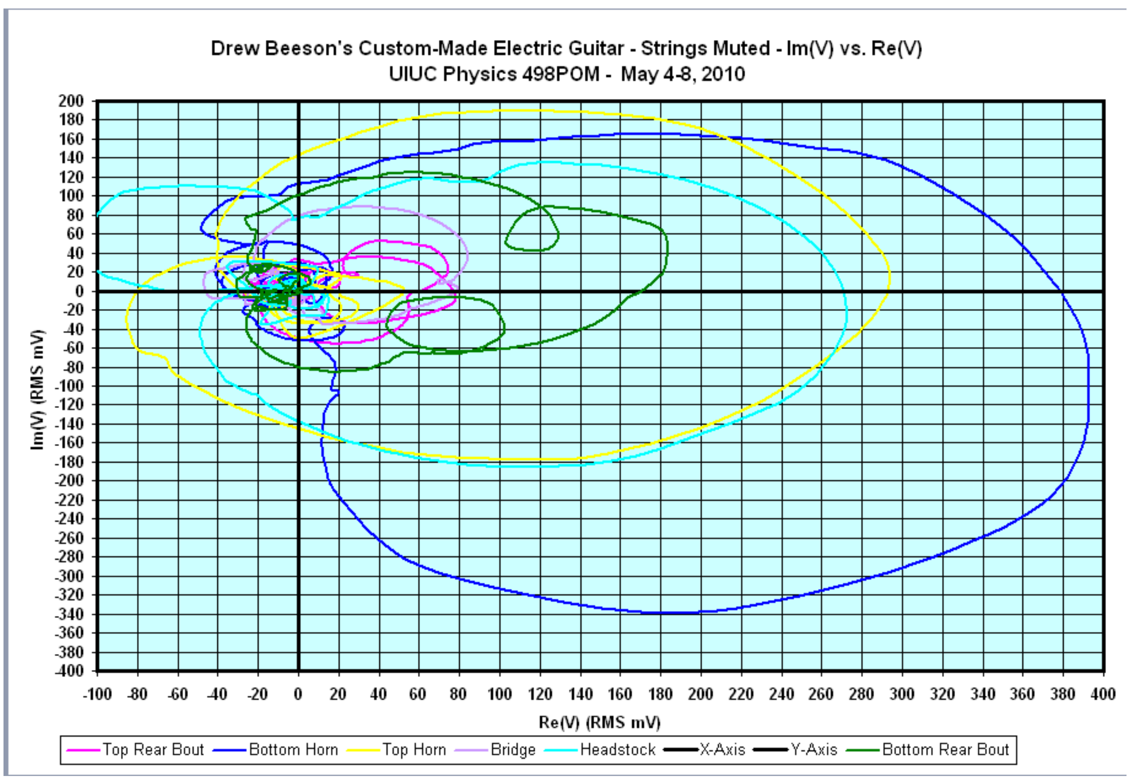


This graph shows a lot of absorption when resonated at approximately f≈570 Hz





Drew Beeson's Custom-Made Electric Guitar - Strings Muted - Im(V) vs. Frequency
UIUC Physics 498POM - May 4-8, 2010
Im(V) (RMS mV)
Frequency (Hz)
Top Rear Bout
Bottom Horn
Top Horn
Bridge
Headstock
X-Axis
Bottom Rear Bout



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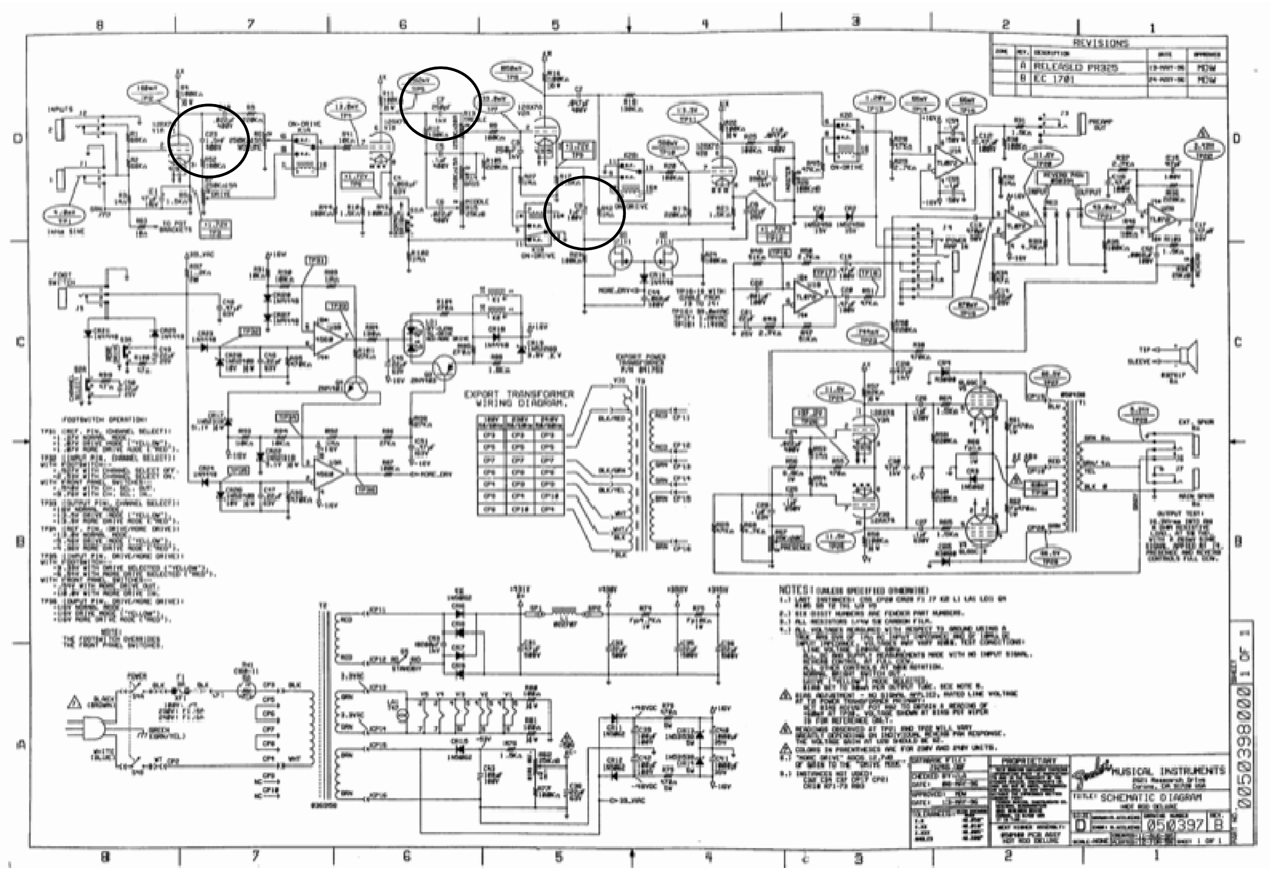
Im(V) (RMS mV)
Re(V) (RMS mV)
Top Rear Bout
Bottom Horn
Top Horn
Bridge
Headstock
X-Axis
Y-Axis
Bottom Rear Bout

Fender Hot Rod Deluxe

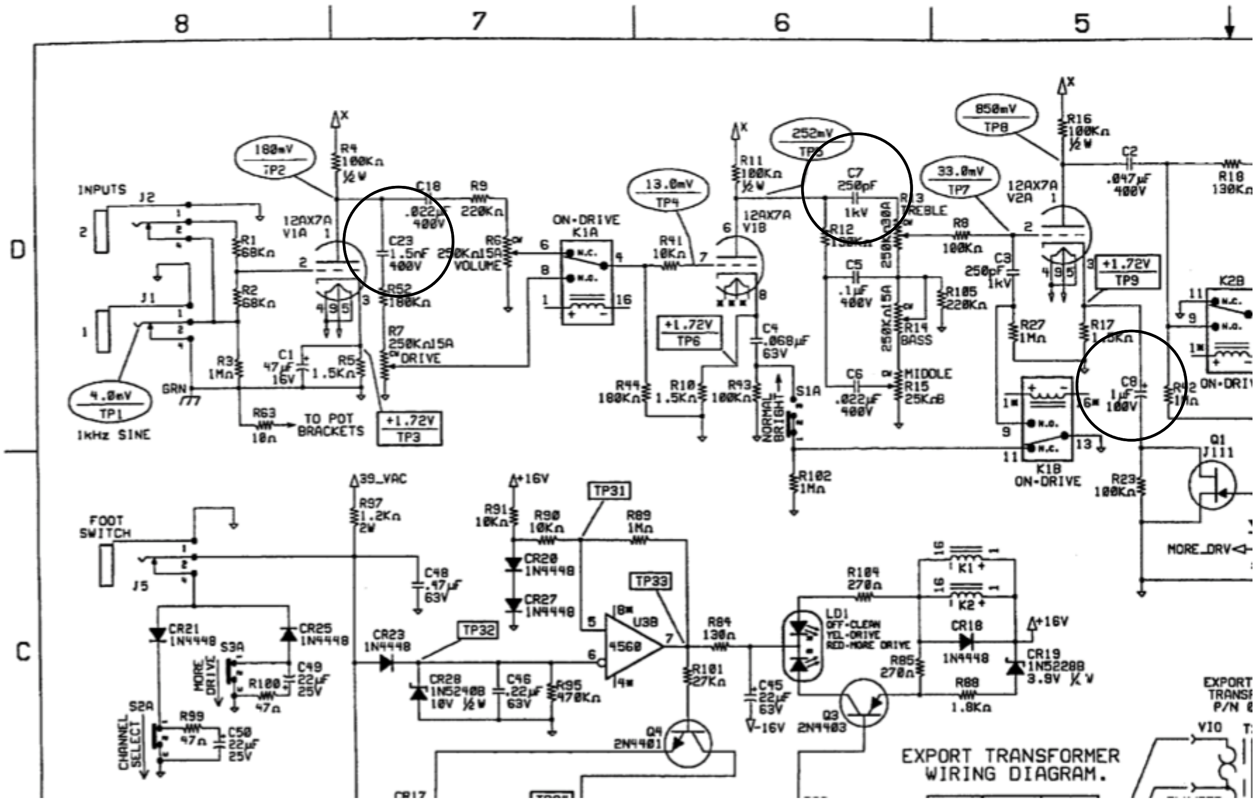
After finishing my second project, revisiting errors on my custom-built guitar, I moved onto my third; i.e. modifying my Fender Hot Rod Deluxe amplifier. This amp had always sounded muddy to my ears and had too strong higher harmonics when using the drive channel. After telling this to Professor Errede, he offered a few suggestions on what to modify.



Prof. Errede suggested replacing a few low-quality capacitors with some higher-quality caps, some of which would have different ratings. These caps were C7, C8, and C23. C23 is a capacitor in the early preamp section, which boosted more of the mid frequencies. Prof. Errede suggested replacing it with a 0.022 μF cap, which would lower its frequency emphasis. We can see this by taking the RC time constant, τ, and plugging it in to find its frequency dependence.

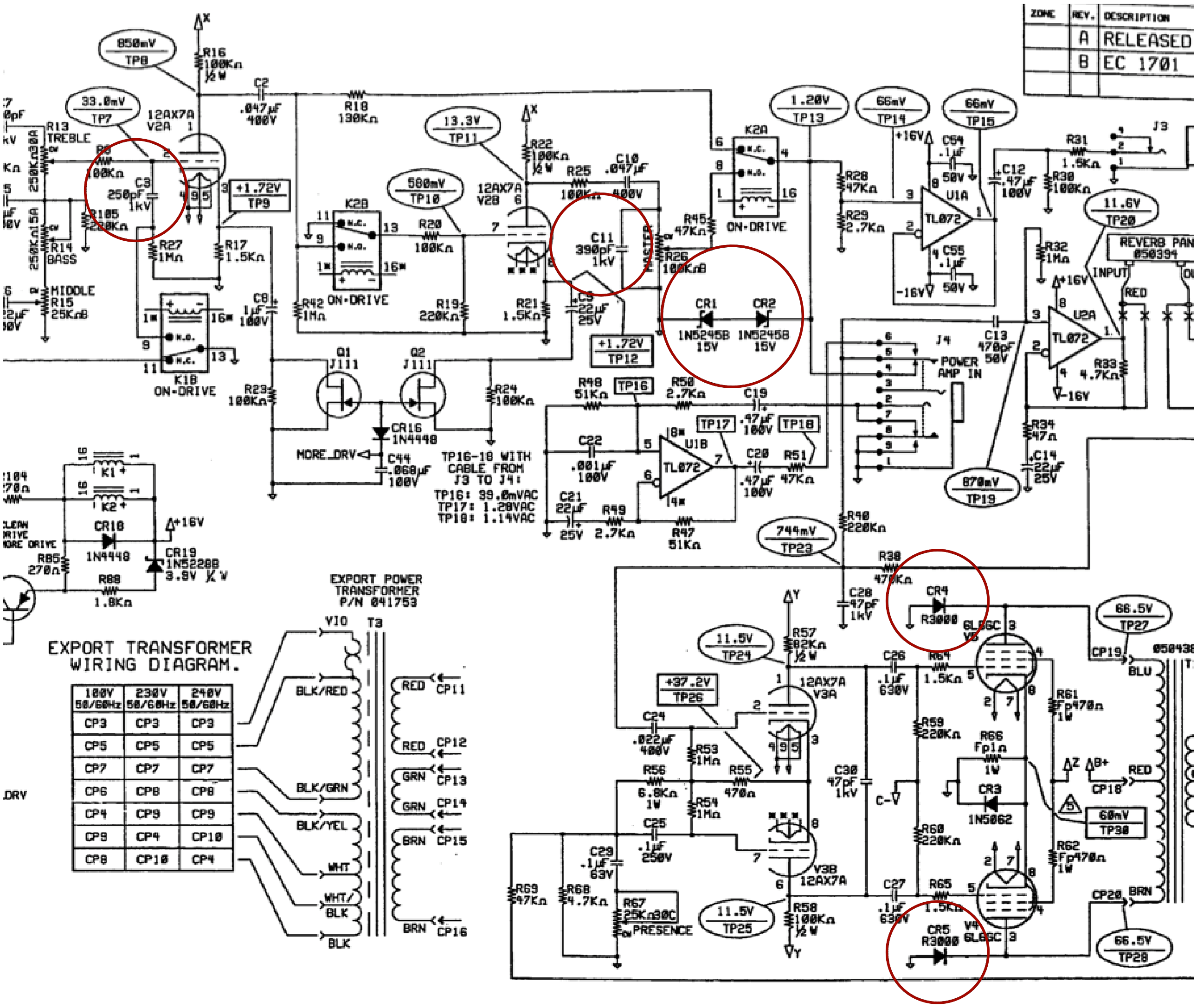
$\tau_{RC}=RC$ (s)	$f_{-3dB}=1/(2\pi\,\tau_{RC})$ (Hz)
$\tau_{RC}=(350k\Omega)(1.5nF)$	$f_{-3dB}=1/(2\pi(350k\Omega)(1.5nF))$
	$f_{-3dB}\approx$ **303.15 Hz**

With the new cap, it would emphasize $f_{-3dB}=1/(2\pi(350k\Omega)(0.022\mu F))\approx$ **20.669 Hz**.



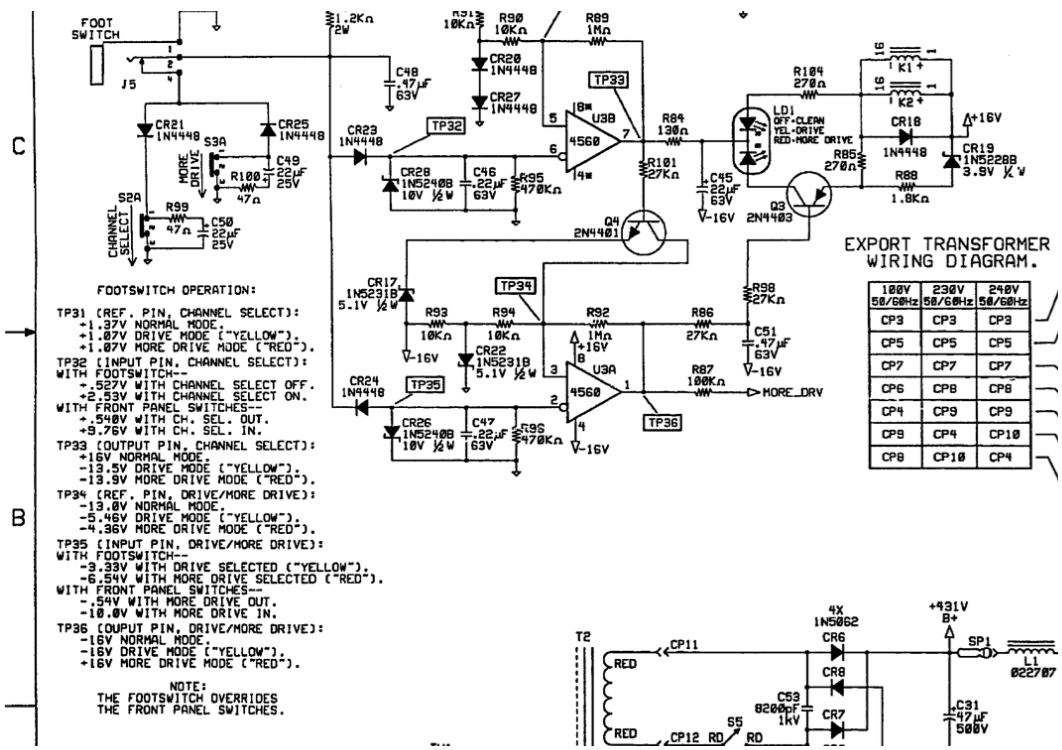
Capacitor	Old Rating	New Rating
C7	250 pF	250 pF Silver Mica
C8	1µF	25 µF
C23	1.5 nF	0.022 µF

We also removed some capacitors and diodes, which were excessive to the schematic and were hurting the amp's tone by either cutting out wanted frequencies or adding unwanted higher harmonic distortion. The caps removed were C3 (excessive cap after tone section; tremble, bass, mid) and C11 (cap over master volume pot which hurt tone on output). We also removed diodes CR1/CR2 (unnecessary diodes for power-amp in) and CR4/CR5. CR4/CR5 are used as "fly-back" protection diodes for the power tubes, however, they are rated much too high to actually have much use (3000V) and were creating unwanted high-frequency distortion. Looking back at vintage amps of the 1960's, we also noted that Fender amps didn't use these diodes in their schematics for this purpose. In hopes of turning this reissue Fender amp into something more similar to the original, tone-wise, we removed these diodes.



Close-up of the Hot Rod Deluxe schematic showing which parts we removed from circuit: C3, C11, CR1/CR2, CR4/CR5.

After altering the circuit and replacing these capacitors, we moved onto fixing the channel selector, which was not switching the circuit from the clean channel to the drive channel or adding in the more drive section. Looking at the printed circuit board we noticed the op-amp (U3A) in the channel selector section had two pins (#3 and #4) that crossed leads. The solder must have somehow melted and was now connecting the two pins, causing a short. After going through this section carefully, using the schematics test points, we noticed TP 35 was not matching the pre-determined voltage. This led us to diode CR26, which we found to be dead. After separating pin #3 and #4 on U3A, and replacing CR26, the amp's channel selector and more drive switch were working correctly once again.



Close-up of schematic showing channel select sections.

In summary, these three projects complemented each other very well. Starting off with a simple circuit and moving along to more difficult ones, I was able to gain a lot of hands-on experience with various circuitries. Not to mention, I now have a complete (and functional) guitar rig to play. Not too bad for only having to purchase only a few capacitors and a potentiometer.

I would like to thank Professor Errede and Adam Watts for all of their support and knowledge. It was very beneficial to have such useful help and advice on these projects. My greatest gratitude goes out to them.