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5.15.05

Construction of a Fender Champ-Style Tube Amp

One of my first experiences in college was meeting a friend who had built his own guitar amp in high school. I had always known to recognize guitarist by their sound but I never realized exactly how much went into crafting a guitarist's tone. As he explained the difference between vacuum tube and solid-state amplifiers I was amazed to think that all that stood in the way of me and sounding like Hendrix or Page was a little circuit. Of course, now that I am a little wiser (and realistic) I have realized that I will never sound like that but I do see that I can share the same equipment and even make improvements upon the design of their amplifiers.

In this report I will outline all of the steps and decisions I made in my journey to build a tube amp. Similar to other reports from Professor Errede's students I will discuss design and analysis issues. Also, I would like to add in my daily notes from working with Professor Errede. I compiled all of my notes for my own future reference and figured that it all may be helpful to others as well.

Also in contrast to the other reports I would like to thank Professor Errede right at the beginning of the paper for the priceless hours of advice and hard work he sacrificed to get this all done. His help was the most important factor in finishing everything and I am extremely grateful to have had the chance to work with him. Thank you Professor Errede.

Design:

After I was enlightened to the wonderful way of the tube freshman year I began researching exactly what goes into building an amp. In all of my research I gathered that a Champ style amp was a modest design for a beginner. It is a simple single ended amp that operates at relatively low power without concern for reverb or other more advanced effects. When considering my particular needs as a guitarist I specifically knew that I did not want a high output, high volume amp. I simply wanted an amp that would sound good in my apartment working at low levels. The tweed-era Fender 5F1 Champ/5F2-A Princeton Amp seemed like a safe choice.

Armed with only the most basic idea about what I wanted I brought my ideas to Professor Errede. He was well aware of my needs and recommended some simple upgrades to improve the performance while maintaining the elements I described above. First, he explained that the original tweed-era Champ/Princeton Amps used a small power transformer producing about 10 W of output power. As a result I decide to use the 125P23B Power Transformer. This is normally used in a Tweed Deluxe amp. It can produce 680 V or 540 V on the secondary winding and a maximum of 20 W power. I choose to operate the amp off of the 540 V winding to produce a dirtier sound. I also increased the values of the preamp cathode resistor, the preamp plate load resistors and the feedback resistor. These design decisions are more consistent with a Gibson GA-5 amp type tone for the same era.

In general I always made my design decisions to achieve a dirtier sound. In the future I may consider running the power off of the red winding on the secondary to achieve a cleaner sound. I may also reduce the values of the 2.2k preamp cathode resistor, the 220k preamp plate resistors and the 47 k feedback resistor.

Another simple design change was the usage of a 6L6 tube rather that a 6V6. This is because of the subjective reason that 6L6's are so sonically pleasing.

Construction:

4/16/05

- To avoid problems with metal shreds in the amp it is best to make all cuts into the chassis before any circuit work is done. Therefore it is very important to think ahead as to how the chassis will need to be laid out.
- For the input jacks it is best to use Marshall style phono jacks or to add a rubber washer to the Fender style phono jacks. Otherwise, problems with grounding may arise because the Fender jacks are not electrical neutral. These modified jacks do not necessarily fit in the preexisting chassis holes so the old holes must be reamed out to make them fit.
- This was about three and a half hours worth of work.

4/17/05

- The enlarged output transformer required additional holes to be made in the chassis.
- Once all of the holes are drilled the components can start to be placed on the chassis. The power transformer was placed in the existing holes. The black wires are faced towards the outside of the chassis. The output transformer must be placed orthogonal to the power transformer to avoid interference. It should be placed with the power lines facing the bottom (towards the tubes). A hex driver is used to secure the transformers.
- Unfortunately, the size of the output transformer caused its screw placements to overlap with the location of the circuit board. To avoid interference with high voltage on the circuit board it is best to countersink the screw holes underneath it.
- Installed Fender style phono jacks with rubber washers to maintain electric neutrality.
- Installed 8 pin tube sockets for power and rectifier tubes. Pin 8 is placed according to the layout drawing with pin 8 towards the inside. On the chassis it is generally best to keep the tubes as far away from each other as possible to help heat dissipation.
- Installed grommets (5/8” outer, 3/8” inner) so the sharp metal edges of the chassis do not scrape and/or expose wires.
- Installed pots for volume, tone and presence control. When these are laid out it is important to place the presence as far away from the input jacks as possible. The presence is tied to the speaker and therefore may face problems with feedback otherwise.
- This was about four hours worth of work.

4/22/05

- Shark tube retainers placed on sockets.
- Installed 9 pin tube socket for pre amp tube. Pin 4-5 are placed inward in accordance with the layout.
- Installed 1M Audio Pots (logarithmic scaling) for Volume and Tone control and 5k linear pot for Presence control.
- All components should initially be placed on the brass faceplate loosely and should be tightened at the end to prevent the faceplate for locking up.
- Installed 3 lead phono jack for grounded speaker out and 2 lead for extra speaker out. A star washer was placed on the back but there is no need for grommets because we have already considered grounding issues prior to the output.
- It is best to work on the power supply before moving to the circuit board. First separate the earth ground (green lead from power cord) and main star ground.
- The black lead on the power cord is line and the white is neutral.
- The fuse should be placed prior to the switch. This will protect the circuit in the event of an electrical malfunction from an AC power source. The fuse should have electrical tape around it also. This should be secured with a cable tie that is cut flush because the tape will not remain sticky very long. This is for safety purposes although the exposed metal at the base will remain live.
- On each power lead heat shrink should be placed around the connections after they are soldered.
- This was about three and a half hours worth of work.

5/5/05

- Because I am using a Princeton based schematic on a Deluxe chassis I needed to be careful when laying out the circuit. The layouts are not the same for each. Luckily, the Princeton is a simpler circuit than the Deluxe so it was not difficult to make the change.
- All resistors and capacitors should be installed so there values can be read from left to right and up and down.

- Do not bend leads on resistors and caps too close to the component. Use needle nose pliers to secure the lead.
- Used Sprauge electrolytic caps for grounded caps near power supply.
- Used Sprauge 715 P Orange Drop 600 V caps for plate cap in pre amp and grid cap in power tube stage.
- Mount resistors on power tubes slightly off board for convection cooling purposes.
- Use fairly heavy gauge Teflon wire because of its high dielectric constant and breakdown constant. Stranded wire results in reduced inductance.
- Wires for power supply, heaters and filaments do not need coaxial cable because of high voltage.
- Grounding considerations are very important. The Earth ground from the AC source should be grounded to the chassis but the leads at zero potential from the power transformer should also constitute another ground. This is called the star ground. Star grounding follows the principle that power should be returned to its source as directly and rapidly as possible. For each ground node a separate wire should be run to the star ground. In other words, if a ground is decoupled through a resistor or other voltage drop a separate lead should be run to star ground.
- This was about three and a half hours worth of work.

5/7/05

- Continued and finished wiring board.
- To install the board a capacitor had to be temporarily removed in order to fit the screws into the chassis.
- Once the board was installed all of the dangling leads on the chassis and board needed to be soldered to their joints. It is best to first solder all of the wires from the board to the tube sockets. This should be done with the pins on the bottom being soldered first. Be careful not to solder the tube pins too much. Too much solder may seep into the casing and cause shorts. Also, the stripped wire leads to the pins should be kept short.
- All transformer leads should be tinned before they are soldered. With untinned leads the extremely high voltage may cause corona- a major safety hazard.

- The unused secondary windings should be double heat shrunk, covered with electrical tape and tied to avoid shorting.
- Teflon wire is preferred over PVC as an insulator.
- The 1M resistor on the input jack should be soldered directly to the connection of the jack. On the jack you can actually see the ground.
- Coaxial cable should run from the input jack to the pre amp tubes. This is nothing more than a simple extension of the guitar cord and helps reduce hum. To separate the coaxial cable, first strip the insulator. Then push the exposed metal coaxial shield inward (like a Chinese finger trap). Next, find a hole in the braid and make it larger until the poker can be threaded through to the other side. Pull the wire out. Pinch and twist the shielding. Trim the end, tin it and heat shrink the joint.
- Soldered 68k resistor to pin 2 on the pre amp socket.
- This was about five hours worth of work.

5/12/05
- Continued wiring board to all tubes and outputs.
- Coaxial cable should also be used for the signals to the pots. Essentially all main signals should be shielded.
- Connected primary and secondary windings on output transformer. The 125ESE is designed to be used with a Tweed Deluxe model amp that uses 6V6 tubes in its power stage. The 6V6 has 10k Ohms of resistance. The 6L6 that I am using has 5k Ohms of resistance. Because of this the secondary windings are matched as the following:

WHT = 16 Ohms
YEL = 8 Ohms
GRN = 4 Ohms
ORG = 2 Ohms
BLK = 0 Ohms

Because I am using an 8 Ohm speaker I connected the YEL lead.
- This was about four and a half hours worth of work.

5/13/05

- Wired heaters to tubes.
- Installed 2 Amp fuse.
- Installed GE 47 bulb (6.3 V) for pilot light along with red jewel cover.
- Cleaned up circuit layout by cable tying ground leads together.
- It is a good idea to mount the coaxial signal wire into the circuit board to a more rigid wire (i.e. HV from power transformer). Adding mass will lower the resonant frequency of the mechanical vibrations to an inaudible level.
- Installed chassis into cabinet. The cabinet is made of soft pine.
- The power cord should be mounted to the cabinet to avoid an accident that may damage the power supply.
- Installed Jensen speaker. For speakers white=hot. Match up like colors for phasing purposes. To avoid putting stress on the speaker jack input it is a good idea to cable tie the speaker leads to the back of the speaker cone.
- Completed a working version of the amp using Professor Errede's Jensen 12'' speaker as well as his tubes.
- Played for first time!
- This was about 4 hours of work.

5/17/05

- Bought 12" UTAH Blue Frame Speaker from Ben Juday to replace the Jensen speaker. This was originally in a Baldwin organ from the early 60's. Ben also provided a Groove Tube 6L6GE (#7) and a 12AX7C.
- Made pertinent measurements regarding the operation of the amp (See below).
- This took about 4 hours.

5/18/05

- Finished installing new speaker and tubes.
- 90-95% shielding is a good amount for coaxial cable.
- Installed precious steel tube shields. Modern tube shields are made of aluminum and are not capable of soaking up the magnetic field lines as well.
- When playing the amp there were two audible noise problems.

- The first problem was a crackling sound. A dry solder joint on the tone control pot caused this. Because the cap used here was old it had a large degree of oxidation on its lead. When creating a solder joint the resin in the solder eats through the oxide by way of a chemical reaction that is temperature dependent. In this case the temperature was not hot enough for the resin to eat through the large amount of oxide. Because of this the connection is physically switching between an on connection and an off position. This was the cause of the crackling and was fixed once the joint was resoldered.
- The second was a mechanical vibration when the low E string was played. This was also fixed once the cap was resoldered.
- Another problem was a weak connection on the input jack. The ground shielding on the coax was not firmly attached. This would eventually break adding more noise. This was also fixed by resoldering the joint.
- Once the noise problems were addressed we decided that the new speaker was not an improvement. It likely did not have enough power handling capabilities and this resulted in a muddy sound. A possible replacement is a Celestion Legend Speaker.
- This was two hours work.

General notes:
- All voltage measurements made with FLUKE 87 III True RMS Digital Multimeter.
- The soldering equipment used throughout this project was a Weller WSD 81 gun and SN 6040 Tin/Lead Ersin Multicore at 700 degrees F.

Analysis:

After the amp was fully operational we measured the DC voltages at all important nodes. These values can be observed in Appendix A. All values were as expected.

The output signal in time domain was also measured. These graphs as a function of time are presented in Appendix B. The volume setting was varied as tone and presence were kept at constant settings (5). Here it is evident that the signal is basically sinusoidal.

To measure the gain stages I measured voltages at the A, B and C points as specified in Appendix A. For a 10 mV peak to peak input signal at 1kHz the signal at A was measure as 6.9 mV AC. At point B the voltages were measured at a tone control volume of 0 as well as 12 as the volume was varied. A 8 Ohm dummy load was attached to the output. The line voltage was measured at 118.6 V AC. The voltages varied from 6 mV to 4.73 V AC at maximum volume. With the tone control at a maximum the voltages ranged from 6.0 mV to 10.41 V AC. With a similar procedure at point C the values ranged from 4.9 mV to 3.32 V AC. At maximum tone settings the values range from 5 mV to 5.99 V AC.

The frequency response is plotted in Appendix C. Here the output voltage at point C was measured at 20 Hz, 100 Hz, 200 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 700 Hz, 800 Hz, 900 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 5 kHz, 6 kHz, 7 kHz, 8 kHz, 9 kHz, 10 kHz and 20 kHz.

I also measured the frequency response for 10 mV peak to peak input signal at 1kHz using a dynamic signal analyzer.

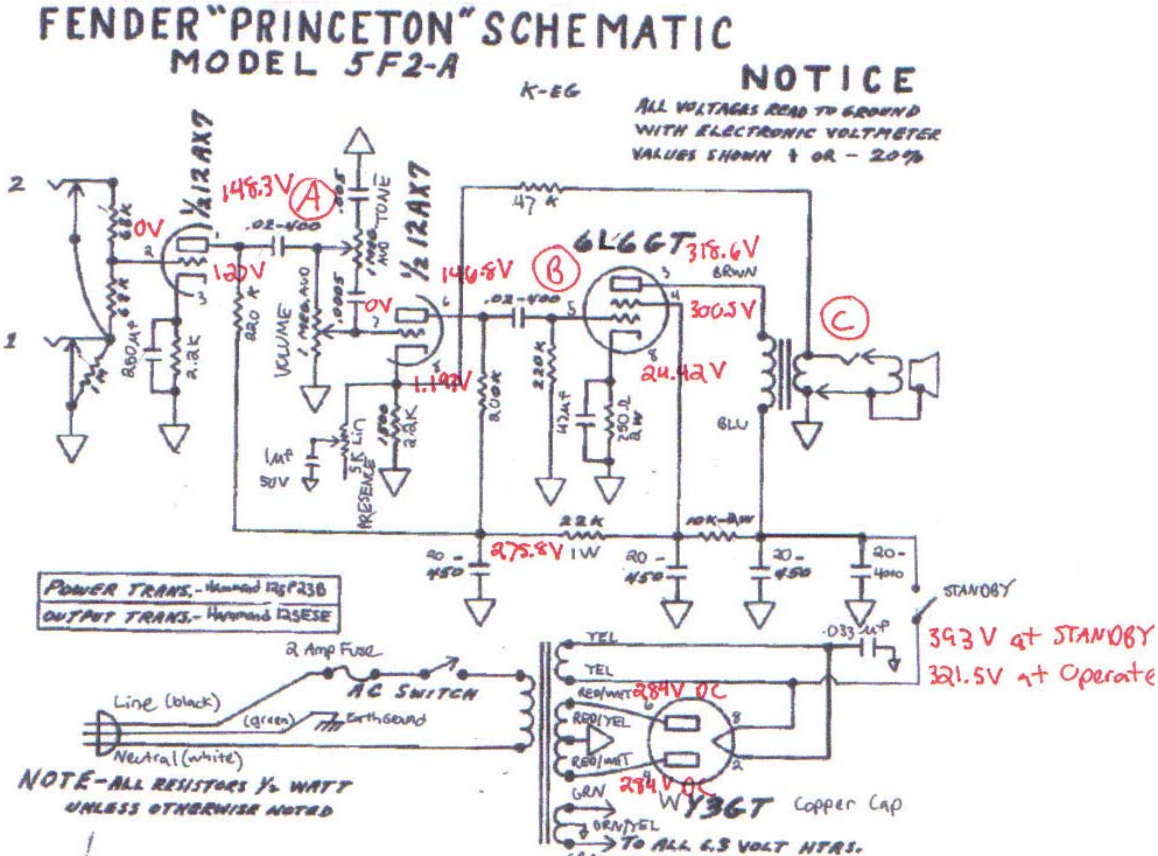
Conclusion:

I am now convinced that the best way to learn how to build a guitar amp is to simply do it. At first, I felt timid about my abilities to do all of this. I was worried that if I choose the wrong tubes or the wrong values for the caps that the amp would become a disaster. Certainly, every design decision affects the final tone but that is part of the challenge. I have not built an amp that will just sit behind me as I play. I have something that I can work WITH. I will always have the ability to open it up and make it better or different at least. I think that is the most exciting part about all of this.

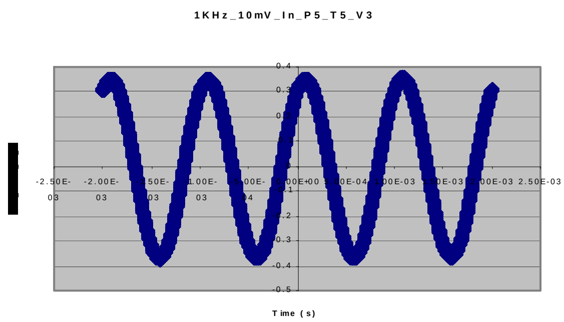
Overall this project took several weeks for design considerations and at least 35 hours for construction. I spent about $600. (A complete parts list is included at the end of this report.) It was all worth it.

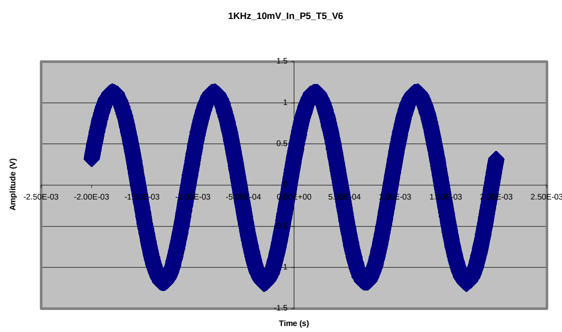
I learned so much throughout this project and know that the work and time commitments have provided me with knowledge which I will hopefully use for the rest of my life. No matter what my career I am certain that I will always maintain a love for music and guitar.

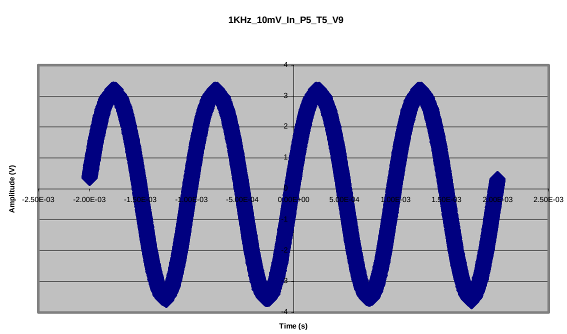
Appendix A


FENDER "PRINCETON" SCHEMATIC
MODEL 5F2-A
K-EG
NOTICE
ALL VOLTAGES READ TO GROUND WITH ELECTRONIC VOLTMETER VALUES SHOWN + OR – 20%
½ 12AX7
½ 12AX7
6L6GT
148.3V
A
B
C
0V
120V
146.8V
0V
1.197V
318.6V
300.5V
24.42V
275.8V
47 K
.02-400
.02-400
22 K
10K-2W
220 K
220 K
100 K
1 MEG AUD
VOLUME
TONE
.0005
.005
1 MEG AUD
68K
68K
2.2K
880µF
1M
1500
2.2K
5K Lin
PRESENCE
1µF
50V
47µF
250Ω 2W
BRWN
BLU
POWER TRANS.-Hammond 125P23B
OUTPUT TRANS.-Hammond 125ESE
20-450
20-450
20-450
20-400
1W
STANDBY
393 V at STANDBY
321.5V at Operate
.033 µF
2 Amp Fuse
AC SWITCH
Line (black)
(green)
Earth Ground
Neutral (white)
YEL
YEL
RED/WHT 284V DC
RED/YEL
RED/WHT
284V DC
GRN
WY3GT
Copper Cap
GRN/YEL
GRN
TO ALL 6.3 VOLT HTRS. AND PILOT LIGHT
NOTE-ALL RESISTORS ½ WATT UNLESS OTHERWISE NOTED

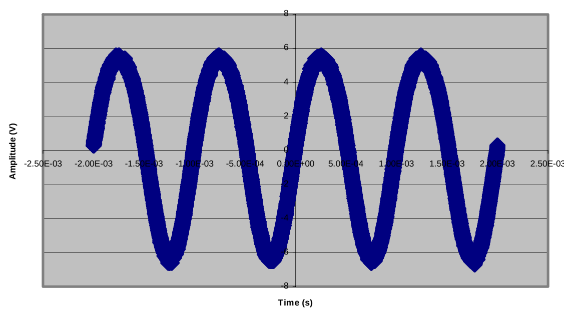
Appendix B


1KHz_10mV_In_P5_T5_V3
Time (s)

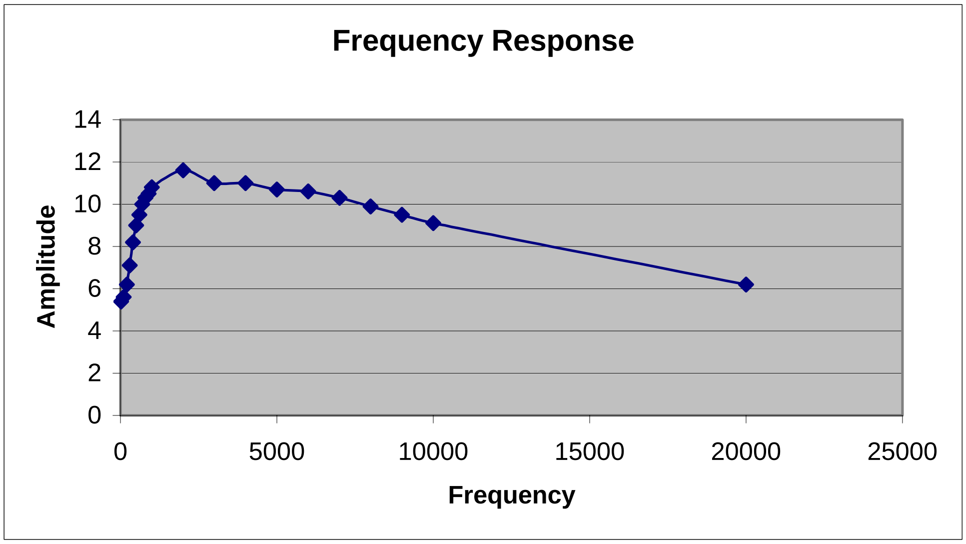

1KHz_10mV_In_P5_T5_V6
Amplitude (V)
Time (s)


1KHz_10mV_In_P5_T5_V9
Amplitude (V)
Time (s)

1KHz_10mV_In_P5_T5_V12

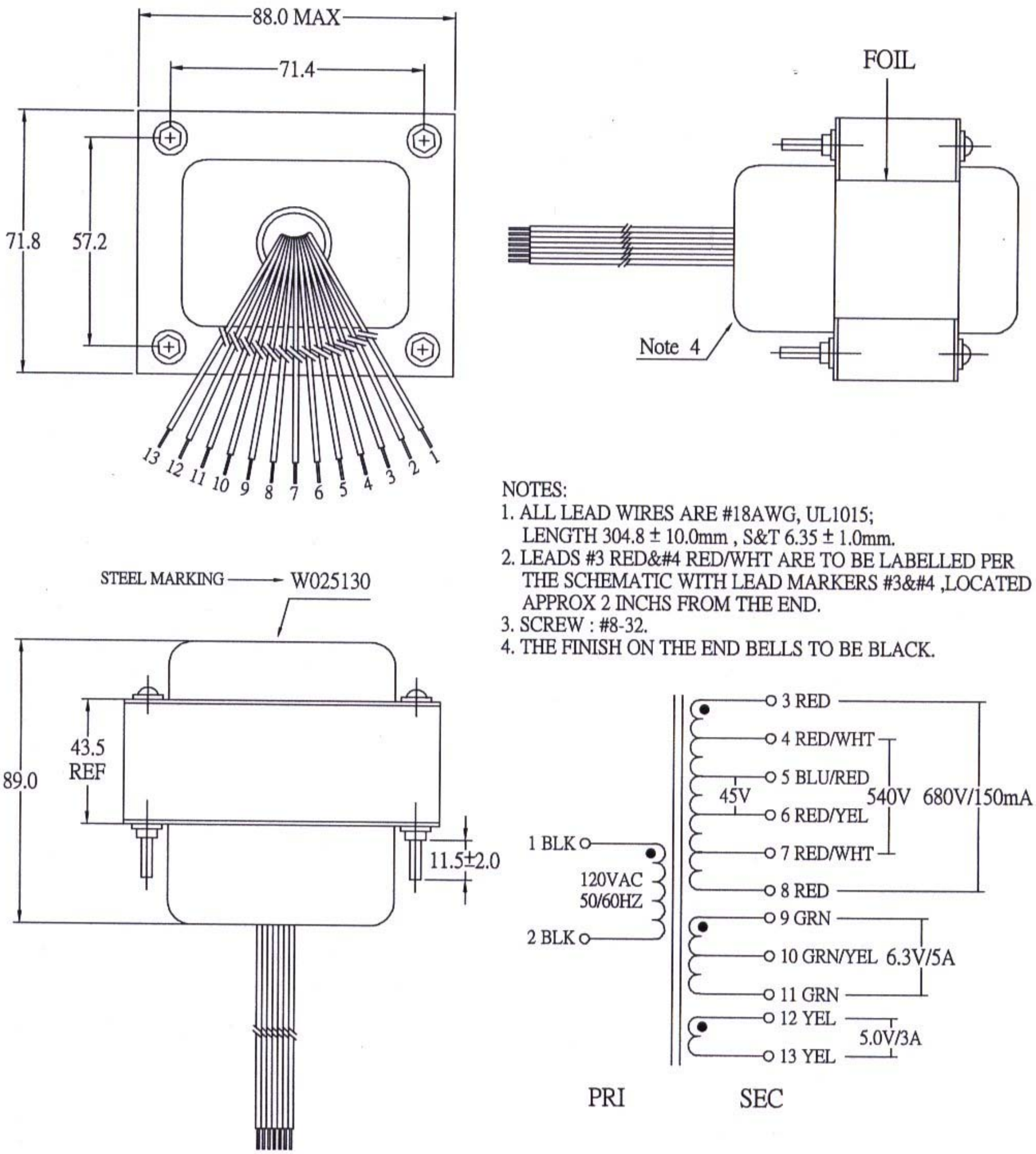


Appendix C


Frequency Response
Amplitude
Frequency
0
2
4
6
8
10
12
14
0
5000
10000
15000
20000
25000

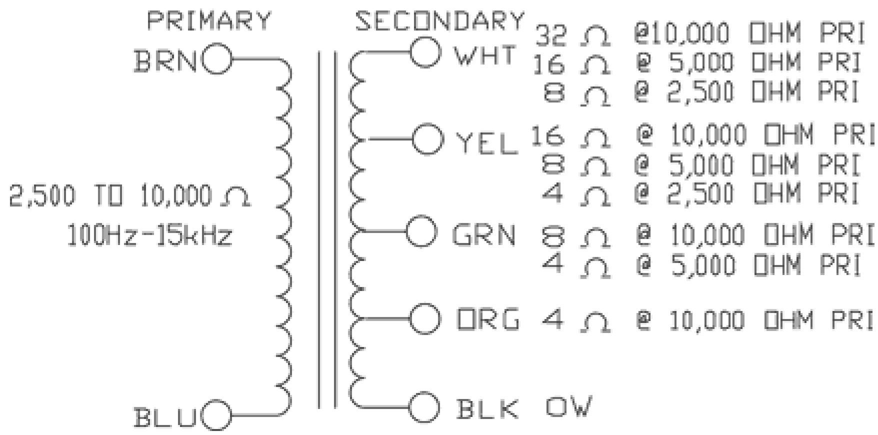
Power Transformer W025130 Hammond 125P23B

https://weberspeakerscom.secure.powweb.com/store/magnetic.htm



Output Transformer Hammond 125ESE

http://www.hammondmfg.com/125SE.htm



5F2-A Princeton with following changes:

Presence control added, SS Rectifier instead of 5Y3, Standby switch added

6L6 instead of 6V6, Cap values modified to more closely mimick Gibson tone (dirty)

	Part	Price	Qty	=	Supplier	Notes
1	5E3 Chassis Kit		1	-		
2	125P23B Power T.		1	-		
3	125ESE Output T.		1	-		
4	Octal Socket		2	-		For Power, Rectifier
5	9 pin socket		1	-		For Preamp
6	AC Jack		1	-		
7	1/4" NS jack		1	-		Speaker jack
8	1/4" jack		2	-		Input jack
9	1MA pot		2	-		Volume, Tone
10	5K Linear pot		1	-		Presence
11	Pilot Light		1	-		
12	6.3V lamp		1	-		
13	Fuse Assembly		1	-		
14	Fuse 2A		1	-		
15	Switch DPDT		1	-		Power switch
16	Switch SPST		1	-		Standby switch
17	Gnd lugs		5	-		
18	250uF/50V		1	-		
19	20uF/600V		4	-		Sprauge Electrolytic Caps
20	47uF/ 50V		1	-		
21	1uF		1	-		
22	.02uF/400V		2	-		Sprauge Orange Drop
23	.005uF		1	-		
24	.033uF/HV		1	-		
25	.0005uF/500V		1	-		Silver Mica Cap
26	1M		1	-		
27	220K		3	-		
28	68K		2	-		
29	47K		1	-		
30	22K/1W		1	-		
31	2.2K		2	-		
32	1500/2W		2	-		Put in parallel to form 750 Ohms
33	10K/2W		1	-		filament balance
34	0-10 knobs (4)		3	-		Volume, Tone, Presence
	FIRST ORDER TOTAL			270.00	First Order from Webervst c/o Ben Juday	
35	12AX7		1	15.00	Groove Tubes	Preamp Tube
36	6L6		1	30.00	Groove Tubes	Power Amp Tube
37	WY3GT		1	22.00	http://www.webervst.com/ccap.html	Copper Cap Rectifier
38	12" Speaker		1	45.00	Ben Juday	Utah Blue Frame 12"
39	Narrow Panel Tweed Cabinet		1	230.00	Mojo Musical Supply	Soft Pine
	Total			612.00		