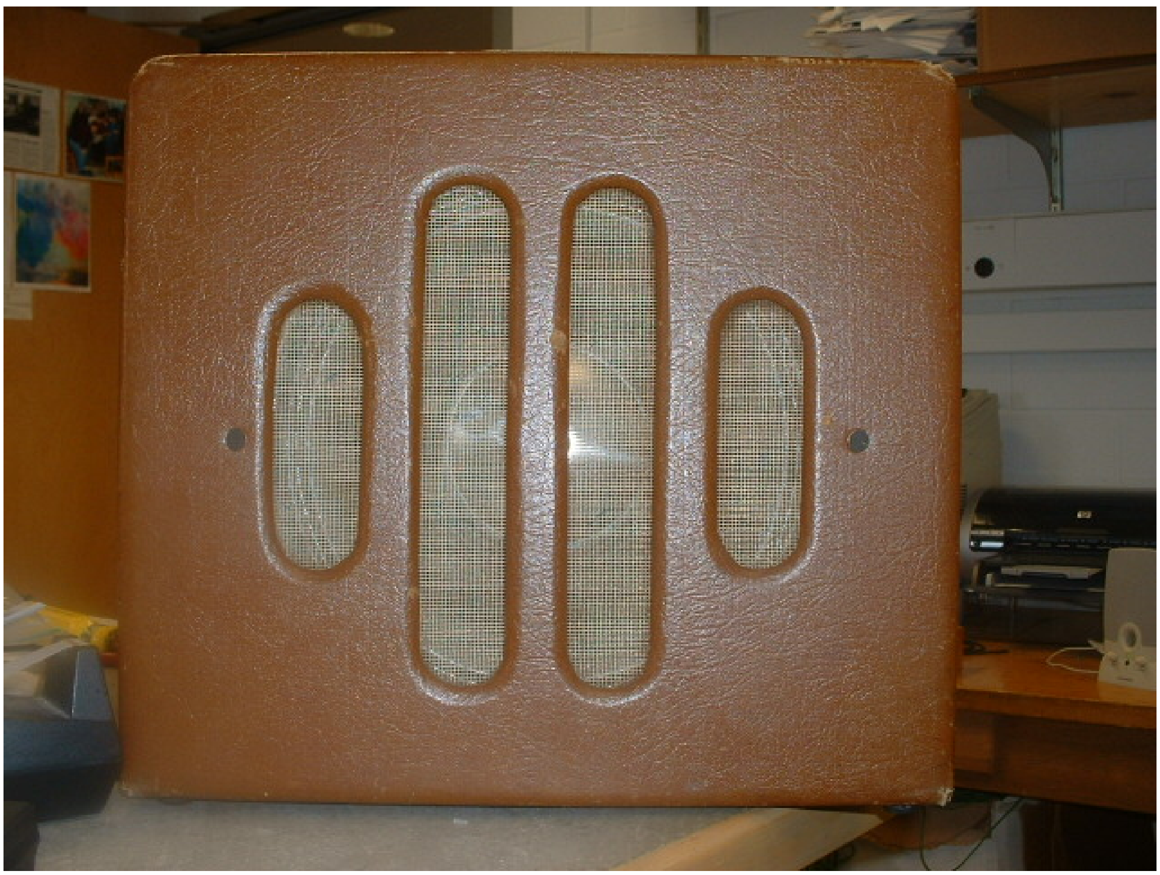
Fixing/Rebuilding a Rickenbacker M-10



James Milsk
Physics 498
May 9, 2005
Professor Errede

My uncle had given me a 1950's-era Rickenbacker M-10 guitar amplifier to fix because he tried plugging a guitar into it and it didn't work. He doesn't know anything about the circuitry of a guitar amp so he decided to give it to me for a project in Physics 498. My knowledge of amplifier circuitry is a little limited, having only built a Fender Deluxe 5E3, but Professor Errede is an amplifier guru, so, with his help, I was able to map out the existing circuit and from that create a working, nice-sounding guitar amplifier.

The first problem that I encountered was that I could not find an original schematic for this guitar amplifier. I searched on the Internet and even emailed Rickenbacker for this schematic but the schematics they found did not match my amp. Running a google search on the Rickenbacker M-10 produced minimal results. The most accurate web page was just a large listing of guitar amplifiers. Professor Errede tried to search through his large databank of amplifier schematics and also could not find an accurate match. So, we looked at the circuit and drew it out completely by hand. It was obvious that whoever previously owned this amp had tinkered with the circuit, replaced parts, and had even wired the input jack straight into the output transformer to use the cabinet as an external speaker (which basically bypassed the circuit and ran straight into the output transformer and then into the speaker). This amplifier had one preamp stage (powered by an 6SL7), a single-ended power stage (powered by a 6V6), and one rectifier tube, which was missing, so we used a 5Y3, a relatively low current tube rectifier which was common to many old tube guitar amplifiers.

The chassis was wired with many parts that were obviously not original. The date code on the tone and volume potentiometers indicated that they were from 1950. However the date code on the speaker and capacitor bank revealed that those components were from the 1970s. The speaker was too deep for the cabinet, so the previous owner had bent the metal chassis somewhat to make it fit. In addition, the power transformer was not original and seemed too large for the amplifier; its main secondary AC voltage was too high for the B+ needed for a 6V6, which likely contributed to its failure. It was also unclear as to whether any of the capacitors and resistors were original. Orange drop capacitors were used in the preamp stage and these capacitors are a more recent development. These capacitors produce a favorable tone, so we kept them in the circuit. The ceramic capacitor on the 6V6 was probably not original either and its nasty tone prompted us to replace it. There were many carbon composition resistors, which were used in older amps, but, again, it is hard to discern whether they were original. We kept these resistors that retained good leads in the amp. There were also several carbon film resistors, another recently-developed component, which were not kept in the amp, we replaced these with carbon composition resistors because they have small non-linear properties that give a warmer tone. The remaining hardware seemed to be original.

The output transformer looked to be the oldest part of the amplifier excluding the chassis and speaker cabinet so it was very likely that it no longer functioned. After conducting inductance and voltage tests on the output transformer, it seemed like the transformer would work, but the voltage and inductance tests gave different results in determining the turns ratio and primary source impedance. The voltage test is usually more reliable and robust because the inductance test depends on a parallel or series configuration in the LCR meter for each frequency, so the measured inductance for 1kHz, which we used, was probably off because of that. Another possibility was that the windings were starting to fail and that could have screwed up the magnetic properties and, thus, the inductance readings. This means that the amplifier might stop working shortly because of the output transformer failing. The measurements carried out are as follows:

$$Z_{source,primary} = (L_{pri}/L_{sec})*Z_{load,sec} * Z_{speaker} = (8.92/0.00674) * Z_{speaker} = 1323.4 * Z_{speaker}$$

The data sheet for the 6V6 lists that for a 315V plate voltage, one should expect a source impedance of about 8500Ω. A 4Ω-speaker would produce a source primary impedance of 5294Ω, pretty low compared to what is expected, and an 8Ω speaker would produce a 10588Ω impedance, a bit on the high end of the expected impedance, but closer than the 4Ω result. The impedance derived from the AC voltage turns-ratio measurement was:

$$Z_{source,primary} = (V_{pri}/V_{sec})^2*Z_{load,sec} * Z_{speaker} = (10.02/0.2886) * Z_{speaker} = 1205.4 * Z_{speaker}$$

For this measurement, a 4Ω-speaker would produce a source impedance of 4821Ω, which is almost half of what we want. An 8Ω-speaker, on the other hand, would produce 9643Ω, which is pretty close to the expected 8500Ω impedance. That means, that the 8Ω, 10-inch speaker mounted in the cabinet is fine if it still works. Both tests suggest that an 8Ω-speaker gives a closer impedance value to what is expected out of a 6V6 tube with a plate voltage of 315V or higher.

The first step was replacing the power transformer because this transformer seemed too big and its hex-aluminum mounting posts were badly corroded – a sign that it probably did not function well. Extra holes had been drilled in the chassis to attach that transformer – another indication that it was not the original power transformer. We recognized the holes that probably held the original transformer in place and measured them. We found a suitable Hammond Transformer that fit the physical and electrical properties needed and mounted that on the back of the chassis.

My next step involved basically removing all soldered circuit components from the chassis. In addition, I added tab onto two nuts holding the power transformer in place. One tab served to connect the earth ground coming from the wall power. The other tab was to help ground components. In particular, the capacitor bank and center taps on the power transformer were grounded there. Originally, components were grounded directly to random spots on the chassis, the back of the output transformer, and the back of the potentiometers. This method of grounding is a big cause of ground loops and hum. It was too difficult to implement a star grounding technique because there was no fiber board or substitute to lift the components off of the chassis. I settled on using the grounding tabs on the tube sockets to ground the appropriate components. This method is not as effective in reducing noise as using star ground, but it is cleaner and more successful than soldering directly onto the chassis.

The most important step was removing the two-prong power cable from the amplifier and replacing it with a grounded three-prong plug. All older amplifiers used unpolarized two-prong AC line cords and it was a problem because there was no real earth ground for the amp to be connected to. The amplifier's ground was the chassis, and the chassis potential was really a floating signal ground. This had the huge risk of someone getting shocked if they touched the amp and another piece of electrical equipment. Neither was at earth potential! In many cases, a musician playing a guitar out of an amp grounded to a different prong than his microphone preamp (same wall power) would get a static discharge shock when he sang into the microphone. This was caused by the potential difference problem between the two grounds. The three prong AC line cord solved this problem by forcing the chassis potential to earth ground. Obviously, the entire metal chassis is not at the exact same potential because of inconsistencies in the chemical composition, but it is astronomically better than having a random floating signal ground caused by a two-prong AC line cord.

After installing the three-prong AC line cord through a grommet-filled hole, the appropriate wires were soldered (all exposed leads and metal were treated with heat-shrink for safety considerations), and the power transformer was also connected appropriately. The yellow wires powered the rectifying tube, the green wires went to the lamp (later attached to the filaments of the 6SL7 and 6V6 after the rest of the circuit was wired), and the center-tapped red leads went to the 5Y3 to power the circuit.

Because the amp had been tinkered with so much, it was impossible to know what the original arrangement of the circuit had been. However, Professor Errede found two amplifiers that used the same tubes and had similar circuit configurations – the Fender Princeton Amp from the late 1940's and the Valco 510-11. Professor Errede used both schematics in influencing the design of our final circuit.

The power supply section was not altered in the schematic as it was similar to the Princeton and Valco. The power tube circuitry was kept the same except for the cathode bias resistor. That was increased to 500Ω from 250Ω in order to lower the DC current through the 6V6 and thus lower its power dissipation. The M-10 and Princeton power stages were almost identical to each other.

On the preamp stages, we changed the plate resistor from 100kΩ to 270kΩ to increase the voltage drop and thus lower the plate voltage (and, consequently, the voltage gain from the grid to the plate), which would help ensure that we did not try to overpower the amp. The 270kΩ is the same value of plate resistance used in the Valco 510-11 preamp stages. Similarly, the cathode resistors on the 1st and 2nd preamp stages were increased to match the Valco values to 2.2kΩ and 3.9Ω respectively (which again reduced the current through the tube). The Princeton and 510-11 amps both used a 25uF bypass capacitor on the 1st preamp stage, while the M-10 used a 50uF. There is no need to change the capacitor value to follow the other amps because the 3dB point would not change by too much to affect the audio range. F_{3dB}=1/2*pi*2200*50u=1.45Hz. If the capacitor is changed to 25uF, the 3dB-point would be 2.9Hz. Both points are extremely low and practically inaudible to distinguish a difference. In fact, in reconstructing the amp, a 250uF capacitor was used because of convenience, and this did not make much difference in terms of operation. In fact, the capacitor was unnecessarily high, but made for a nice flat frequency response over the entire audio range.

The equalization section of the M-10 was not completely connected. Most of the equalization circuit of the Princeton was utilized with the original 500kΩ potentiometers on the M-10 retained. However, the wipers of the tone and volume were tied together (as it had originally been). The wiper of the volume in the Princeton circuit was connected with the maximum of the tone potentiometer through a 500pF capacitor. So, in the M-10 circuit, the input of the tone potentiometer was connected through a 500pF silver mica capacitor to the cap-coupled output of the 1st preamp gain stage, which was also connected to the input of the volume potentiometer. In fact, we changed value of the capacitor between the tone pot and ground from 5nF to 10nF because that orange-drop capacitor had been connected somewhere previously. This would provide a better bottom-end for the amp's tone. Valco's equalization circuit did not have the volume wiper tied directly to the 2nd stage grid. It went through a voltage divider connected to the tone network. The tone control in these circuits is basically a knob that controls the 3dB-point of a high pass filter.

The M-10 had no resistors connected to its 2 input jacks, which may or may not have been the way it was originally constructed. We followed a typical Fender Amp arrangement as used e.g. in the '57 5F2-A Fender Princeton Amp: two high-ohm resistors went from the tip of its respective input to the grid of the 1st preamp stage (in this case we used two 47kΩ resistors). A 1MΩ resistor was soldered from the tip of the 1st input jack to ground. The 47kΩ resistor pair were soldered and heat-shrunk insulated to the inner conductors of two RG-174 mini-coax cables used to route the signals from each of the input jacks in to reduce the amount of signal noise amplified in the circuit. The junction point of these two resistors were twisted together and soldered directly to the input grid of the 1st stage 6SL7 preamp tube. We also reamed out the input jack holes to insert insulating spacers (Switchcraft S-1098's) and thus ground-lift the input jacks off of the chassis to reduce hum. The ground tabs on the jacks were connected directly to a grounding tab on the 6SL7 tube socket.

After connecting the circuit according to our M-10 schematic, we drilled a hole to put a speaker jack into the chassis, which is a better way to connect the speaker because of durability issues and because it allows the flexibility to plug the amplifier into a different 8Ω speaker load, if desired. After double-checking the connections, we turned the amp on. After nothing exploded or shorted out, it seemed that the components were working properly and we tested the DC voltages throughout the circuit. These measurements are displayed below. We calculated the DC power dissipation in the 6V6 power tube as follows:

$I_k = 21\text{Vdc}/500\Omega = 42\text{mA}$

$P_{dissipated} = V_{plate\text{-}cathode} * I_k = (345\text{V}-21\text{V}) * 0.042\text{A} = 324\text{V} * 0.042\text{A} = 13.6\text{ W}$

(Note that $I_k = I_p$ is assumed)

The DC power dissipated in the 6V6 was dangerously close to its power limit, which is 14W. We quickly held our hands in front of the 6V6 tube and it did indeed feel hot. So, we needed to bias the tube such that less power would be dissipated. To do that, we increased the 6V6 cathode bias resistor from 500Ω to 750Ω to reduce the DC current (current and resistance have an inverse relationship). In addition, the 6V6 screen had higher DC voltage than the 6V6 plate's DC voltage. Even though the plate swings more than the screen, there will be times when the instantaneous voltage on the screen will be more than the plate and that will result in reverse current, which is undesirable. Since the 6V6 screen was directly connected to the power supply, that point in the power supply needed to be reduced in voltage. To accomplish that we increased the resistor value before that point (point C on the schematic) from 1kΩ to 4.7kΩ in order to generate a greater voltage drop and, thus, a lower DC voltage on the screen.

After making these changes to the circuit, we measured the circuit again. This time all of the voltages were a bit higher, especially in the power stage. This change resulted from less total current flowing through the power supply pushing the voltage higher. Looking at the measurements, we see that the DC voltage of the plate is indeed higher than the DC voltage of the screen, albeit by one volt, but one volt is all we need. Next, we needed to measure the dissipated power through the 6V6 to make sure that the power dissipation had lowered. (See Table 1 for more details)

$$I_k = 23.8\text{Vdc}/750\Omega = 31.7\text{mA}$$
$$P_{dissipated} = V_{plate\text{-}cathode} * I_k = (366\text{V}-23.8\text{V}) * 0.0317\text{A} = 342\text{V} * 0.0317\text{A} = 10.8\text{W}$$

The power dissipation reduced significantly to safer levels and even the current lowered to its desired level. Note that the DC voltages imposed on the 6V6 plate and screen are well above the rated values in the original specification sheets for the 6V6, but are far below those present e.g. in a Black-Face Fender Deluxe/Deluxe Reverb Amp. The 6V6GT spec sheet listed 34mADC current in conjunction with a 315Vdc plate voltage level for single-ended class-A operation. Since both objectives had been reached, Professor Errede tried to play a guitar through it. He claimed that the output sounded very weak, even for a small amp. One theory was that the tube sockets had dirty socket/tube pin connections and, indeed, they looked badly oxidized. He tried to clean them using a filing tool, ultra fine-grit wet-or-dry sandpaper and some cleaning fluid but it still did not change the sound of the amp. After looking at the amp, he realized that the multi-section can capacitor had not been properly grounded, especially since we had lifted it off the chassis with two nuts and a make-shift restraining clamp. After getting slightly electrocuted when trying to pull the ground tabs back for safety (ironically) and noting that this was a dry multi-section can capacitor which had a great affinity for storing charge, he wired the can capacitor's ground directly to the chassis. When we tried playing a guitar through the amp, this time it worked! It wasn't extremely loud (as expected), but it had a fabulous bluesy tone, with great sustain. The fat tone of this amp is in part due to the sweet, non-linear/distortion characteristics of the 6SL7 gain stages of the amp, but it is also in part due to overdriving the 6V6 power tube, and the compressive sag of the B+ associated with the 5Y3 rectifier tube.

Table 1. DC-voltage comparison before and after changing the second power supply resistor and the 6V6 cathode bias resistor

Voltage Point	Before Changing Resistors	After Changing Resistors
V_A	397V	405V
V_B (= V_{screen})	366V	379V
V_C	362V	365V
V_D	348V	351V
$V_{cathode,6V6}$	21V	23.8V
$V_{grid,6V6}$	60mV	80mV
$V_{plate,6V6}$	345V	366V
$V_{cathode,preamp2}$	2.43V	2.46V
$V_{grid,preamp2}$	0V	0V
$V_{plate,preamp2}$	179V	181.3V
$V_{cathode,preamp1}$	1.62V	1.64V
$V_{grid,preamp1}$	0V	0V
$V_{plate,preamp1}$	137V	140V

Fig.1 Professor Errede's Rickenbacker M-10 Amp Design

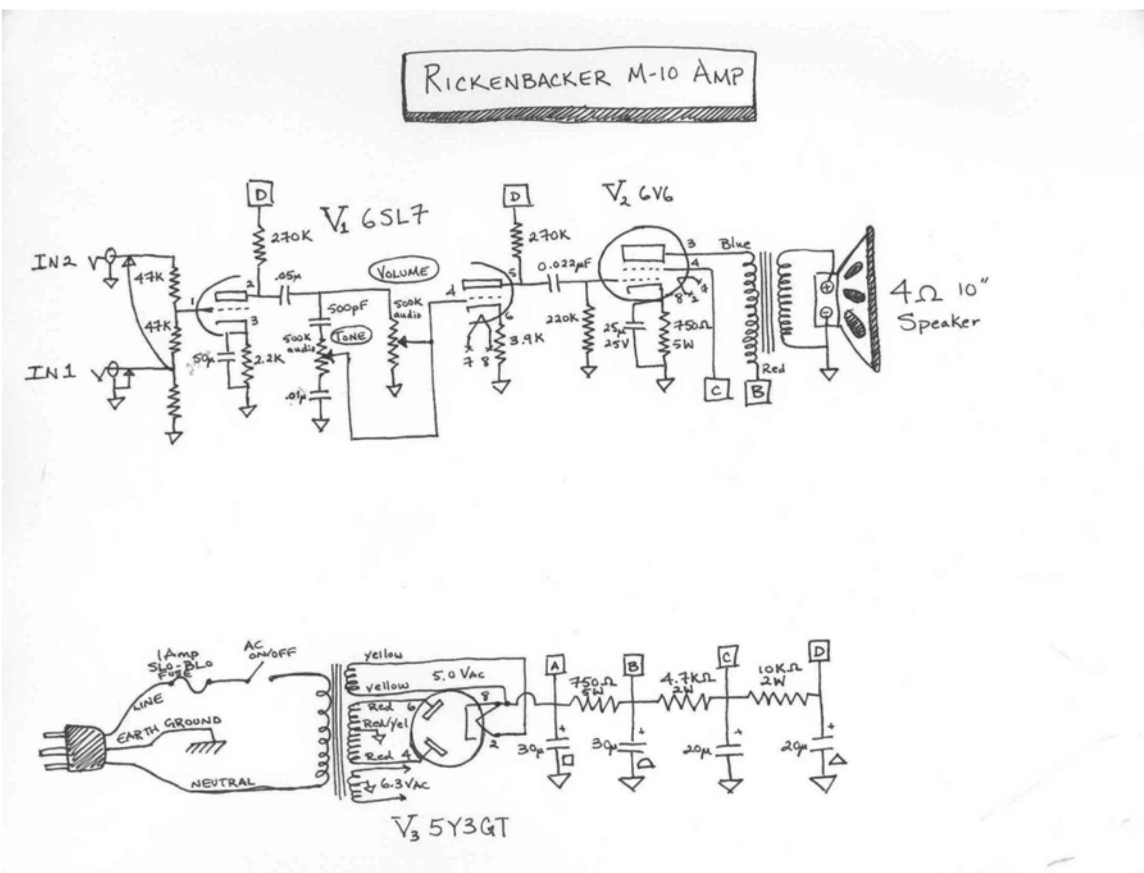


Fig. 2 Late 40's Fender Princeton Amp schematic drawing

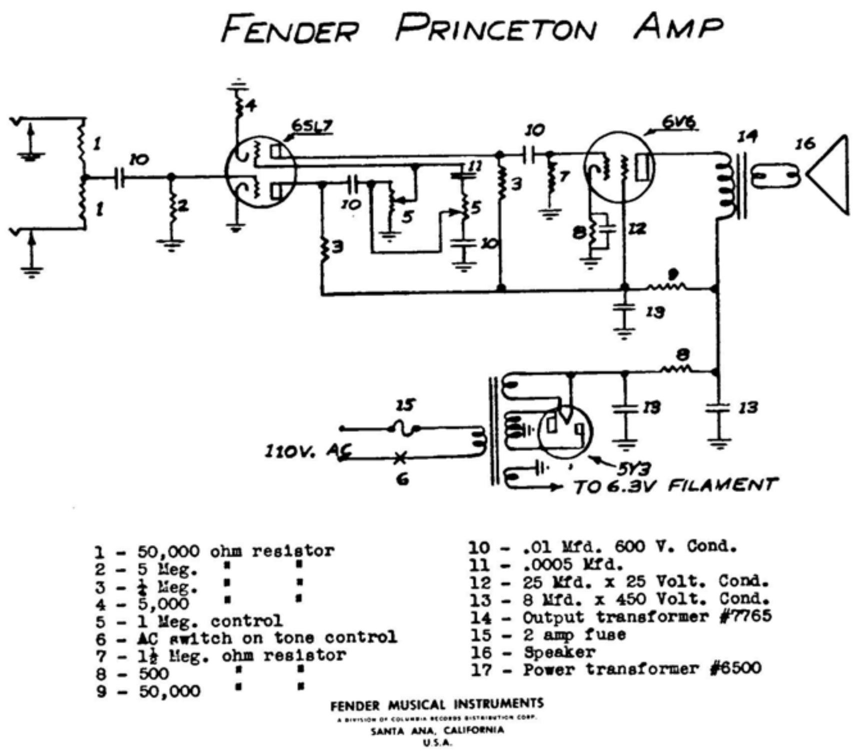
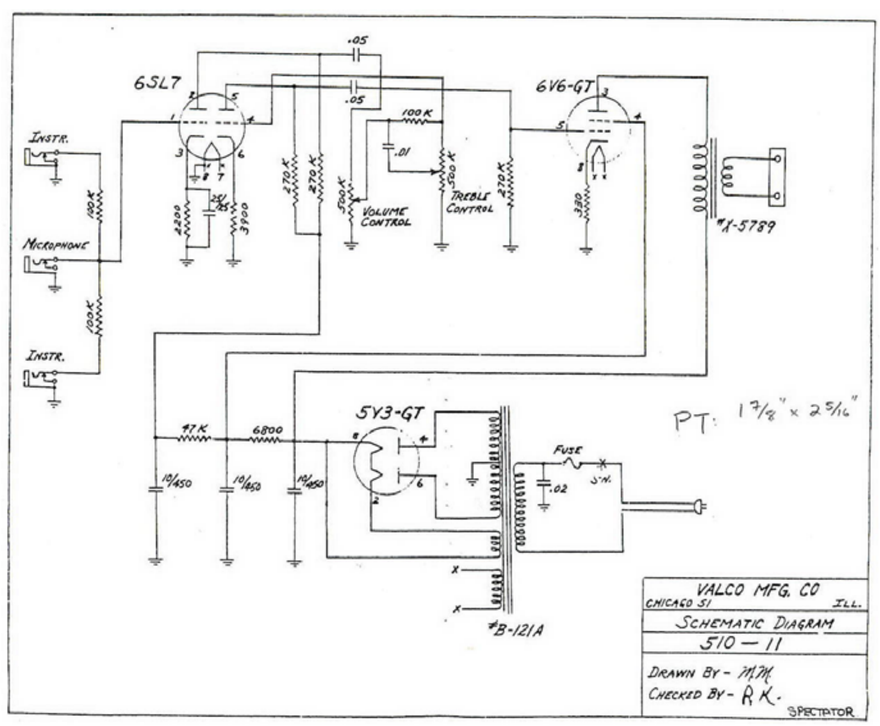


Fig. 3 Valco 510-11 Amp schematic drawing



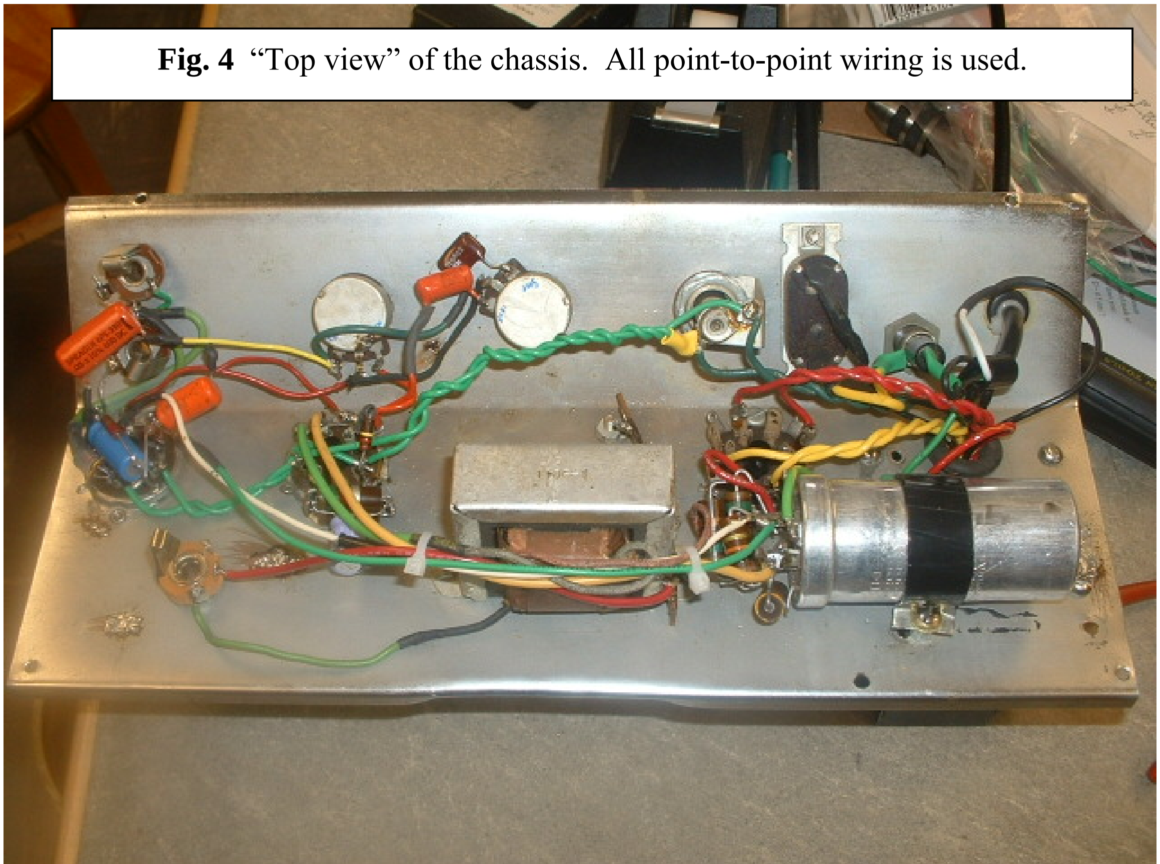


Fig. 4 “Top view” of the chassis. All point-to-point wiring is used.

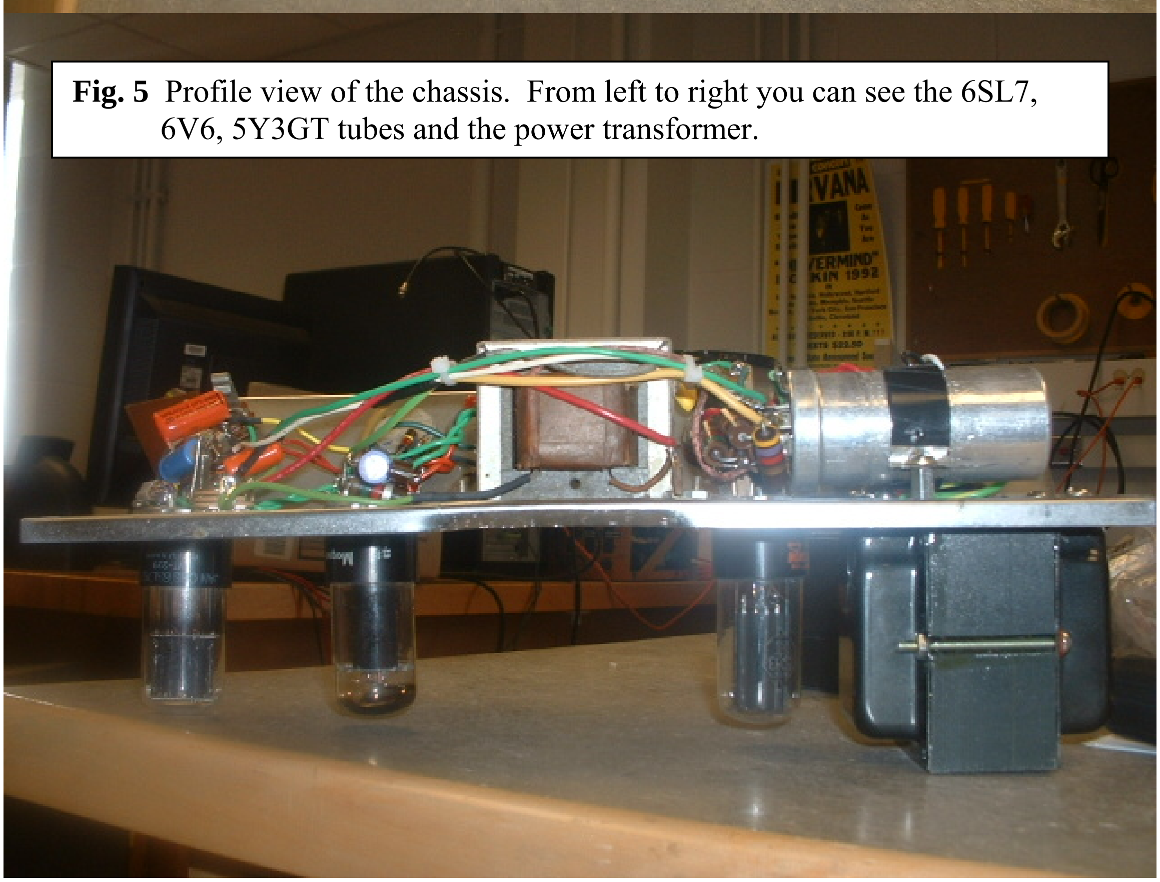


Fig. 5 Profile view of the chassis. From left to right you can see the 6SL7, 6V6, 5Y3GT tubes and the power transformer.

Fig. 6 Examples of poor grounding techniques from earlier wiring. The ground wires were soldered directly to the chassis, as can be seen by the pools of solder.

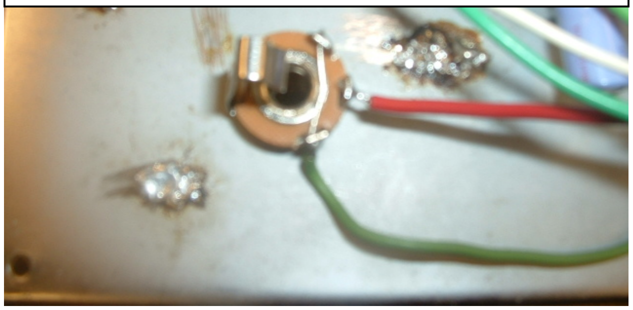


Fig. 7 Top view of the can capacitor

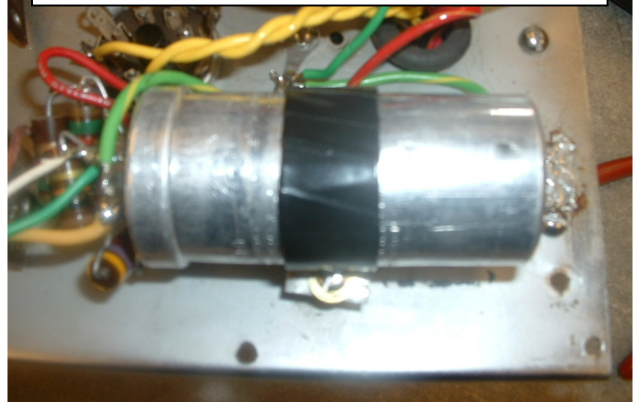


Fig. 8 Rear view of the speaker cabinet with the chassis mounted inside