SINGLE-ENDED TUBE-BASED GUITAR AMPLIFIER

by

Joe Linn

Senior Project

ELECTRICAL ENGINEERING DEPARTMENT

California Polytechnic State University

San Luis Obispo

2010

Table of Contents

Appendices

List of Figures

Acknowledgements

I would like to thank my advisor, Vladimir Prodanov, for guiding me through the design process for my amplifier. In addition to his advisory contributions to my project, the knowledge that I gained in his EE 308 course was crucial for the execution of this design endeavor.

I. Introduction

Since the advent of the transistor, the vast majority of designers and manufacturers of electronic devices have abandoned the vacuum tube. Compared to transistors, tubes are orders of magnitude larger, more power hungry, more expensive, less reliable, and dissipate much more heat. In short, transistors are superior devices for almost all applications. Despite this fact, many makers of high-end audio and instrument amplifiers continue to base their designs on tube technology.

Given all of their shortcomings, the obvious question is: Why bother with tubes? Proponents of tube-based audio amplifiers cite a certain "warmth" that tube circuitry lends to the sound that is absent when using solid-state amplification. While audio amp designers are looking to get the clearest possible sound reproduction out of their tubes, guitar amp makers, and especially their rock-star customers, prefer tubes due to their unique distortion characteristics. Designers have gone to extraordinary lengths, using complex analog and digital solid-state circuits, in attempts to emulate the so-called "soft distortion" that even the simplest of tube amplifiers exhibit. Despite their best replication efforts, the consensus among performing and studio musicians remains that there is no substitute for a well-designed tube amp. Being a guitarist who shares that opinion, I chose to design a tube amp of my own.

II. Design

My design involves a four-stage preamplifier, which uses two dual-triode 12AX7 tubes. The power amplifier involves three stages, two of which use a 12AX7, and the last of which runs through an EL34 pentode tube. The use of a single tube in the output stage of the power amplifier is commonly referred to as a "single-ended" design. This design was chosen for its relative simplicity compared to the more efficient but more complex push-pull output stage, in which output tubes are configured in matched pairs.

As the bias voltages required for tube circuitry are a great deal higher than that which can be supplied by any of the power supplies found in the EE department laboratories, I had to build my own power supply. The supply for my design consists of a transformer which converts 110V AC to 300V and 6.3V. The 6.3V AC is used to power the heater filaments for all four vacuum tubes. 300V_{RMS} AC was converted to 400V DC by means of a bridge rectifier and a simple RC filter, as shown in Figure 1.

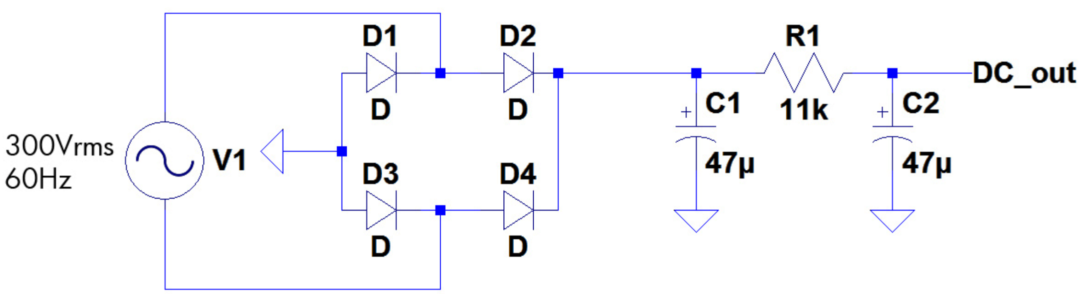

Figure 1: Power Supply Schematic

Though none of the courses in the EE curriculum at Cal Poly cover tube-based amplifier design, the principals of transistor-based amplifier design were derived from those of tube-based design. The circuit structures seen in BJT and FET-based amplifiers (common-collector and common-emitter, common source and common drain), are paralleled in tube-based circuitry (common-plate and common-cathode). Thus, I was able to use my pre-existing knowledge of amplifier design, coupled with computer design tools, to come up with schematics for a four-stage preamplifier and a three-stage power amplifier.

LTspice[1] was the primary tool used in development of the circuit design. Once the gain and output stages were designed, I used Duncan Amplification's Tone Stack Calculator[2] to design the RC filter network which would function as a basic three-band equalizer. This program was extremely useful, as it allows the user to choose from several commonly used network designs, vary the capacitor, resistor, and potentiometer values, and observe the effects of those changes on the magnitude response of the network. An example of this can be seen in Figure 2.

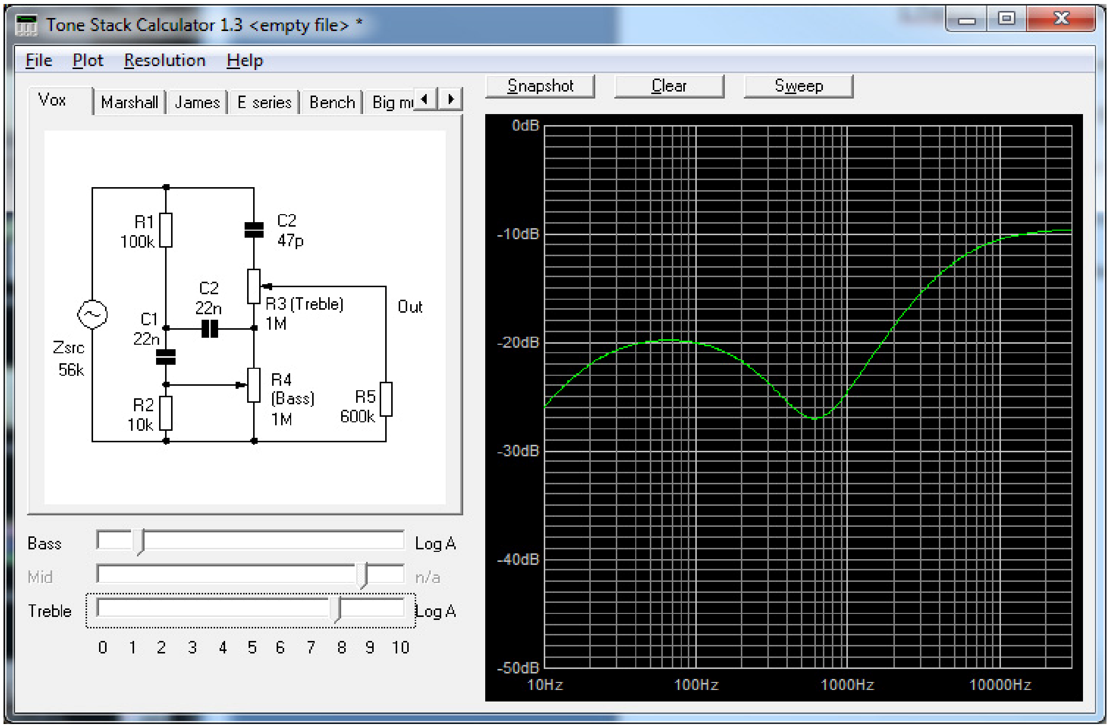

Figure 2: Tone Stack Calculator by Duncan Amplification

Completion of the preamp gain stages and output stage, as well as the so-called "tone stack" resulted in the schematic in Figure 3. Development of the power amplifier culminated in the design pictured in Figure 4. Resistors with names such as "Rgain1" and "Rgain2" represent potentiometers, with the node between the resistors being the wiper. Note that the 6CA7 / EL34 vacuum tube is, in actuality, a pentode tube, although it is shown in the schematic as a tetrode.

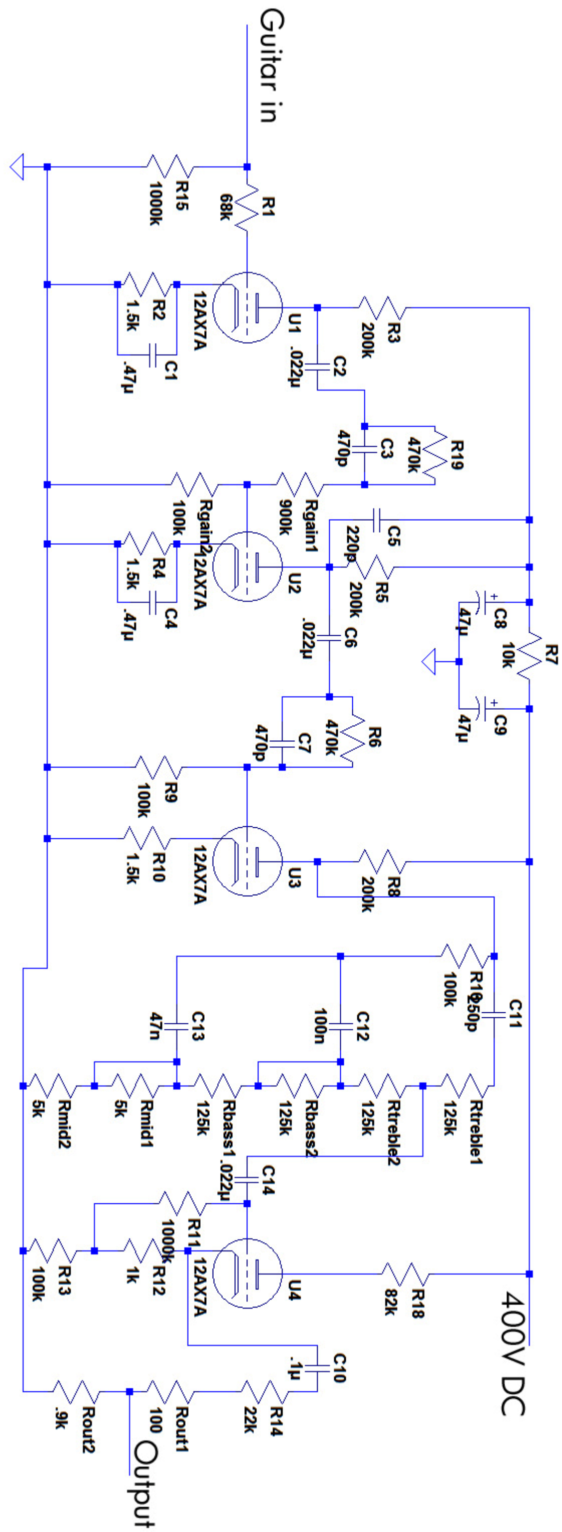

Figure 3: Preamp Schematic

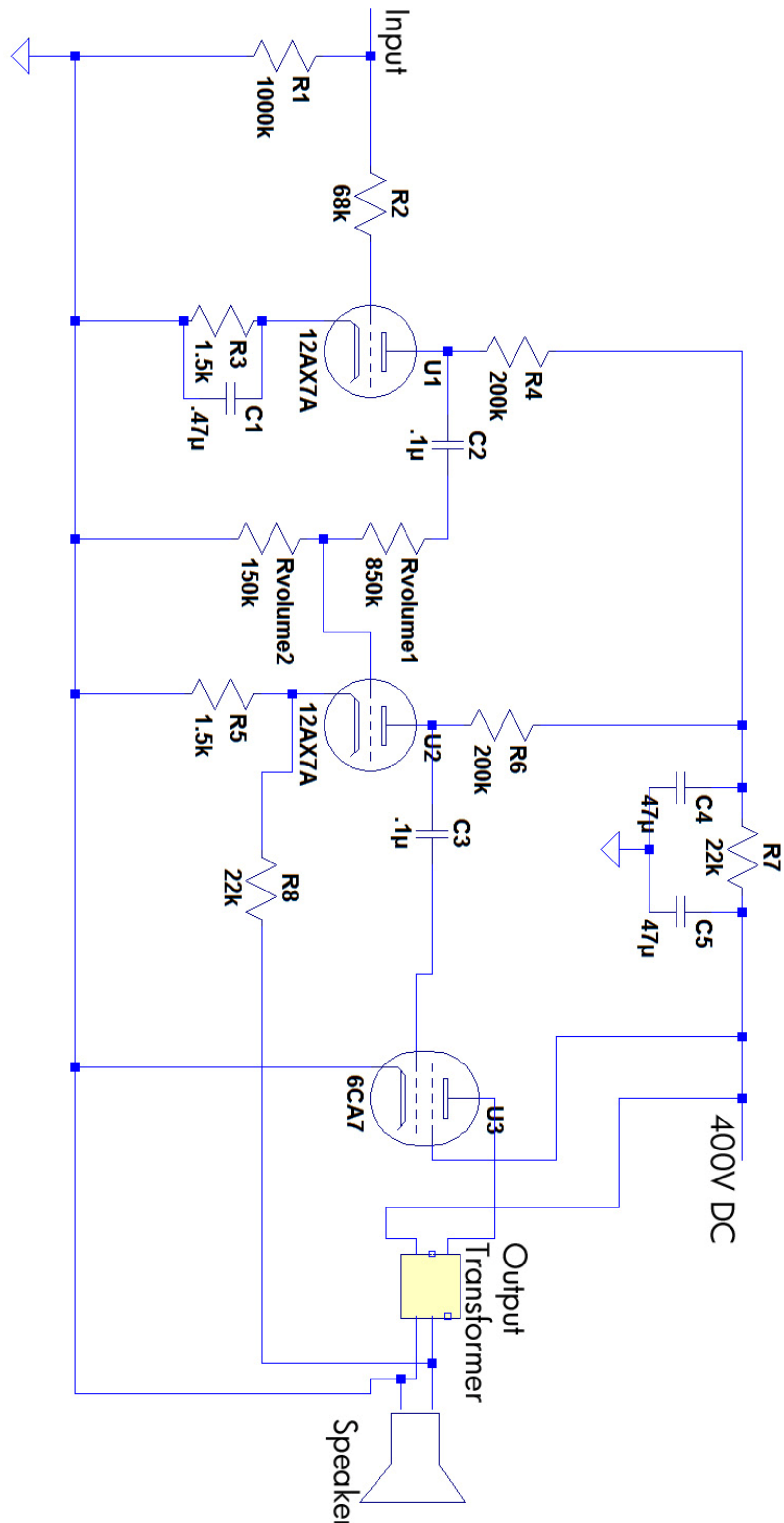

Figure 4: Power Amp Schematic

III. Simulation

I was able to find SPICE models for EL34 and 12AX7 vacuum tubes, as well as for an output transformer similar to the one I would be using. Additionally, I obtained a model for the guitar speaker that I already owned, Celestion's Vintage 30. After incorporating these models into my LTspice netlist, I was able to simulate the performance of my amplifier. By connecting a voltmeter to the output of one of my electric guitars, I determined that 500mV_{pp} was an appropriate amplitude to use for a test input signal. The frequency that I chose for transient analysis was 110Hz, which is the standard tuning frequency of the fifth (A) string on a guitar. Figure 5 depicts the input (blue) and output (green) waveforms with the preamp gain control set at a tenth of its full value, and power amp volume and all tone controls at half of their full values.

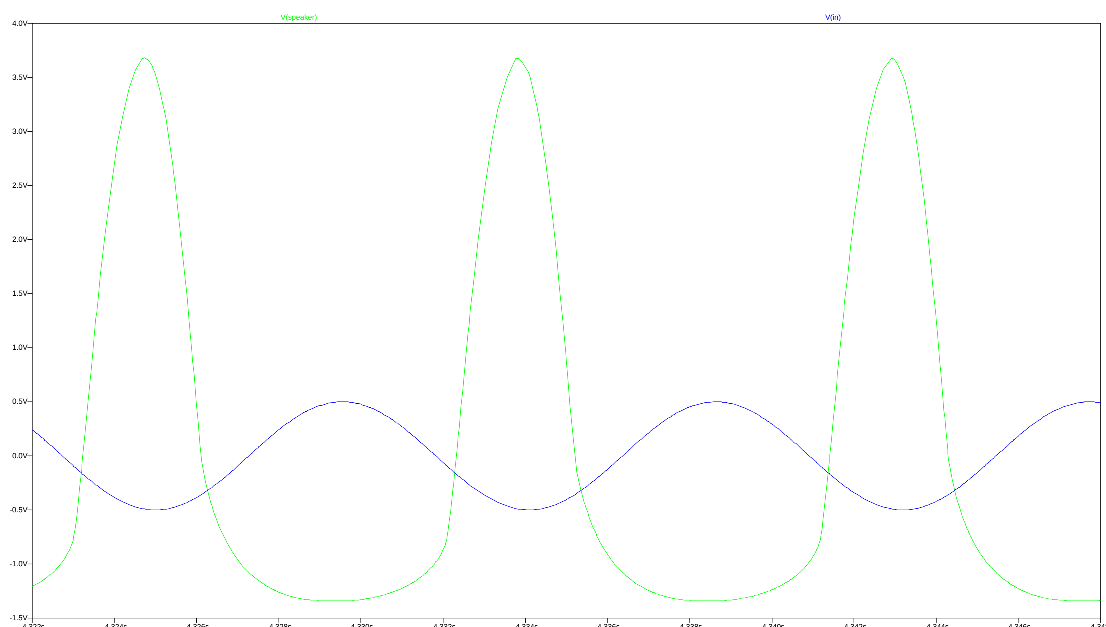

Figure 5: Input and Output Waveforms (simulated)

IV. Construction

Prior to soldering any circuitry together, I had to construct a chassis for my amplifier. For ease of customization, I chose to build the chassis using wood-based materials. The platform on which the tube sockets and power transformer would rest was made from plywood, the front and back panels from masonite, and the bottom, sides, and top from melamine-coated shelving boards. Bolts and spacers were used to elevate the tube / transformer platform and the circuit boards off the bottom of the chassis, as illustrated in Figure 6. Holes were drilled in the plywood to accommodate the secondary wiring from the output transformer and the four tube sockets.

The next step was to build the power supply, which can be seen in Figure 7. A switch was installed between the AC power socket and the primary winding of the power transformer for use as an on / off switch. Another switch was placed between the bridge rectifier and the RC filter for use as a standby switch. Closing the on / off switch while keeping the standby switch open would allow the tubes to warm up before applying bias voltage and input signals. This practice prolongs the life of vacuum tubes.

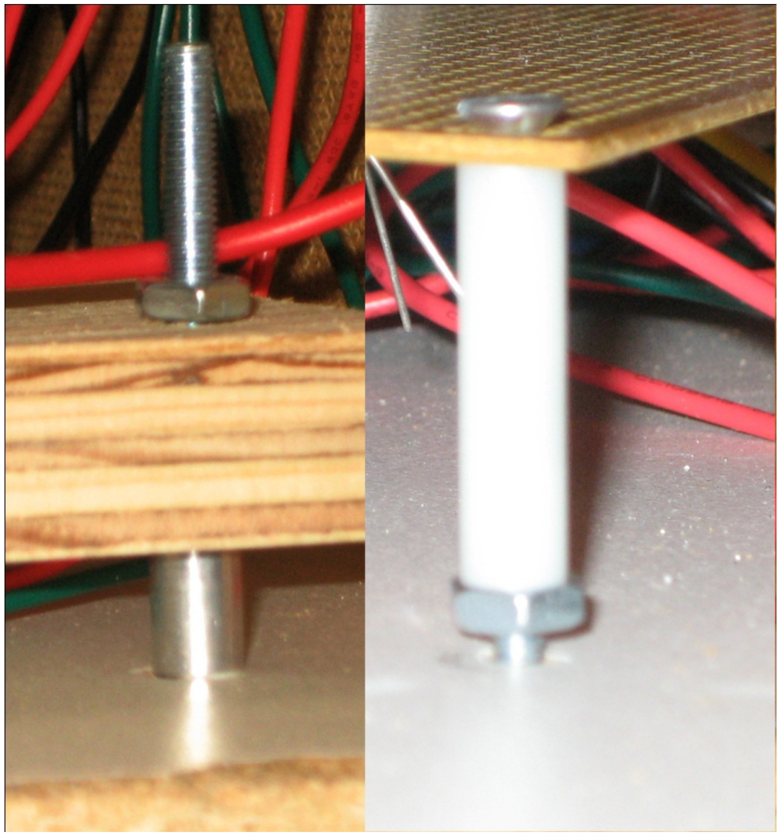

Figure 6: Plywood (left) and Perfboard (right) Supports

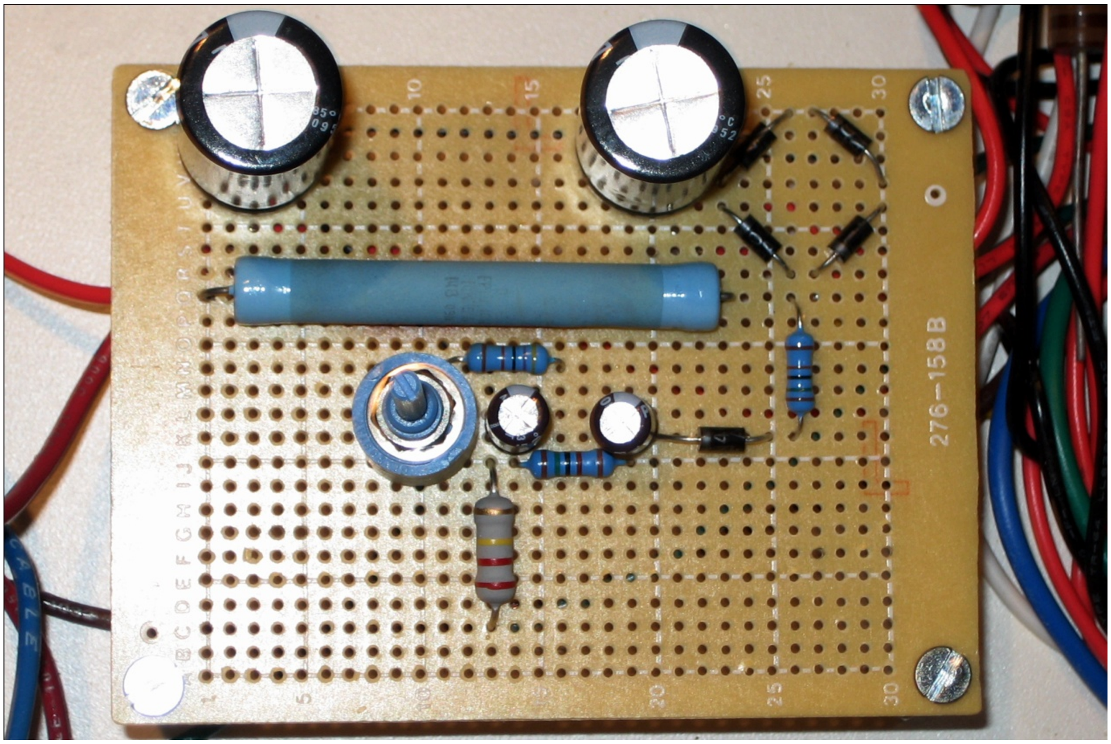

Figure 7: Power Supply Circuit

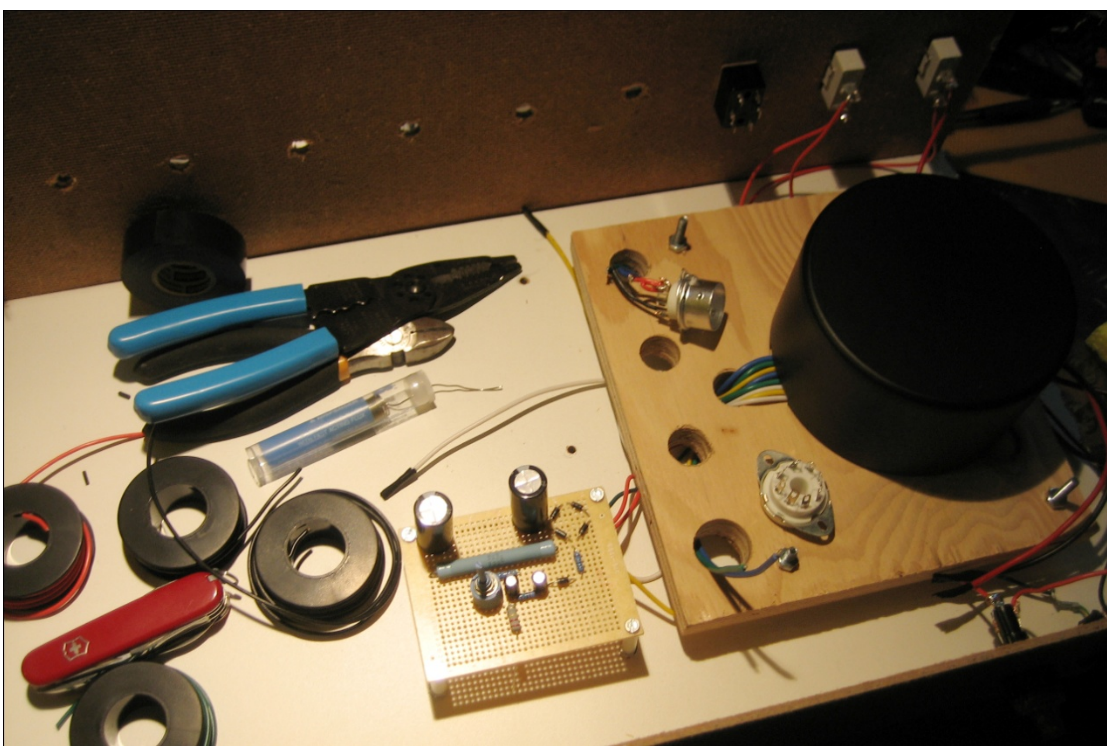

Figure 8: Connecting Heater Voltage Lines

After testing the power supply to verify that it was producing 400V DC, I then began assembling the preamp and power amplifier circuits. The first step was connecting the 6.3V AC to the appropriate lugs on the tube sockets. This process is shown in Figure 8. Once that was done, components on the perfboard could be wired to the tube sockets, as well as to the potentiometers, which were mounted on the front of the chassis. The completed amplifier circuit board can be seen in Figure 9. All components next to and below the bottom pair of large electrolytic capacitors comprise the power amp. The rest of the components are used in the preamp.

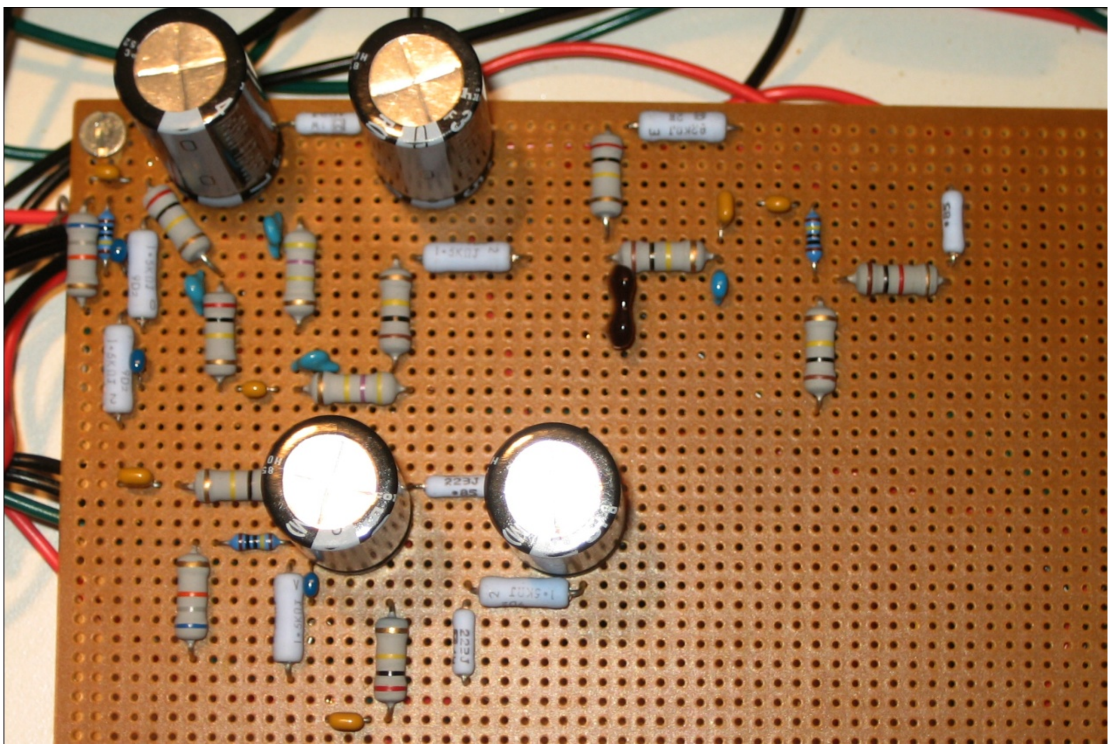

Figure 9: Preamp and Power Amp Circuitry

Once all of the potentiometers were soldered into the appropriate places in the amplifier circuit, they were affixed to the front of the chassis and their knobs were attached. The front of the chassis can be viewed in Figure 10. When all other soldering and wiring was finished, the output transformer was mounted in place and connected. It can be seen in the lower left of Figure 11, which is a top-down view of the finished product. Finally, the vacuum tubes were seated in their sockets, as showing in Figure 12. The three tubes on the left are 12AX7 dual triode tubes, the first two of which are used in the preamp. The right-most tube is an EL34 pentode. It and the 12AX7 next to it are the active elements in the power amplifier.

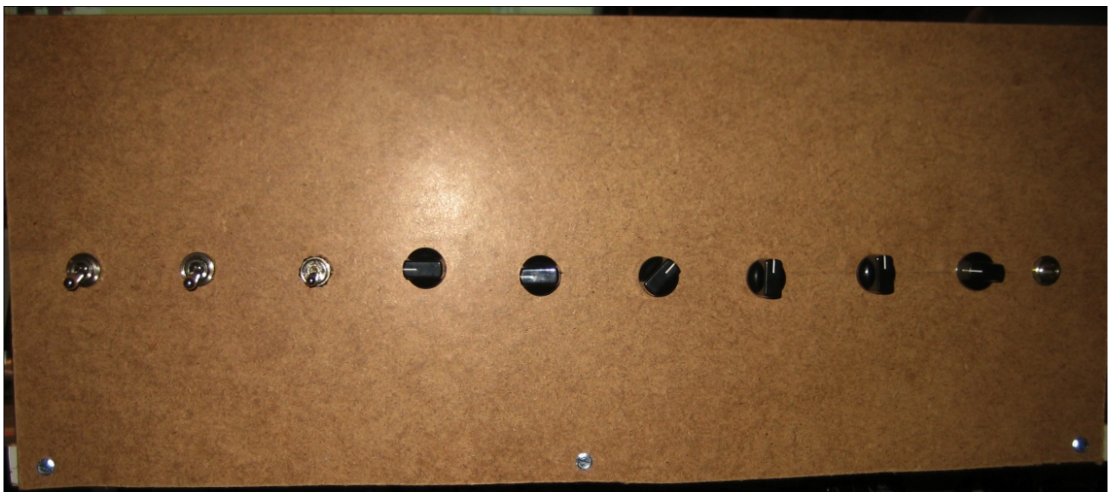

Figure 10: Switches and Potentiometers

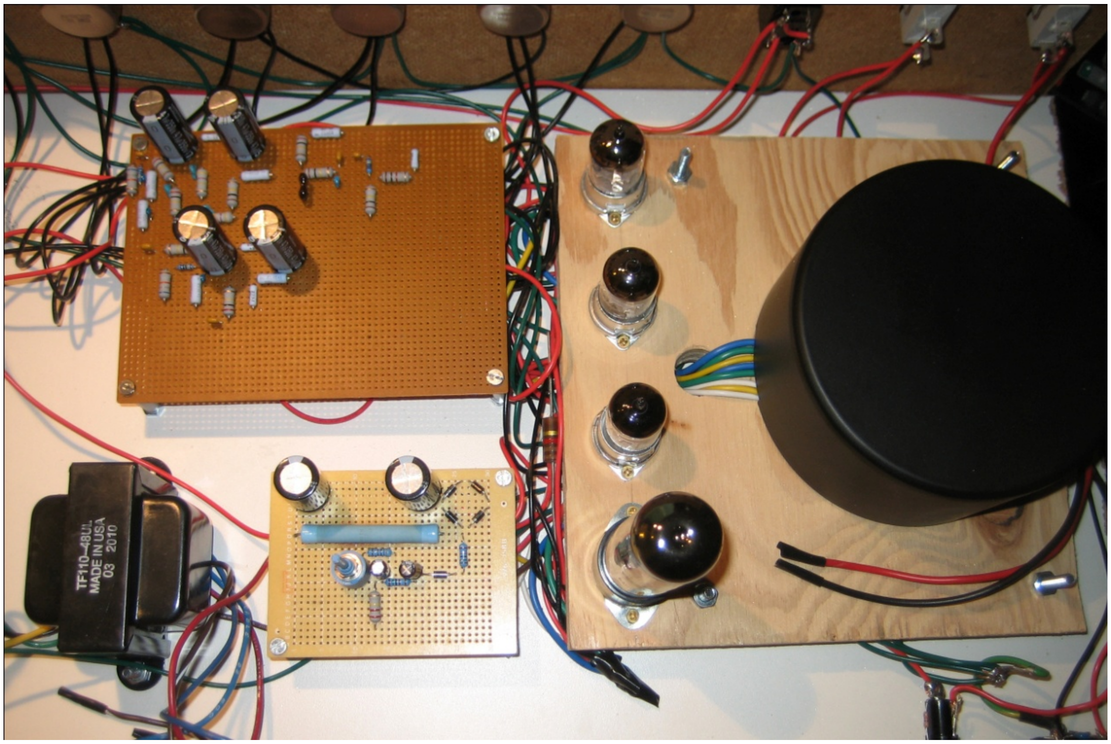

Figure 11: The Finished Product

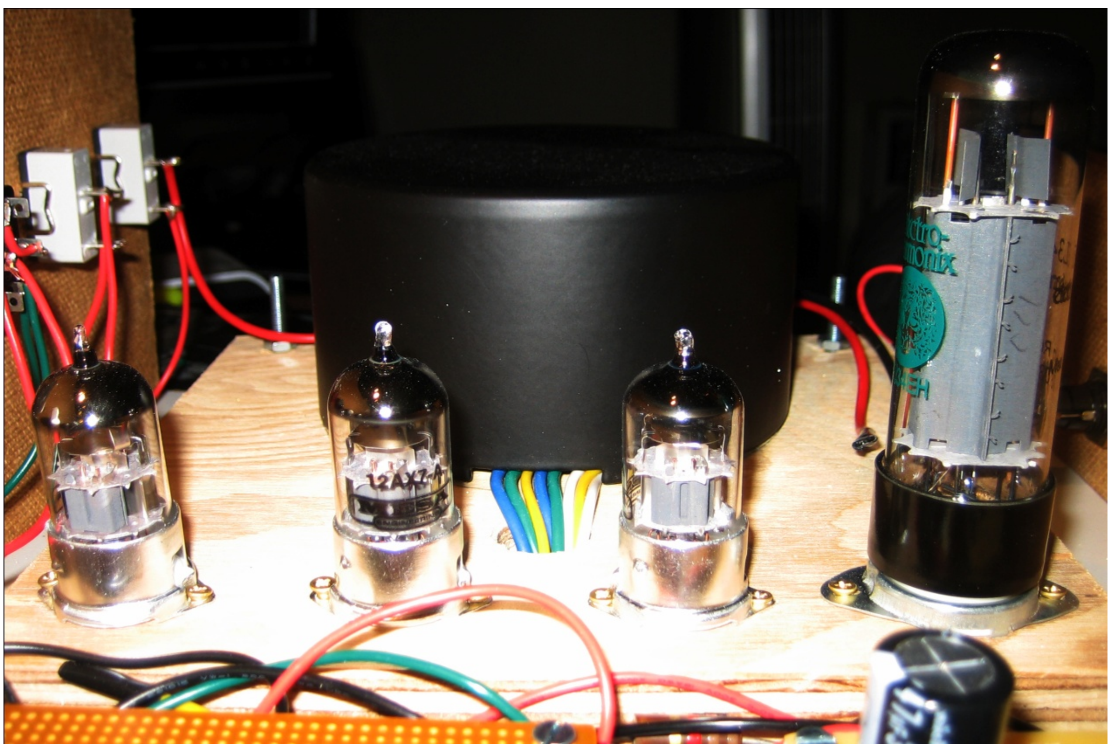

Figure 12: Vacuum Tubes in Sockets

V. Testing and Results

As this amplifier had never been switched on before, I could not be certain that the desired signal would emanate from the output jack. Good guitar speakers being quite expensive, I had no desire to risk mine on an untested amplifier. A Weber headphone tap with an eight ohm dummy load was connected in lieu of a speaker. The tone controls were set at halfway, and the gain, preamp out, and power amp volume knobs were all set at a quarter of their full values. I connected a guitar to the input, and then flipped the power switch. The heater filaments in the tubes began to glow normally. After allowing approximately thirty seconds for the tubes to warm up, I closed the standby switch.

Where I was expecting an auditory indicator of success, I was instead greeted by visual and olfactory signs of failure. Smoke had begun to emanate from the large 10kΩ, 10W-rated resistor in the power supply (the large, blue cylinder in Figure 7. Apparently, a 10W rating was not high enough. Since the resistor in the RC filter of the power supply went up in smoke, the amplifier obviously could not function. My proposed fix is to acquire a resistor with a higher power rating and install it in the power supply.

VI. Conclusion

Although my design has yet to function in physical circuit form, my simulation results indicate that, given a proper power supply, it should properly amplify and distort electric guitar signals. Since any further result analysis is qualitative, and cannot be discerned from simulations, a conclusion as to whether or not my design constitutes a “good” guitar amplifier will have to wait until an adequate power supply is constructed.

VII. References

1. LTspice. Computer software. Vers. 4.06t Mike Engelhardt, Linear Technology Corporation, 2010
2. Tone Stack Calculator. Computer software. Vers. 1.3 Duncan Munro, Duncan Amplification, 2006

VIII. Appendices

A. Parts List and Costs

Description	Quantity	Cost
Masonite sheet	1	donated
Melanine-coated shelving board	1	$13.00
Noval tube socket	3	$6.00
Octal tube socket	1	$1.75
AnTek AN-1T300 transformer	1	$35.00
Perfboard	2	$5.00
Hardware (bolts, spacers, screws)	20	$10.00
Mono audio jacks	2	$5.00
SPST Switch	2	$4.00
DPDT Switch	1	$3.00
Potentiometer, 25k	1	$7.29
Potentiometer, 1M	2	$22.88
Potentiometer, 250K	2	$16.02
Potentiometer, 10K	1	$8.01
Potentiometer, 1K	1	$11.44
Capacitor, 0.47uF	5	$1.43
Capacitor, 0.022uF	3	$0.93
Capacitor, 470pF	2	$0.34
Capacitor, 220pF	1	$0.17
Capacitor, 240pF	1	$1.61
Capacitor, 0.1uF	3	$3.84
Capacitor, 47000pF	1	$0.23
Capacitor, 10uF	2	$0.44
Capacitor, 47uF	6	$9.06
Resistor, 68K	2	$0.32
Resistor, 1.5k	5	$1.03
Resistor, 200K	5	$0.80
Resistor, 470K	2	$0.32
Resistor, 10K	1	$0.23
Resistor, 100K	3	$0.48
Resistor, 82K	1	$0.28
Resistor, 1M	5	$0.53
Resistor, 1k	1	$0.16
Resistor, 22k	3	$0.69

Resistor, 220K	1	$0.16
Resistor, 47K	1	$0.14
Resistor, 10K	1	$4.56
Resistor, 15K	1	$0.18
Resistor, 150K	1	$0.16
Fuse holder	1	$18.32
Diode, 1N4007	6	$0.36
Vacuum tube, 12AX7	3	$51.00
Vacuum tube, EL34	1	$17.50
Triode Electronics TF110-48 output transformer	1	$29.95
TOTAL		**$293.61**