DIY Audio Projects
DIY Tube Projects
DIY Tube Amp Kits
DIY Speaker Projects
Speaker Drivers / Tweeters
DIY Solid State Projects
DIY IC / Op-amp Projects
DIY Phono Projects
DIY Cable Projects
Misc. Audio Projects
Hi-Fi Audio Schematics
Technical Audio Information
Testing Equipment / Tools
DIY Audio Links
Contact / About Us

6EM7 Single-Ended Triode (SET) Vertical Amplifier

Matt Renaud Suncalc@YAHOO.com

6EM7 Single-Ended Triode (SET) Vertical Amplifier

Just An Idea...

What really drove me to build this 6EM7 amp was an idea about amplifier layout. Looking back at most of my tube designs, and most of those on the internet, revealed a very typical pattern. Amplifiers tended to be flat chassis with tubes and transformers above and electronics below. From a historical perspective this makes perfect sense. Metal chassis were built this way to facilitate packaging and assembly. When people started to make tube amplifiers again, they just removed the upper case and built in the same way.

But I wanted something a little different. I wanted a case design that would really showcase the tubes and hide the rest of the electronics. I also wanted a more old time look. Something that harkened back to early tube equipment of the 1920s. My primary design elements were shadow box alcoves for the tubes themselves, panel meters for monitoring operation, large old style controls, a jeweled power indicator, and an nice accent of leather in the handle to imply portability.

Photograph 1: Single-Ended 6EM7 Vertical Amplifier

But I also needed a good electrical design for this amp as well. So I decided to go back to a design I first presented on the forum in the 6EM7 Power Amp thread. This amplifier is based on a tube intended to drive the vertical deflection circuits in larger televisions, the 6EM7. The 6EM7 tube has two dissimilar triodes in one envelope. One is a high gain, low power unit intended as an amplifier or oscillator, and the other is a higher power unit intended to drive the magnetic deflection coils on the back of a CRT. At audio frequencies the combination is just what we need to build a nice little audio amplifier. One 6EM7 tube per channel.

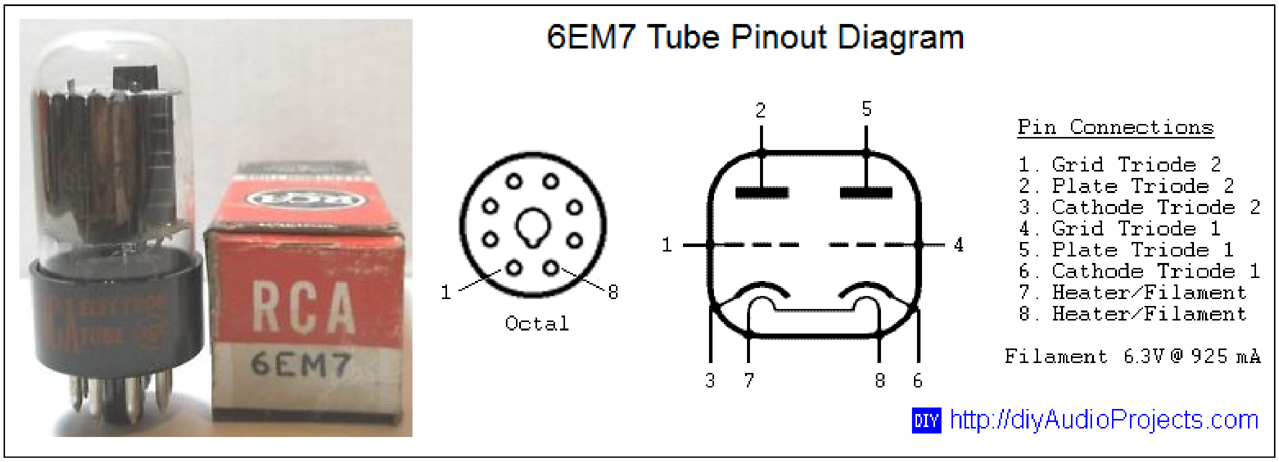


Figure 1: Tube Pinout Diagram - 6EM7 Double Triode

The Electrical Design - 6EM7 SET Amplifier

I first posted a version of this design in the forum in September 2011 and then in a slightly improved version in December 2013. But I wanted to make sure that the design was really what I wanted. So I decided to go back and revisit the whole design process. The first step in this process was to review and update the power stage design.

The power stage in this amp is formed by the "Unit No. 2" triode. This triode has a peak plate dissipation of 10W meaning that in a SET design we should be able to get at least a couple of watts very cleanly. Below is the revised load line design for the power stage based on the plate characteristics from the RCA data sheet dated August 1960.

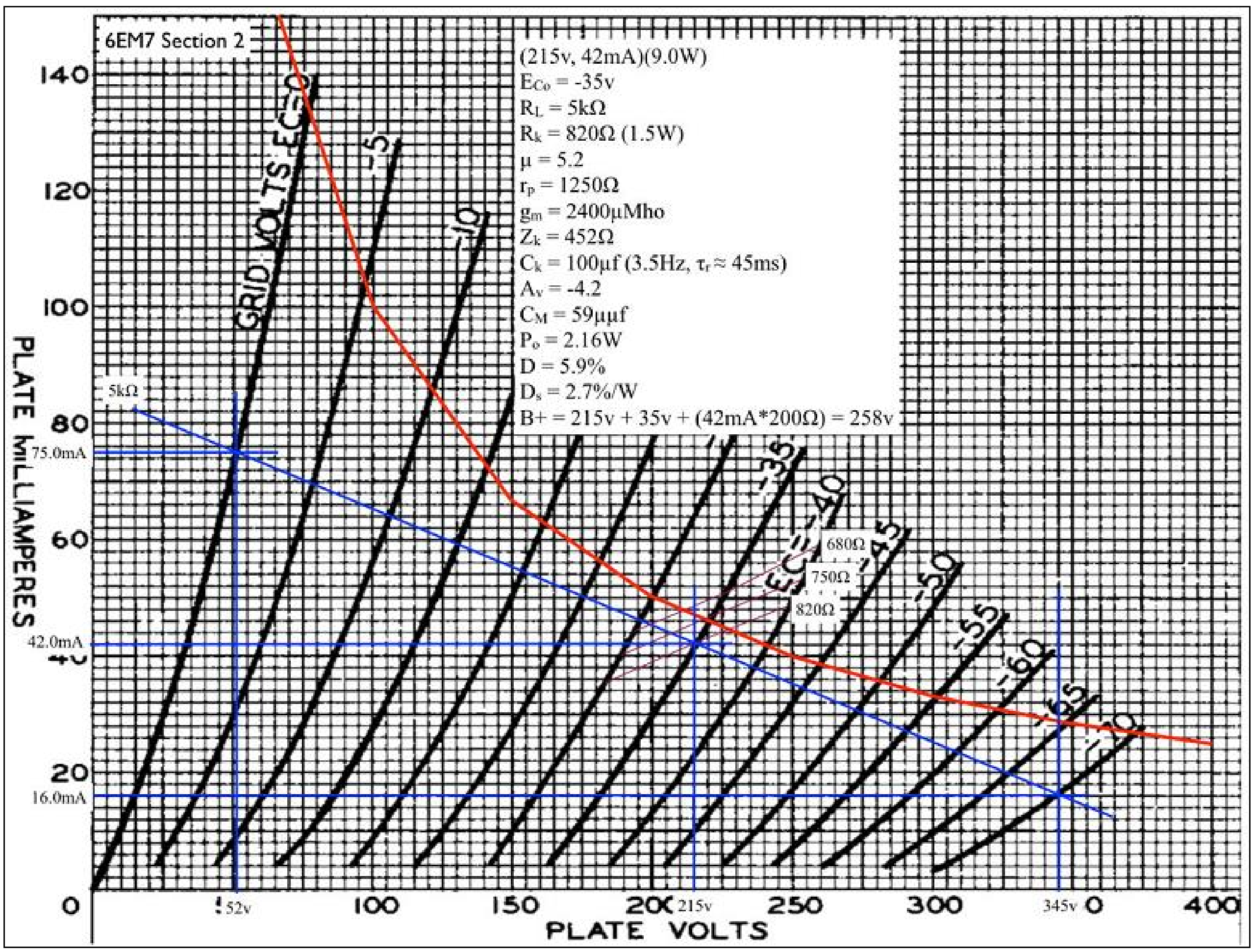


Figure 2: 6EM7 Plate Load Line Design - Triode 2

This 6EM7 design is very similar to the one presented back in December 2013. The only differences is that the cathode bypass has be returned to the original 100µF value. This was done solely to provide a more solid bass response. Although the bias excursion recovery time constant is a little longer than I usually prefer, I will correct for this by using a 10kΩ grid stopper resistor on the power stage to control excursions.

I am very comfortable with this amplifier design. The power stage plate dissipation is down at 9 Watts allowing for some design to build variability. The low end frequency response is good with provisions for controlling bias excursions. And finally, the distortion is well controlled at 2.7%/W (almost entirely 2nd harmonic). I could have gone with a lower load impedance and gained a little bit of power, but the distortion would have suffered. Overall the 5kΩ load impedance is a very good sweet spot for this triode.

So what about the 6EM7 driver stage? Well, the power stage is biased at about 35V. This means that the driver stage will need at least this much output voltage swing and it will need to do it from a line level input. This means a gain of at least 25dBV. This really isn't too much of a problem for the section 1 triode of the 6EM7. The power stage calls for a B+ voltage of approximately 260VDC. So I decided to use a 250VDC B+ for the driver stage. This will give me about 10 Volts of drop for an additional stage of B+ filtering. Below is the final load line design for the 6EM7 driver stage using the same data sheet referenced above.

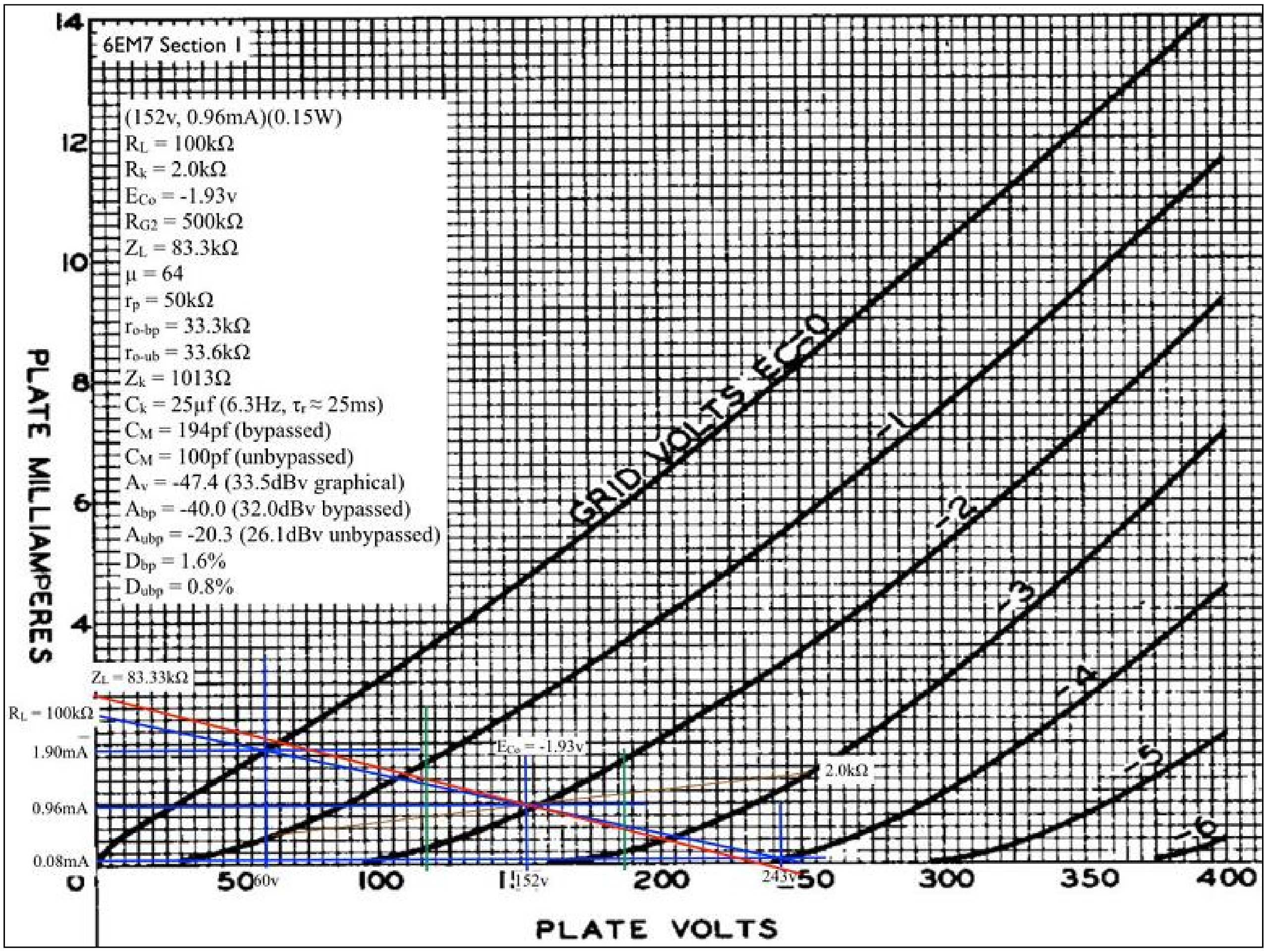


Figure 3: 6EM7 Plate Load Line Design - Triode 1

The amplifier design could use either a bypassed or unbypassed cathode and still get the gain required. However, by going with the bypassed cathode the amplifier only requires ≈1.4V-peak to reach full power. This is a better design point and the overall distortion is still acceptable. The calculated coupling capacitor value is 0.047μF for an interstage rolloff of 6.3Hz. This plus a volume control on the front of the amp and the electrical amp design is finished. Here is the resultant schematic.

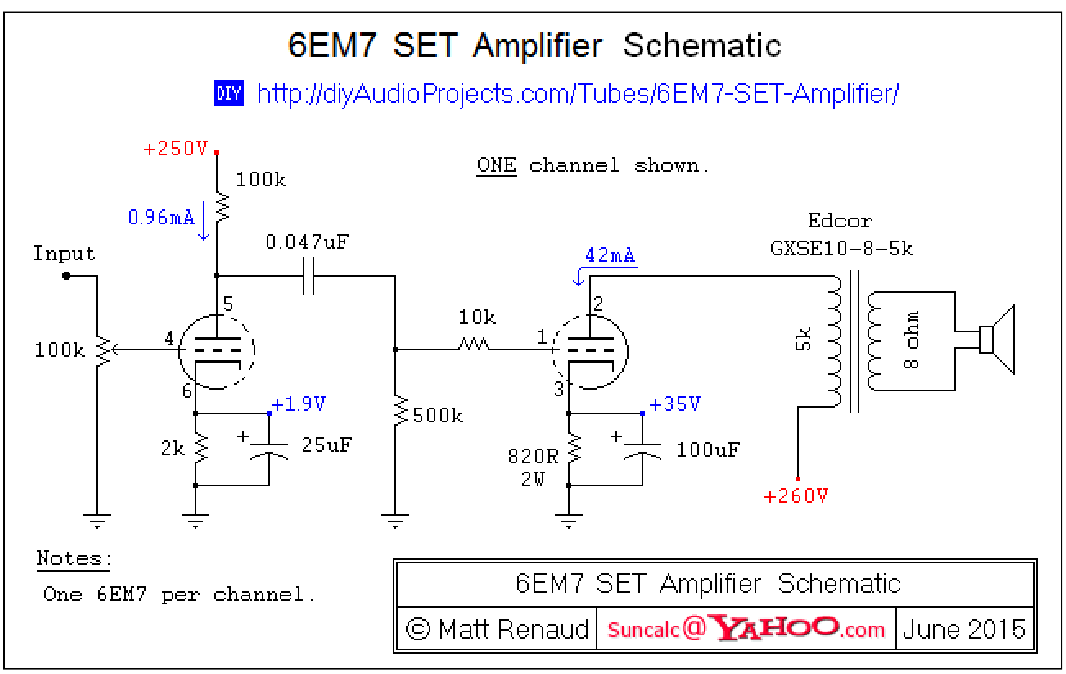


Figure 4: Schematic - 6EM7 Single-Ended Triode (SET) Amplifier

This is a relatively simple amplifier circuit which will be very easy to drive.

The Power Supply Design - 6EM7 SET Amplifier

The other thing that I really wanted out of this design was excellent channel separation for a deep and wide sound stage. This requires that the power supplies for the two channels be well isolated at their output to the circuits. To achieve this I decided to use three chokes (one main filter and one additional one for each channel) and then provide the gain stage B+ from an additional filter stage after the B+ supply filter. The power supply schematic is shown below.

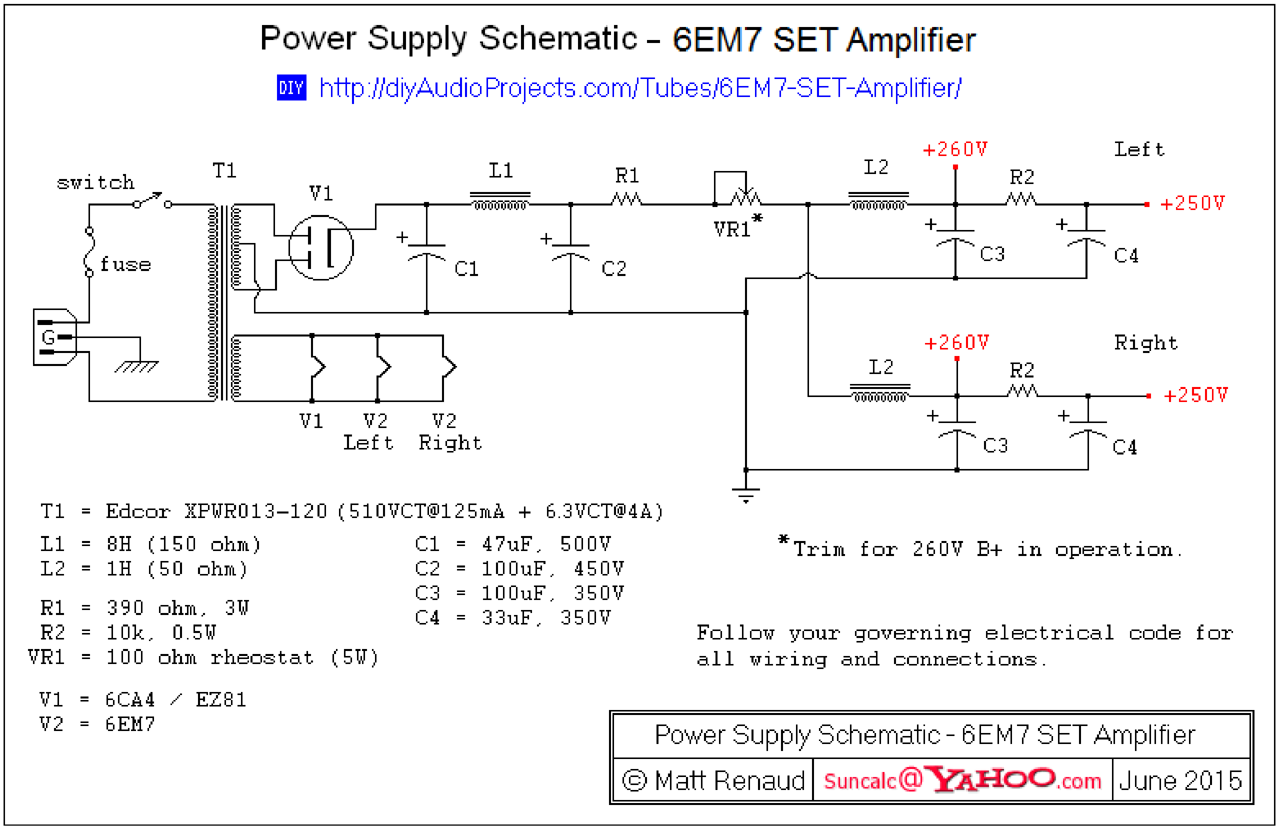


Figure 5: Power Supply Schematic - 6EM7 Single-Ended Triode Amplifier

Please note that the capacitor immediately following the 6CA4/EZ81 vacuum tube rectifier must never exceed 50µF.

This power supply design puts ≈75dBV of B+ filtering between channels at 20Hz. At the primary ripple frequency (120Hz) the B+ channel to channel isolation is ≈165dBV and by the time you get to 1kHz the isolation is a (theoretical) ≈276dBv. I say theoretical because at these levels just putting the wires in the same chassis causes more coupling than this. Regardless, this is a VERY well "channel-to-channel" isolated power filter. The use of the 390Ω dropping resistor and the 100Ω rheostat was to trim the power stage B+ voltages to exactly +260VDC.

This is the final electrical design which I took into my amplifier build. For more information regarding amplifier power supplies, see my notes on power supply design for vacuum tube amplifiers.

Warning: This vacuum tube amplifier project uses high voltages. Contact with voltage potentials of this magnitude can cause serious injury or possibly be fatal. If you do not know how to build high voltage vacuum tube projects or you are not comfortable with projects that use these voltage levels, it is strongly recommended that you do not build this vacuum tube amplifier. Follow your governing electrical codes for all wiring and connections.

The Vertical Amplifier Chassis Build

After collecting up my various parts for the 6EM7 amp, I began to lay out the chassis. I wanted to balance the need with making the chassis large enough with the desire to make the amp easily portable. I also wanted a small footprint. Something small enough that I could place it on a book shelf or on top of a cabinet or hutch without overhanging the front. This is the final layout of the 6EM7 vertical amplifier with dimensions. Click the image for a full size chassis layout plan.

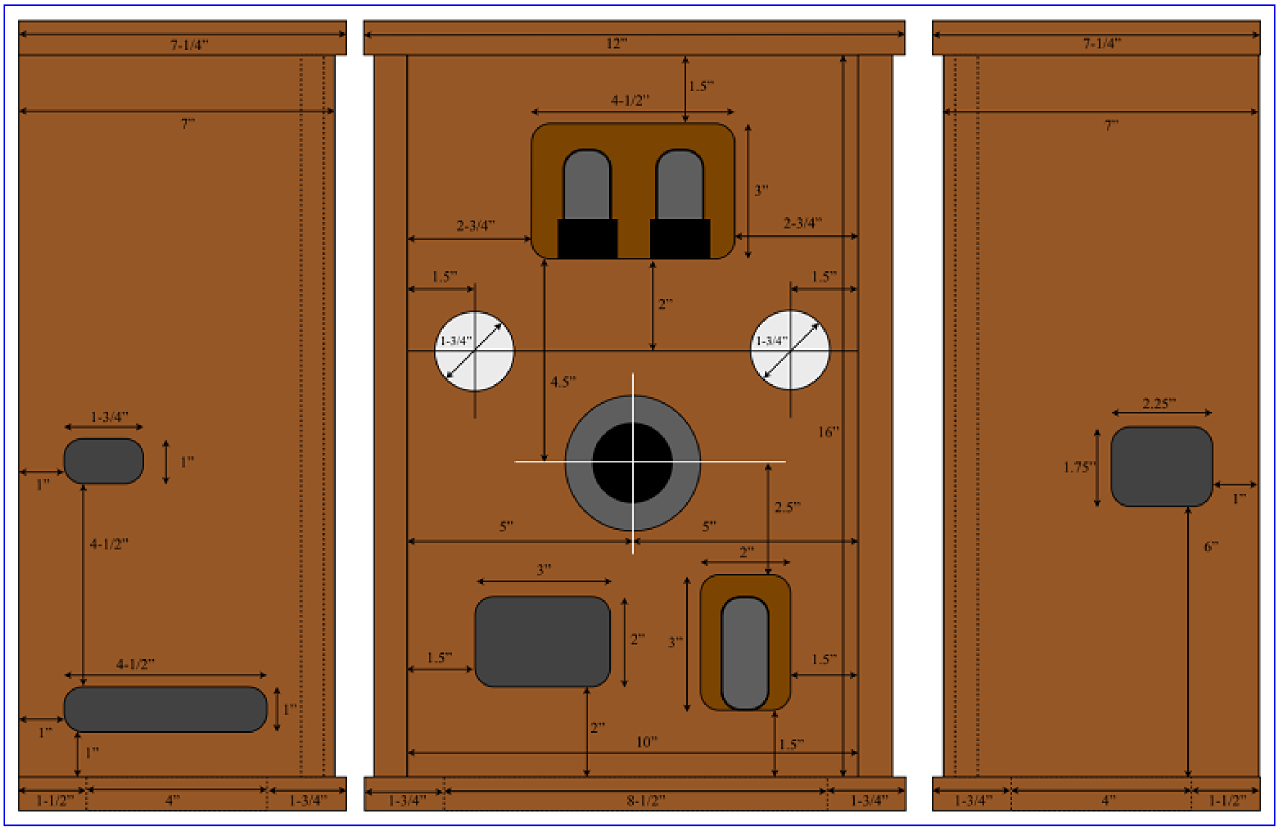


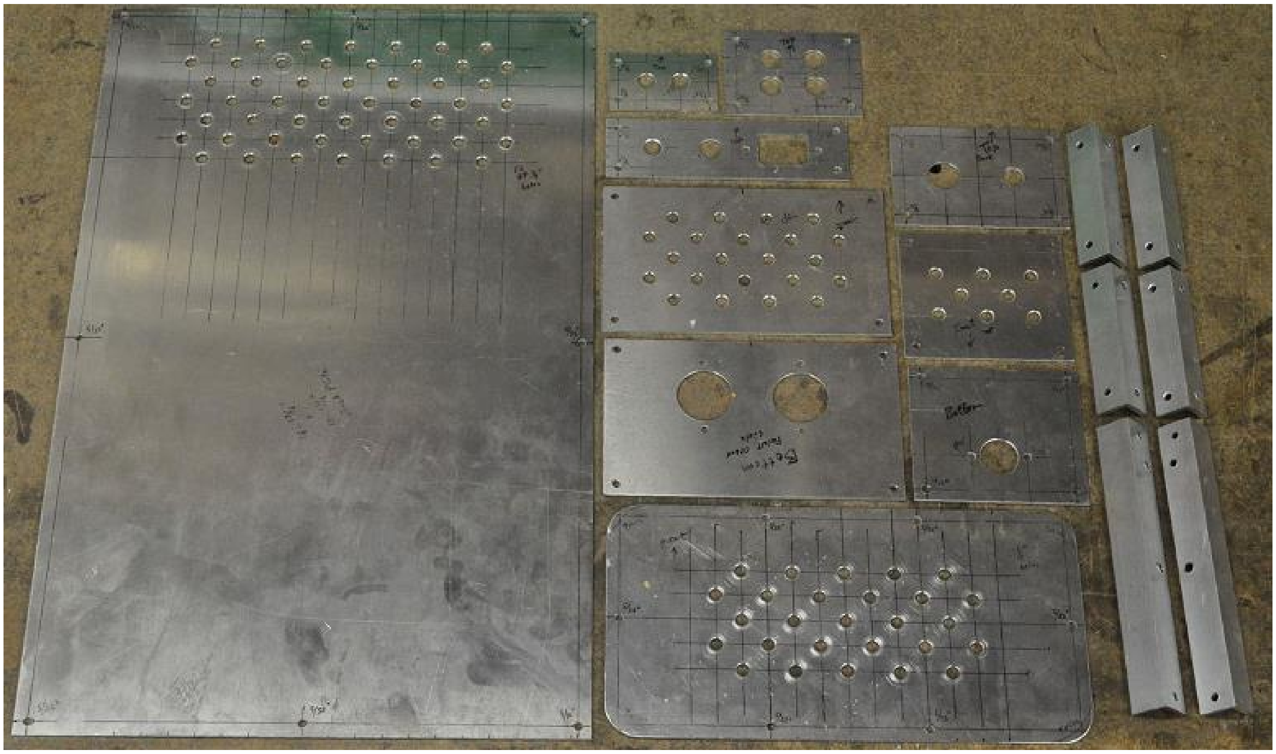
Figure 6: Chassis Layout Plan - 6EM7 Vertical Amplifier

This chassis layout provides several benefits. First, it has the small footprint I wanted (12" wide x 7-1/4" deep) to fit the amplifier on a shelf or cabinet. Second, it is tall enough to provide good separation between the power supply section and the audio components. And third, it has lot of internal volume in which to work. So, I chose some nice dark walnut from my wood pile, to reflect the look of the old early 1920's tube equipment, and went to work. Here is a picture of the main wood chassis sitting dry fit on my workbench.

Photograph 2: Vertical Amplifier Chassis - Dark Walnut

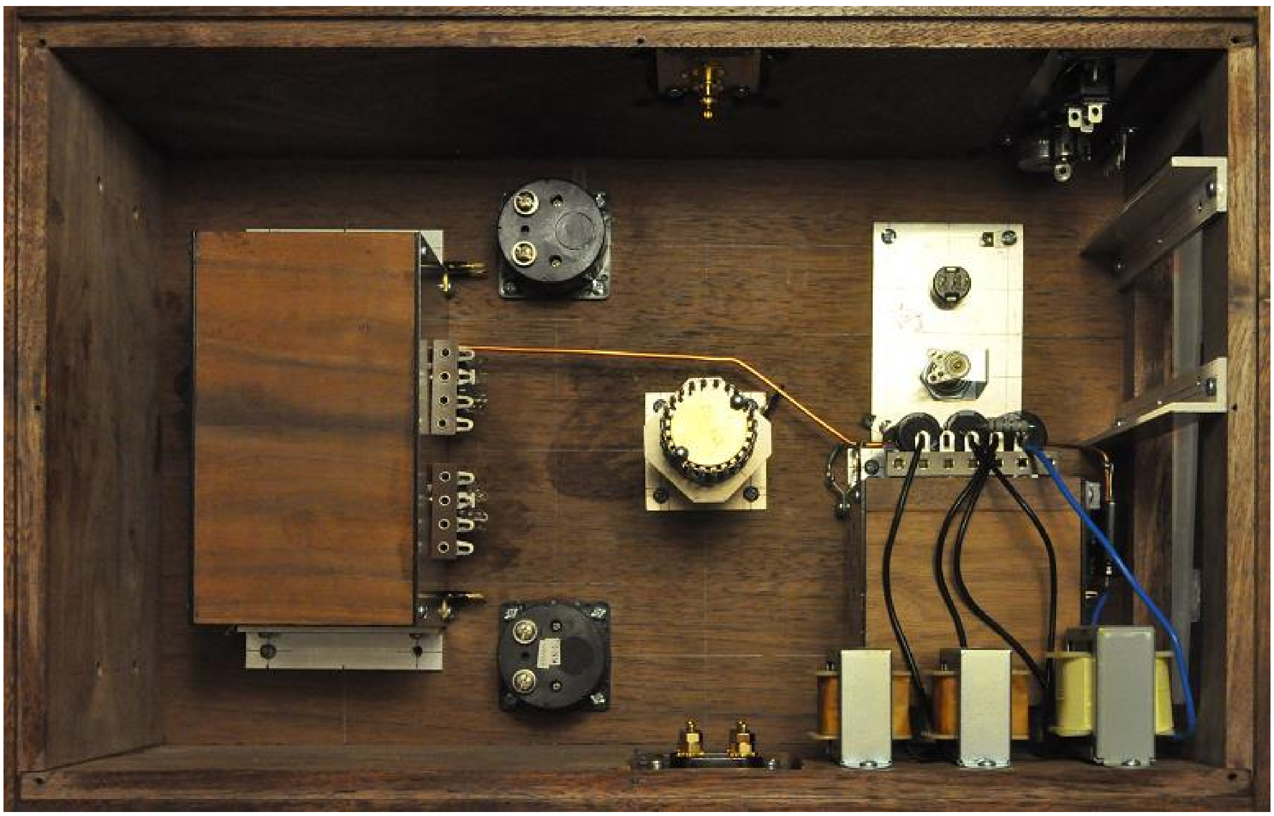
At this point, I was still not quite sure how to construct the shadow boxes for the tubes. I could make them all of wood, all of metal, wood with a small mirror in the back, or even something more exotic. In then end, I decided that the tops and bottoms of the shadow boxes would be painted aluminum plate and the back and sides would be matching black walnut. Now it was time to start cutting metal.

There is a lot of aluminum required for this tube amp, in addition to the top and bottom plates for the shadow boxes, there are all the mounting plates, a large back panel, and a bottom access panel. There is also a bunch of aluminum angle required for mounting the shadow boxes and suspending the power transformer over the bottom access plate. Here is a picture of all the metal parts, cut and drilled, prior to final finishing and painting.



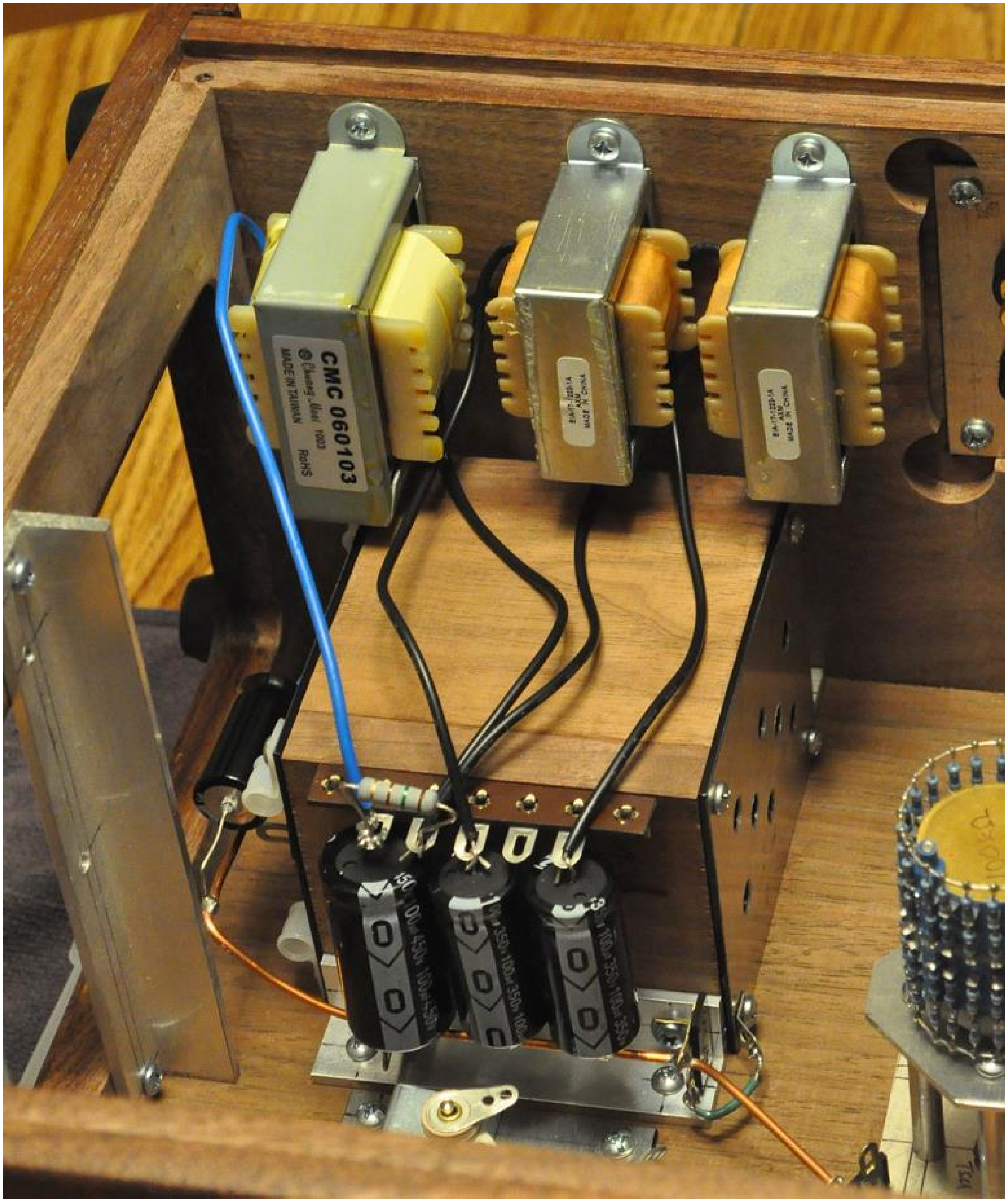
Photograph 3: Cut and Drilled Aluminum

After getting everything painted and the wood pieces assembled and finished, it was time to start some assembly. Here is a picture of the inside of the chassis with the shadow boxes and mounting plates installed.



Photograph 4: Chassis Inside Bare

In this picture, the rectifier wiring, main power supply filter components, and master ground buss have also been installed. The filter capacitors are mounted on the bottom and side of the rectifier housing and the chokes are mounted on the side of the chassis wall behind the rectifier shadow box. This picture shows how the power supply filter components are mounted.

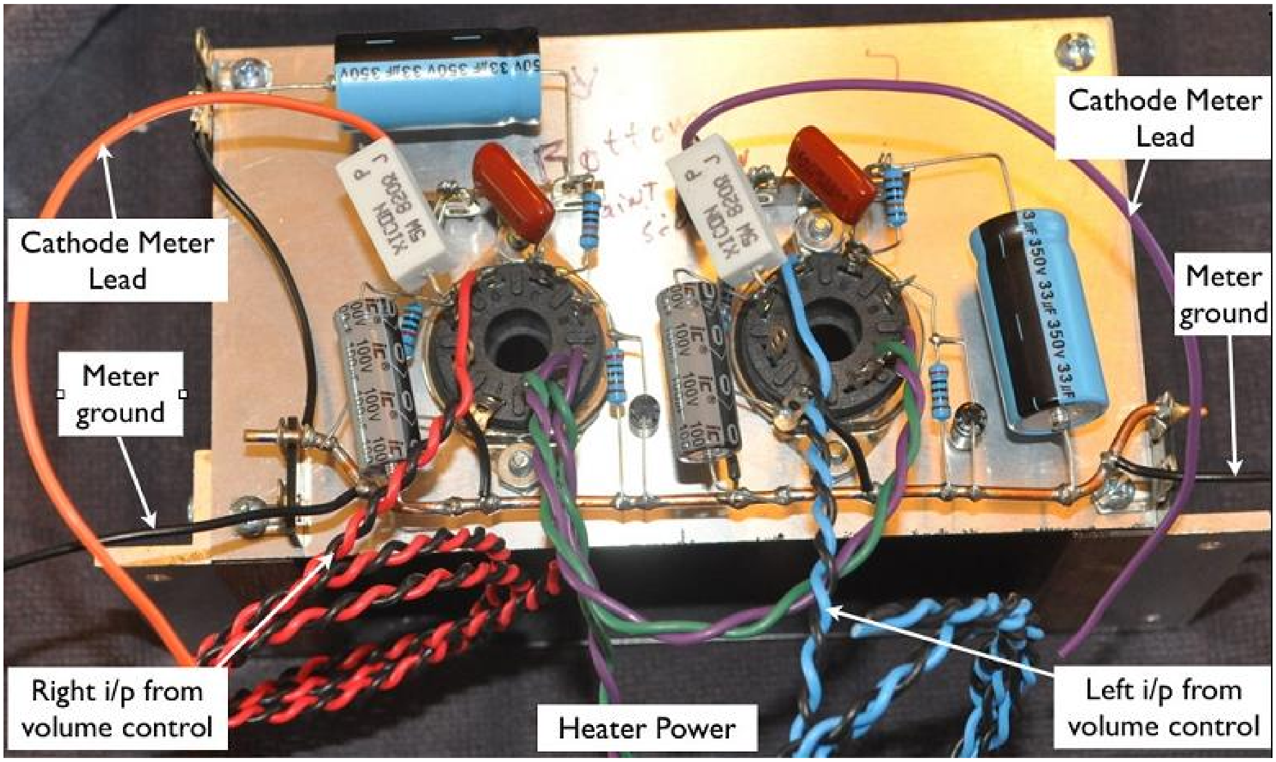


Photograph 5: Mounted Power Supply Filter Components

Note that the 150Ω resistor seen in this photo was later replaced with the 390Ω resistor and 100Ω rheostat shown in the 6EM7 power supply schematic above. Following this stage, the main power transformer was installed on the angle bracket seen on the left above and the main power supply was wired up. The photo below shows how the transformer wiring looks from the underside.

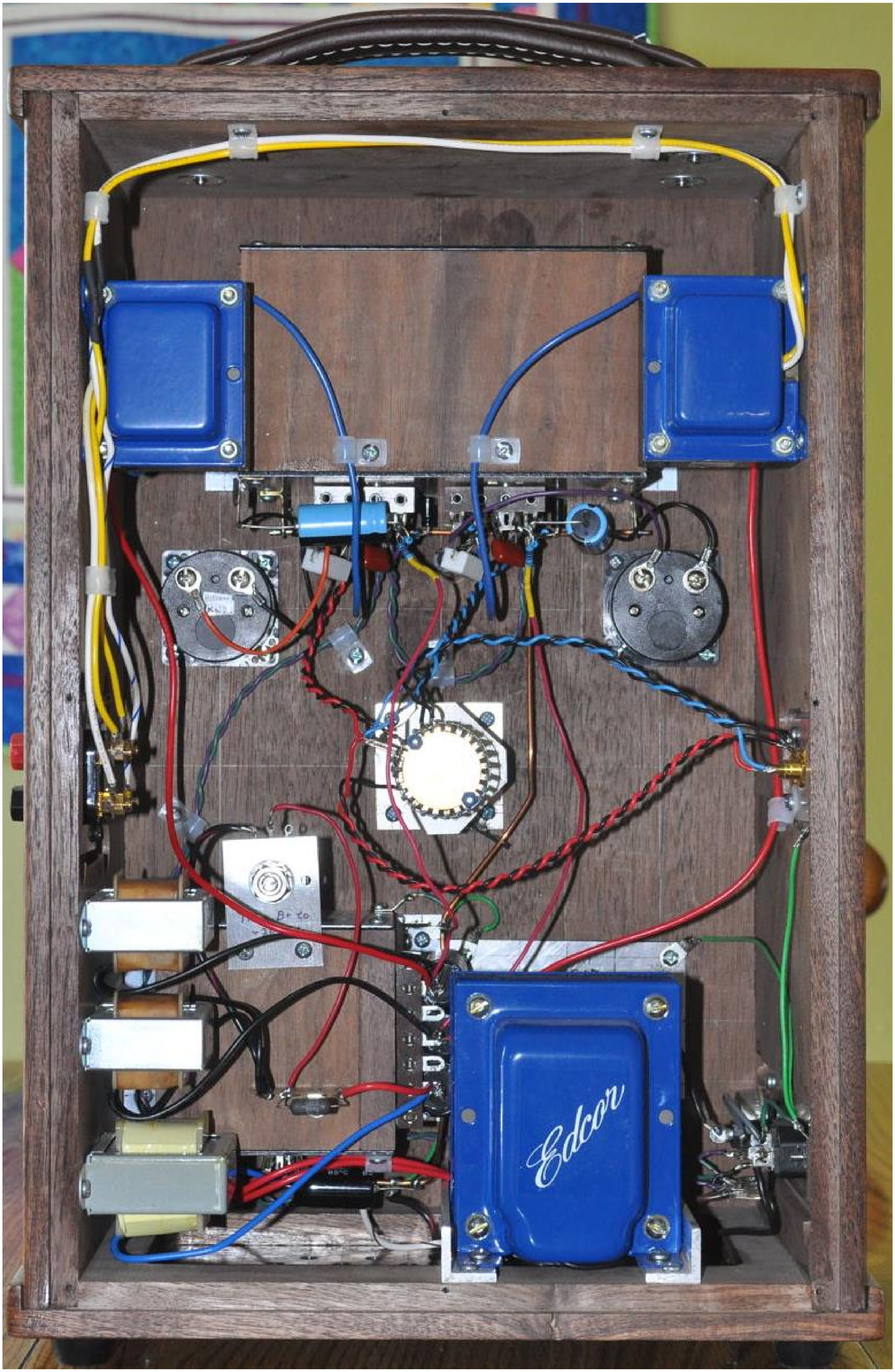
Photograph 6: Power Supply Wiring

The inside of the chassis, while providing lots of space, still presents the bottom of the upper shadow box containing the 6EM7 tubes in an awkward position. As such I decided to wire up the entire section with the shadow box removed from the chassis. Below is a picture showing how it looked prior to being inserted back into the chassis.



Photograph 7: Wired 6EM7 Amplifier Section

By proceeding in this manner, there are only four wires that need to be soldered to the sockets and two wires soldered to the terminal strips following install. The two large 33µF 350V capacitors in this picture are actually the last stage of B+ filtering for the driver stage on each amplifier channel. Finally here is the inside of the chassis with everything wired up and ready to go. The inclusion of the power transformer and three filter chokes at the base of the chassis make this a very stable build that is in no way top heavy or prone to tipping.



Photograph 8: Wired Chassis Inside - 6EM7 Vertical Amplifier

Testing the 6EM7 Vertical Amplifier

I didn't submit this amp to a lot of formal technical testing. This design (or variations thereof) has been built by many different people since I first developed the electrical design back in September 2011 (and then revised it in December 2013). The clean output power from the 6EM7 SET amplifier is 2.2 Watts per channel and the frequency response is consistent with the advertised performance of the audio output transformer (40Hz to 18kHz). Below is a plot of the measured frequency response for the 6EM7 Vertical Amplifier.

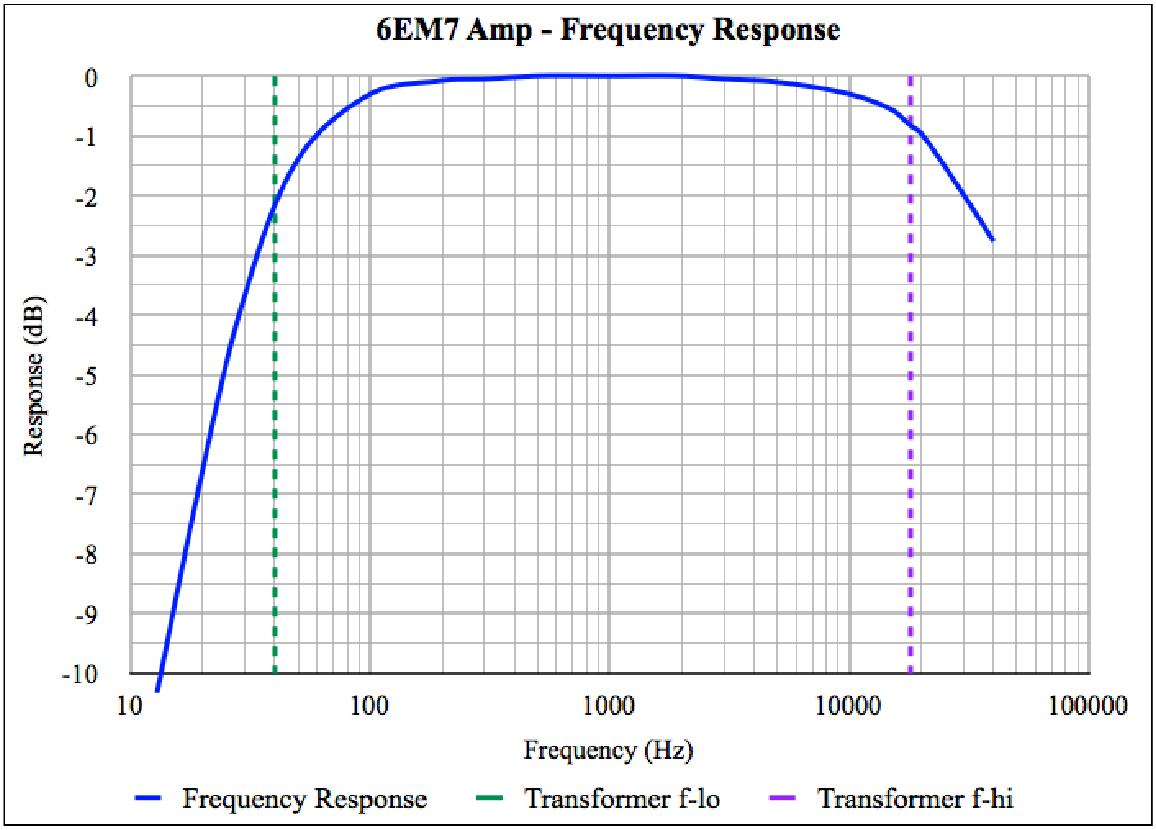


Figure 7: Measure Frequency Response - 6EM7 Vertical Amplifier

This is actually an excellent response curve for an amplifier of this type. It represents a good balance between bandwidth and transient response control. I am quite pleased with the result.

Impressions - 6EM7 Vertical Amplifier

The 6EM7 amplifier sounds wonderful! There is really nothing which can compare to the sound of a single-ended triode (SET) amplifier. Bass is well articulated without being boomy, mid-tones are clear and even, and the highs are crystal clear. The amp has exceptional transient response; reproducing my favorite classical recorder piece ("Frederick The Great : Sonata in B-Flat - Allegro" performed by Michala Petri) with clarity, lightness, and vibrancy.

The 6EM7 amplifier build is a success on two different accounts. First, the electrical design and execution has resulted in a fine sounding single-ended amplifier. And second, the physical design of the amp, with it's different approach to showcasing the tubes, has resulted in a unique and beautiful amplifier with just the early 20th century feel which I wanted.

Some Design Postscripts

There are two additional items about this amplifier which are worthy of note. The first is its thermal design. With the tubes contained in small cubby holes, there was some concern with respect to overall heating of the tubes and chassis. This is especially true with the power tubes where the quiescent power dissipation is over 32 Watts. The design approach was to have the tops of the compartment ventilated with holes. The thought was that the air flow pattern would be in through the front, through the vent holes into the chassis, up through the inside of the chassis, and out the vent holes in the chassis back. This would create a convection cooling flow which would keep chassis heating down.

This approach was successful in the lower rectifier compartment where peak dissipation was less than 8 Watts. In the upper compartment the design is just marginal. The heat load due to direct infrared radiation was not fully appreciated. The tubes themselves still remain well below their maximum bulb temperature. The impact is on the chassis itself. The black top plate on the power tube compartment has an equilibrium temperature of approximately 156°F (≈ 69°C) in normal operation. This is still well below my standard internal chassis derating temperature of 185°F (≈ 85°C) but it is still higher than I would like. If using this design approach again, I will endeavor to keep these temperatures somewhat lower through larger compartment size, better ventilation, and perhaps the use of a higher emissivity finish on the metal parts.

The other design item of note is a small addition I made to the design. Looking at the side of the amp revels a little control knob right next to the fuse holder. This control has a special purpose.

Photograph 9: Jewel Light Dimmer Control - Rear 6EM7 Vertical Amplifier

When building up this amp I decided to use a jewel power indicator with a typical 6.3V indicator bulb. However, when testing out the various design elements I decided that even the 0.5 candela type 47 bulb (6.3V @ 150mA) was far too bright. However I did find that the 0.9 candela type 47 bulb (6.3V @ 250mA) could be dimmed across a large portion of it's range by a simple 50Ω variable resistance. So a small 50Ω, 5W wire wound rheostat was put in line with the indicator to tailor its intensity to match the glow of the tubes. It is purely an esthetic addition to the amp but it is one of those little things that can make a piece of equipment just "look right".

This 6EM7 amplifier is a great success. It not only sounds good, but it looks good as well. This is a good example of what can be accomplished by simply thinking a little differently about the entire design process. Comments and questions about the amp are welcome in the Vertical 6EM7 Portable Amp thread.

About the Author

Matt Renaud is a career Electrical Engineer with over 25 years experience in advanced radio frequency system design. He has a passion for tube audio and teaching tube based circuit design to others through participation in tube audio forums and his own website, www.CascadeTubes.com. The majority of his designs are fully original and may be found on his website and on this forum. Here are a some DIY audio projects and articles contributed by Matt:

- 4S Universal Preamplifier for 12A*7 Tubes
- Switched (Stepped) Attenuator Passive Volume Control
- Dummy Speaker Load Box
- Power Supply Design for Vacuum Tube Amplifiers
- 6V6 Single-Ended (SE) Ultra Linear (UL) Bias Optimization
- 6V6 Single Ended Ultra Linear Tube Amp