I came across some NOS Philco globe 47's for $3.00 each at a local surplus shop. They were so pretty I just had to bring some home with me. This led to a whole new project and brings out my first entry into the PP world.

Night shot of 47's famous blue glow.

The first version of the amp uses an input transformer to do the phase split duties. The input tranny feeds a 6SN7 differential stage that is DC coupled to the 47's. The output stage uses voltage feedback from the plates of the 47's to lower the output impedance. Without feedback the output impedance was 85 ohms. With feedback the output z is 16 ohms on the 16 ohm tap for a damping factor of 1. I'm quite surprised as the bass is nice and clean and sounds great. The output transformers are Fisher 500C units. The 47's would like to see 14K as the output tranny so I am driving my 16 ohm speakers with the 8 ohm tap. Not the ideal way to get there but it sure sounds good.

This amp is a simple straight forward design that does not have any CCS's in it (yet ;-}). There are no coupling caps which is a nice touch. I did try it as a RC coupled setup but did not like the sound. The highs were a bit harsh and the bass was not coherent. Going to DC really tightened up the bass and smoothed out the highs.

There is a 50 ohm tweak pot on the cathodes of the 6SN7's. This allows the dc offsets of all 4 tubes to be nulled out. Using 2 DMM's connected to the 1 ohm sense resistors between the output tranny and the plates of the pentodes you can adjust for equal current in the output stage.

The cathode resistor on the output stage is not bypassed ensuring class A operation. The high value cathode resistor required for the DC coupling acts as a long tail for biasing which should help with the common mode rejection of the output stage.

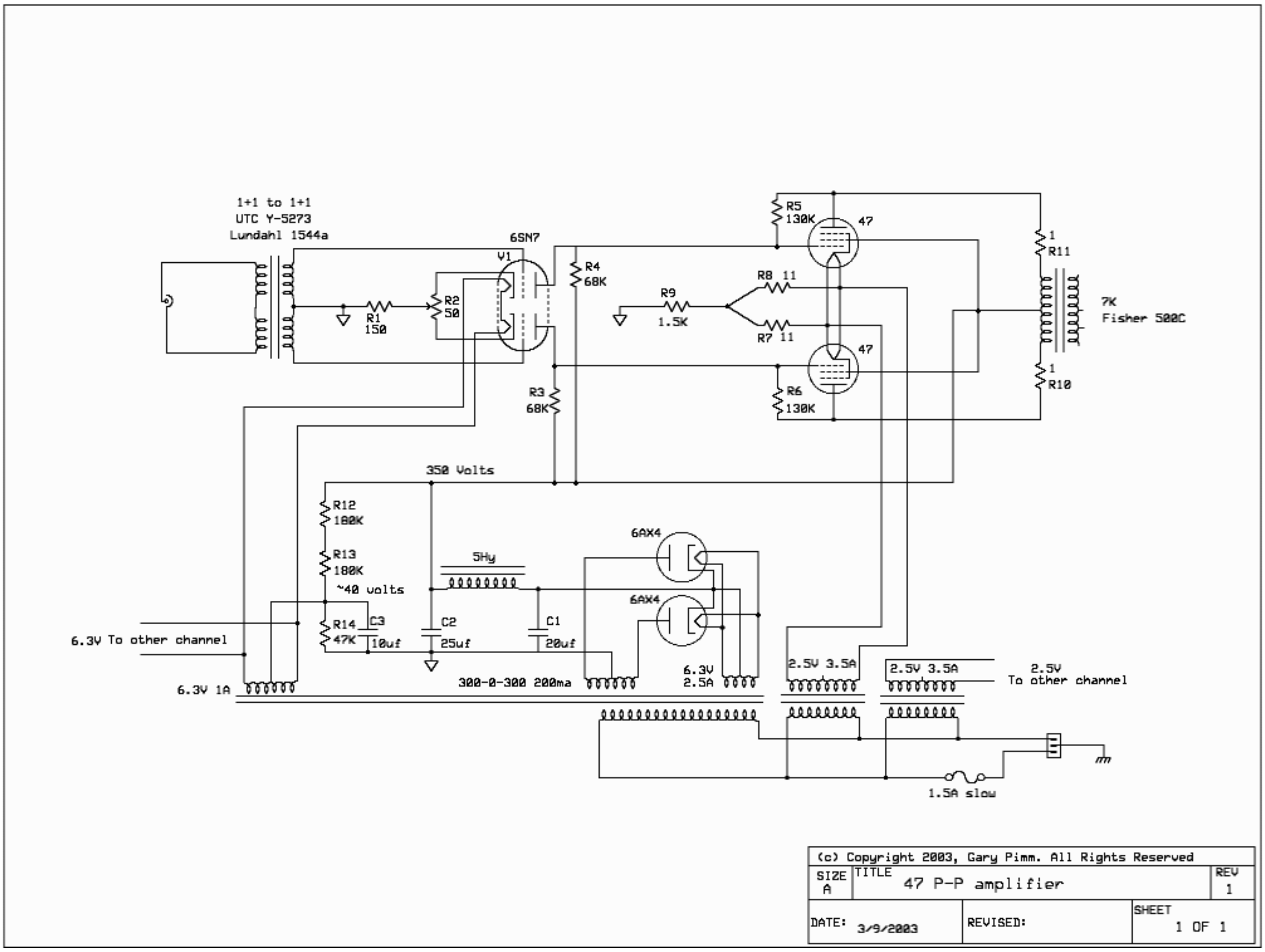
At this point there is no extra decoupling for either the screens or the driver stage. Most likely experiments will be done here to see what affect it has on the sound. Would like to try a CCS fed shunt reg for the driver stage and screen supply.

The amp puts out about 4 watts per channel.

Sound quality: Very clean and dynamic. Good balance. A more romantic sound than my 300B amp. I really like listening to this amp.

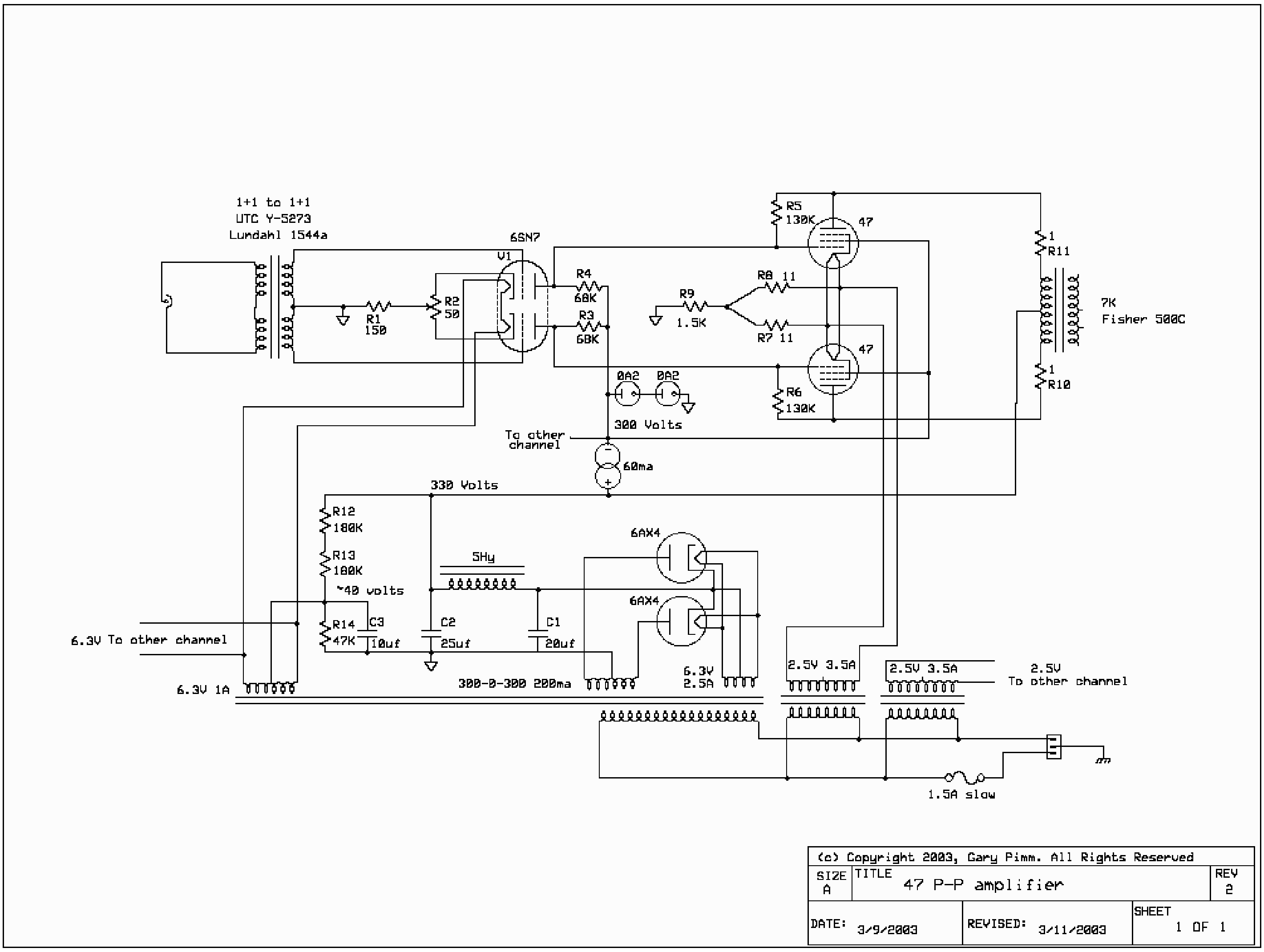
Future things I want to try. Replace the 6SN7's with pairs of 27's. This would give me a place to use some of the stash of globe 27 mesh plates I have. Possible arrangement would be a setup similar to the Aurora with a 85 parafeed into the phase split tranny feeding the 27's DC coupled to the 47's.

The schematic:



After a couple of days of listening I added a CCS fed shunt reg to supply the plates of the driver stage and the screens of the pentodes. This helped to clean up the sound. You can hear deeper into the music now.

The updated schematic:

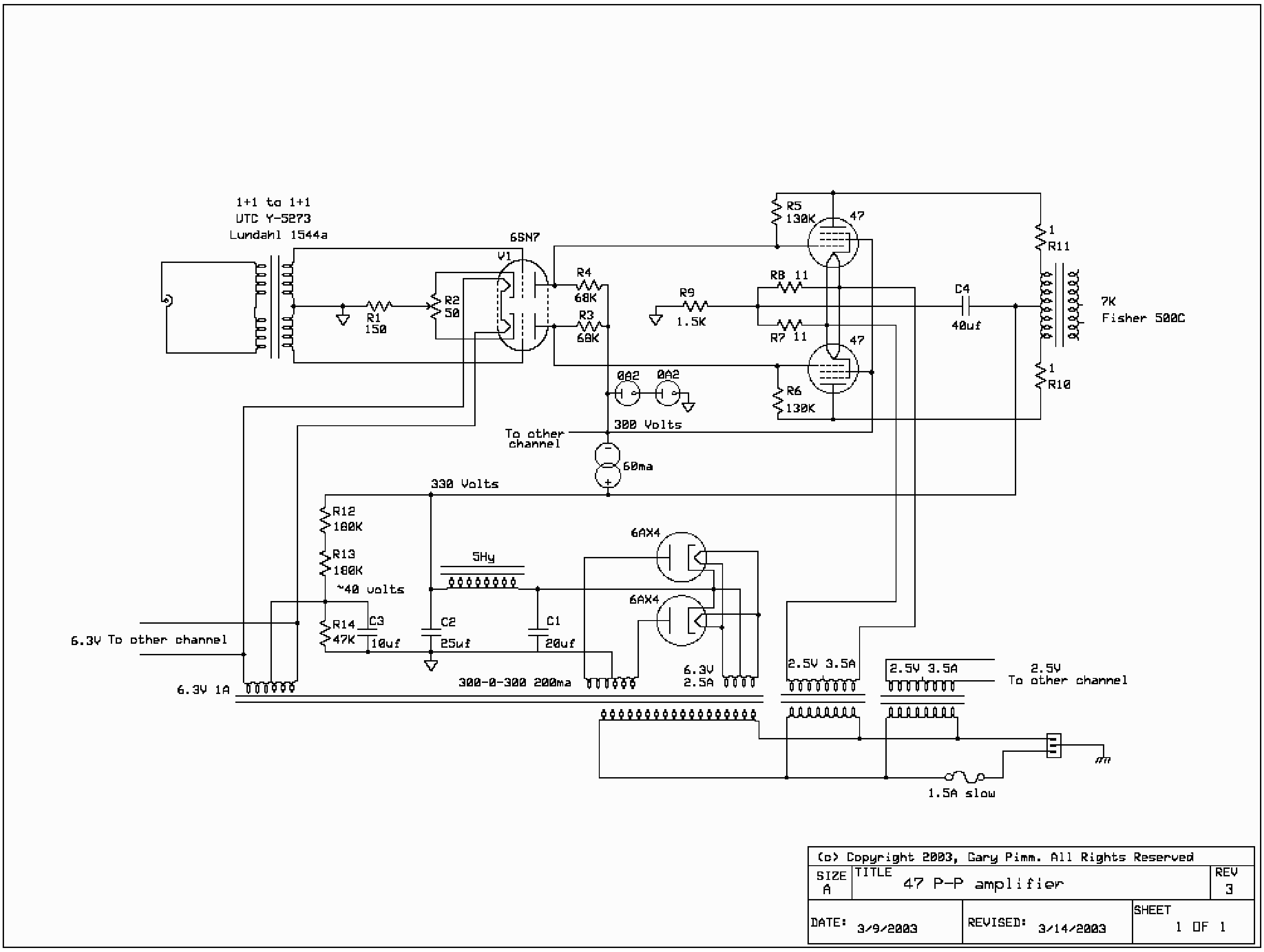


The latest change to the design was the addition of a cathode bypass capacitor. As the purpose of this cap is to handle the error currents caused by tube mismatch, I placed the cap between the cathodes and the centertap of the output transformer. This connection closes the AC signal loop around the output stage without messing with the common mode rejection provided by the long tail biasing provided by the 1.5K cathode resistor. This change was made during a listening/BS session with Lynn Olson. We were discussing the differences between the ideal balanced P-P output stage and the real world where tubes do not really match. The idea were tossing around is the output stage really is 2 separate amplifiers. You have a perfectly balanced P-P, and a SE amp in parallel all sharing the same components. The SE amp represent the unbalance of the P-P circuit.

When there is no bypass capacitor the signal currents caused by the tube mismatch has nowhere to go. When one tube creates a error signal caused by small tube mismatches, the only path to close the AC signal loop is through the other side of the amplifier. We end up using the opposing SE amp as the signal return. With the cathode bypass cap in place it closes the AC signal loop for the "virtual" SE amp. This allows the error currents to be returned to the "virtual" SE amp directly.

The change in sound quality was quite amazing! Bass tightened up bunches but the biggest change was the increase in depth and detail in the sound stage. This really brought the amp to life! It actually makes the active loaded 300B amp seem slow and dull in comparison! It has that quality that makes it really hard to get up and turn it off, even when you know that you have to go to work in the morning and it is already 2:30am.

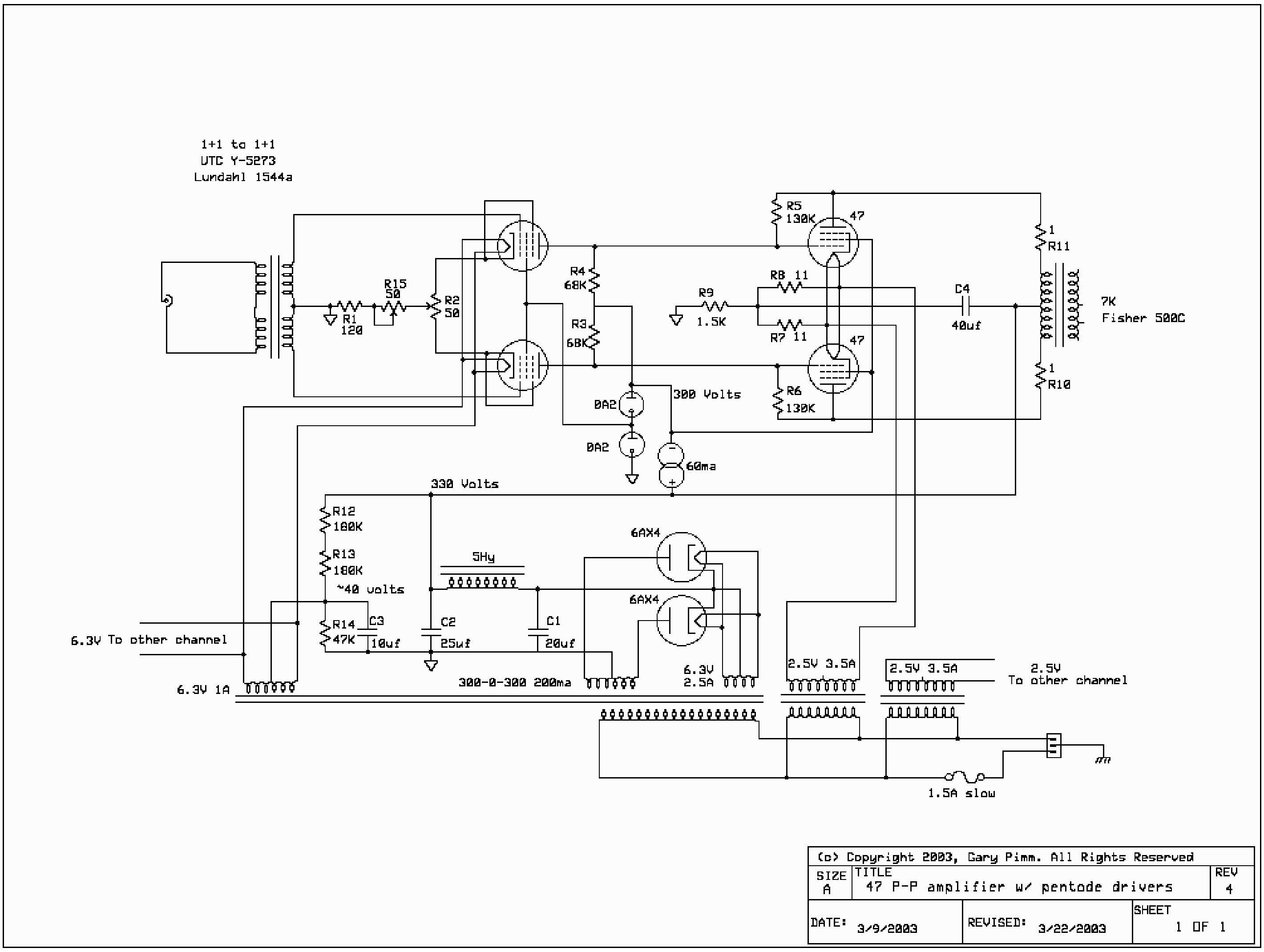
The 47's really sound a whole lot like 45's. If you were to listen to this amp and not know what you were listening to, it could easily be mistaken for a 45 P-P.



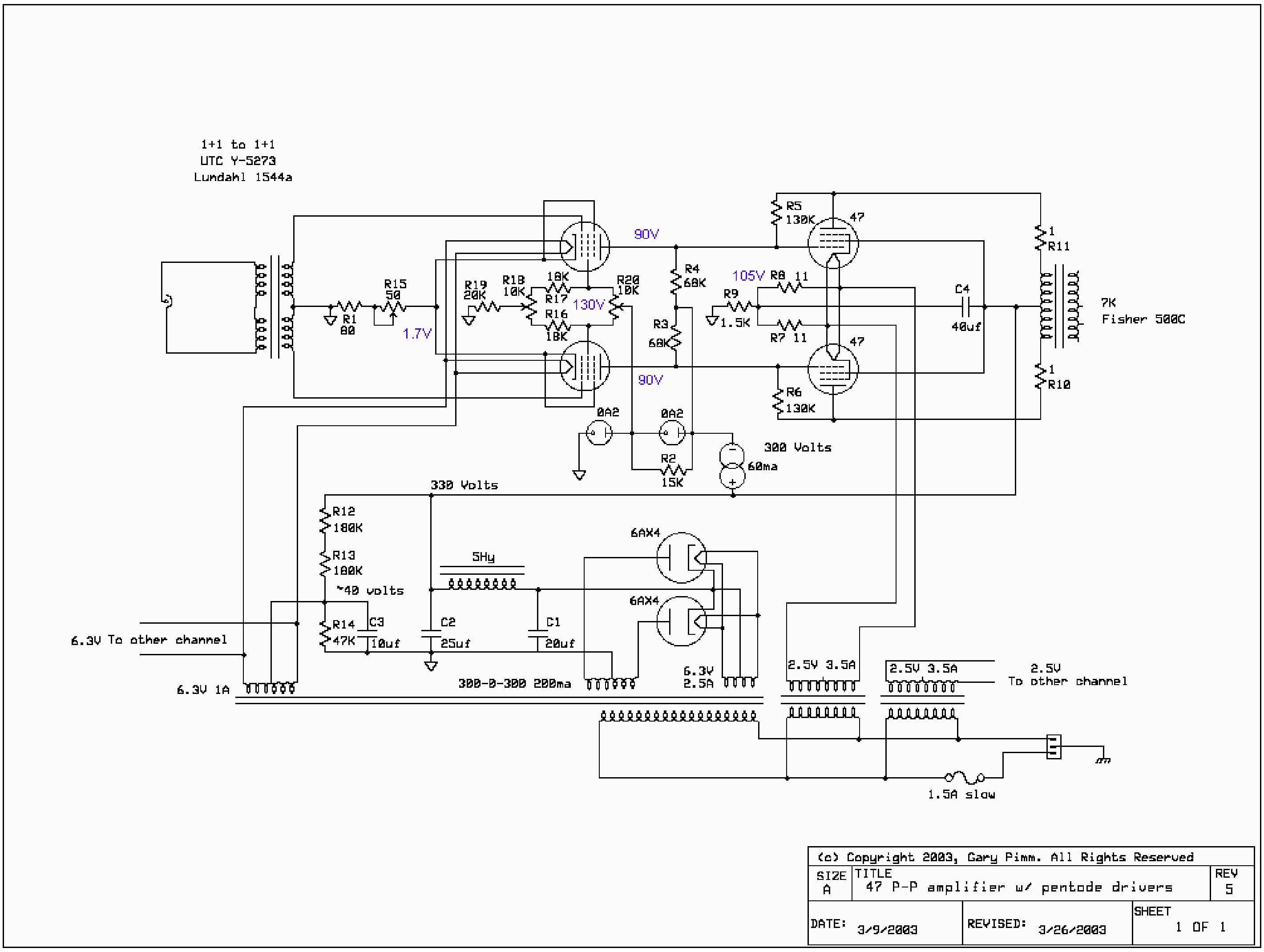
The next experiment is a pentode driver stage. This is based on comments in the past that a pentode driver with a low impedance load sounds nice. With the output stage having a low input impedance this seemed like a natural. Sound wise I think it is a small improvement. More listening tests are needed. I have installed the pentode driver without removing the triode driver. You can plug in either the 6SN7 driver or a pair of 6AU6 pentodes. The amp is setup with separate bias and balance tweaks for each driver setup.

There are DC stability issues to work out though. With 47's in the amp with the pentode driver is reasonably stable. With EL84's in the amp the balance could be called dicey at best. It needs to be adjusted every half hour or so. I have some circuit changes to try based on the schematic from my Tektronix 502 oscilloscope. It has a differential input vertical amp that uses 4 6AU6's cascaded. I want to try the DC balance method used in the scope circuit

Here is the pentode driver schematic.



I did some more work on the DC stability issue. This is the real challenge with a DC coupled circuit. For better control of the DC balance I have changed the circuit to have the balance done with the screens of the input tubes. I used a 2 pot system that gives coarse and fine control. The coarse control (R20) handles the large changes needed when using non matched input tubes. The fine control (R18) makes the final adjustment much easier. Another change is the screens of the output tubes are connected to B+ again. This seems to help the circuit not be so sensitive to line voltage changes. Also increases the output power a bit. With the screens on the 300V regulator it only put out 3 watts, with the screens on B+ I'm getting 3.8 watts. These changes have not degraded the sound. I had tried running the 68K driver plate resistors to B+ but it did not help DC stability and did not sound as good. Had a slightly foggy sound that hid some of the finest details. The shunt resistor across the upper VR tube is to help balance the current. The input screens and balance circuit draws enough current that the lower VR tube was light on current where the upper was cooking pretty hot. The resistor shunts 10ma around the upper VR tube to compensate for the current drawn by the screens. I still want to mess with screen voltage and see if there are any gains in sound quality to be found there.



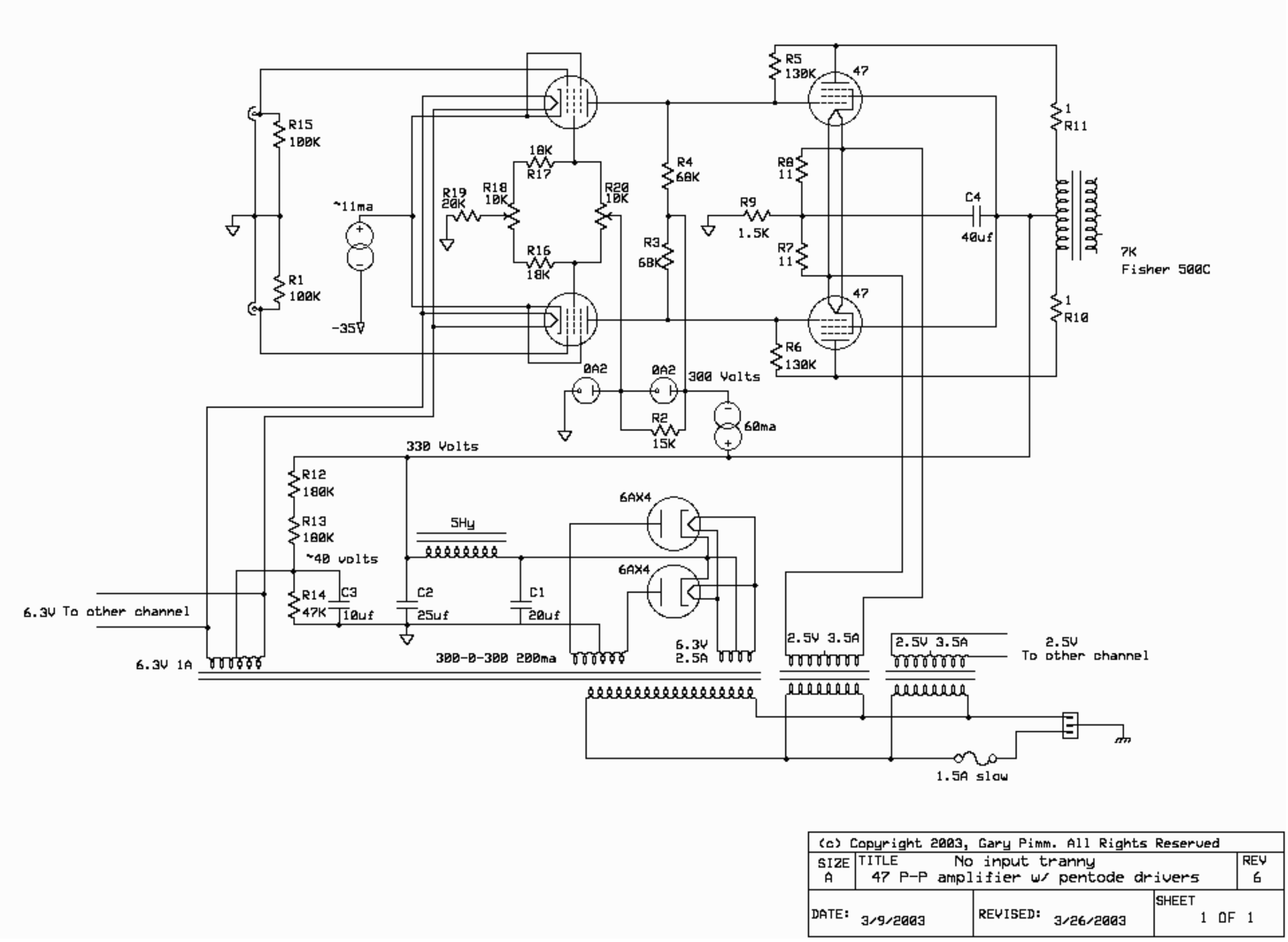
The next version tried has the input tranny phase splitting replaced by a CCS on the cathodes of the input tubes. This makes the amp easy to drive and is sensitive enough to run without a line stage.

Phase splitting is done by the input tubes. To accomplish this the input stage is loaded with a CCS. To keep the CCS happy we will need a negative supply to run it from. Anything in the -20 to -50 volt range will work. Filtering needs are low as the CCS will isolate the ripple and noise. I have drawn up a schematic for this version but have not built it yet. This would be a cheaper version to build.

Somewhere along here the DC servo that is shown below was installed.

Another change that was made was the 40uf polly in oil caps on the cathodes were replaced with 12uf paper in oil. This was a good improvement in transparency. Didn't get this change shown until the Rev 8 schematic.

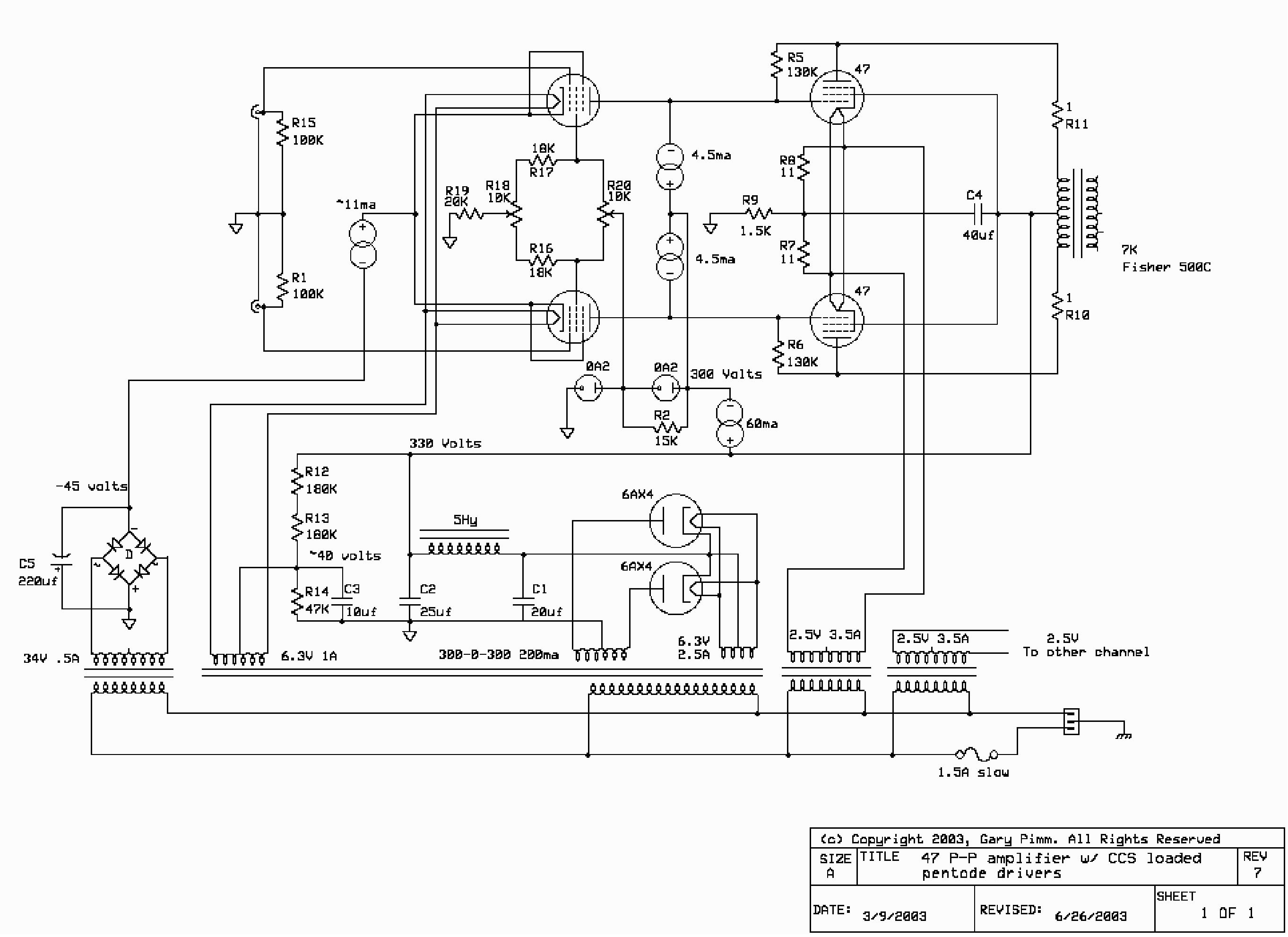
Another output tube that is much more common that will run in the circuit with some mods it the EL84. The output stage would need to be setup with a 6.3 volt heater and wired for the indirectly heater pentode. Sound wise it's great with the EL84's. I have a quad of powered 5 pin to 9 pin adapters so I can take out the 47's and plug in the EL84's. The 47's are a touch more open and have the DH sound that the IDHP's don't have.



After listening to the version above for awhile it was time for more experiments. I had been thinking about the details of how the circuit works. The more I thought about it the more it became apparent that the 68K plate resistors on the input pentodes were really messing with the feedback arrangement.

The next step was to replace the 68K resistors with CCS's. This improved the sound quality noticeably but the real change was the output impedance dropped. The 16 ohm 3uf zobel network and 35 ohm resistor across the speaker were not needed any more. The zobel was used to tame the hot high end response that only showed up on the pentode amp. The 35 ohm resistor tightened up the bass as the amp didn't see the wild phase and impedance swings of a vented box alignment. There was almost no change in sound balance and bass control when the parts were removed. The CCS's were a nice improvement but the circuit was really getting messy.

At this time the feedback was working much better and I started using the 16 ohm tap to drive my 16 ohm speakers.



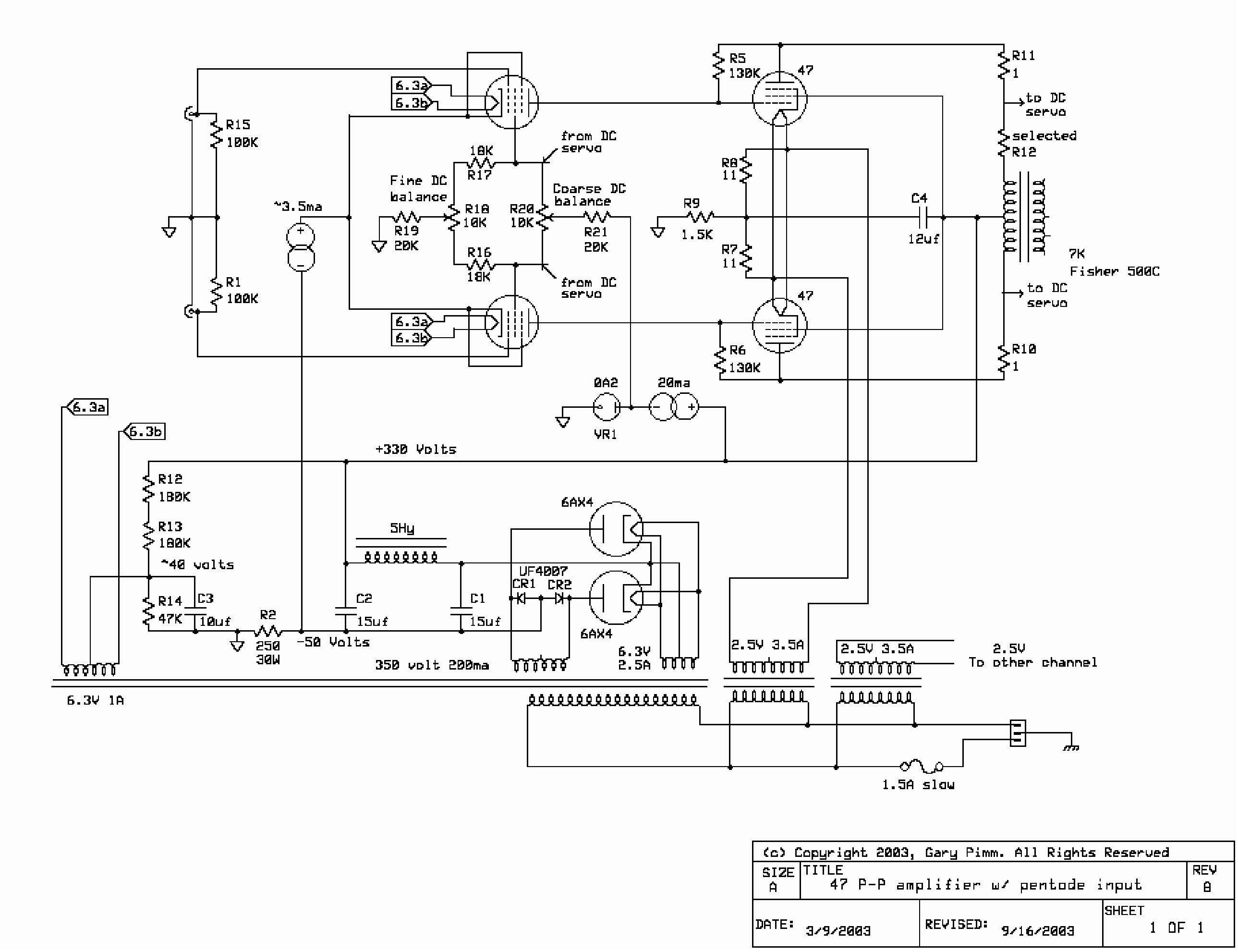
The next step was done after getting feedback from Anthony D that his version of the amp was working great running the input stage just on the current from the feedback resistors. The input CCS's were reprogrammed for ~3.5ma and the CCS's on the input pentodes plates were removed.

This was a major improvement! Everything that made this amp nice to listen to got better. Faster, cleaner, blacker, etc.

Another change done at this time is in the power supply. A transformer that puts out 50 volts more was substituted in. A 250 ohm 30 watt resistor was added between the - end of the power supply and ground. The 250 ohm resistor drops 52 volts at the normal operating current of the amplifier. A free -50 volt supply with slow turnon!

A power supply has been constructed in a matching case. Gone is the piece of plywood with parts screwed to it as seen in San Francisco. While building the new supply the 20uf and 25uf polly in oil caps were replaced with 15uf paper in oil caps.

I have also drawn in the connection points for the DC servo.



Got some more ideas from Anthony. He has added a choke and oil cap per channel to create separate screen supplies. Said that it was a nice improvement. Kurt tried it and agreed that it was nice. I'll have to give it a try myself.

I played with the screens on the output tubes. The chokes I have have too much DCR to use here. Instead, I connected the screens to the top of the VR tube stack (+300 volts). Even though the schematic only shows 1 0A2, the amp still has 2 from earlier experiments. I had left it in because if the upper VR tube was removed the heat sink on the CCS feeding the shunt reg would have to be bigger.

In this case it did not work at all. With the screens referenced to ground the amp hummed quite loudly and oscillated during power up. I'm using quite small caps in the power supply so there is a lot of ripple. The output stage is referenced to B+, not ground. With the output stage riding up and down on the ripple and the screens referenced to ground, the output stage was trying to use the screens as a signal input to amplify the ripple on the supply.

The ripple is not an issue as far as amplifier function goes. We have 3 things working in our favor here. 1)The output impedance of the pentode input stage is very high. 2) The input impedance of the output stage is quite low. 3) the output stage sees ripple as a common mode signal. 1 and 2 work together to insure the amplifier's input stage is very insensitive to voltage changes seen by it's load, the output stage. 3 insures that what little bit of signal does get to the output stage is rejected by the common mode rejection of the output stage. The feedback also helps to reduce the hum.

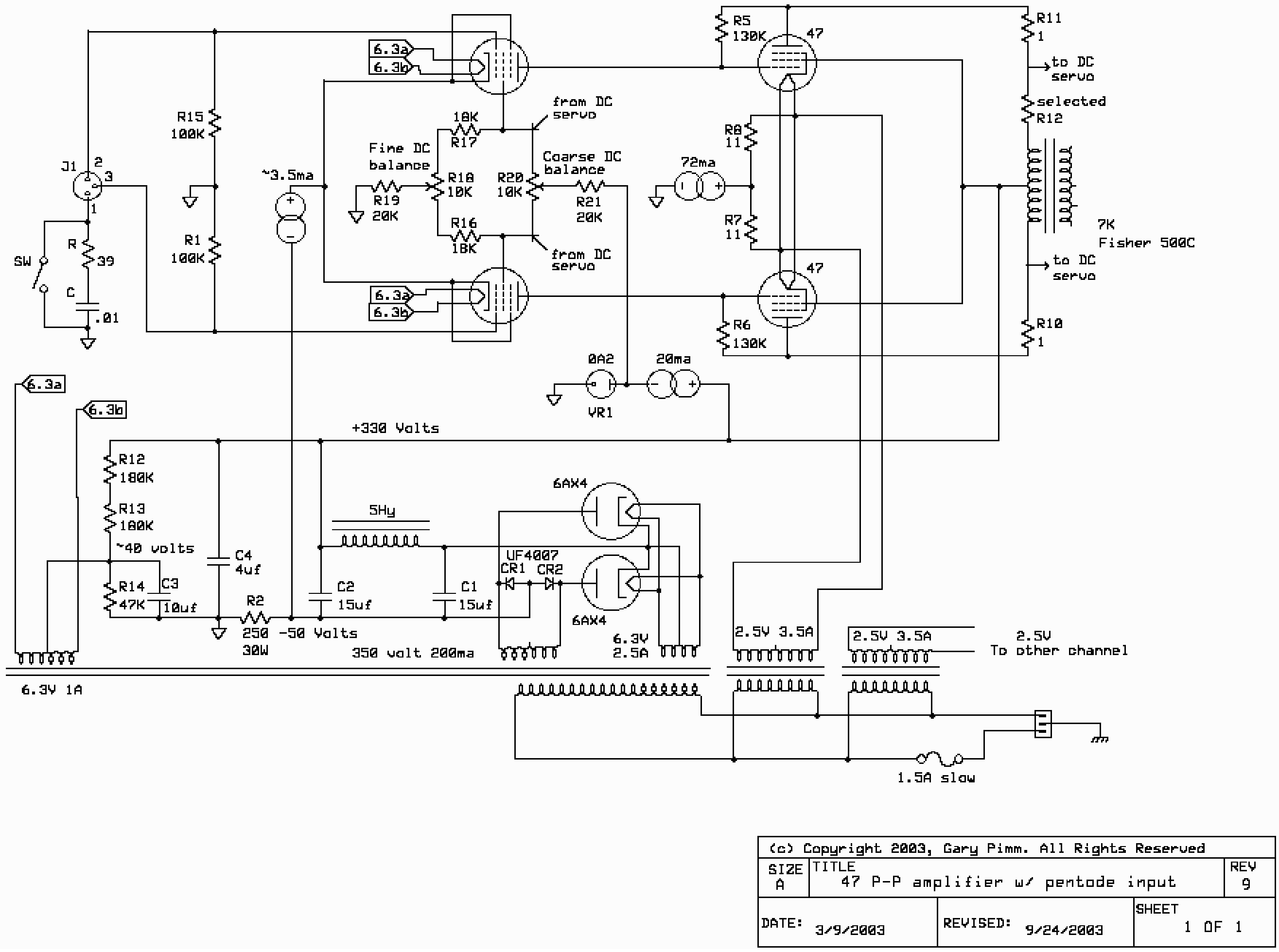
On to new developments. Had an interesting email exchange with another designer who is well known for CCS's and differential amps. At one point he basically said "But as *the* CCS man- why haven't you gone all the way & CCS'd the output stage? WE both know 1.5K doesn't a CCS make!". Well that finally got me going. CCSing the output stage has been on the idea list from about the 3rd revision. Just had not taken the time to set it up. Last evening I built up a pair of 72ma battery biased CCS's and came up with a heat sink scheme that would fit in the already over crowded box. Every thing worked out pretty well. The heat sinks are 2" x 10" .060 aluminum sheet. These are attached to the sides of the cabinets inside the box. After a couple of hours operation the amp was shut down and quickly opened. I could hold my fingers on the heatsink directly by the mosfet. Was nice and warm but not uncomfortable. Looks like the heatsinking is adequate.

Sound? I feel like I'm starting to sound like a broken record. Everything the has made this amp a pleasure to listen to has improved. Faster, better low level information retrieval, more open sound, bigger sound stage, yada yada yada.

With the CCS in the cathode circuit I tried removing the 12uf cathode bypass capacitor. At this point I can't tell any difference in sound if it is in or out of the circuit. If this proves out it is a good thing! Without the need for a cathode bypass cap it gets the last cap out of the signal current loops. This makes the amp a DC coupled with no caps in any of the signal loops. A good thing for someone who thinks caps are evil! Even in the older versions were the cap was needed it only handled the imbalance AC current of the output stage. ~5% of the total signal current at a guess.

The inputs were changed from 4 RCA jacks to 2 XLR jacks. This gets the amp ready for differential signal sources. I have made a pair of XLR to RCA adapters that connect pins 1&3 to the RCA ground shell and connect the center of the RCA to pin 2. With the switch at the input open it effectivly breaks ground loops.

Here is the updated schematic with the output stage CCS.

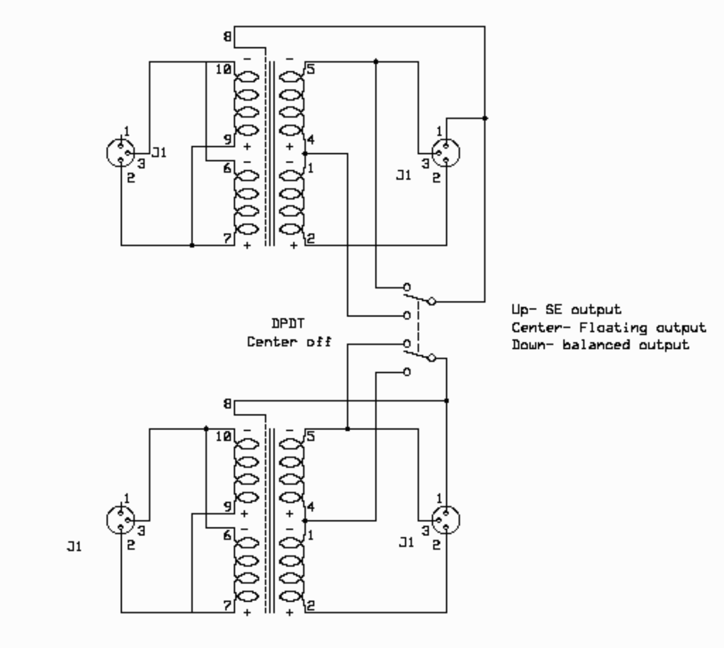


After getting back from VSAC got the opportunity to try out one of Dave Slagel's autotransformer volume controls. This was a very welcome improvement! The transformer volume control (TVC) just has a "rightness" to it that the 10K Dact stepped attenuator can't match.

After listening to my system in this configuration for a few weeks I added a Lundahl LL1676 transformer between the TVC and the input of the amplifier. The transformers are in a small project box with XLR plugs and jacks. There is a switch setup to configure the output of the transformer to be balanced, SE, or floating. The electrostatic shield is connected to ground on the output side. With the LL1676 in the system everything just got better. One of the things that stands out as a big improvement is the tone and texture of the bass. The switchable output configuration is useful to try and determine where the improvement is coming from, the phase splitting capabilities or the ground isolation and bandpass limiting of the electrostatic shield. If we assign the improvement in sound using the phase splitting configuration at 100%, the improvement in sound using the transformer in SE configuration and having the amplifier do the phase splitting is at 90%. I could not hear any difference between balanced and floating configuration. Being able to run the transformer in SE mode allows me to use it with the 300B amp also. Most of the improvements that are heard with the PP amps can be heard with the SE amp too.

This makes me think that the main improvement in sound quality is from the ground isolation or bandpass filtering of the transfomer. In talking about bandpass filtering I'm referring to blocking high frequency garbage that is well outside of the desired frequency range we want the amplifier to amplify, not having a system with limited frequency response in the audio band. Even with the transformer in series with the amplifier, the high frequency response extends out past 100Khz.

Here is how the Lundahl LL1676 is setup to be plugged in between the TVC and the amplifier.



The next thing that was bugging me is the power supply. The amp wastes lots of power in the output stage CCS. The input stage would be much happier with more voltage also. I also don't like running the input pentodes at 90 volts on the plate and 100 volts on the screens. The catch 22 here is that if the supply voltage is increased to make the input pentodes happier, we waste even more power in the output stage. The output CCS's are already at 8.25 watts dissipation.

I started toying with the idea of using stacked supplies. This way the output supply can be a lower voltage to relieve the stress on the output CCS and we can have a second supply to bias up the input stage.

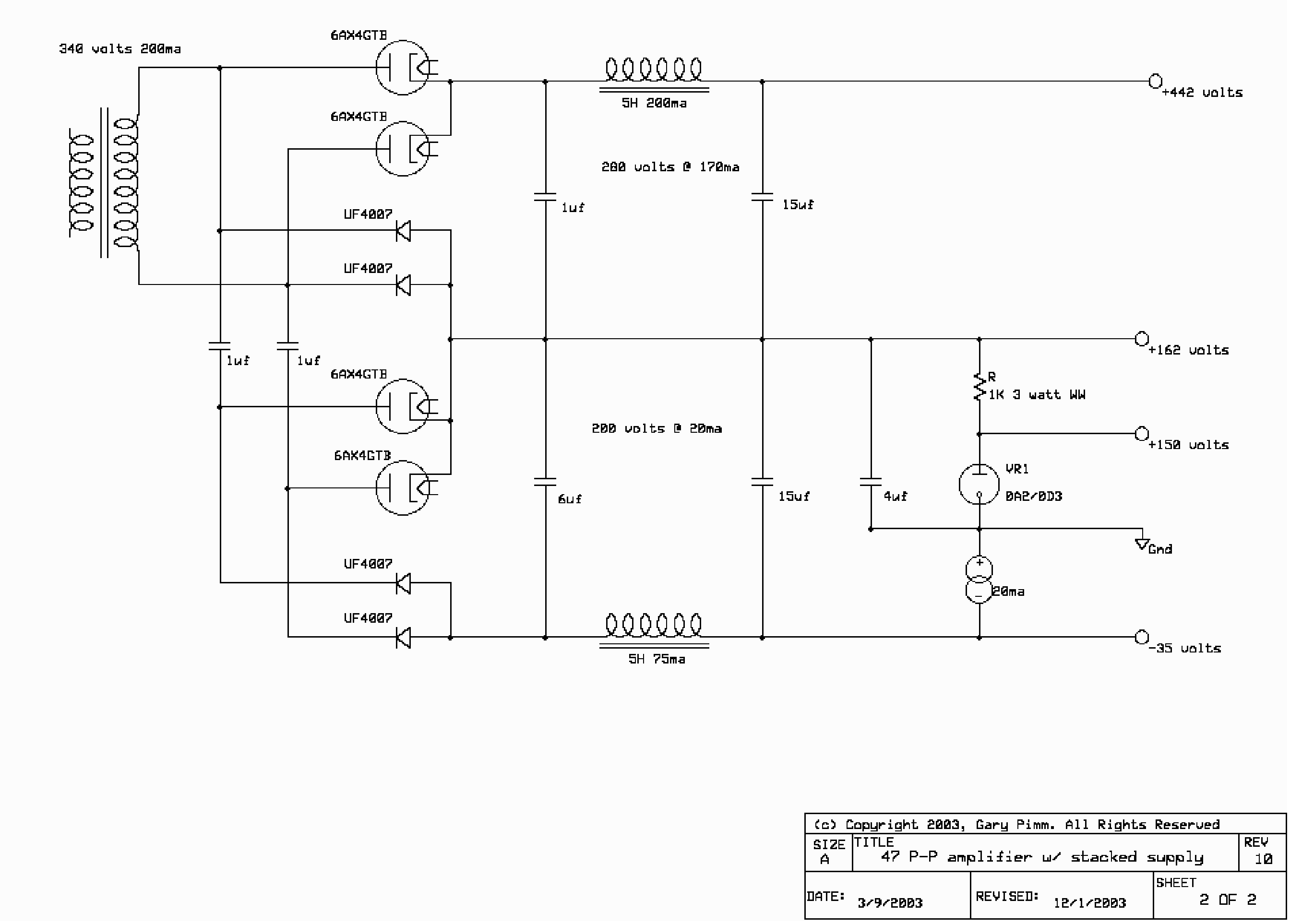
The first ideas called for either another power transformer or a custom transformer with 2 secondary windings. After thinking about it for a few days a new idea came up. Use capacitors to couple the primary voltage of the single secondary to a second rectifier bridge to create the input stage supply. With the current needs of the input stage being quite low I thought I'd give it a try. This also allows you to run the input supply at lower voltage than the output supply and not waste power in dropping resistors. Changing the size of the coupling caps varies the voltage of the input supply. The caps are 2 .5uf 1000 volt Sprague paper in oils paralleled.

The final tweak to the new supply was to connect the + end of the input power supply directly to the 150 volt VR tube and hang the CCS between the - end of the power supply and ground. In this configuration the CCS tries to pull the bottom end of the supply up to ground. When the top of the supply hits 150 volts the VR tube starts to conduct and holds the + rail of the input supply at +150. This left -50 volts for the CCS on the input stages. This increased the plate voltage on the input pentodes to 168 volts and decreased the voltage on the output CCS from 115 to 35. Power dissipated in the output CCS dropped from 8.25 watts to 2.5 watts.

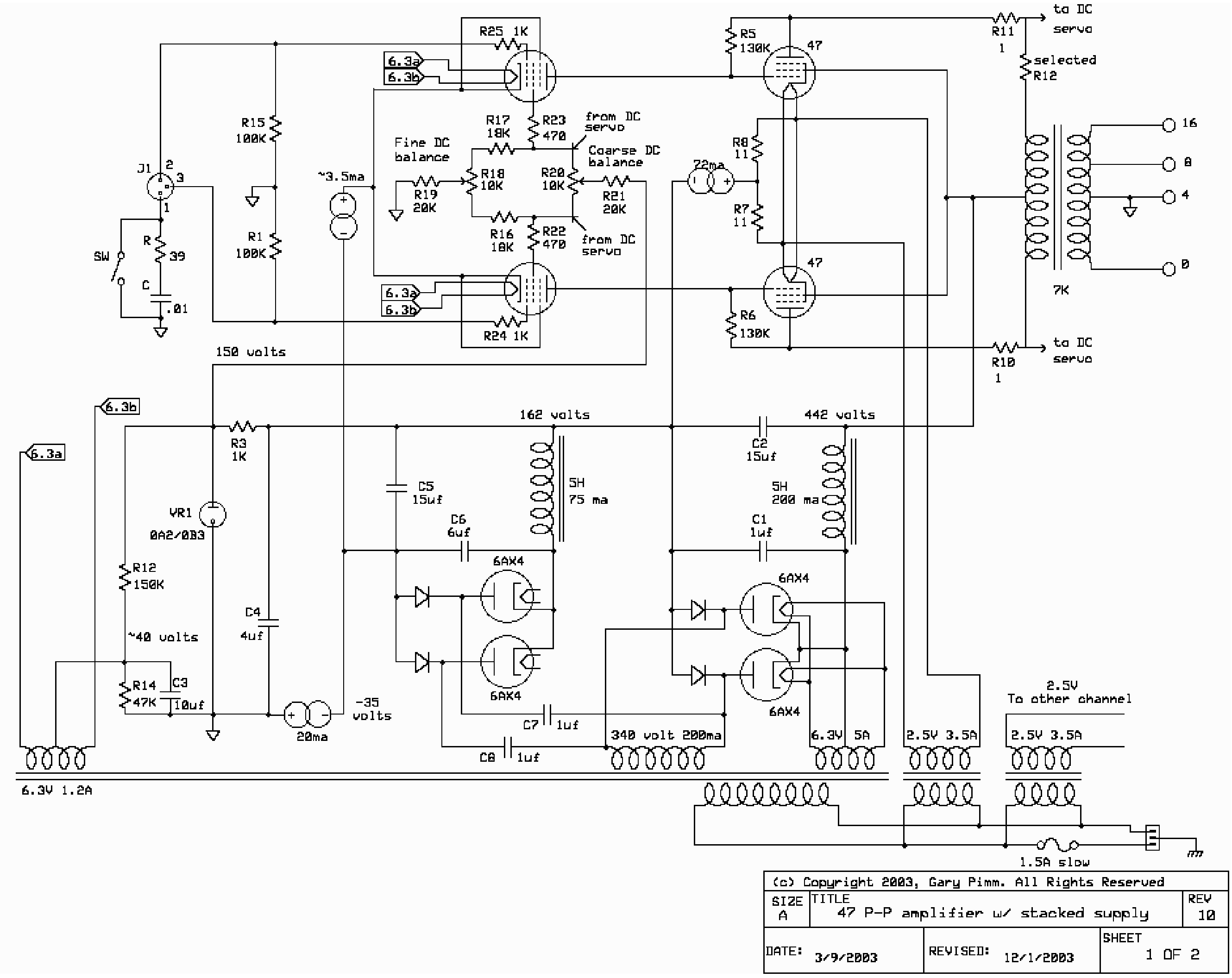
After fiddling around with this on the bench I found that the supply needed a capacitor between ground and the bottom of the output stage power supply. To keep the VR tube happy and isolated from the capacitor a 1K resistor was added between the VR tube and the + rail of the input supply. This increased the mid point of the supply (+ rail of input supply/ -rail of output supply) to 162 volts and reduced the - supply to -35 volts. This increased the voltage on the plates of the input pentodes from 168 volts to 180 volts.

The output stage is connected between the the +442 and +162 volt taps on the supply. The +150 is used for the screen supplies of the input pentodes and the -35 is used for the input CCS's.

Here is a schematic of just the power supply. It's easier to follow drawn out this way.



Here is the amplifier schematic with the new power supply incorporated. The input stage has been updated to show the screen and grid stopper resistors also.



The new power supply is performing very well. The power transformer and the output CCS's are running cooler and the input pentodes are at a much better operating point. All the concerns about the old power supply have been addressed.

The only thing that needs to be addressed it turn on hum. The plate to cathode voltage of the output tubes is set by the current flowing through the feedback resistors. This current is determined by the CCS on the input tubes. The input stage is at full operating current rather quickly and this forces the output stage to try to set the plate to cathode voltage to the standard operating point before the voltage is available. This starves the output CCS of voltage. When the current is below the set level on a battery biased CCS the CCS looks like a resistor with the value of (R1+5 ohms), or in this case about 130 ohms. Everything gets quiet as soon as there is voltage for the output CCS.

The fix for this (I think) is going to be to use the mosfet only version of the Rev 5 CCS on the input stage. It starts in the off state and slowly increases the current up to the operating point, which is the opposite of the battery biased CCS. The battery biased CCS is on hard until the current increases above the set point. By increasing the value of C5 in the Rev 5 CCS the turnon time increased. The right size cap should delay the input stage reaching full operating current and stop the hum during startup. The only thing that is keeping me from trying this out is I have run out of space inside the prototype case. The darn thing is full!

Sound wise, it sounds just a touch cleaner and more dynamic.

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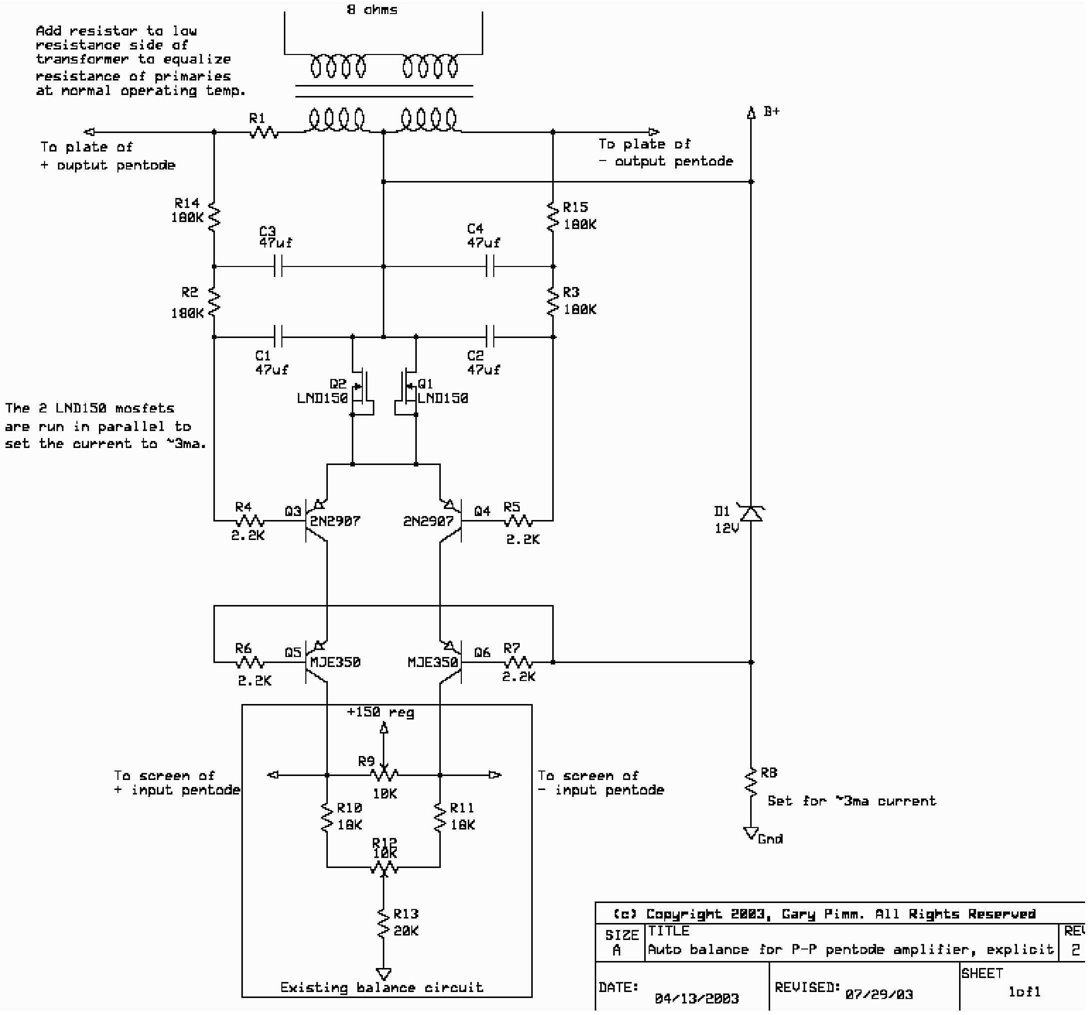
Here is the autobalance servo circuit. Basically, it senses the current in the output tubes by the DC voltage drop across the primary of the transformer. Because it is using the primary for the sense, if the resistance of the 2 halves of the primary don't match you need to add resistance to the low side to make it match with the high side. This must be done with the transformer warmed up to normal operating temp.

When the circuit is balanced the differential amplifier (Q3,Q4) sends equal amounts of the ~3ma bias current provided by the LND150's through both transistors. If the amplifier drifts off center the differential amp will increase the current delivered to the screen of the side of the amp that is drawing more current. This turns the input pentode on harder on that side which in turn pulls down on the grid of the output tube on that side, decreasing the current it draws.

The auto-balance circuit connects to the screens of the input pentodes and works with the DC balance pots. Once you adjust the output balance it does not drift more than .5ma after warm-up.

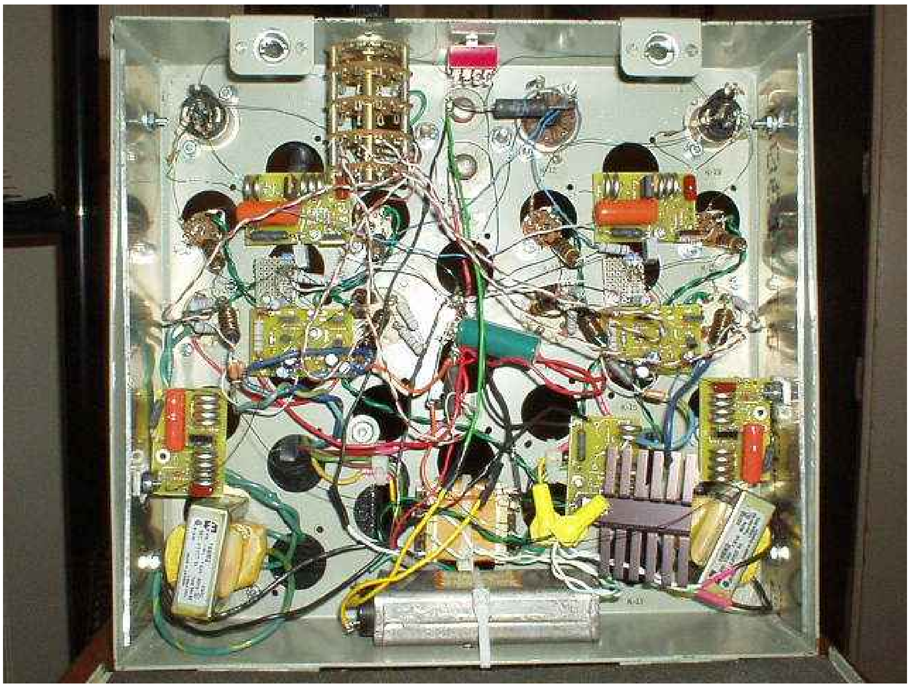
Q5 and Q6 provide both level shifting and cascode isolation to the differential amp (Q3, Q4) The transistors used for Q3 and Q4 are now BC560's. They have a much higher gain than the 2N2907's.



The circuit is constructed in an old relay cabinet. This makes a great prototype chassis. When I'm done tweaking the sound I plan on building a nice chassis for it.

The innocence of a freshly started project...

Followed by the corruption of 9 months of tweaking...



Current front view