diyAudio™ F-5 Class A Power Amplifier Build Guide

Prepared, compiled and written by JojoD818
Build Guide revision 1.0 for use with diyAudio F5 V2.0 PCBs

Introduction:

This diyAudio Build Guide is all about the First Watt F-5 Class A Power Amplifier, one of the most popular amplifiers built in the DIY world. If you would like to ask any questions, please visit the diyAudio Store F5 Build Guide thread.

Conceived by the creative genius known as Nelson Pass, the F-5 is the fifth installment in his First Watt series of power amplifier designs. Nelson is most often spotted on the road less traveled and he's happy to break with convention when he sees a better way to do things. A common theme in his designs is simplicity and that is very much evident in the design of the F-5.

The F-5 is basically a push-pull Class A amplifier that uses JFETs on the input and MOSFETs as output devices. Some of its features are:

- Very low distortion
- High damping factor
- A hefty 50W (25W per channel) of Class A power output
- Can drive highly demanding speaker loads
- Properly built, it is well behaved and sounds great
- No capacitors in the signal path
- Few components to deal with
- It's fun and easy to make, which I'll show you with this build guide

The fun begins in collecting the boards and parts you need for the F-5. Don't forget the power supply parts! Then get a suitable chassis with fairly large heatsinks to accommodate the amp's Class A power dissipation and that's about it. The diyAudio Store 4U x 300mm chassis or something with similar sized heatsinks will do fine. Finding the parts is a big part of the job so don't get discouraged.

The choice of parts types is mostly up to the builder. You can always go overboard and get some pretty exotic resistors and power supply capacitors - nothing wrong with that! It's important to note though that Nelson Pass ranks circuit design over component choice. Doing as he does and getting decent components with recognizable brand names, but that won't break the bank, is a good idea for reliability and longevity. We've also provided a Bill Of Materials (BOM) section for reference in choosing parts for the project.

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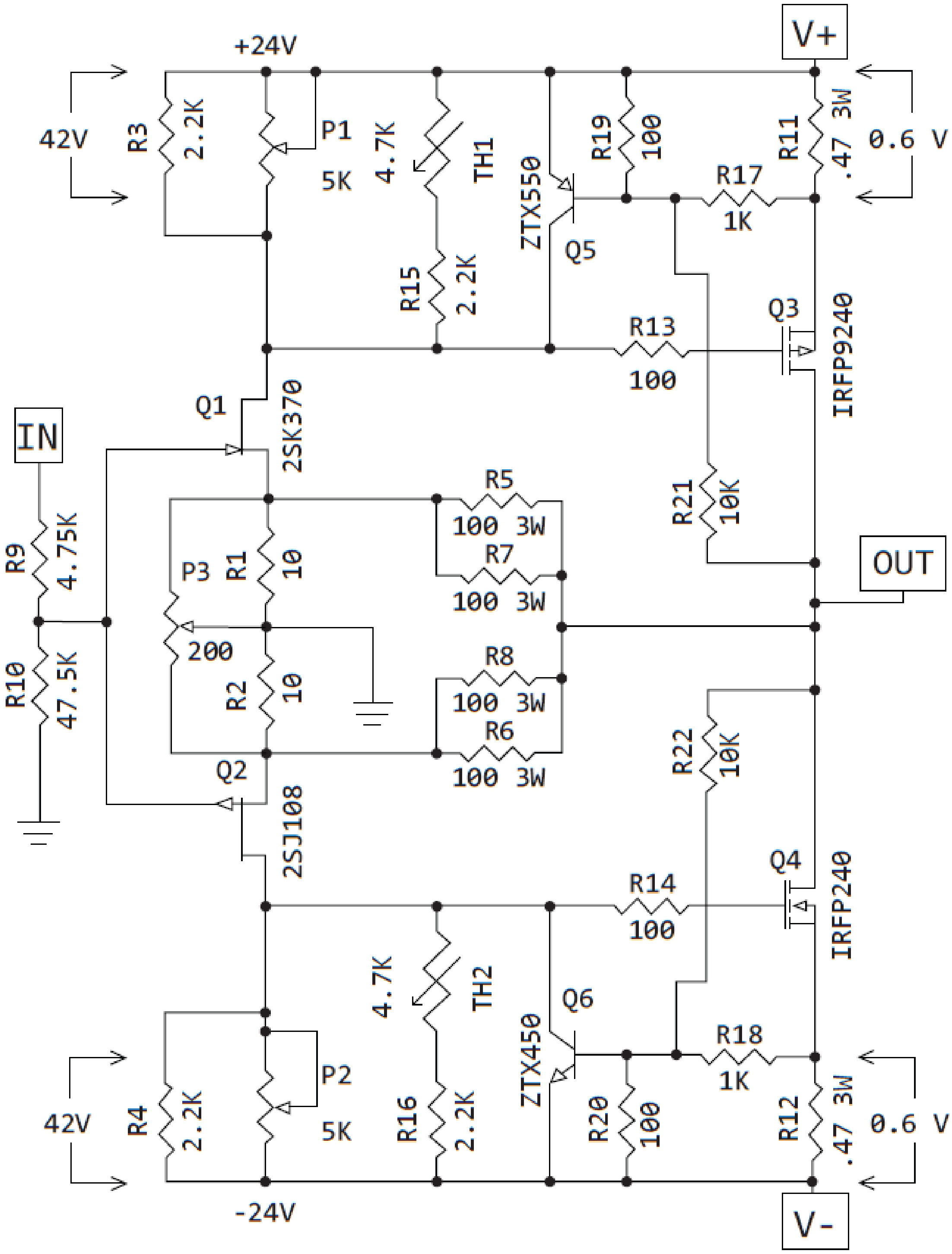
About the circuit:

Below is the schematic for the First Watt F-5 Class A Power Amplifier.



F5 Amplifier (c) 2008 Nelson Pass

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Bill of Materials:

Following is the recommended Parts List for constructing **ONE CHANNEL** of the F-5 Class A Power Amplifier project. Of course you're not limited to these parts, but they represent good quality, and are often the exact same parts that Nelson Pass uses. Please refer to the **Ideas and Alternatives** section for help with alternate parts and other combinations.

Transistors:
Q1 - 2SK170
Q2 - 2SJ74
Q3 - IRFP9240
Q4 - IRFP240
Q5 - ZTX550
Q6 - ZTX450

Diodes:
LED1 – Any color 3mm or 5mm LED. Our amp uses a rectangular LED which is fine too.

Resistors: (All are 1/4W unless otherwise specified)
R1 – 10R / 1W
R2 – 10R / 1W
R3 – 2.2K
R4 – 2.2K
R5 – 100R / 3W
R6 – 100R / 3W
R7 – 100R / 3W
R8 – 100R / 3W
R9 – 4.75K
R10 – 47.5K
R11 – 0.47R / 3W
R12 – 0.47R / 3W
R13 – 100R
R14 – 100R
R15 – 2.2K
R16 – 2.2K
R17 – 1K
R18 – 1K
R19 – 100R
R20 – 100R
R21 – 10K
R22 – 10K
R35 – 33K

P1 – 5K Potentiometer (Variable Resistor)
P2 – 5K Potentiometer (Variable Resistor)
Optional:
P3 – 200R Potentiometer (see **Ideas and Alternatives** section)

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TH1 – 4.7K NTC Thermistor
TH2 – 4.7K NTC Thermistor

Tools Required:

- Screwdrivers - Phillips and Flat
- Miniature Screwdrivers - Phillips and Flat
- Small Diagonal Cutters
- Insulation Strippers
- Needle-nosed Pliers
- Solder, 60/40 Rosin cored or similar
- Soldering iron about 30 - 40 Watts (A temperature controlled workstation makes soldering a lot easier, and they are available for as little as $50)
- Digital Multi Meter (two or three make it even easier)

Miscellaneous Tools:

- Electric Hand Drill
- Assorted Files
- Solder Sucker
- Solder Remover Braid (Solder Wick)
- Extra Flux
- Lacquer Thinner - To remove excess flux from the board after soldering

A good starting point for tool research or purchase is:
http://www.diyaudio.com/recommended

Ideas and Alternatives:

Power Supply Recommendations:

- The amplifier was tested to work with a power supply of +/-24V (from a 0-18, 0-18 transformer) as recommended by Nelson Pass.
- The transformer used in the prototype was an Antek AS-4218, 0-18V x2 @400VA.
- The PSU board used was diyAudio's P-PSU-1V20 boards which are also available at the diyAudio Store.
- The capacitors are 15,000uF and a minimum of 25v.
- The thermistors (TH) are CL60 type, and are different than those in the amp circuit.

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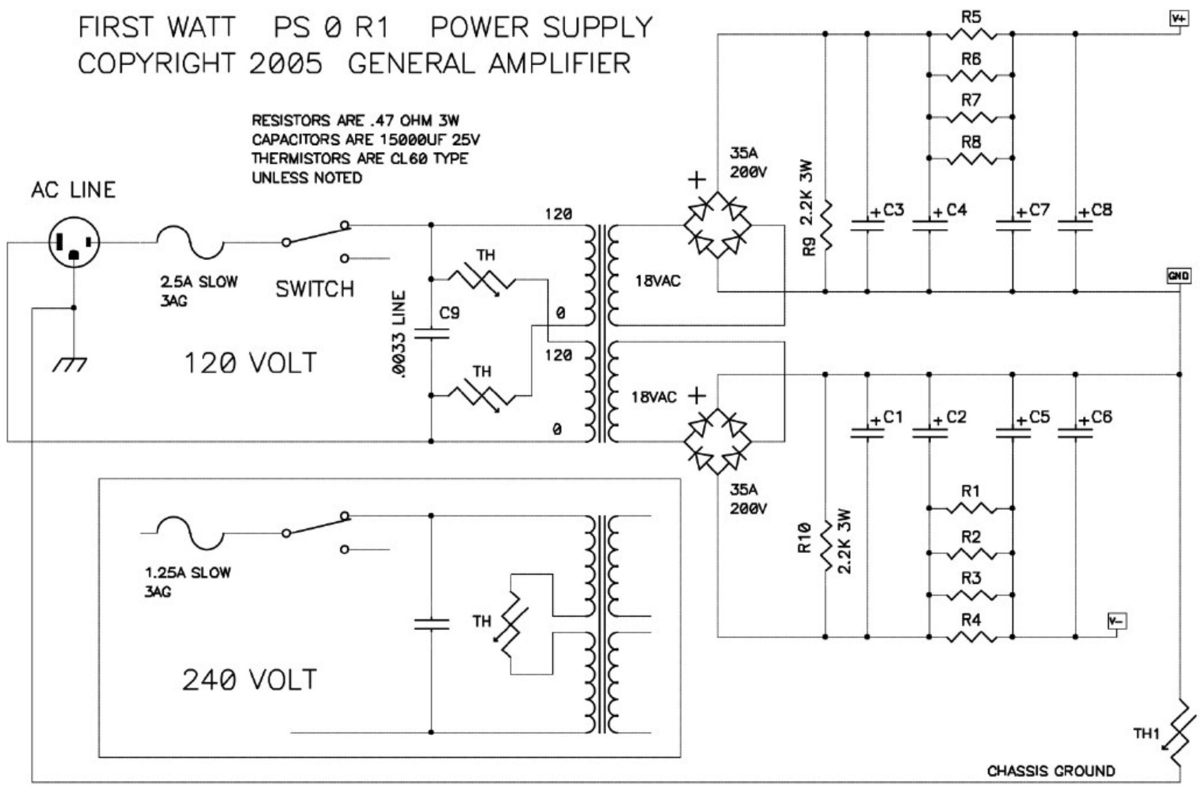
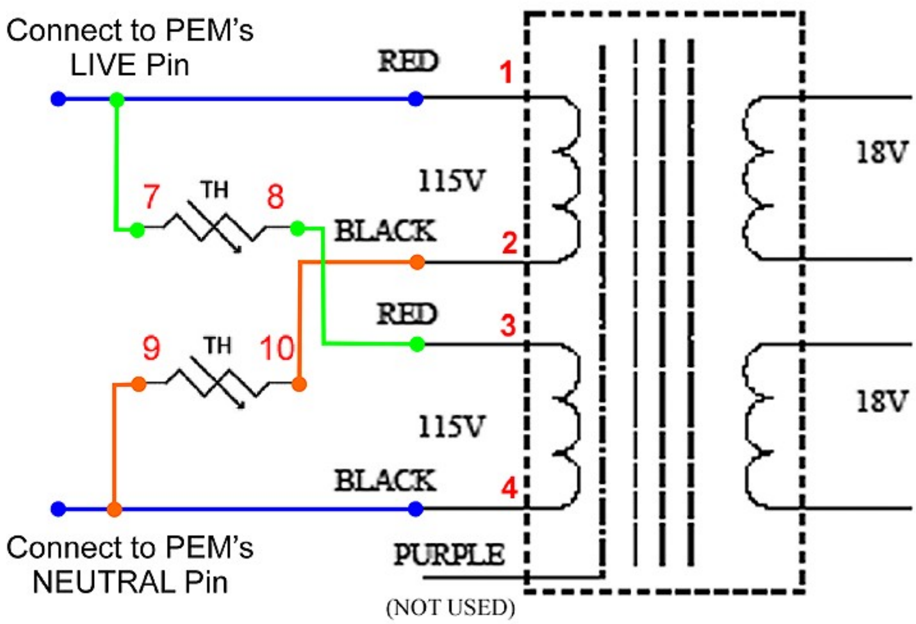
Below is the schematic of the recommended power supply by Nelson Pass.



Wiring your transformer for 120V AC Mains operation:



On the left side are the primary windings, and on the right side are the secondary windings. Notice that there are two pairs of 115V primary windings? There's also a purple wire that's connected to an interstage shield which you can connect to the chassis ground, but let's just leave it unconnected and concentrate on the two pairs of 115V windings for now. Please dress the purple with heatshrink tubing and tuck it away. I have purposedly labeled the wires 1, 2, 3 and 4 for easy reference. What we want to do first is find out which of the four wires are the pairs 1 & 2, and pairs 3 & 4. That is very simple to do.

1. Get your DMM and set it to check for resistance.
2. Now grab one of the red wires and check for resistance between that and the two black wires (Obviously, you will only read a low resistance on one of the black wires).
3. Once you read a low resistance between a red wire and a black wire, label the red wire as 1 and the black wire as 2.
4. Now get the other red and black wire and check for resistance.
5. You should read a low resistance between them confirming that's the other pair.
6. Label the red wire as 3 and the black wire as 4.
7. Prepare two CL-12 thermistors.
8. Get one of the thermistors and label its leads as 7 and 8.
9. Get the other thermistor and label its leads as 9 and 10.

Ok so now we know our pairs 1 & 2 and 3 & 4, and we have our thermistors ready too, we are now ready to wire our transformer for 120VAC operation.

1. Get one of the thermistors whose leads were labeled 7 and 8.
2. Connect the thermistor's lead labeled 7 to the LIVE pin of the Power Entry Module (PEM).
3. Also connect the transformer's red wire labeled 1 to the PEM's LIVE pin.
4. Connect the thermistor's lead labeled 8 to the transformer's red wire labeled 3.
5. Insulate that connection with heatshrink tubing.
6. Get the other thermistor whose leads were labeled 9 and 10.
7. Connect the thermistor's lead labeled 9 to the PEM's NEUTRAL pin.
8. Also connect the transformer's black wire labeled 4 to the PEM's NEUTRAL pin.
9. Connect the thermistor's lead labeled 10 to the transformer's black wire labeled 2.
10. Insulate that connection with heatshrink tubing.

And that's it, your power transformer is now ready for 120V AC Mains operation.

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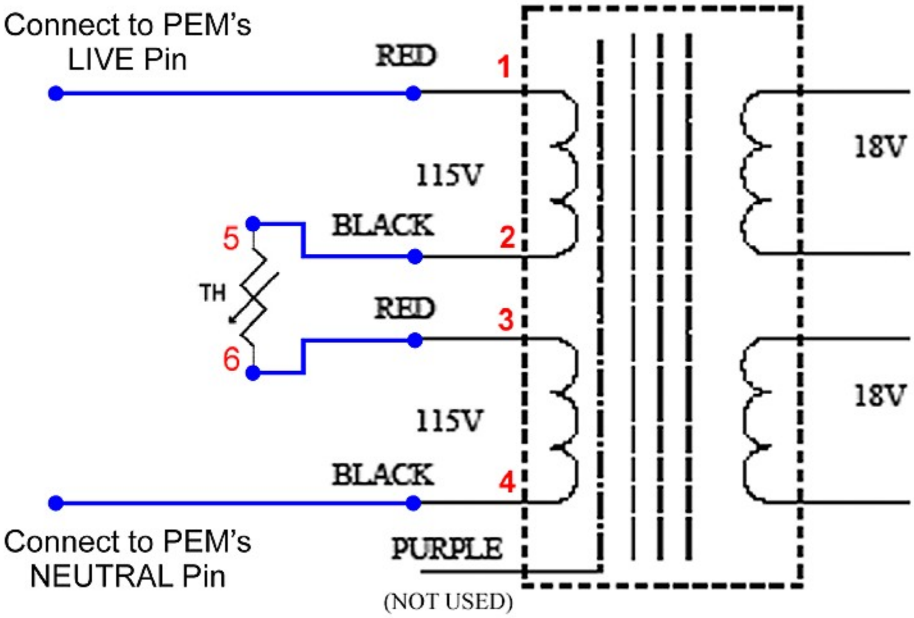
Wiring your transformer for 240V AC Mains operation:



On the left side are the primary windings, and on the right side are the secondary windings. Notice that there are two pairs of 115V primary windings? There's also a purple wire that's connected to an interstage shield which you can connect to the chassis ground, but let's just leave it unconnected and concentrate on the two pairs of 115V windings for now. Please dress the purple with heatshrink tubing and tuck it away. I have purposely labeled the wires 1, 2, 3 and 4 for easy reference. What we want to do first is find out which of the four wires are the pairs 1 & 2, and pairs 3 & 4. That's very simple to do.

1. Get your DMM and set it to check for resistance.
2. Now grab one of the red wires and check for resistance between that and the two black wires (Obviously, you will only read a low resistance on one of the black wires).
3. Once you read a low resistance between a red wire and a black wire, label the red wire as 1 and the black wire as 2.
4. Now get the other red and black wire and check for resistance.
5. You should read a low resistance between them confirming that's the other pair.
6. Label the red wire as 3 and the black wire as 4.
7. Prepare a CL-12 thermistor and label it's leads as 5 and 6.

Ok so now we know our pairs 1 & 2 and 3 & 4, and we have our thermistor ready too, we are now ready to wire our transformer for 240VAC operation.

1. Connect the transformer's red wire labeled 1 to the LIVE pin of the Power Entry Module (PEM).
2. Connect the thermistor's lead labeled 5 to the transformer's black wire labeled 2.
3. Insulate that connection with heatshrink tubing.
4. Connect the thermistor's lead labeled 6 to the transformer's red wire labeled 3.
5. Insulate that connection with heatshrink tubing.
6. Connect the transformer's black wire labeled 4 to the PEM's NEUTRAL pin.

And that's it, your power transformer is now ready for 240V AC Mains operation.

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To P3 or not to P3:

The potentiometer designated P3 was added late in production by Nelson Pass to manually tweak the symmetry of the circuit for the lowest possible distortion with the aid of a distortion analyzer. However, this sophisticated test equipment isn't available to most DIYers and in Nelson's opinion it's not possible to set P3 to lowest distortion by ear.

P3 was not used in the prototype and isn't specifically accommodated for on the circuit boards. However, for those who wish to try it, it can be installed on top of the board by extending the pins of the trimpot (P3) and soldering the leads to their appropriate locations as can be seen in the schematic.

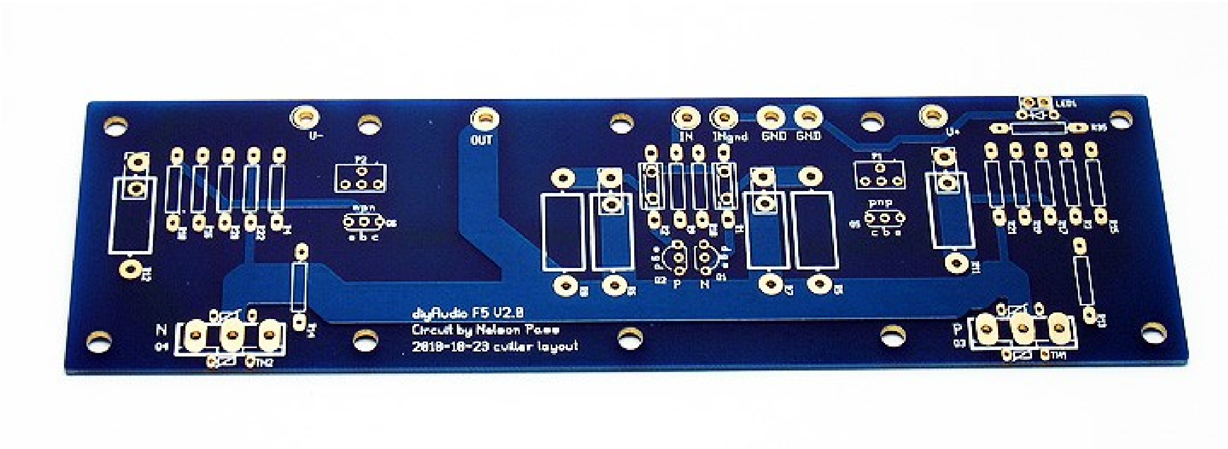
Alternative Transistors:
Here are some of the transistors that can be used in lieu of the original ones listed in the BOM.

Q1 – 2SK370 or 2SK246
Q2 – 2SJ108 or 2SJ103
Q3 – FQA12P20
Q4 – FQA19N20
Q5 – BC560
Q6 – BC550

Construction:

As always, before you begin construction, check your boards and parts and make sure you have everything ready. Familiarize yourself with the board and the schematic, and know where each part must go to before actually placing it. A moment of planning here can save you lots of time later on. There are various ways of doing this, but whether you're just starting to build your amps or already a seasoned builder, following these step-by-step procedures won't hurt. Remember, this is the fun part. :)

Here is an actual photo of one of the F5 boards. They go through a lot of scrutiny before being shipped to you, but anything can happen during transit so check it yourself and make sure all is well.



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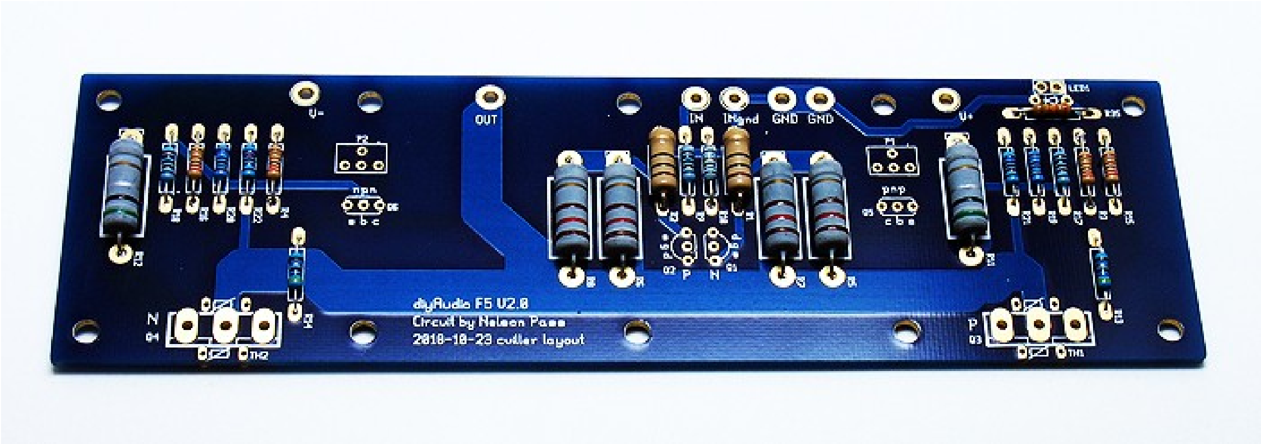
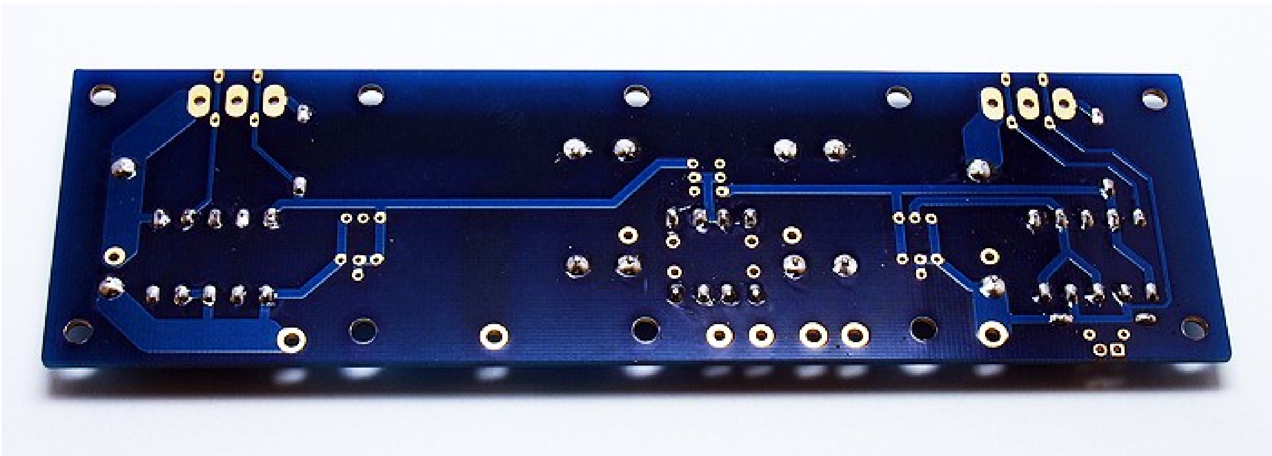


Start construction by populating your board with the resistors, beginning with the smaller 1/4W resistors and then the larger 3W resistors. Pay particular attention to their resistance values. It's very easy to mistake a 68K (68,000 ohm) resistor for a 68R (68 ohm) resistor! It's also a good practice to measure resistors using a digital Multi-Meter (DMM) before soldering them in place. Then bend the resistor leads outwards a bit so they stay in place.

Once you're satisfied with the placement of your resistors, it's time to solder their leads and cut off the excess lead length on the bottom with your diagonal cutter. Don't cut into the thicker solder next to the board.



Note that there are only 23 fixed value resistors on each of the boards so it's very easy to install them and you should be done in no time at all.

Another tip about installing resistors: it's wise to install them with all the bands in the same direction. For all components that have text indicating the value, it's even wiser, and much more fashionable, to install them with the text on top and reading in the same direction if possible. This makes their values easy to make out while checking your resistor placement and making any troubleshooting far easier for you (and the guy on the thread who's trying to help you).

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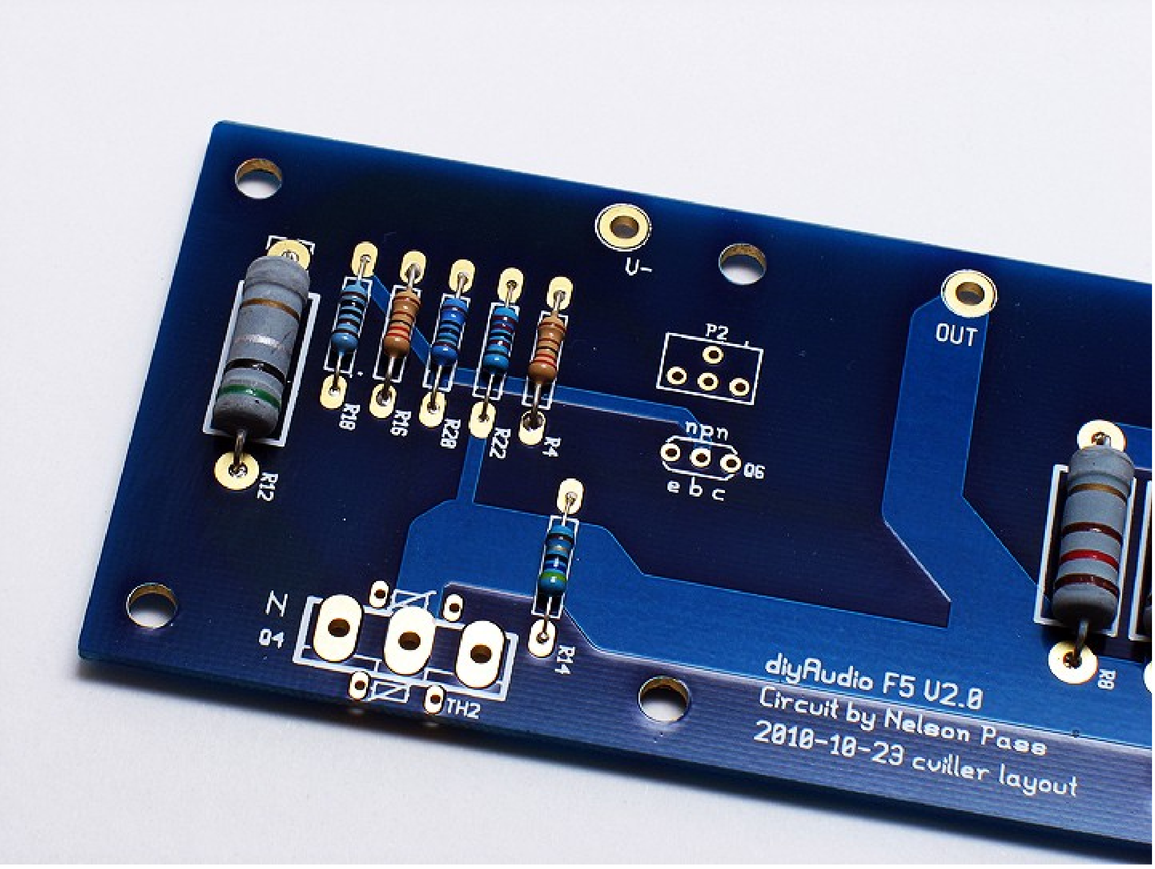

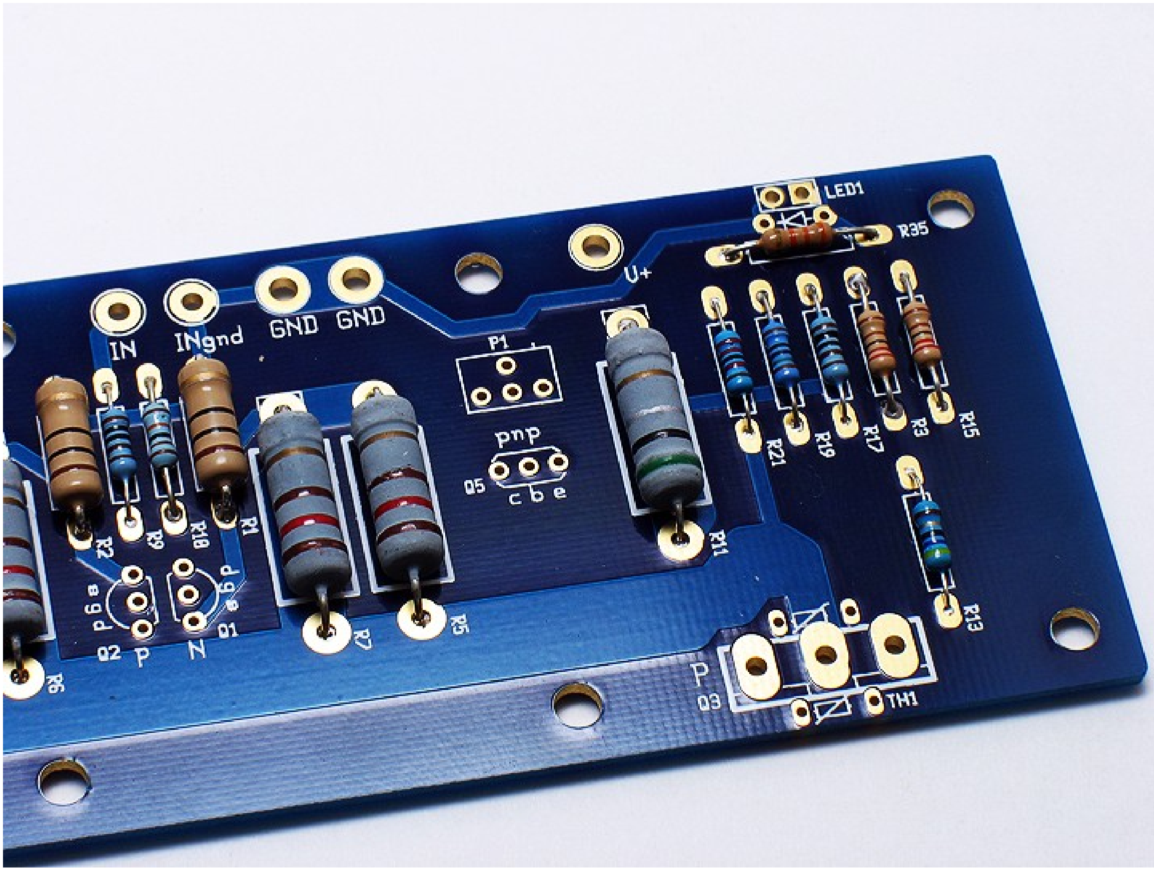

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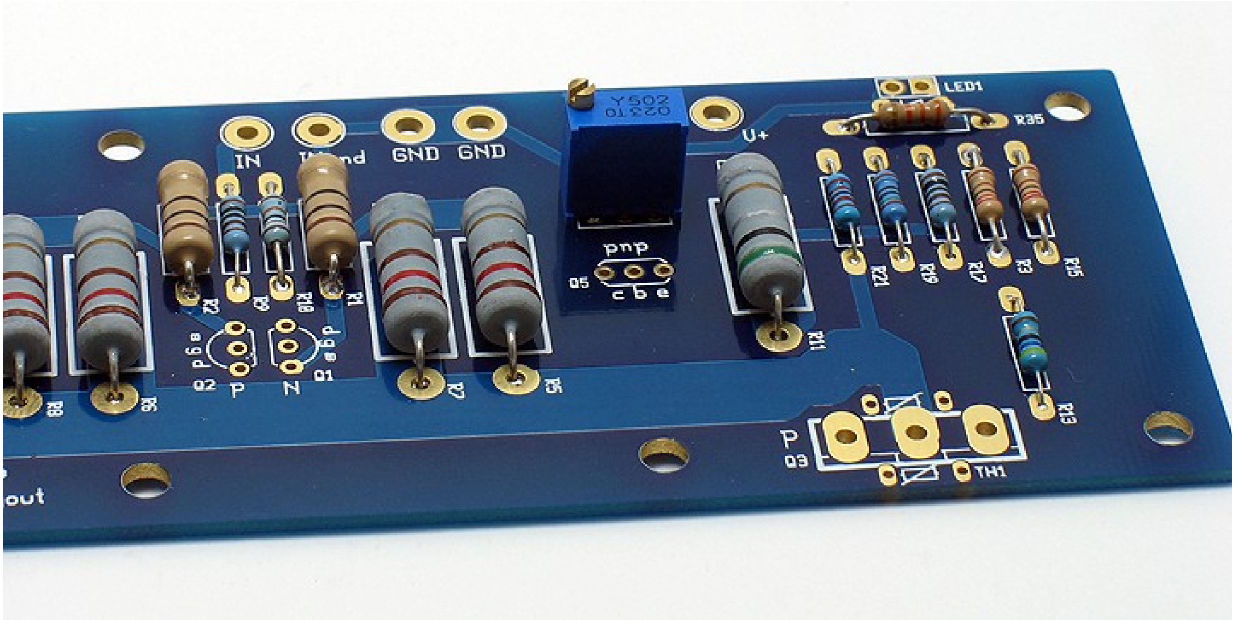
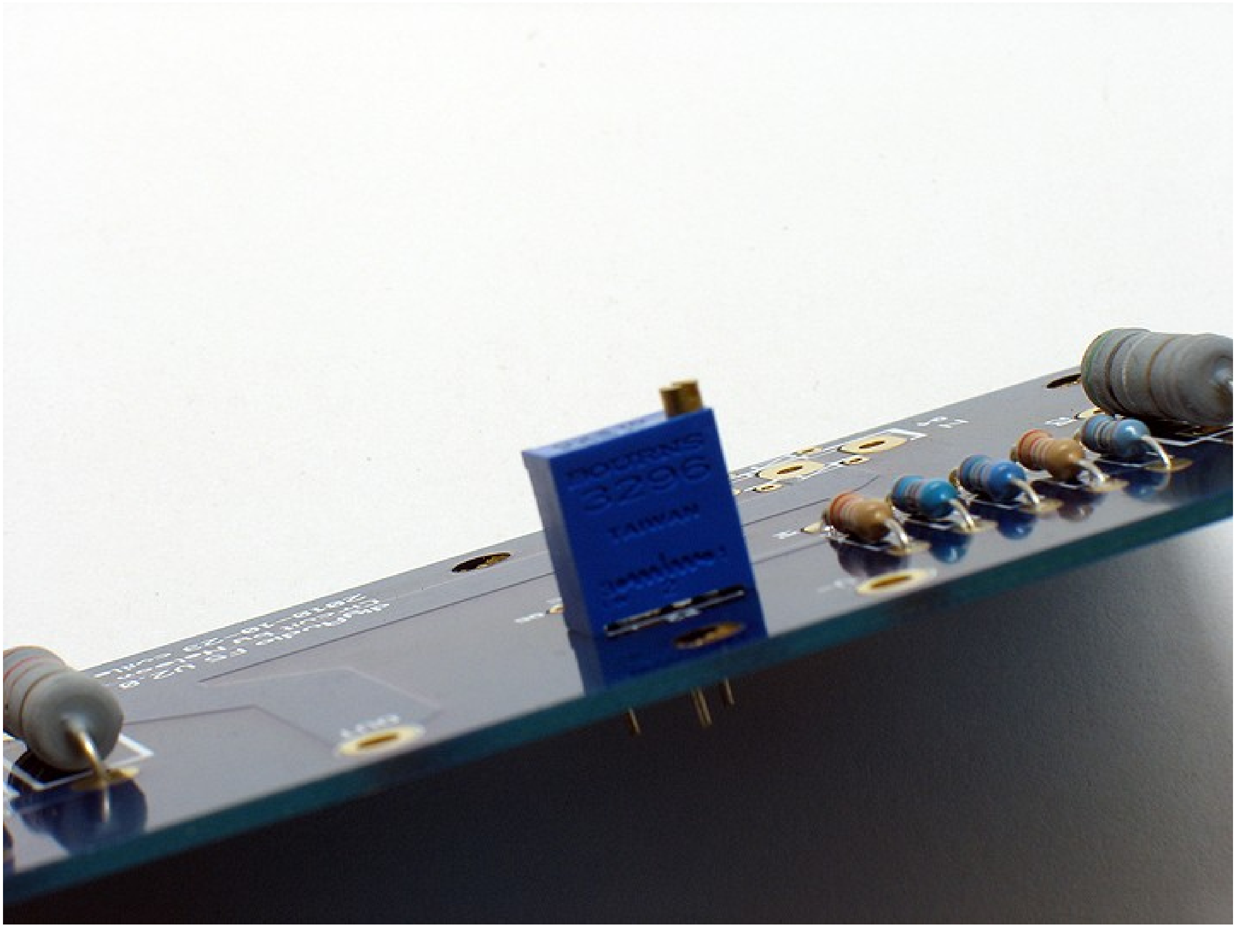
After all those resistors, the next thing to install are the two potentiometers designated as P1 and P2.





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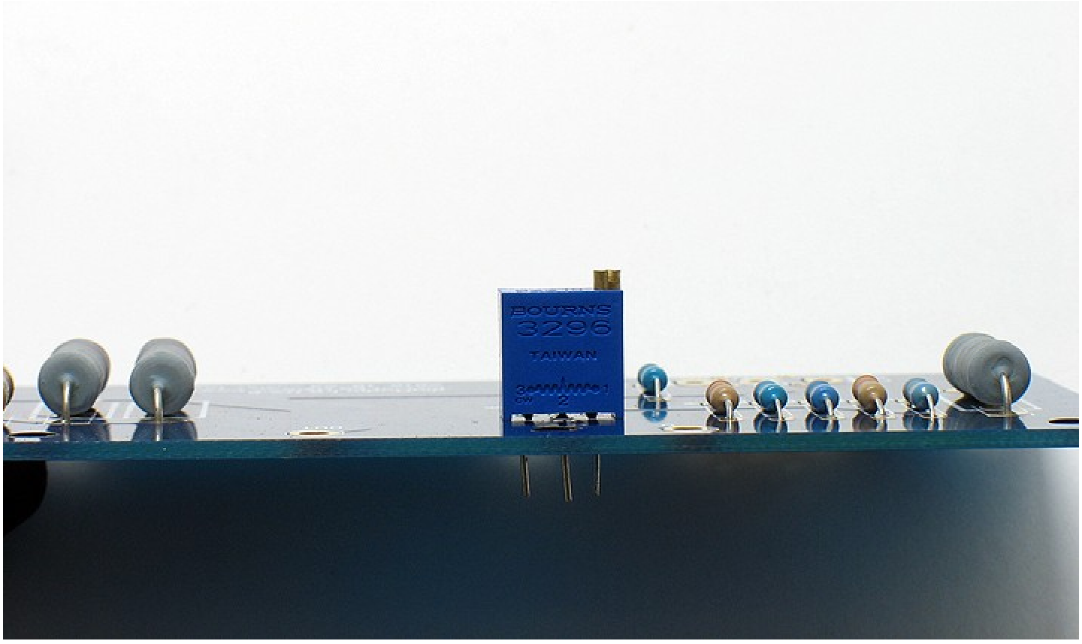
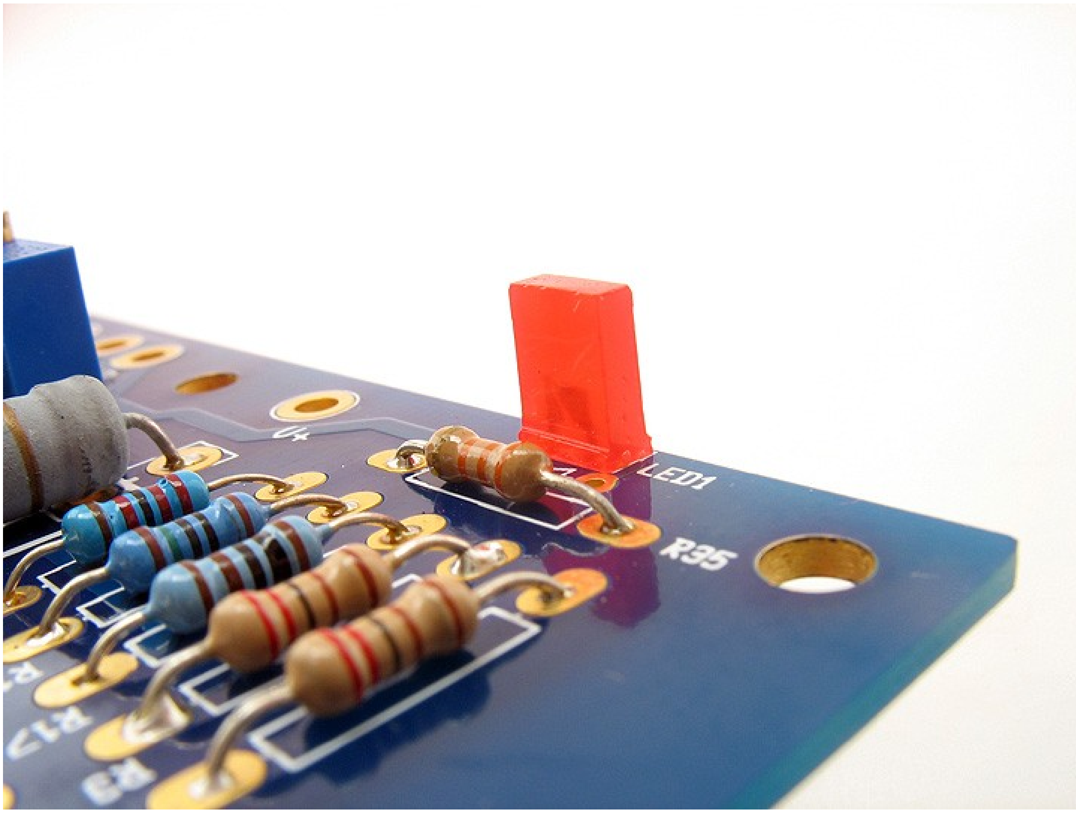


Now that P1 and P2 have been installed and soldered, get your favorite LED and install it on the board. Orient its polarity correctly or it won't light up. The longer lead is the positive one and goes in the round pad on the board, the other lead goes to the square pad. Our prototype has rectangular LEDs but the choice is up to you. The LED can also be round, 3mm or 5mm, and whatever color suits your fancy. Of course you can use wires instead from these same holes to extend the LED location to the front panel or elsewhere.



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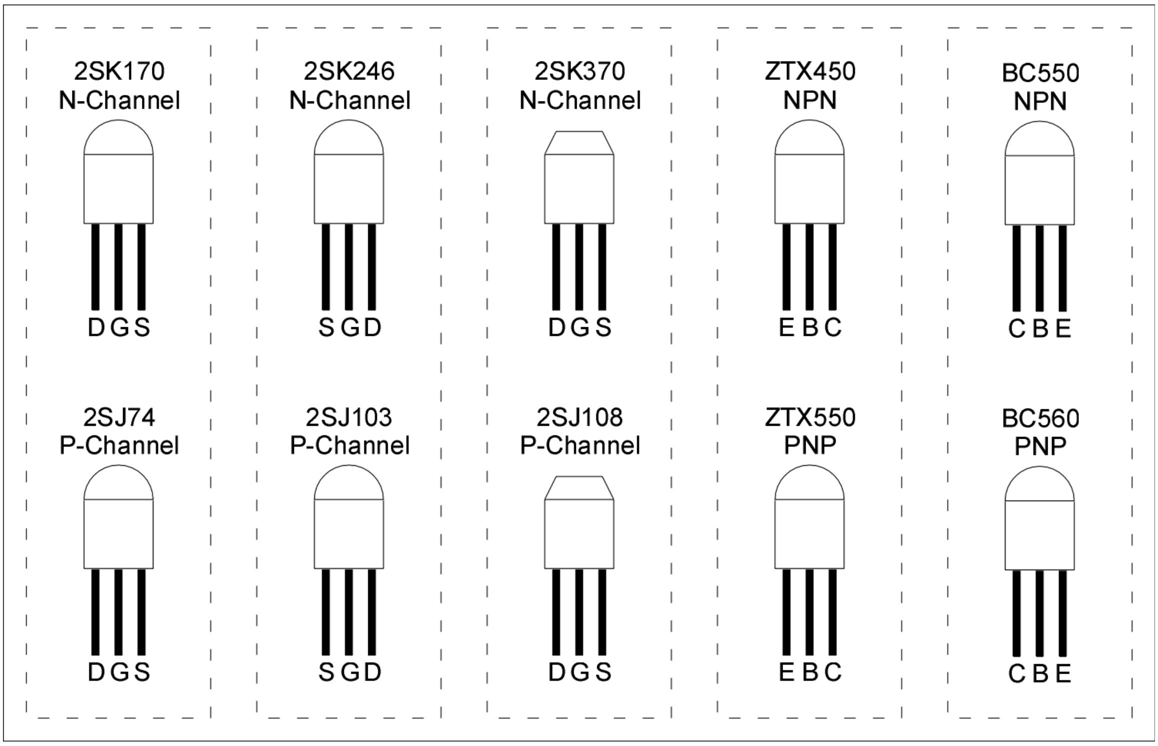
Now that we've installed all the passive components and the LED, the next step is to install the four TO-92 devices which are designated as Q1 & Q2, and Q5 & Q6. I've prepared a chart below so you can easily find the pin orientation of your chosen devices without any hassles. The pin orientations can be confusing so I suggest that you check them one by one. Take your time and always remember that this is part of the fun and enjoyment of building your own power amplifier. ;)



In the chart above, you will find the complementary pairs enclosed in a dashed line. So if you choose to use a 2SK170 for Q1, then it's complementary pair 2SJ74 should be used for Q2. Similarly, if you can't find those ZTX transistors, then the widely available BC560 can be used for Q5 and it's complementary pair BC550 must be used for Q6.

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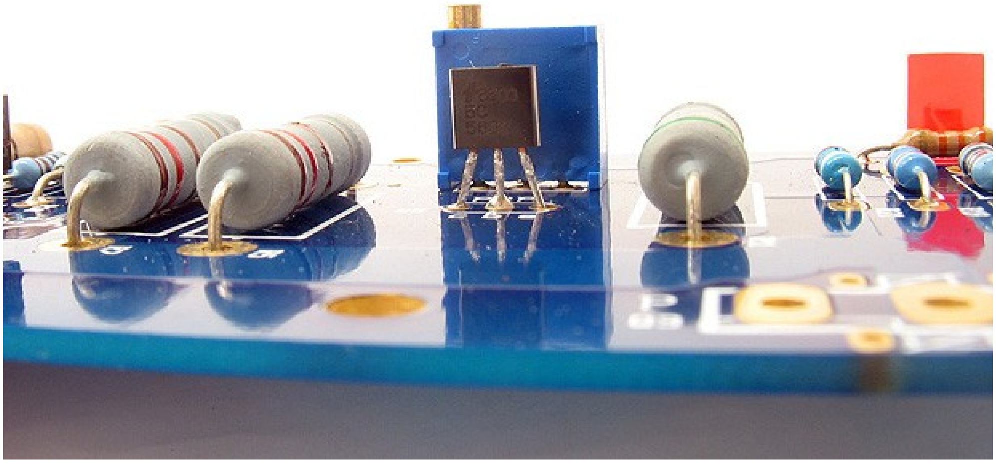
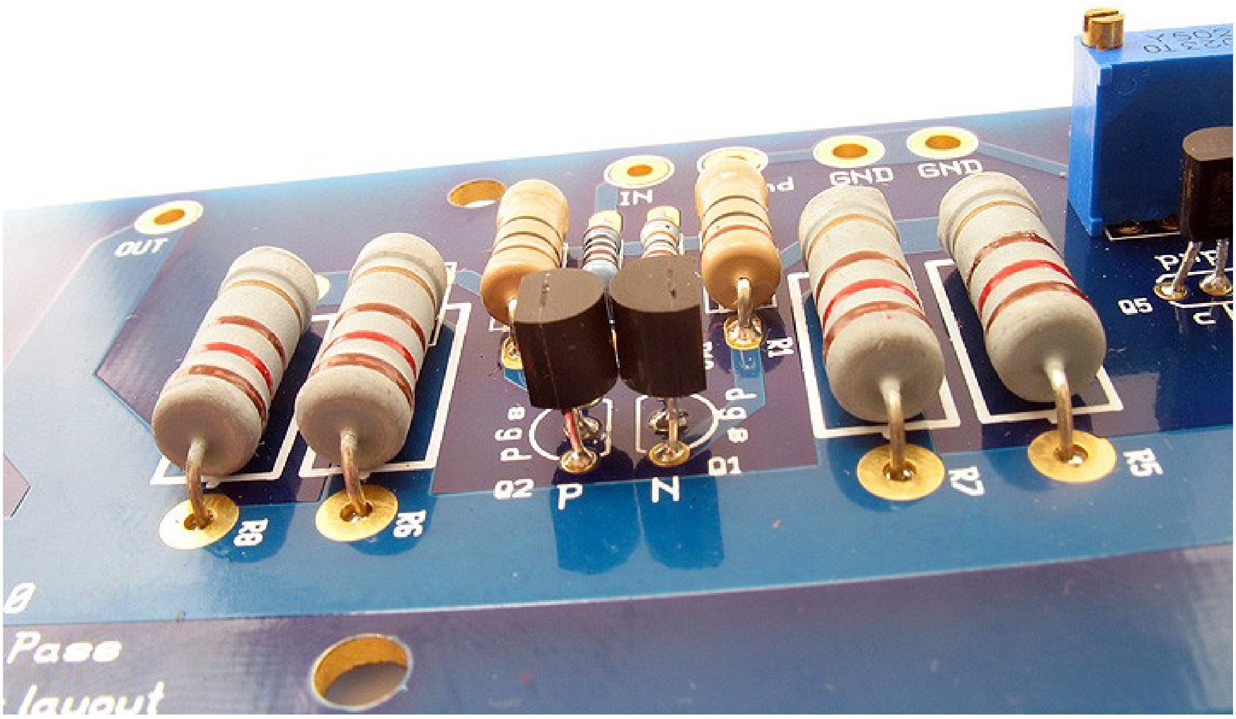
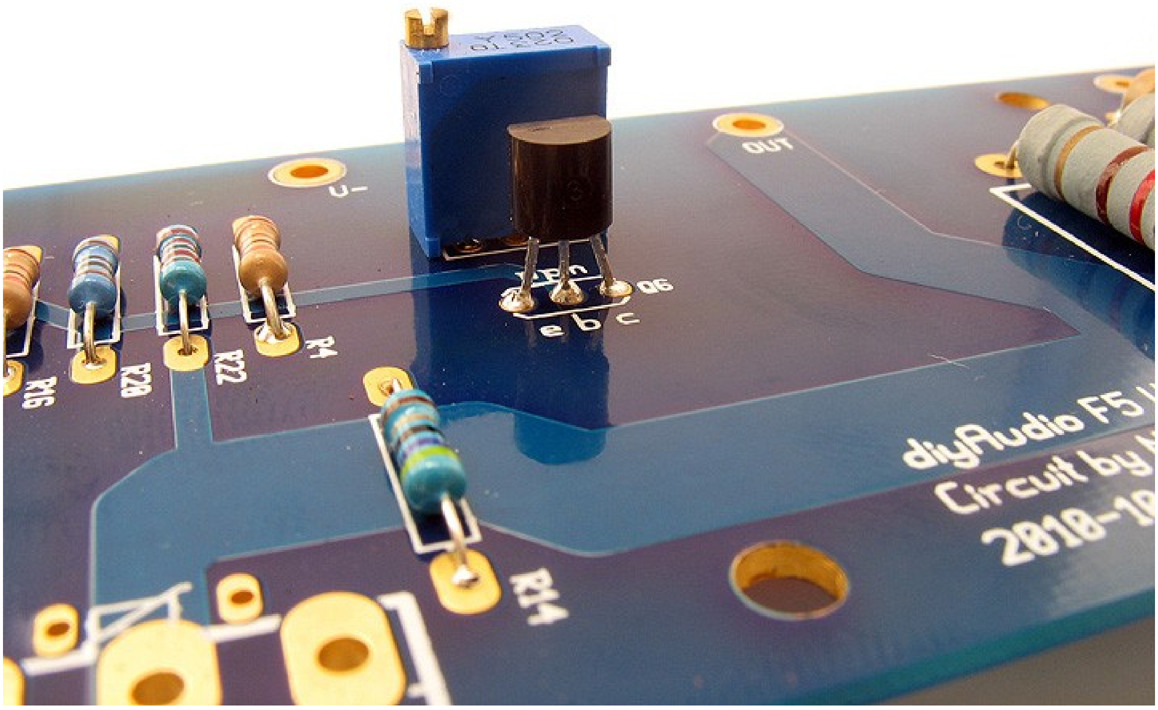
Ain't that quick and easy? When you're ready, let's install and solder those transistors starting with a BC560 as Q5.



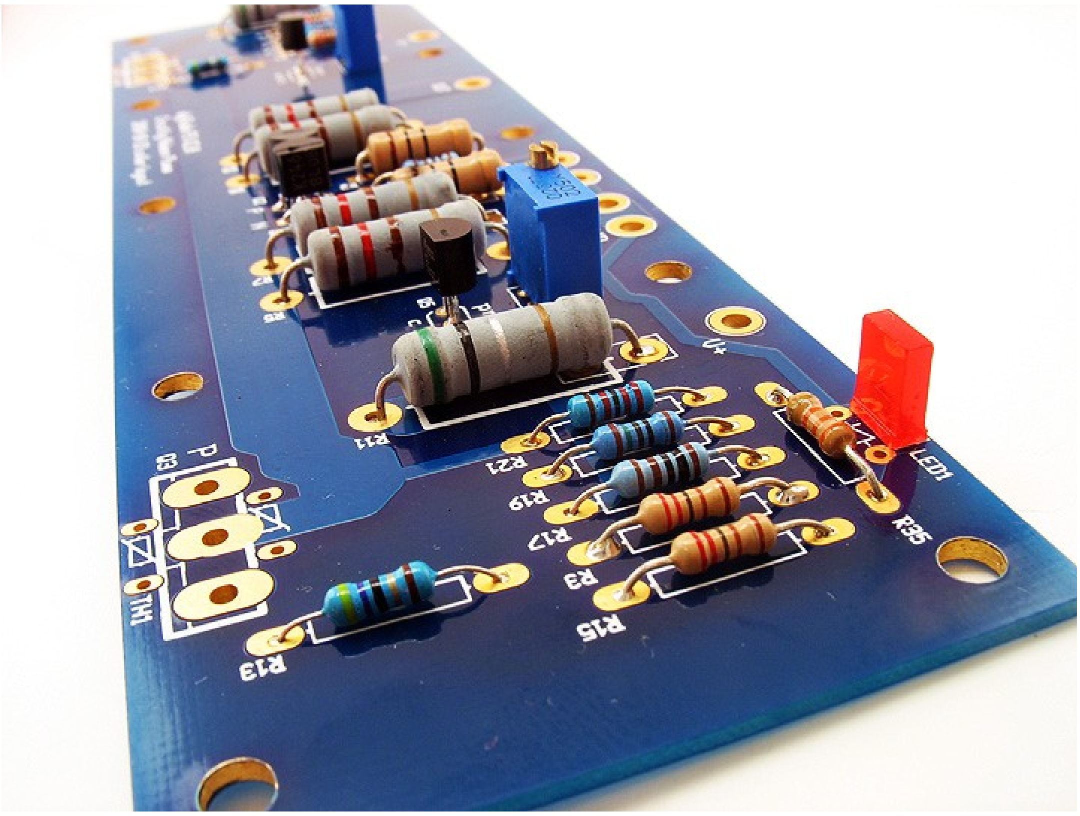
The prototype used the complementary pair 2SK246 / 2SJ103 for Q1 and Q2. Note that in the chart, their pin configurations are SGD instead of DGS, so as you see in the photo below that they are back-to-back instead of being face-to-face with each other.



In the photo below is Q6 with a BC550 transistor.



Now, you should take a breather and savor the beauty of your almost fully populated F-5 circuit board.



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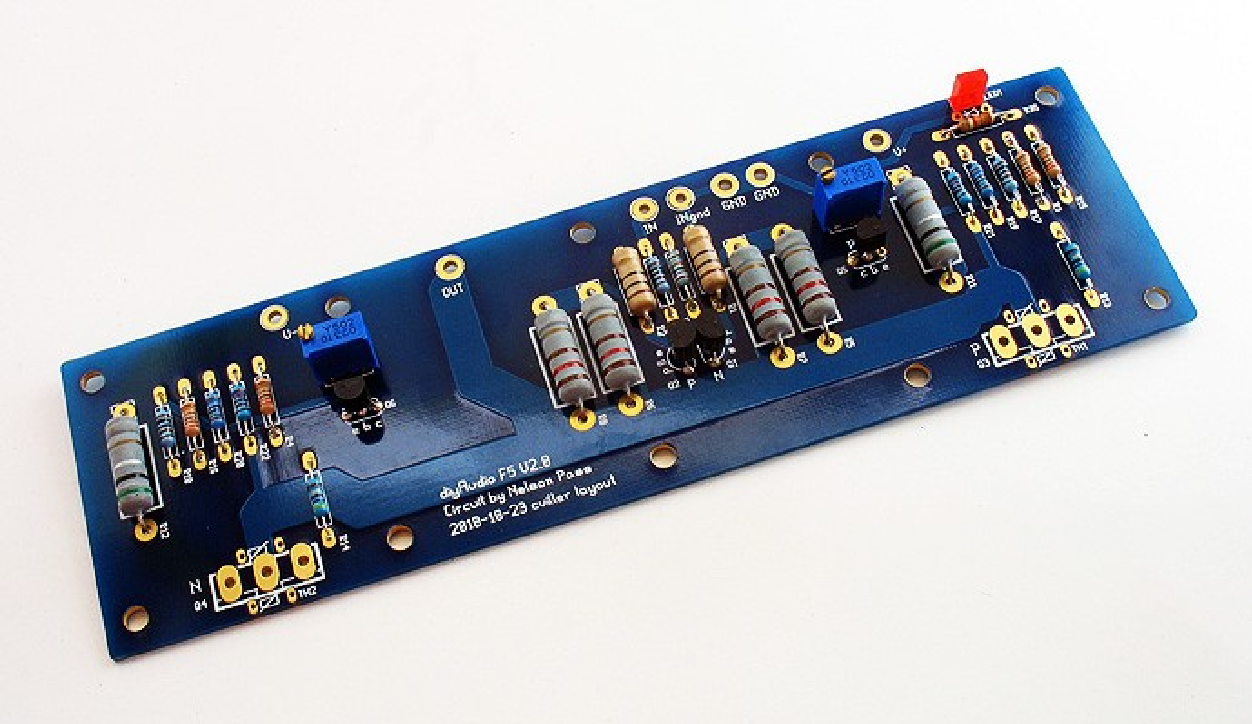
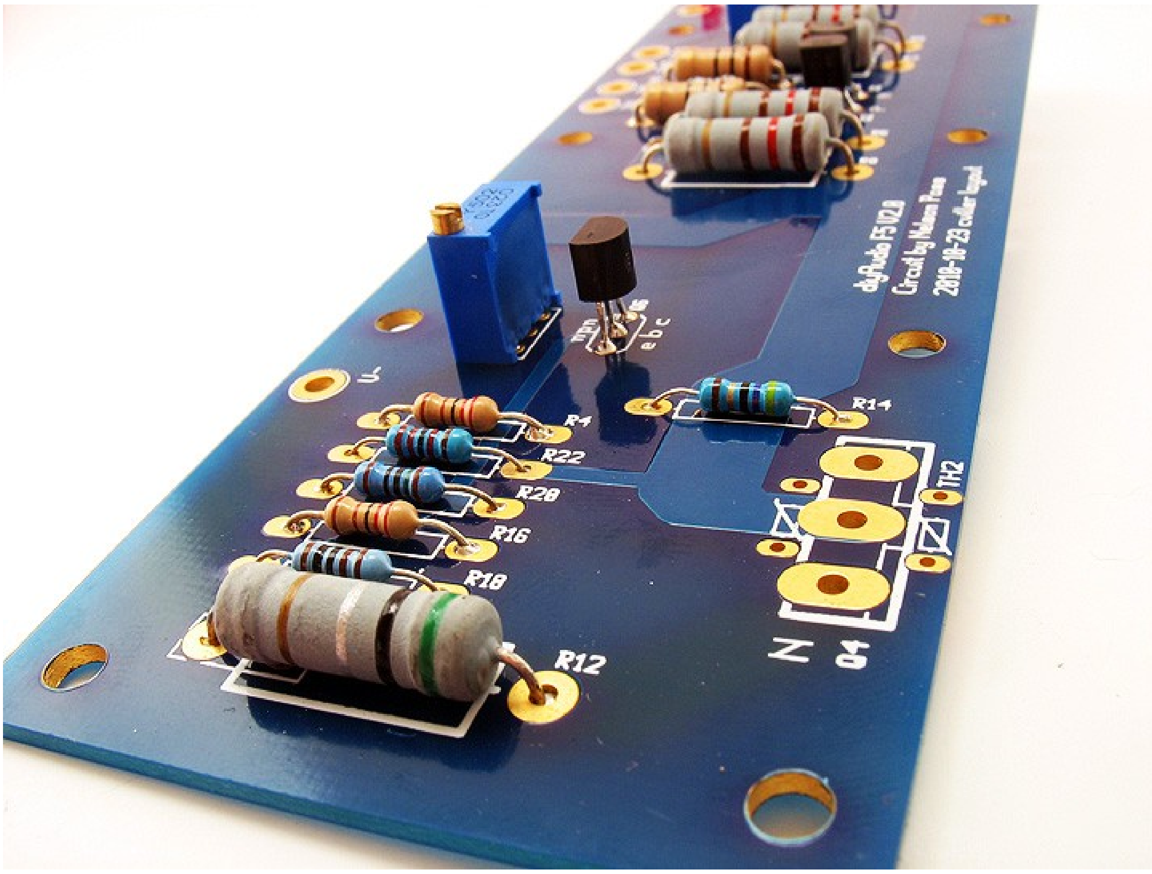
Ain't that a sight for sore eyes? :)





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Now that we're finished populating our boards, it's time to discuss a suitable chassis with sufficient heatsinks to house and cool our amplifier. As noted in the F-5 manual published by Nelson Pass, the idle dissipation of the amp is about 62 watts and will have a temperature rise of about 25 degrees Centigrade (Celsius) above the ambient temperature. If your listening room has an ambient temperature of about 25 degrees Centigrade then you can expect the power amp to stabilize at around 50 degrees. So it's imperative that we give our F-5 adequate heatsinking and ventilation.

In the past, I'd first track down a suitably sized heatsink and then build my chassis around it. Many audio amp builders enjoy this part a lot, but the work involved is considerable, and if you don't have the necessary tools and equipment, to say it's hard work is definitely an understatement! I've donated my fair share of blood and sweat, not to mention dollars, as it can get really expensive making your own chassis.

If this work isn't to your taste or you're a newbie fear not, the diyAudio Store now stocks amp chassis with heatsinks that are perfect for First Watt amp projects. They're sturdy, great looking, and available in various sizes to house and cool any power amp project in the diyAudio Store arsenal.

A key feature of the Deluxe Chassis is the diyAudio Universal Mounting Specification or UMS for short. It is a pattern of pre-drilled and tapped holes in the heatsinks that accommodate all the amp boards available in the diyAudio Store, and increasingly, projects that members develop as Group Buys. The back panels even have CNC'd holes for RCA input jacks, power entry modules (PEMs), and speaker binding posts. For most of us, this means less work and more fun! We're going to use the Deluxe 4U chassis to house our F-5 amp. It has aluminum heatsinks with 40mm fins and is 300mm from front to back, which is more than enough for our application. For more information about this chassis, you may want to visit the diyAudio Store at http://www.diyaudio.com/store/

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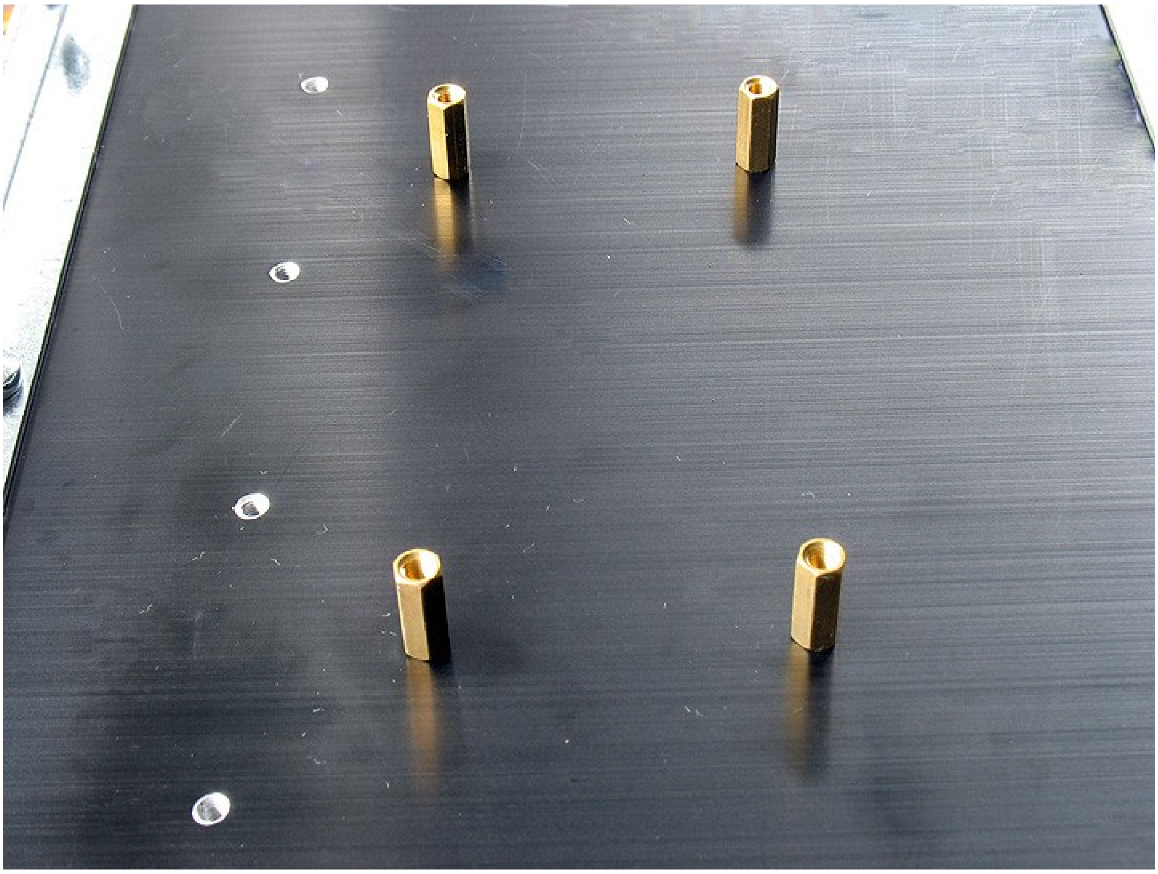
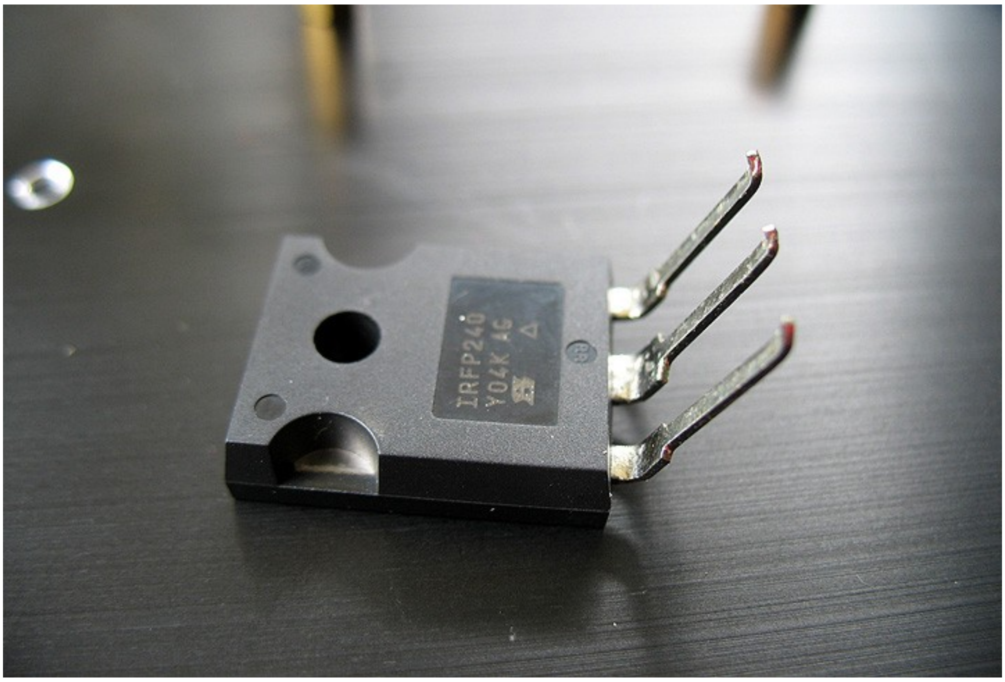
Prepare your heatsinks by mounting four brass standoffs. Simply place your your board over the holes and you'll easily find the correct mounting holes for the board. Don't over-tighten the standoffs, they can be fragile and if they break off in the sink you're in trouble!



Next, prepare your MOSFETs for installation by bending their leads upwards. It's wise to temporarily install the board and place the MOSFETs over their mounting holes to determine where the bends should be.



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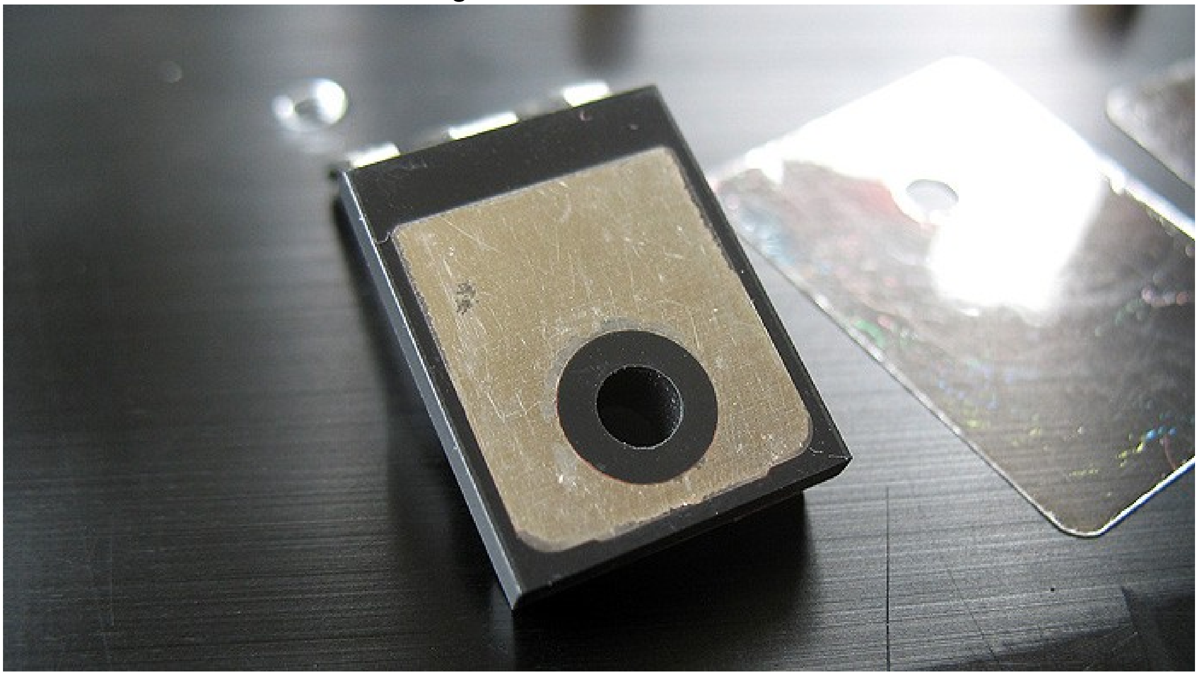
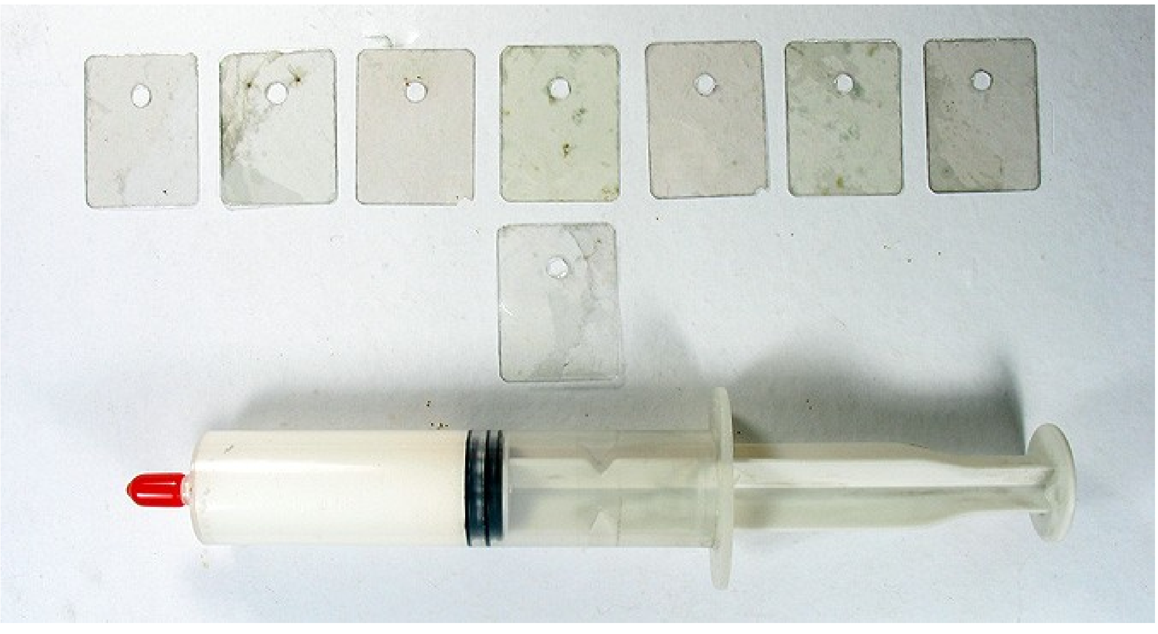
The metal backs of the MOSFETs are electrically connected to the Drain pin so we need to isolate them from the heatsink using insulators.



Normally we use mica insulators that require application of thermal grease for improved thermal conductivity. Another option is to use insulators made of a special film called Keratherm, which don't require the grease, in fact can't be used with grease, yet their heat transfer is exceptional. These insulators have a large minimum order quantity which often keeps us from using them. Fortunately the diyAudio store will soon be stocking them, so you won't need to mess with yucky thermal grease anymore!

Unfortunately for me, I'm still tasked with showing you how to mount the MOSFETs using mica insulators and thermal grease. It's relatively easy once you get the hang of it. The main component in thermal grease is silicone and it comes in different package types. Make sure to choose something with a very high thermal conductivity and that's electrically insulating.



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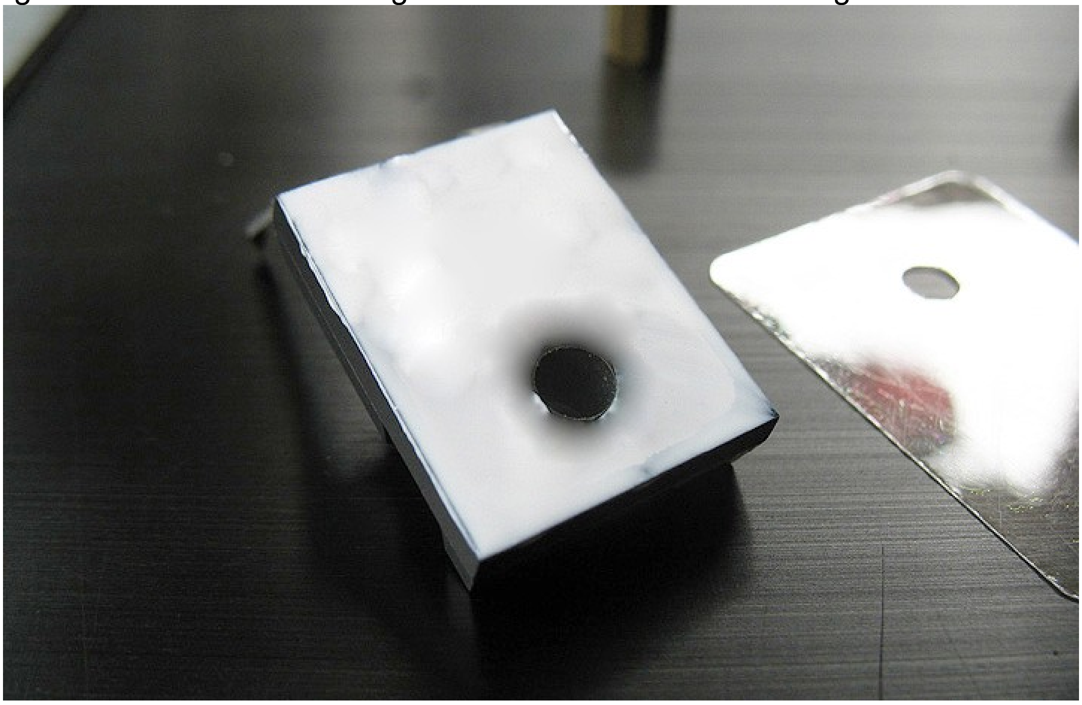
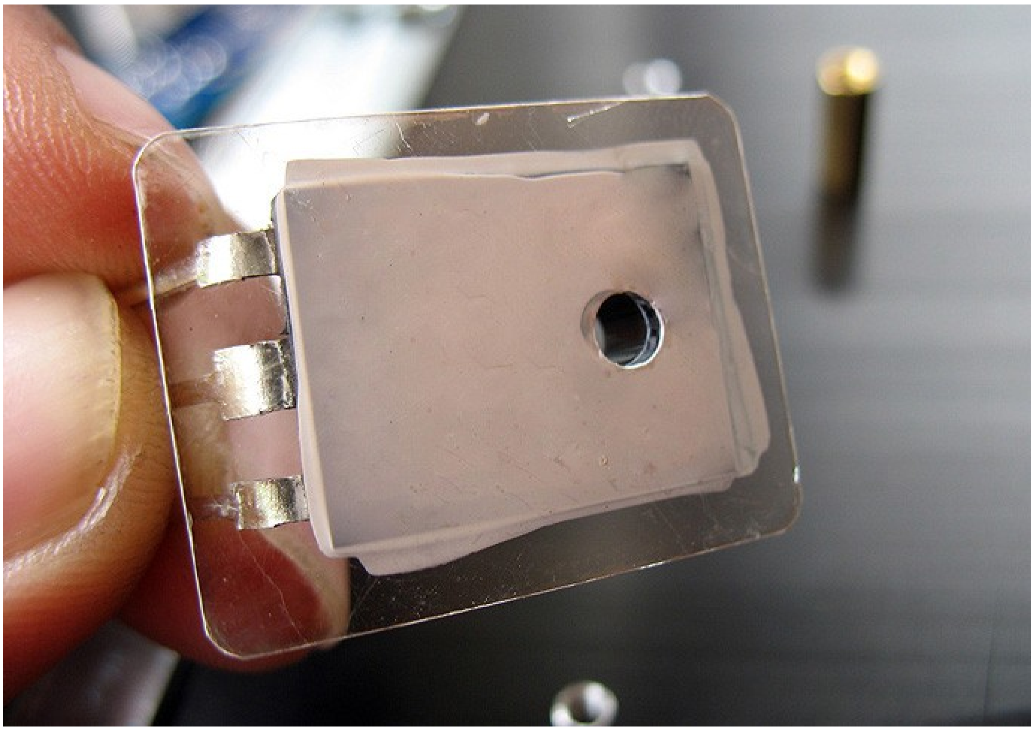
Now what we want to do is to apply a thin coat of thermal grease to our MOSFETs and mica insulators. You can use a small spatula, a pocket knife, or a toothpick to apply the thermal grease. Just make sure to give it a thin and uniform coating.



Next, align and attach your mica insulator to your MOSFET and then apply a thin, uniform coating on the other side of the mica insulator which will contact the heatsink.



Move the mica insulator around a bit to remove any air pockets. You can even remove the mica and then attach it again to the MOSFET. Don't worry, with a bit of practice and patience it's very easy to do. Remember, there must be grease on both sides of the insulator, between the MOSFET and the mica, and between the mica and the heatsink.

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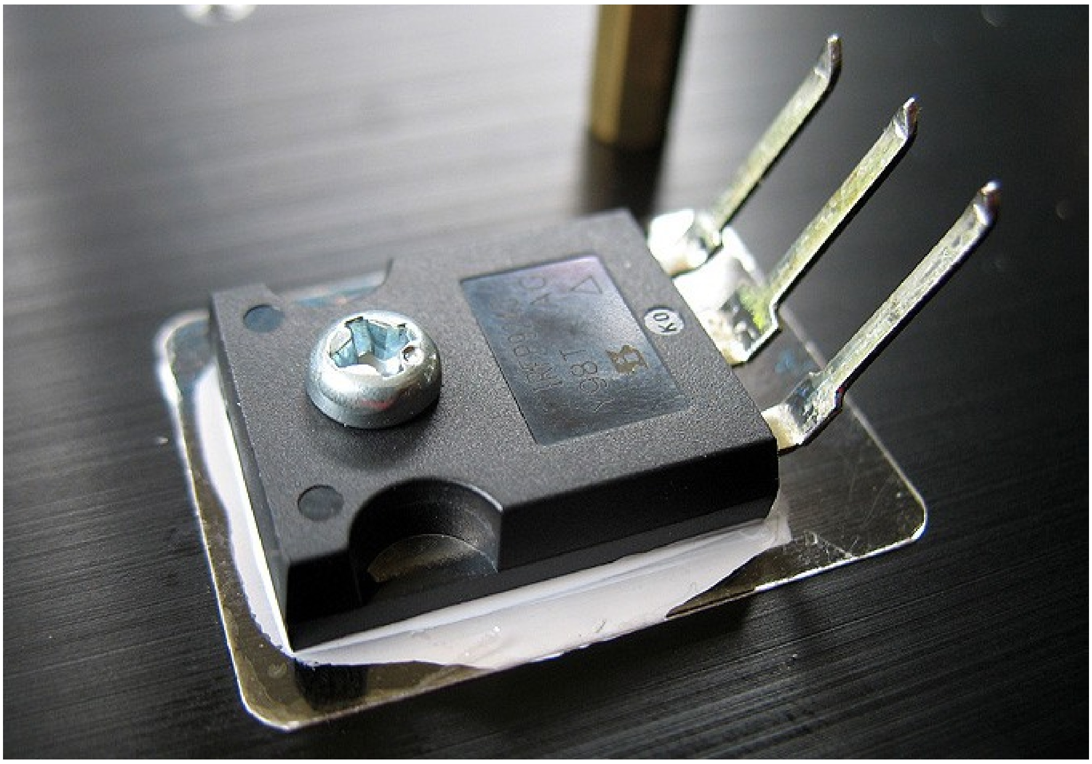
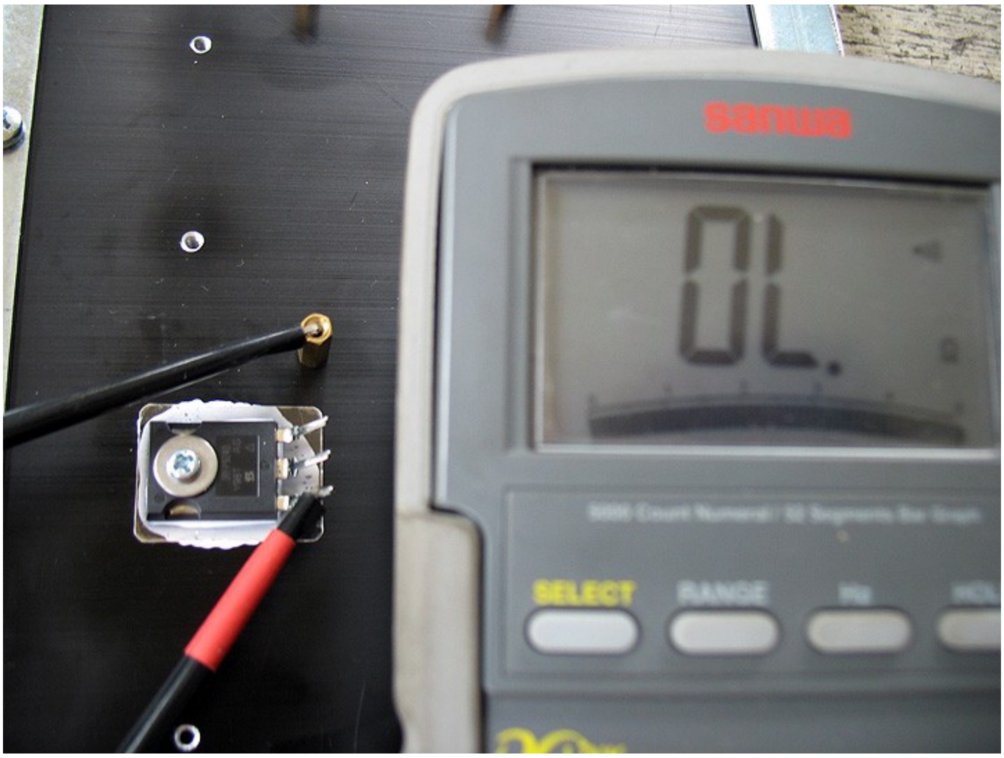
Temporarily attach the MOSFET with the mica insulator to your heatsink with a bolt to hold it in place. Don't tighten it too much yet, just enough to hold it down.



Now let's test if we've successfully insulated the MOSFET from the heatsink. Get your Digital Multi-Meter (DMM) and set it to read resistance. Connect one of the DMM's probes to the heatsink. I used the brass standoff for this so that the heat sink anodizing, which can be insulating, won't be a factor. Then one by one, touch each pin of the MOSFET with the other probe of the DMM and see what it reads.



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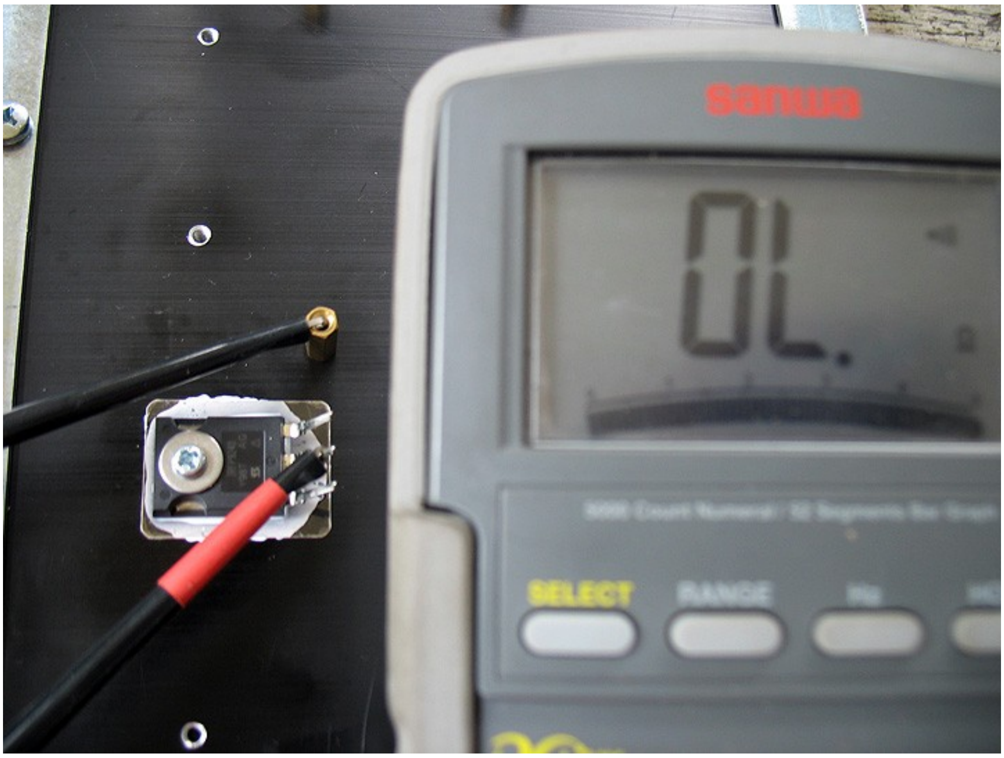
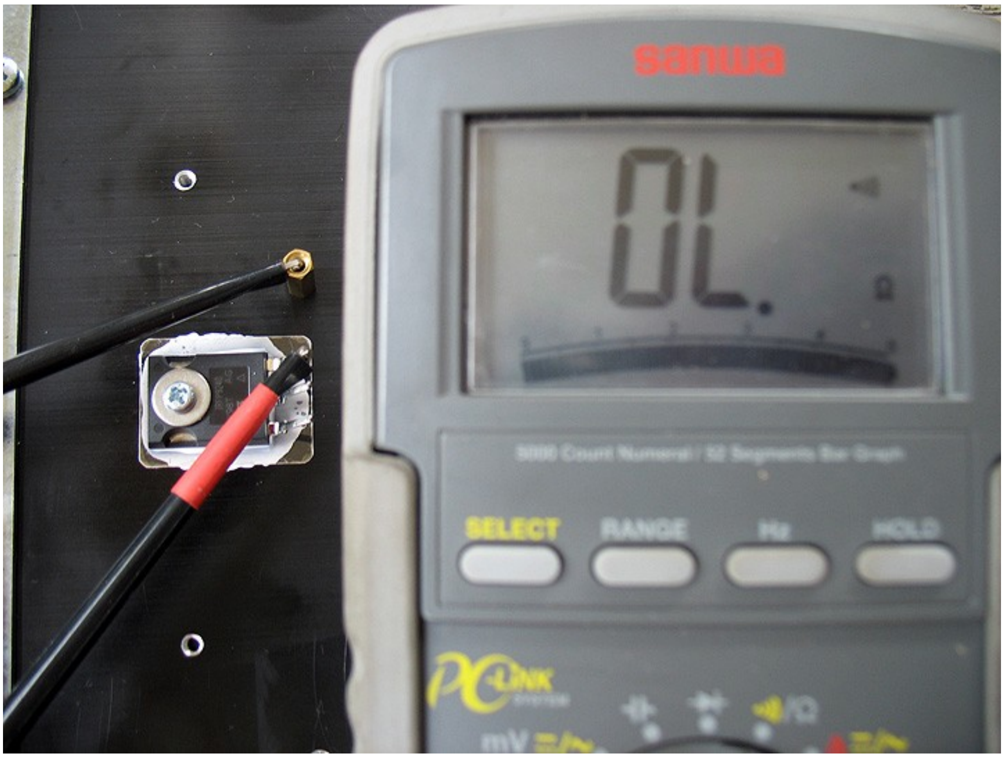
An infinity reading is what we want, which means our MOSFET is electrically insulated from the heatsink.





Perfect! See how easy that was?

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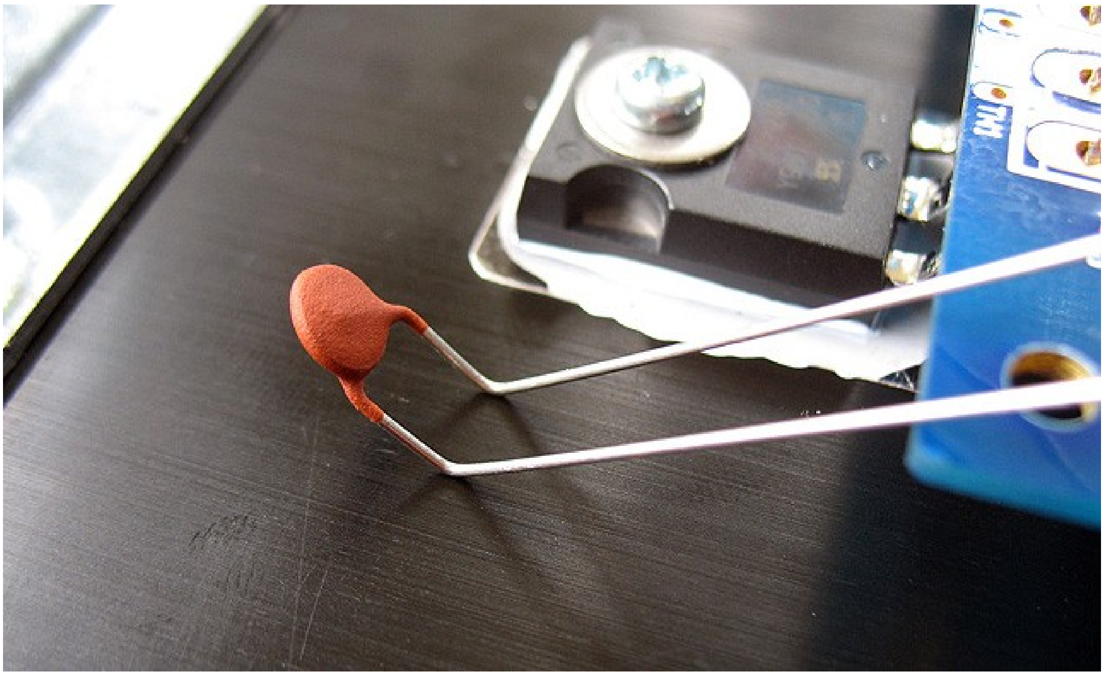
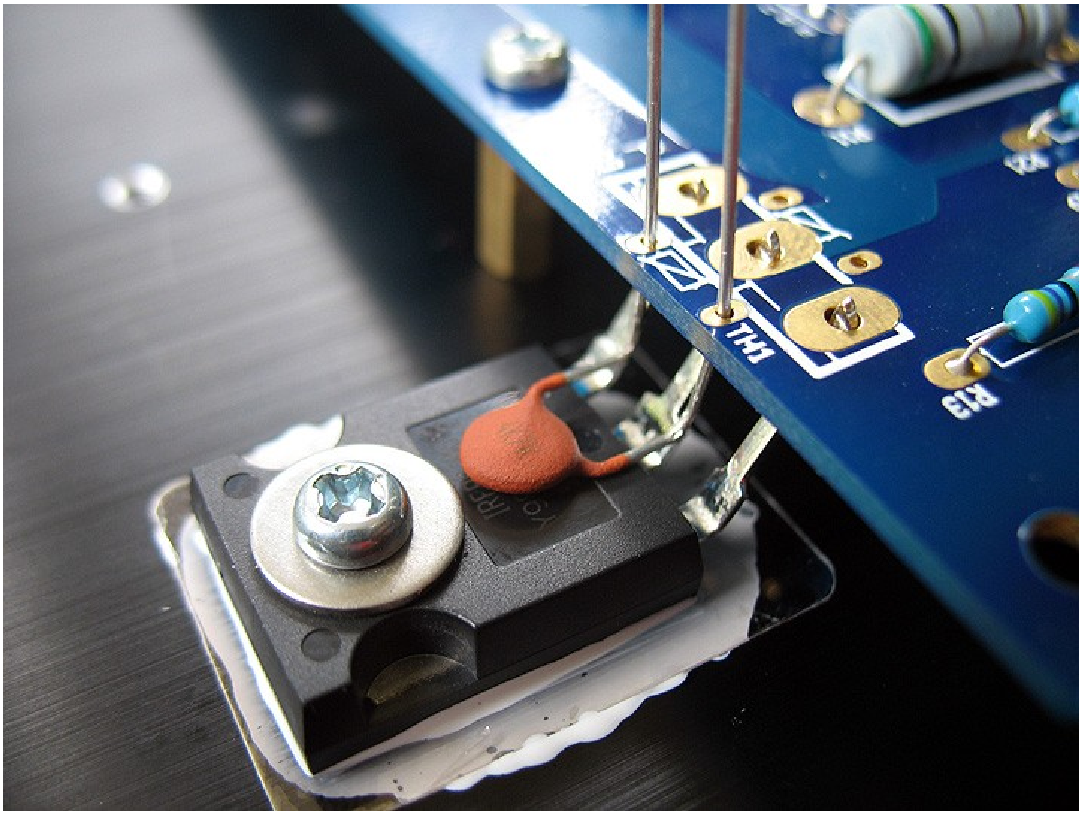
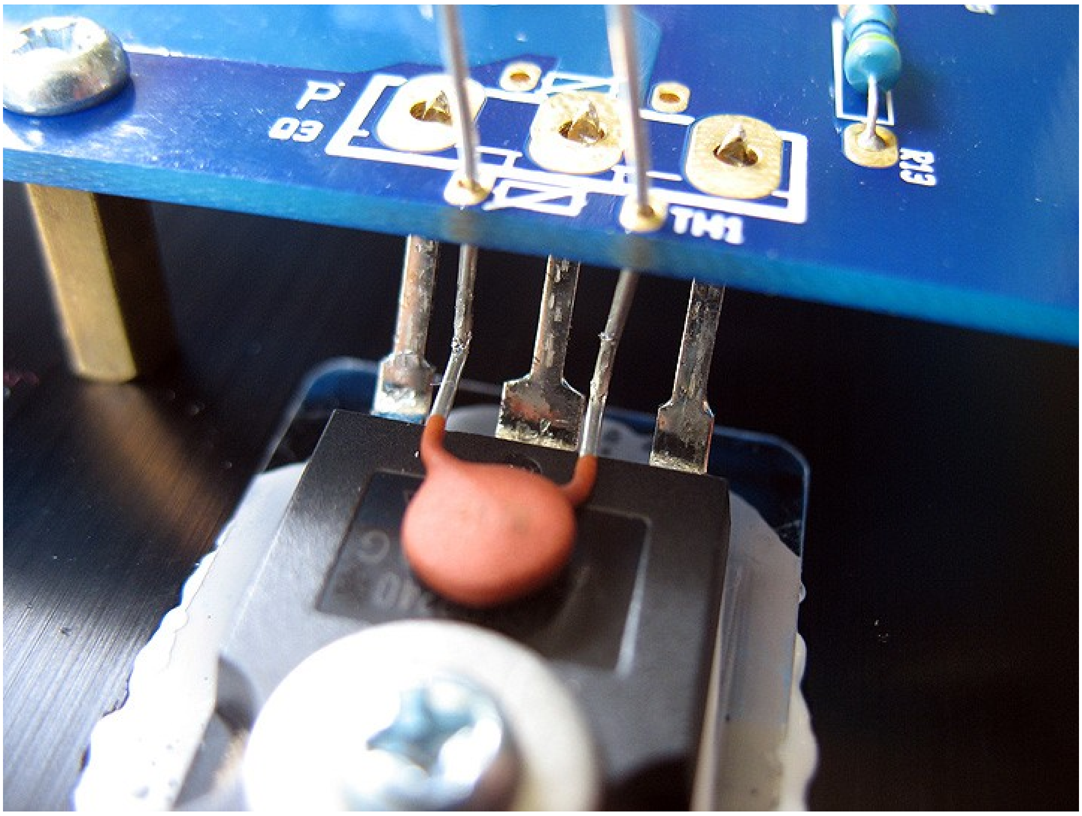
Now let's move on to installing your thermistors. The body of the thermistors must be in physical contact with the body of the MOSFET. You can easily do this with the board and MOSFET in place. First determine the required lead length, and then bend the leads of your thermistor so it will end up physically in contact with the MOSFET



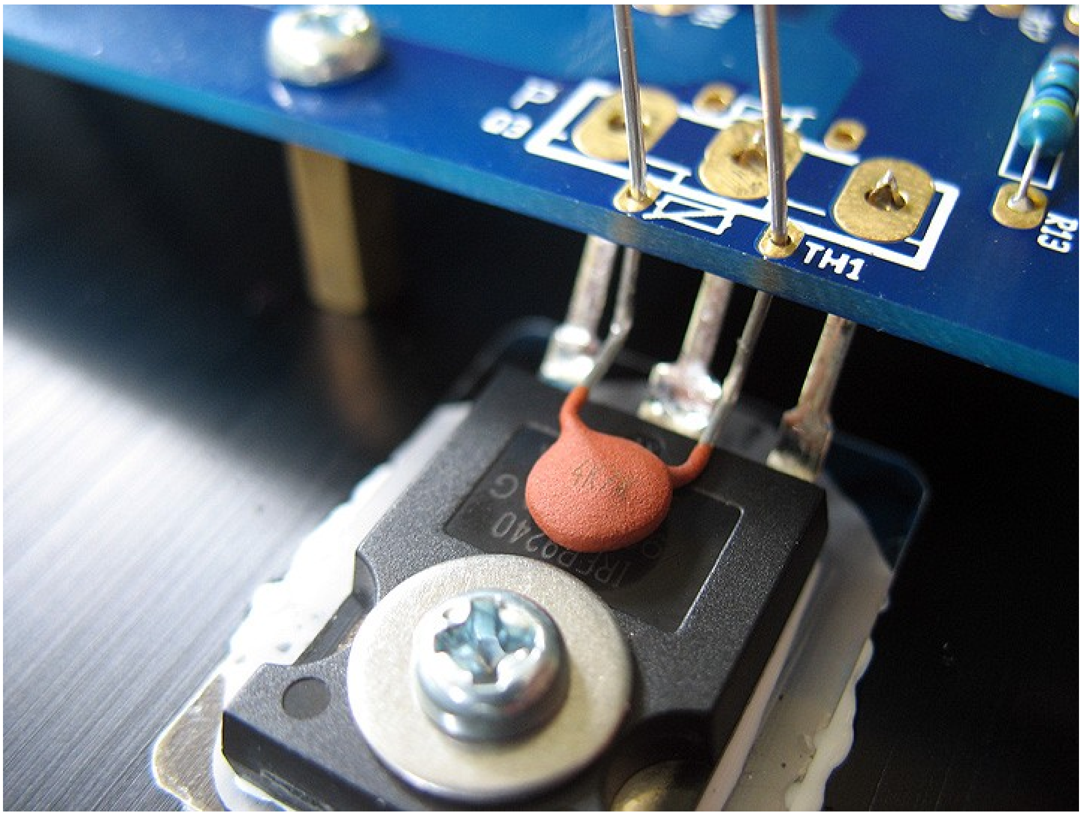
Once you've got the thermistor's leads bent, mount them on the board like in the following photo. Move the body of the thermistor so that it touches the body of the MOSFET.



Also make sure that the leads of the thermistor aren't touching any of the MOSFET leads.



Move the body of the thermistor so that it touches the body of the MOSFET.



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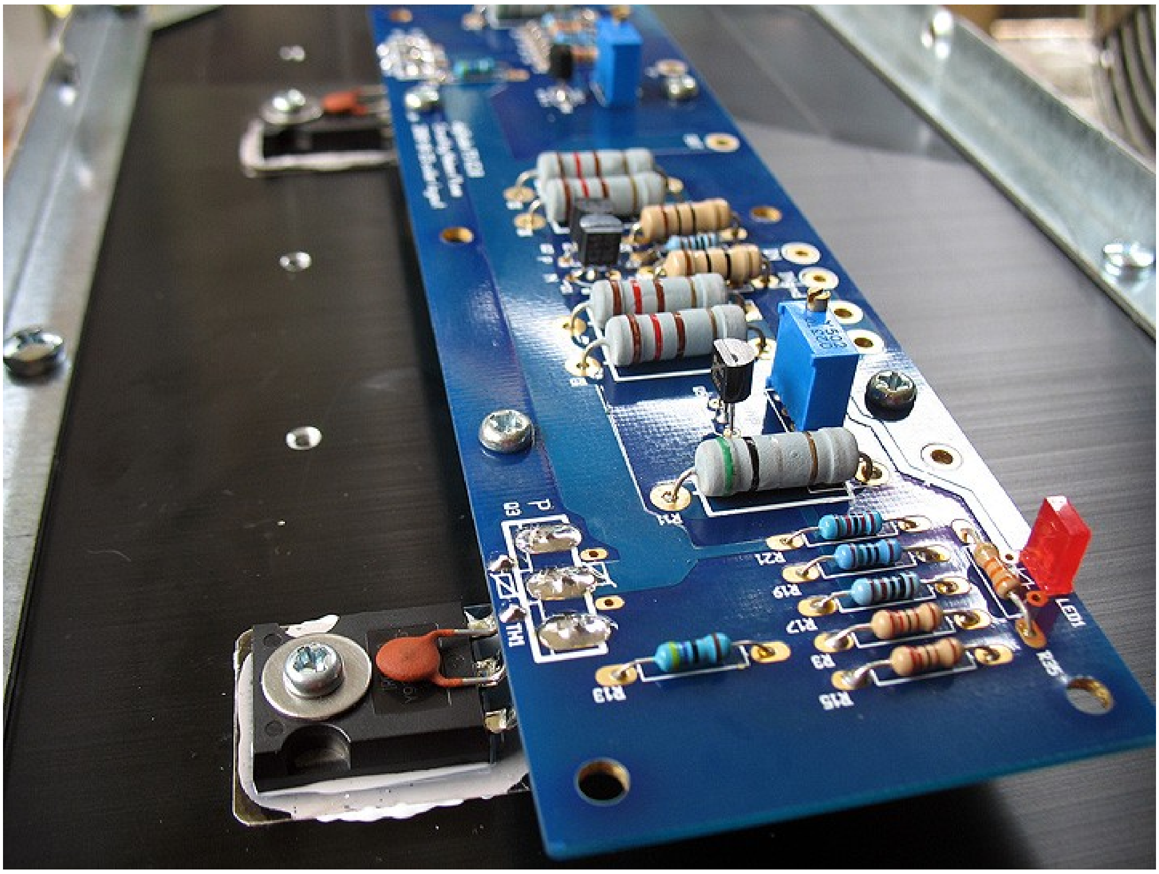
Now tighten the bolts holding your MOSFETs after installing flat washers if you haven't done so yet, to help distribute the force of the bolt and help prevent any damage to the MOSFET body. Tighten the bolt firmly, but the MOSFET can be damaged if you overdo it! Solder the leads of the MOSFET to the board, then the thermistors and that's that!



Now that we've finished installing our F-5 amp board assembly on the heatsinks, the next thing we need to set up would be the amplifier's power supply. You can find the schematic of the recommended power supply under the **Ideas and Alternatives** section of this build guide.

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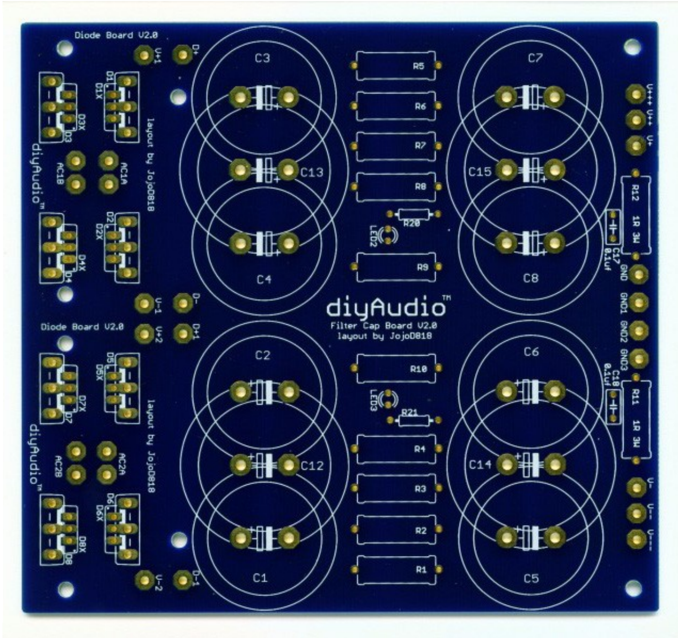
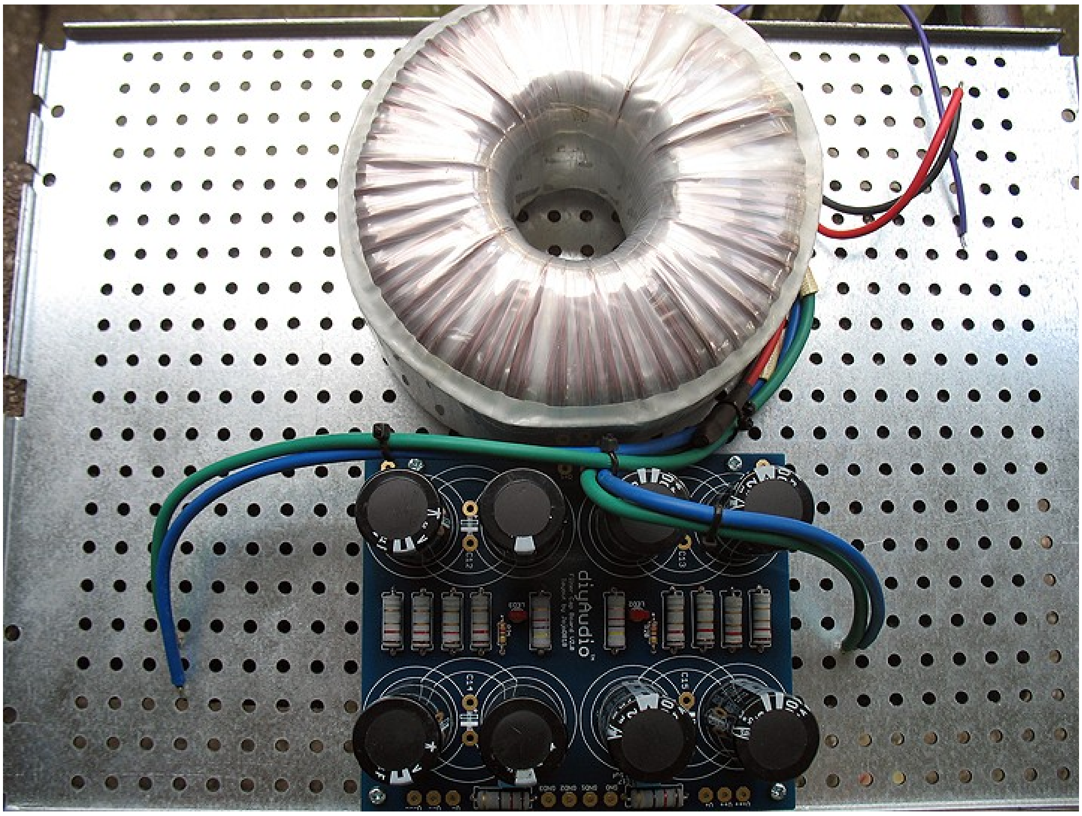
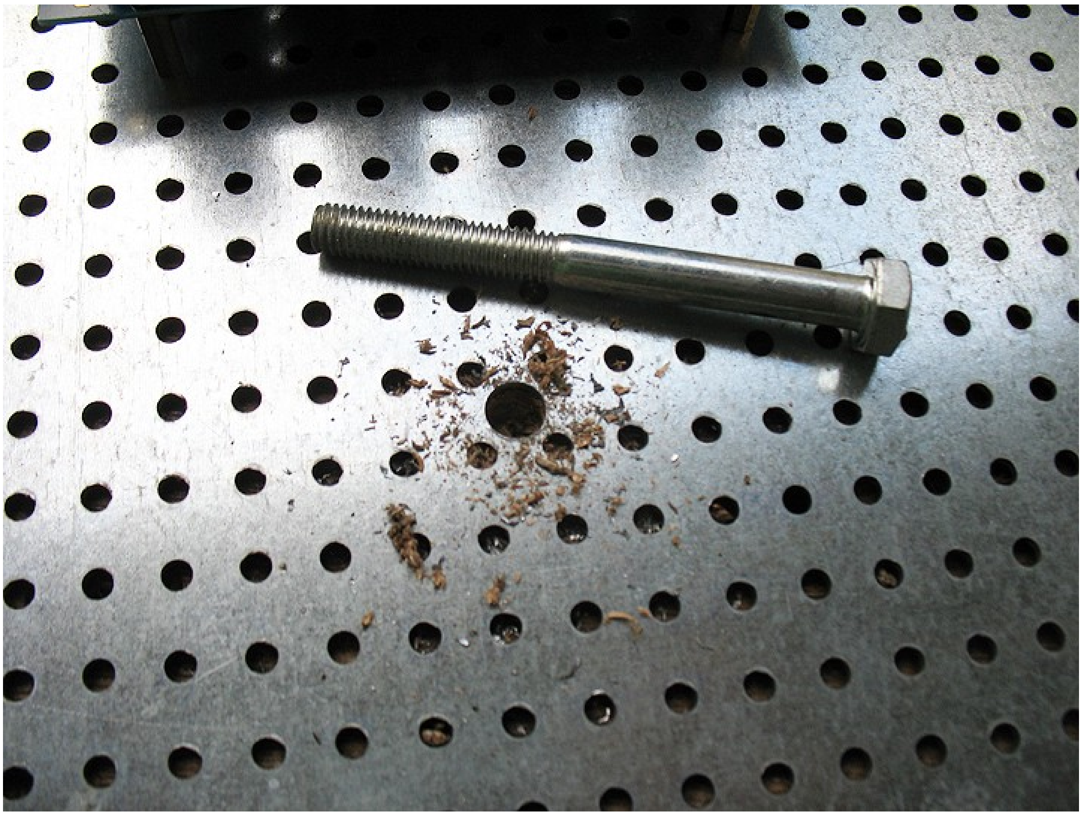
I used the Power Supply Board from the the diyAudio Store and I strongly suggest that you download its build guide for more information and to help you populate your board. It's best to follow the power supply parts values recommended by the amp's designer Nelson Pass for reliable and noise free operation. This PSU board is pre-scored and easy to snap into sections, which is fortunate because the diode section needs to be separated so we can install the diodes on the perforated inner baseplate which serves as the diode's heatsink. The diodes can also be mounted to a small heatsink if you prefer, or aren't using the baseplate.



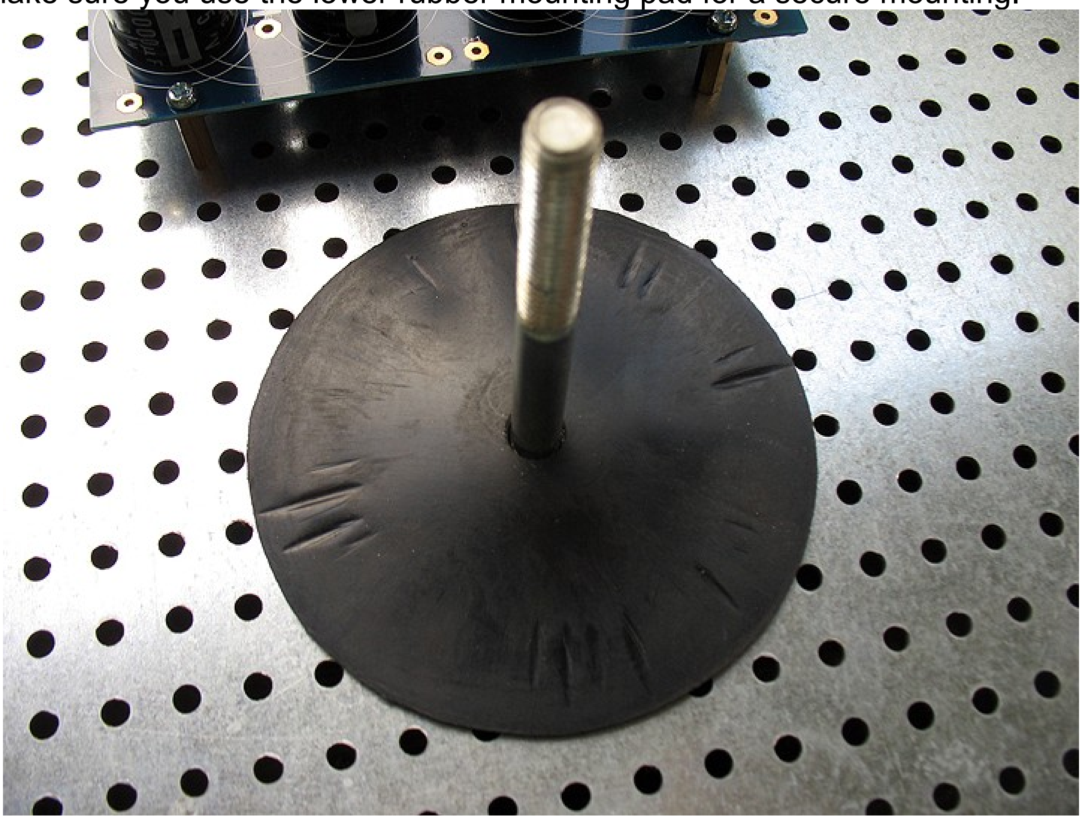
Check the fit of the PSU board and your toroidal transformer. Positioning as shown in the photo below usually works well. Then install your populated PSU board using standoffs.



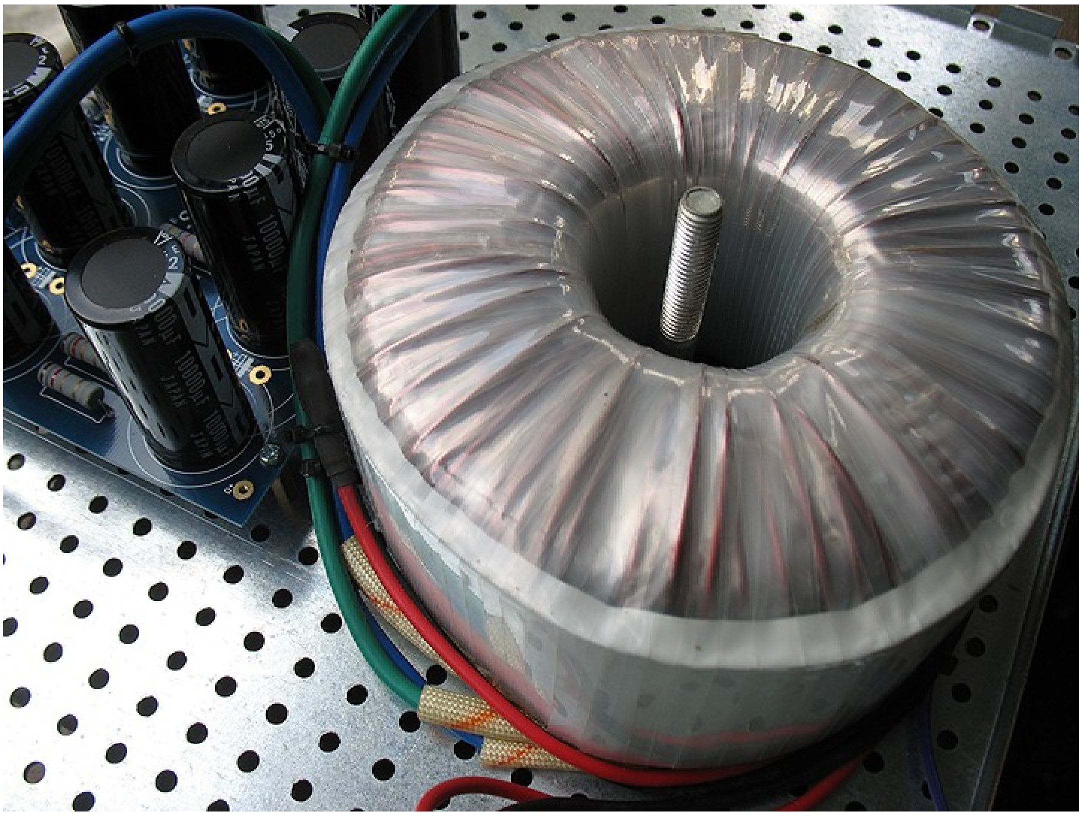
Drill a hole for the toroidal transformer mounting bolt.



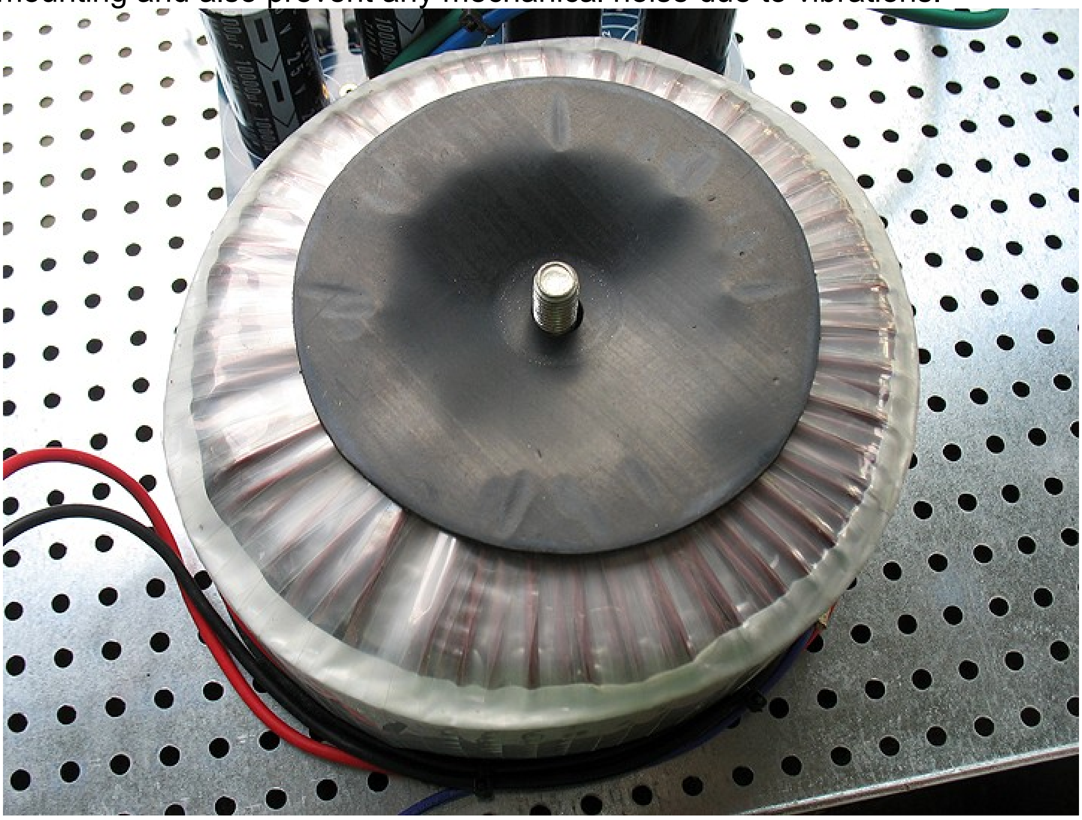
Then make sure you use the lower rubber mounting pad for a secure mounting.



Position the toroidal transformer so that it's secondary winding leads are oriented towards the PSU Board. Center the inner hole and not the outer diameter of the transformer.



Now use the upper rubber mounting pad. These pads protect the toroidal transformer during mounting and also prevent any mechanical noise due to vibrations.



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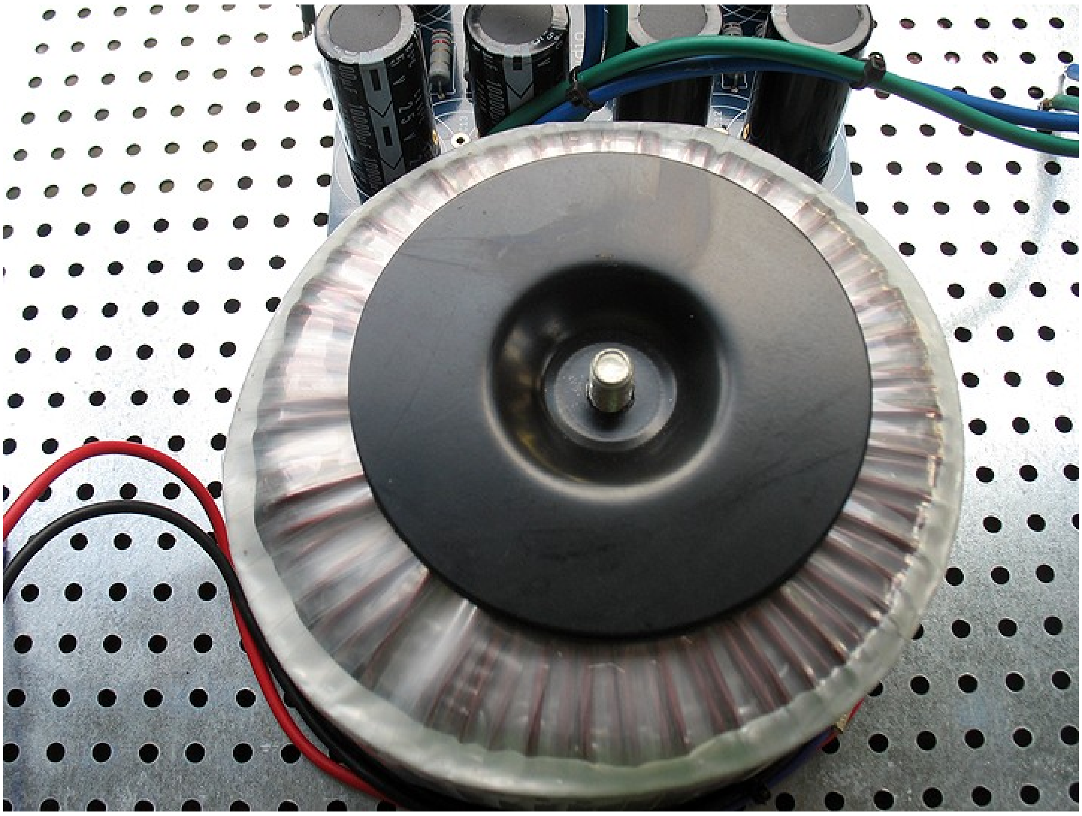
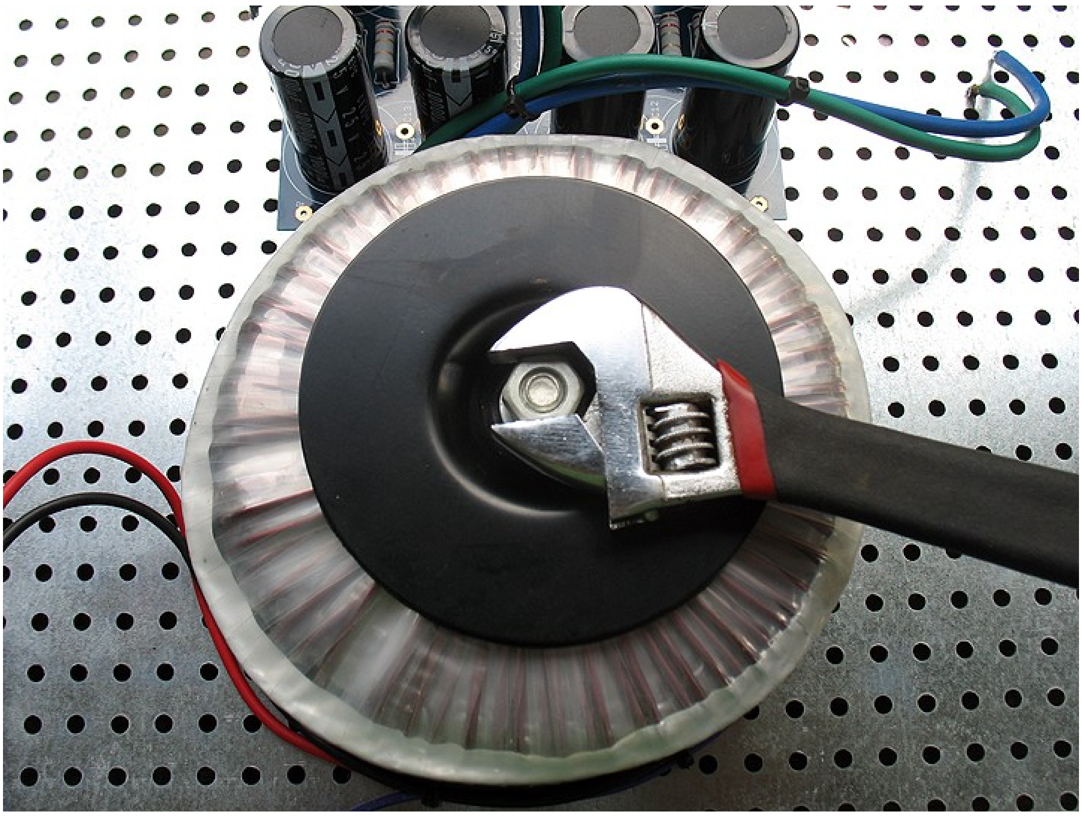
Next is the metal mounting plate.



Finally the lock washer and nut. Tighten the nut using a small wrench but don't overdo it as you risk damaging the windings of the transformer and the base plate or chassis.



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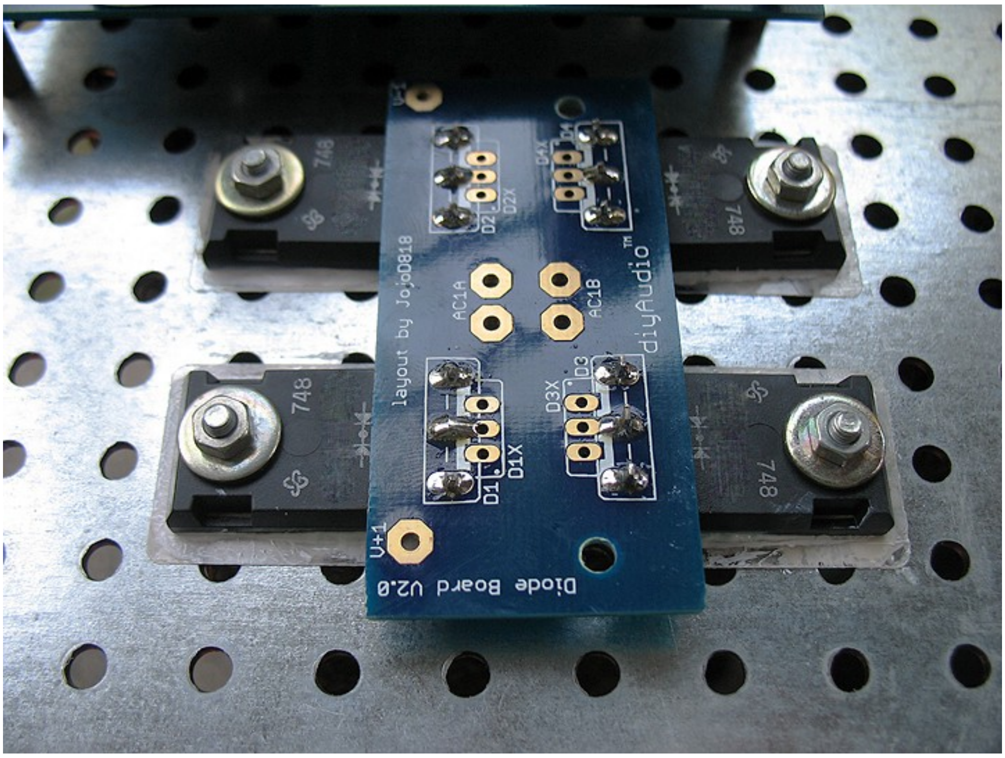
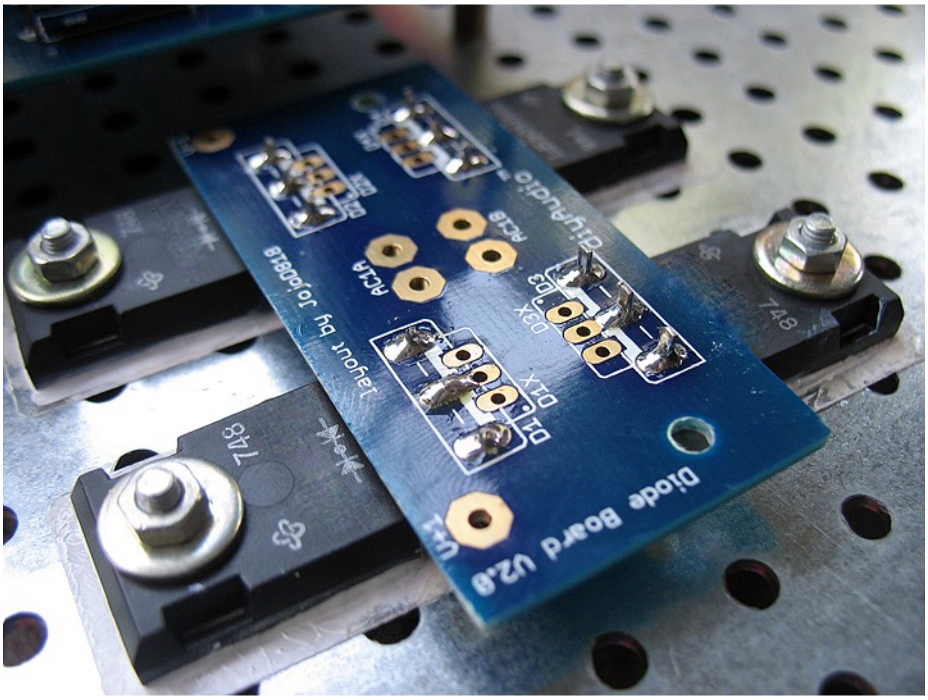
Using TO-247 package style diodes for the rectifier section makes life a lot easier, not to mention they have larger bodies that can be bolted to the perforated base or a separate heatsink.



Of course using mica insulators and silicone thermal grease or another type of insulator is still a must. Remember how we installed our MOSFETs? It's the same thing with the diodes. You don't need to use standoffs for the rectifier board as the leads of the rectifiers are already more than enough to support it. Do a quick resistance check of all the diode leads to make sure they are properly isolated from the perforated base or heatsink just like we did with the MOSFETs.



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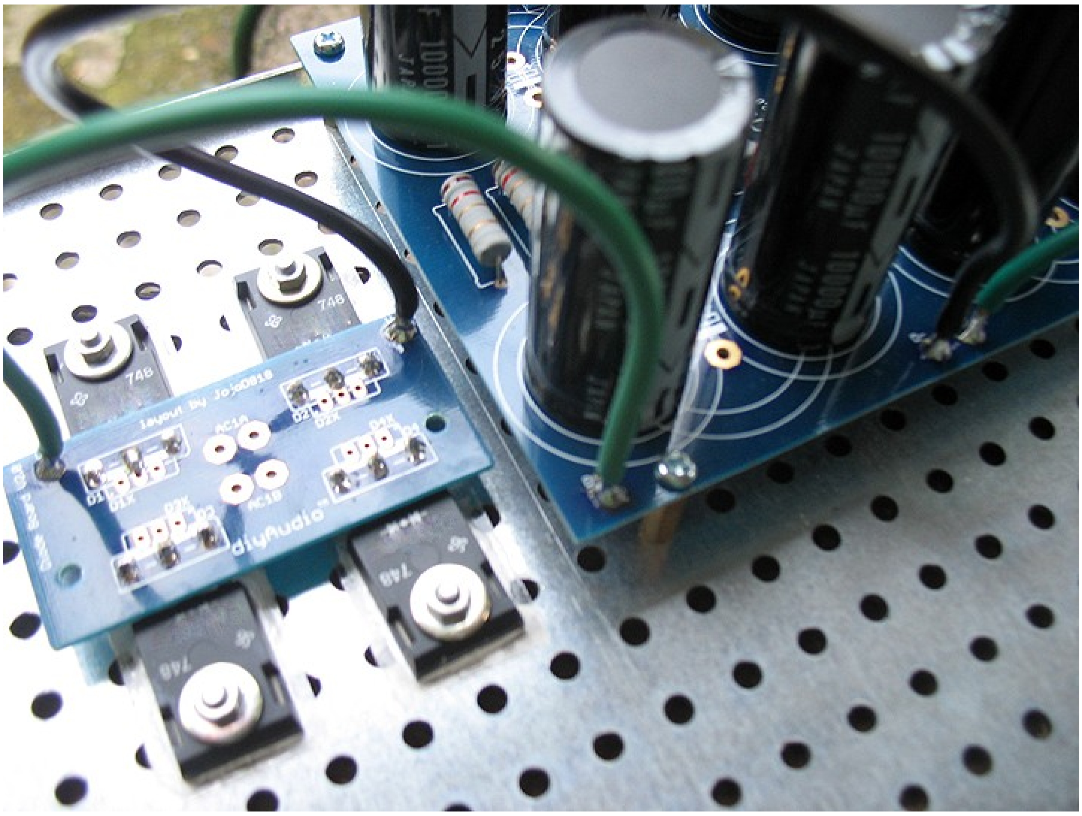
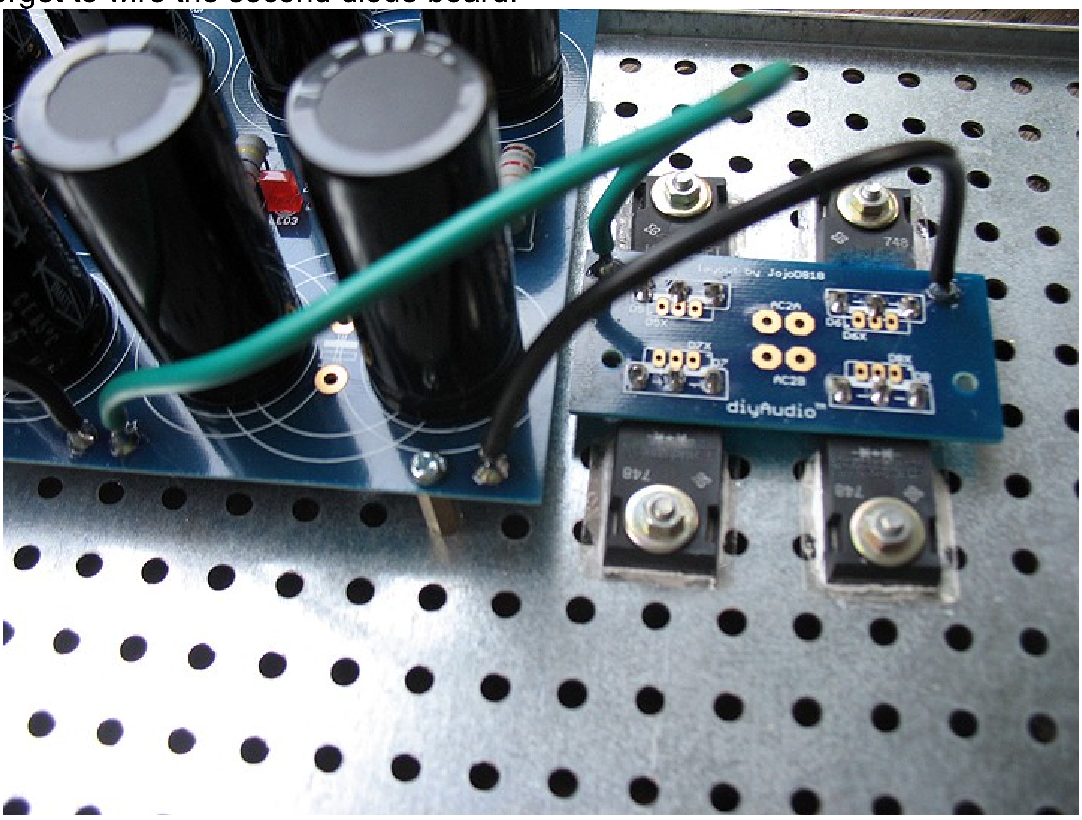
Now let's wire our rectifier board to our capacitor board using a piece of #18 or a larger #16 wire. You can also refer to the diyAudio PSU Build Guide for more information.



Don't forget to wire the second diode board!



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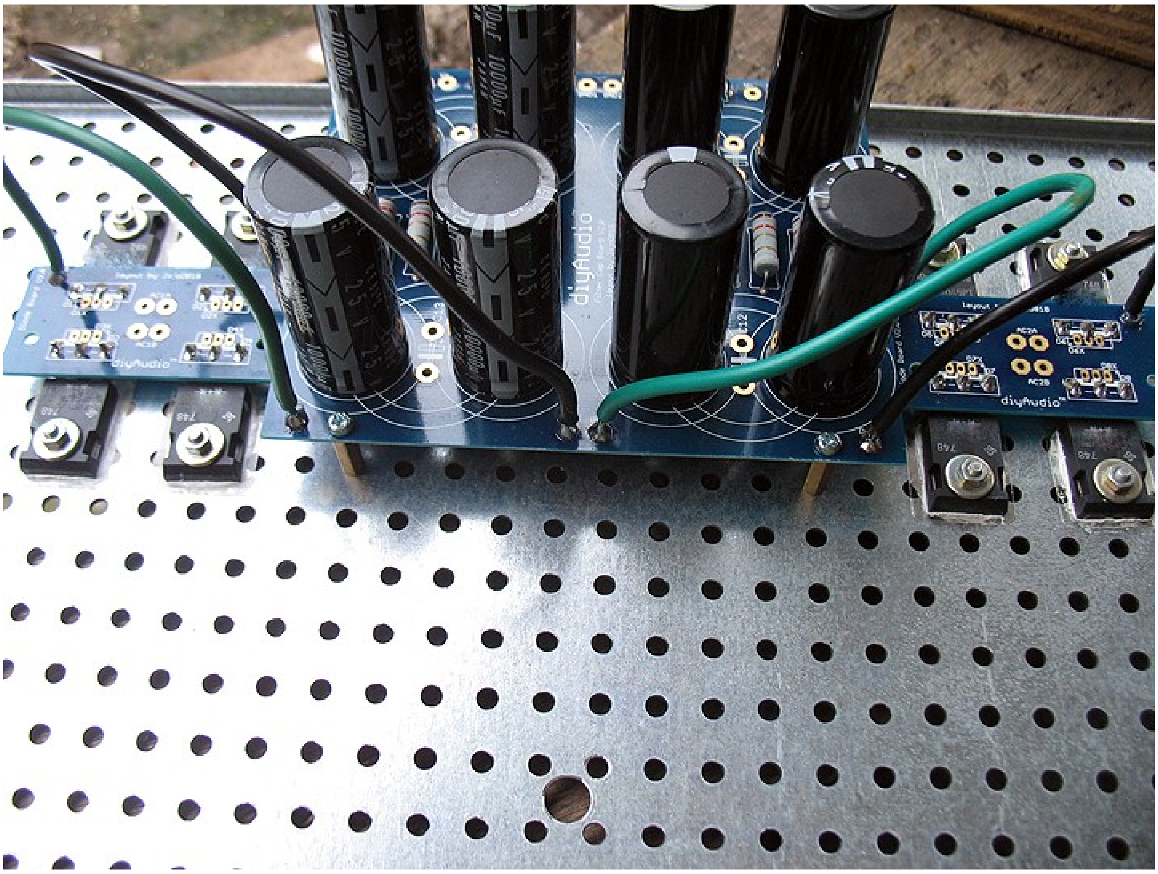
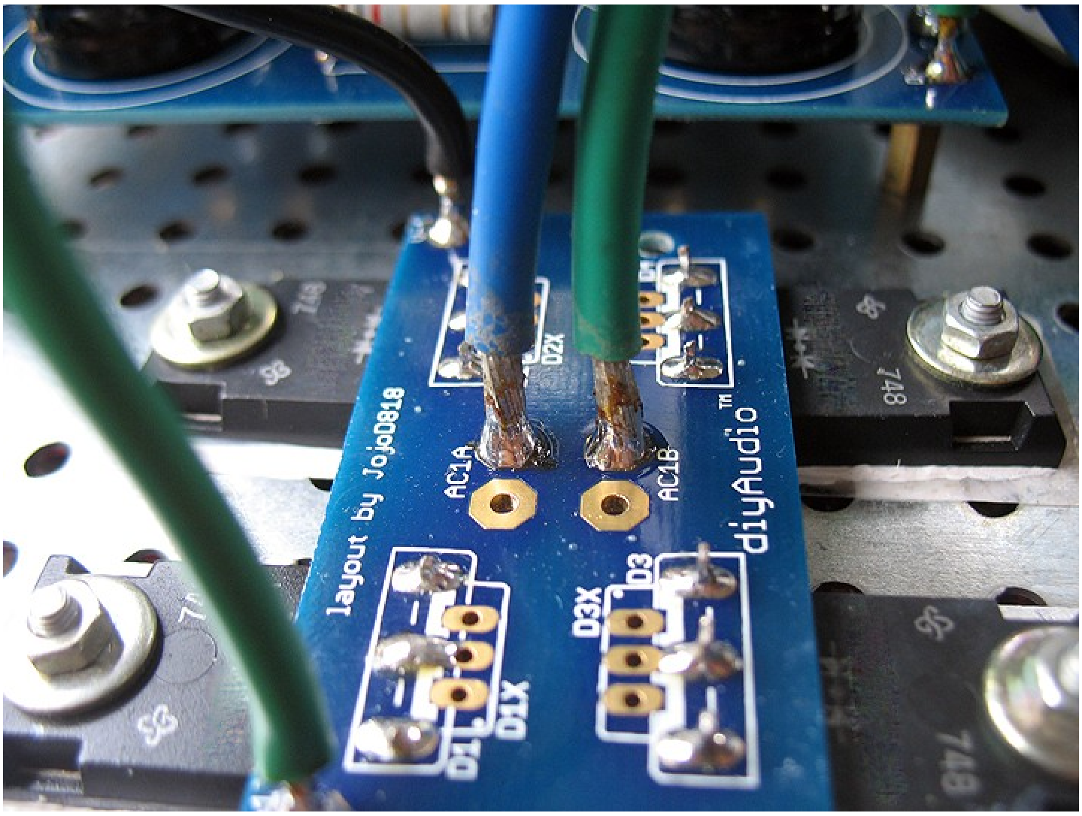
You'll probably notice in the photo that the transformer is missing. I just removed it so we can get a clear view of how the diode board to capacitor board is wired. :)



The secondary windings of the transformer are then soldered to the two diode boards.



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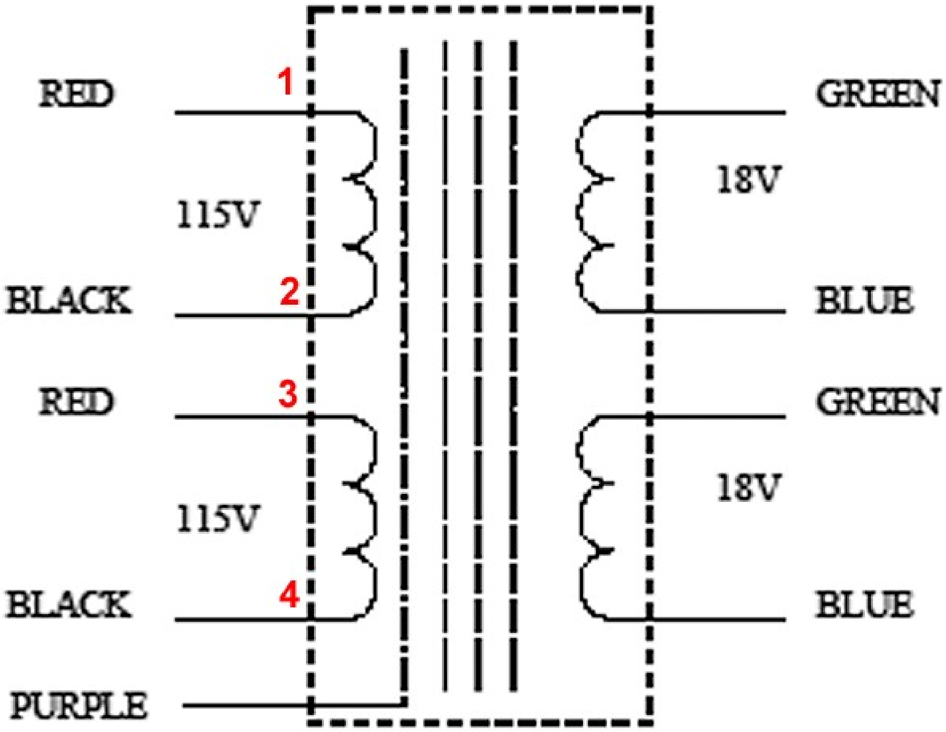
Next thing we're gonna do is the wiring of the transformer's primary side - that's the one that we plug to the AC mains to power our amplifier.

First thing you need to know is your AC mains voltage, in our case, we have 240VAC so we're going to wire the primary to accommodate that. If you have 120VAC lines in your country, just refer to the PSU schematic that is in the **Ideas and Alternatives** section of this build guide, it's real easy, but you must be very careful when doing mains wiring as this is the part of the build where you have to be serious and concentration is a must. But don't worry, I'll be here to show you how it's done. ;)

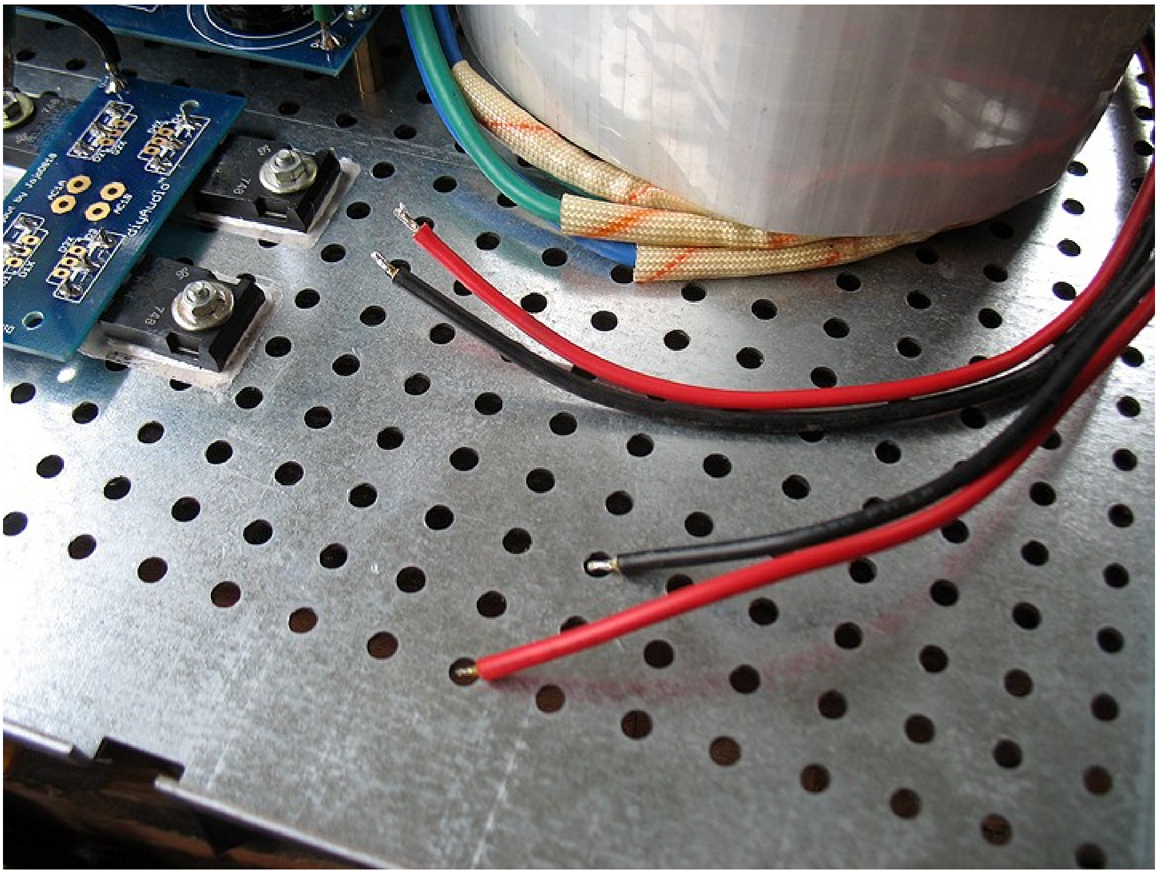
Second, study your transformer's primary windings. Below is a drawing of our transformer's wiring diagram.



On the left side are the primary windings, and on the right side are the secondary windings. Notice that there are two pairs of 115V primary windings? There's also a purple wire that's connected to an interstage shield which you can connect to the chassis ground, but let's just leave it unconnected and concentrate on the two pairs of 115V windings for now. Please dress the purple with heatshrink tubing and tuck it away. I have purposely labeled the wires 1, 2, 3 and 4 for easy reference.

What we want to do is find out which of the four wires are the pairs 1 & 2, and pairs 3 & 4. That is very simple to do, get your DMM and set it to check for resistance. Now grab one of the two red wires and one of the two black wires. Check for resistance. If there is no low reading then that is not a pair. Hold on to the red wire but get the other black wire, now test for resistance and surely you'll read something really low. Now that's our first pair, so label the red wire as 1 & the black wire as 2. Take the other two red and black wires and with your DMM, you'll surely read a very low resistance. Label the red wire as 3 and the black wire as 4.

Ok, now we know our pairs 1 & 2 and 3 & 4 so are ready to wire our transformer for 240VAC operation.



Next, prepare our CL-12 thermistor, which we need to solder in between our two windings.

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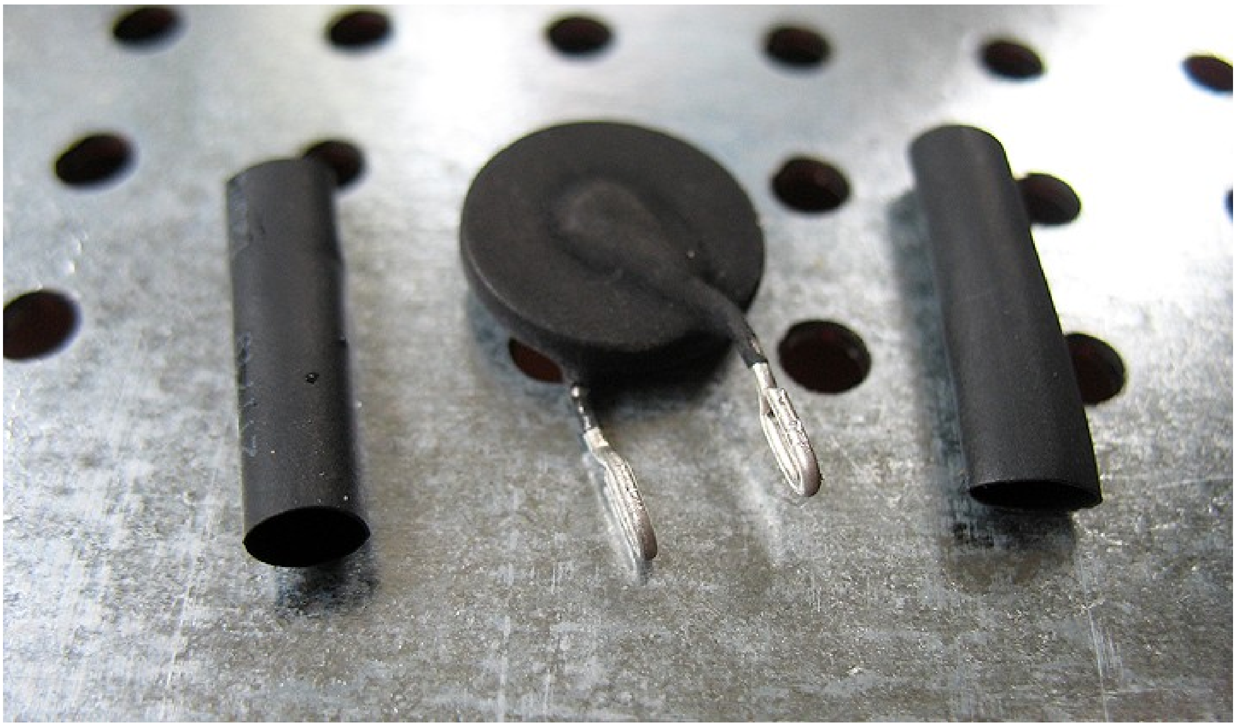
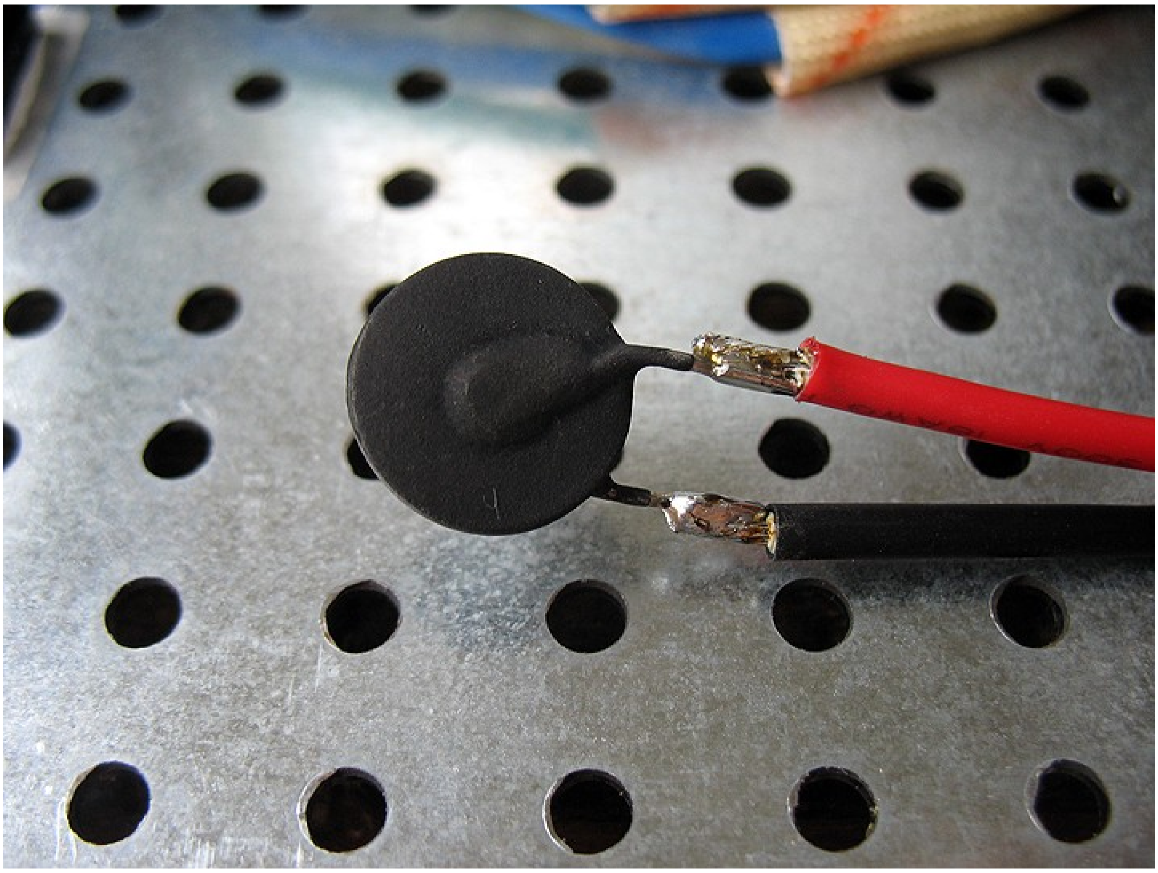
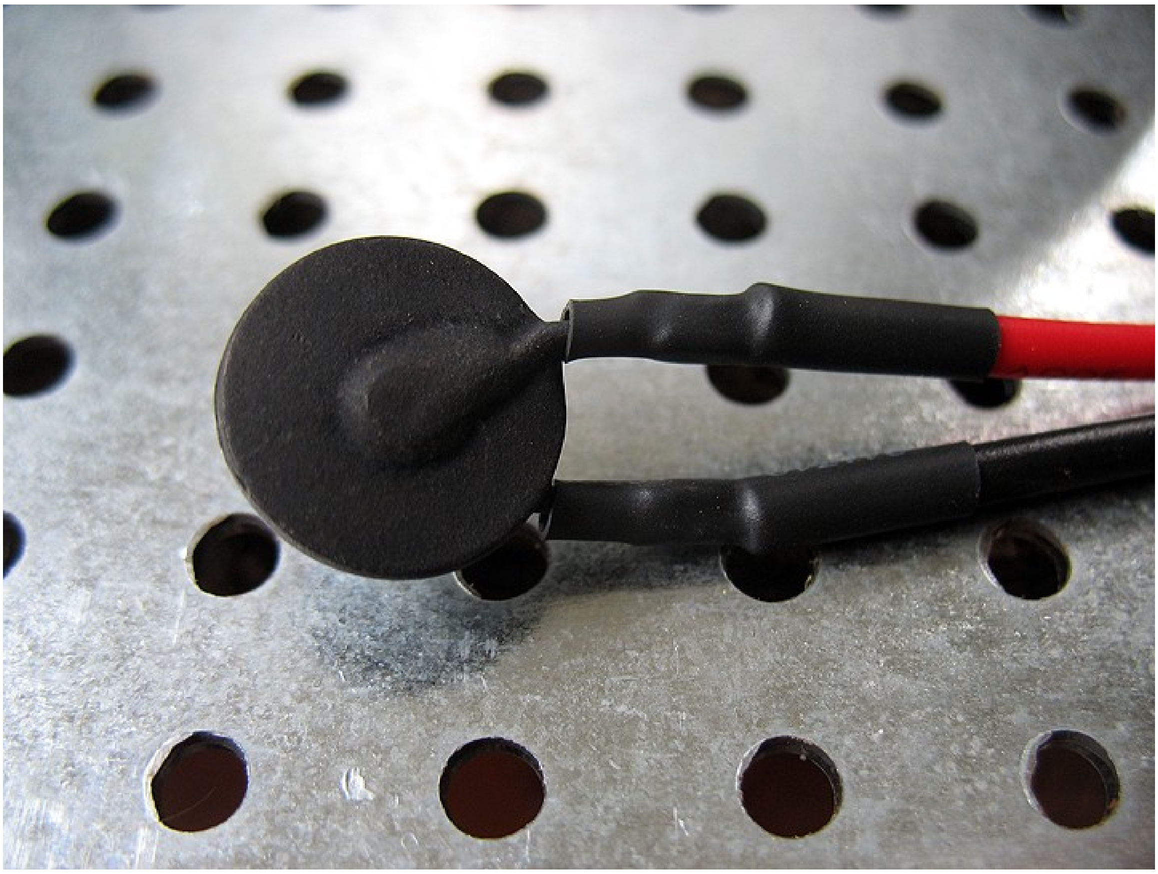
The thermistor is the one labeled TH in the schematic of the PSU. Get one and bend the leads as shown in the photo below. Also, prepare a couple of heat-shrink tubes.



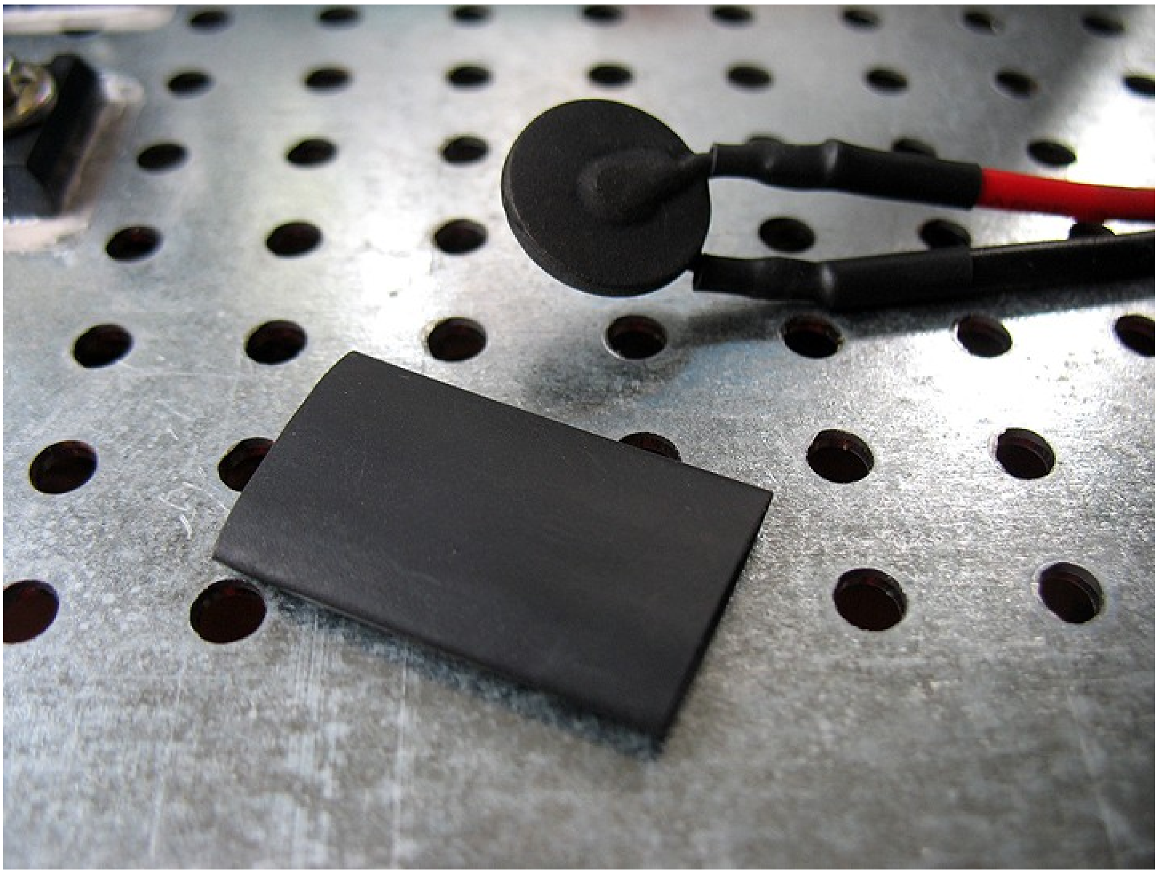
Now solder the thermistor in between the two primary windings, that's wires 2 and 3. Don't forget to insert your heat-shrink tubes on the wires before you solder. ;)



Dress the soldered leads with the heat-shrink tubing.



For safety we need secondary insulation. Get a larger size heat-shrink tube, something that will fit the whole thermistor body.



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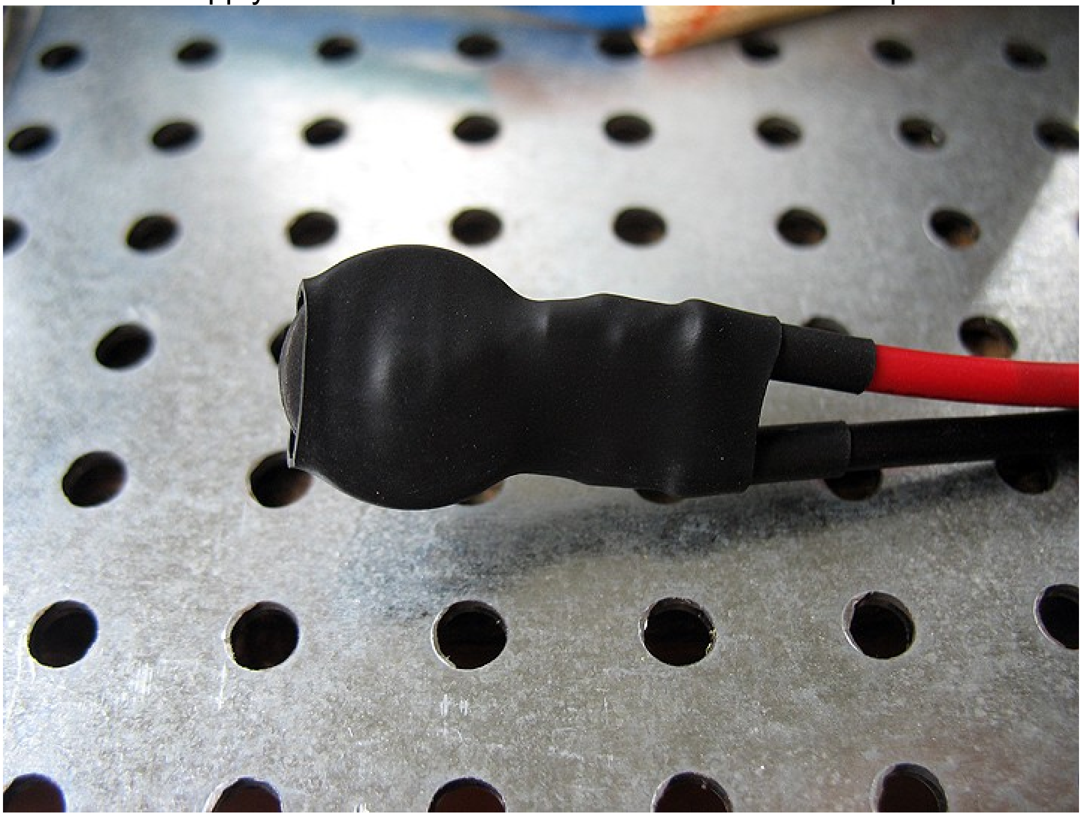
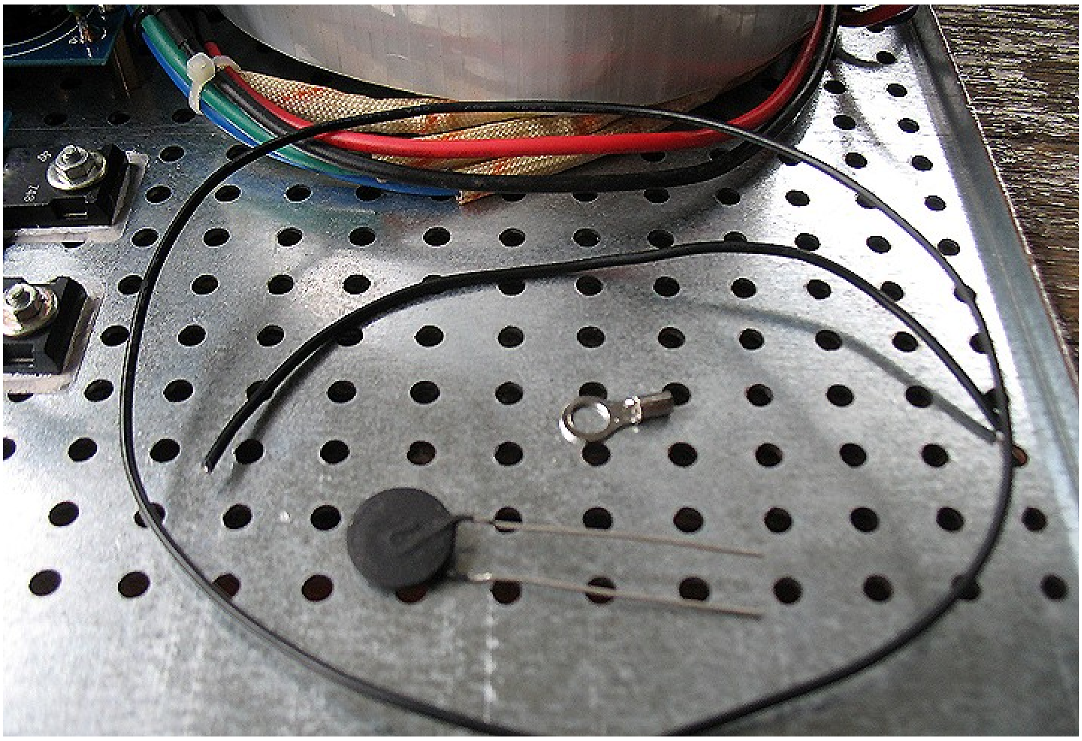
And there you go! You've just successfully wired your transformer for 240VAC operation! The remaining wires 1 and 4 go to your PEM for power. Wire 1 connects to the Live pin of the PEM while wire 2 connects to the Neutral pin of the PEM. Isn't that simple and easy? Refer to the Power Supply Schematic to see how to wire for 120VAC operation.



Now let's move to the last thermistor labeled TH1 in the PSU schematic. It's the connection used to join our Chassis Ground and Power Ground.



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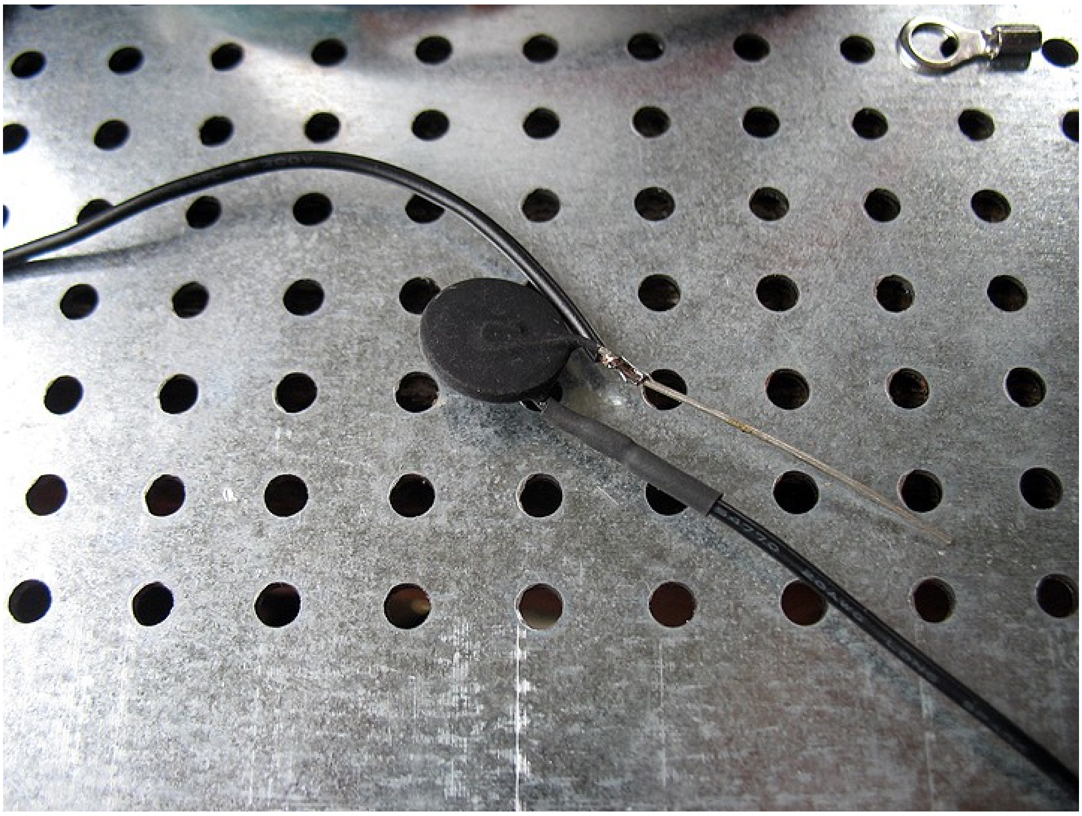
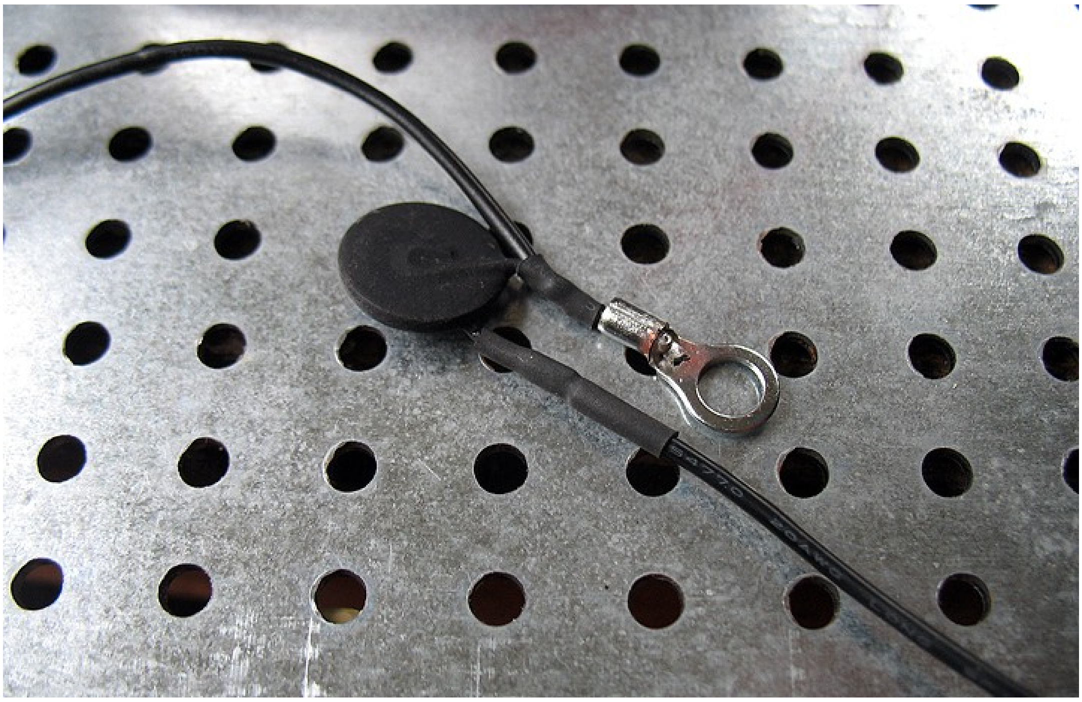
Solder a piece of wire about 300mm long to one of the leads of the thermistor and insulate it with a piece of heat-shrink tube. Then solder a shorter wire, about 100mm long to the other lead of the thermistor. See the photo below for details.



Solder the eyelet to the lead which is soldered to the shorter wire. You may want to insulate it with heat-shrink tubing as I did to make it look good, but it won't matter electrically because we'll connect the eyelet to chassis ground anyway. See photo below.



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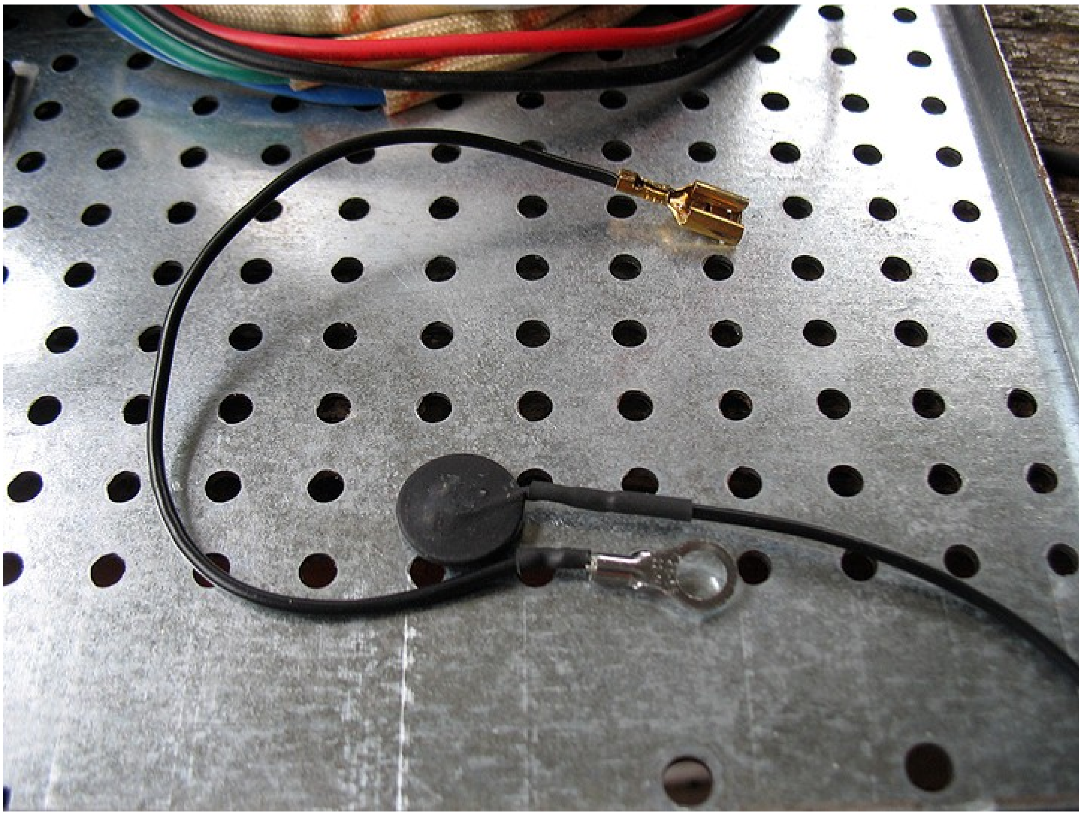
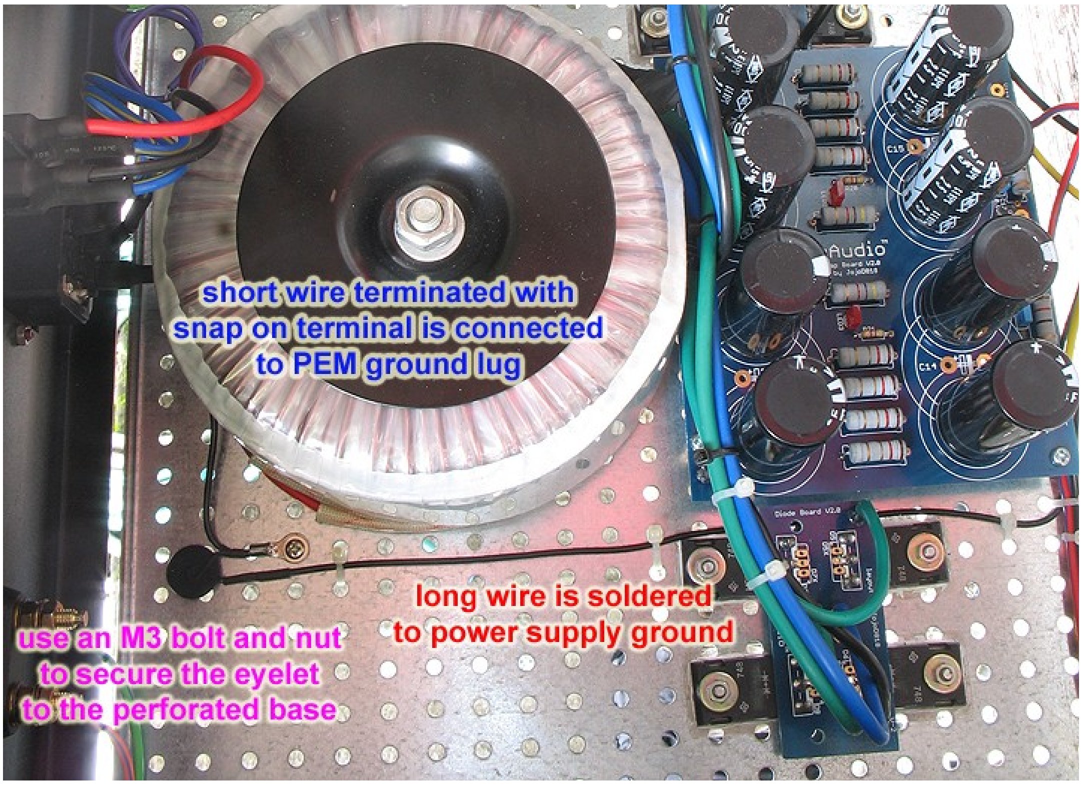
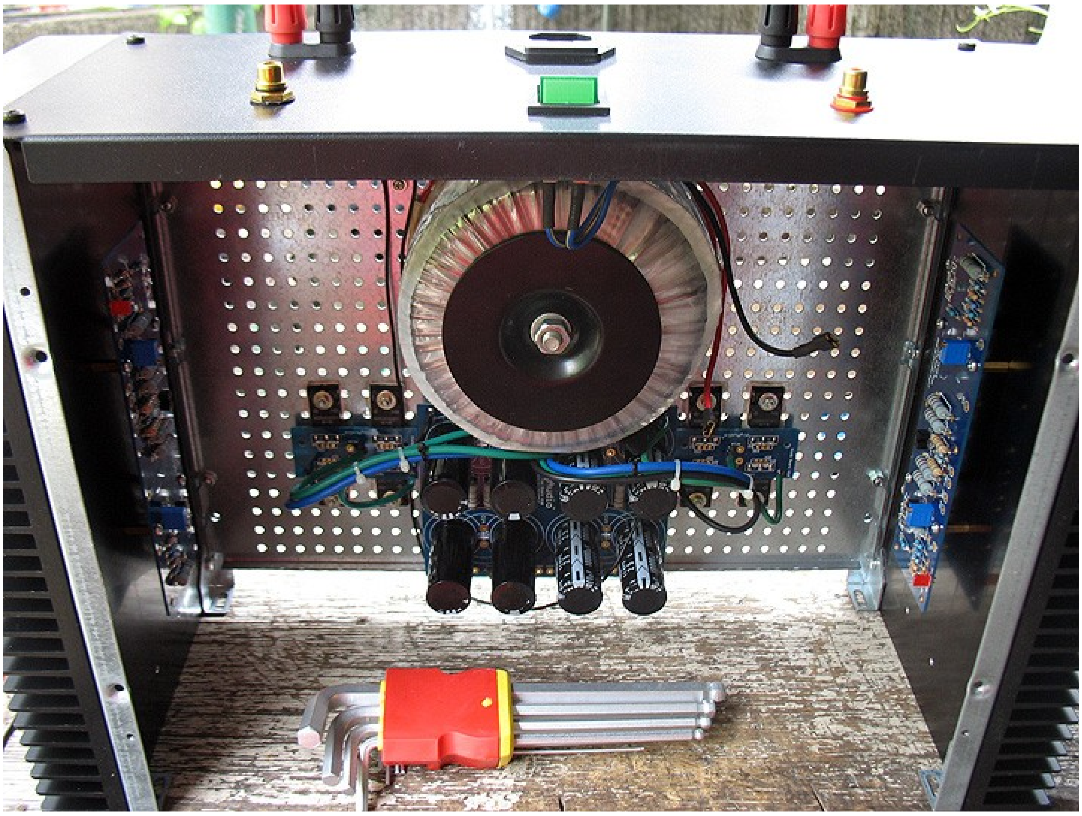
Now we're going to terminate the other end of the shorter wire with a female snap-on terminal. This terminal should then be connected to your PEM's ground lug.



Refer to the photo below for installation of the ground thermistor, designated as TH1.



We're almost there! Install your RCA jacks, Speaker binding posts, and PEM on the back plate and assemble your chassis similarly to the photo below.

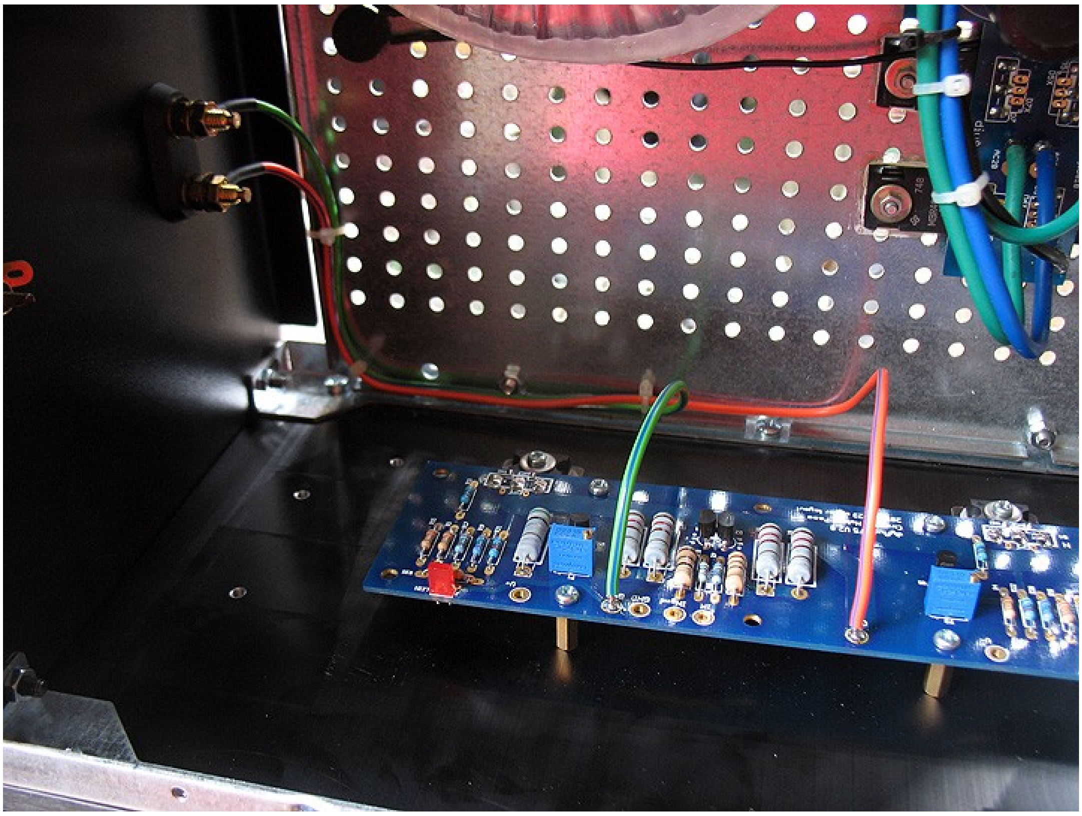


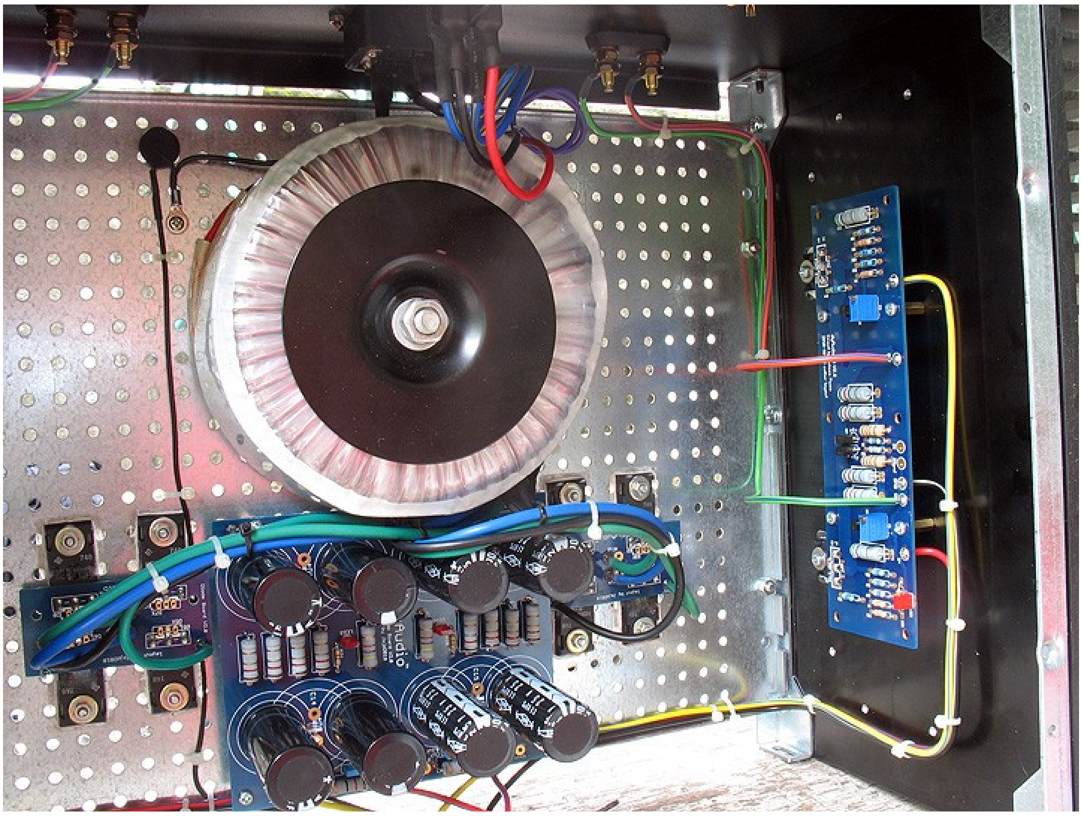
The only thing left to do is wire your amplifier's input and output connections and the power supply. There are just 7 wires that go to each channel.

- 2 wires for the input connection
- 2 wires for the speaker connection
- 3 wires for the power supply connection, but wait on this until the Testing and Calibration steps are done.

I'll leave the choice of wire for you to decide. As an example, you can use either a shielded wire or a twisted solid #22 wire for the input connection. I strongly advise that you use multi-colored wires so that you don't get confused during wiring. For the power supply wiring I used Red for V+, Black for GND, and Yellow for V-. I tend to reserve black wires for wiring ground connections. That way I can readily confirm that a wire is going to ground. There are a multitude of threads at diyAudio concerning the choice of wires, some with horrifying discussions that can confuse even the seasoned builder. For this prototype, I used #22 twisted pair solid copper wires for the input, and #18 stranded copper wires for the speaker outputs and the power supply. For me, what's important is that the wire is made of high quality materials and insulation.

Well don't stop now, let's wire her up and finish this amp!





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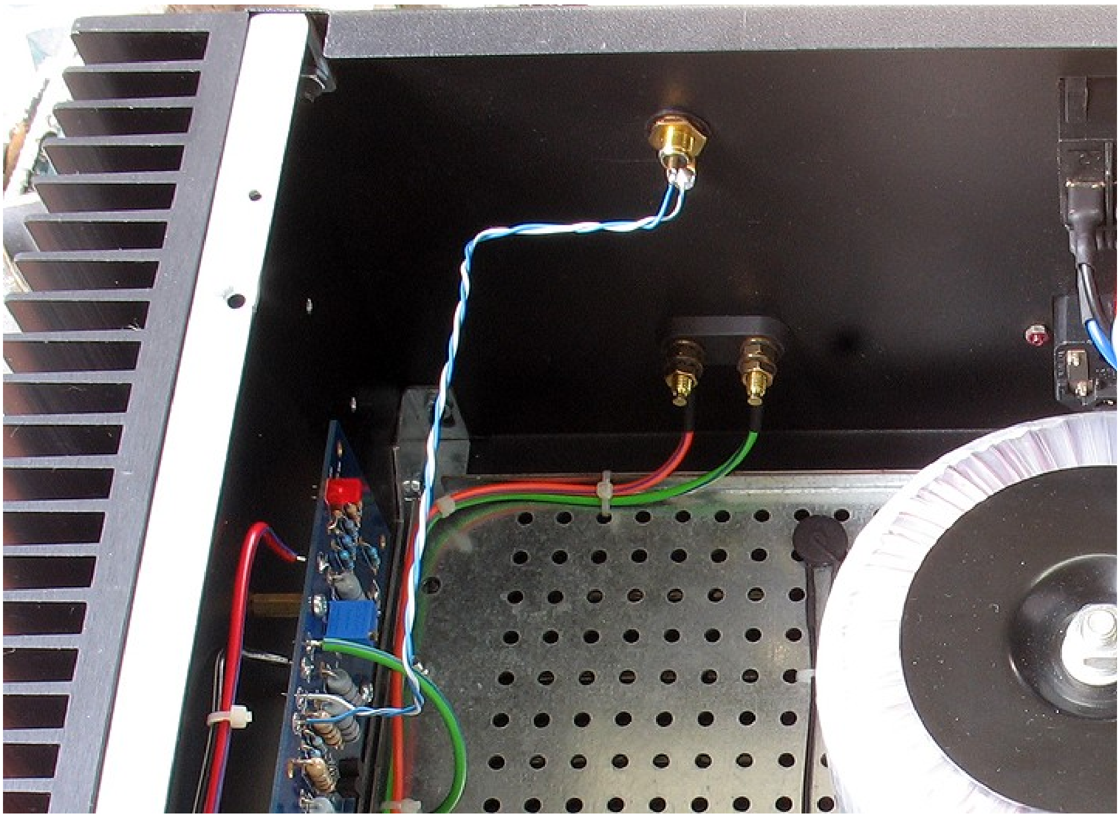
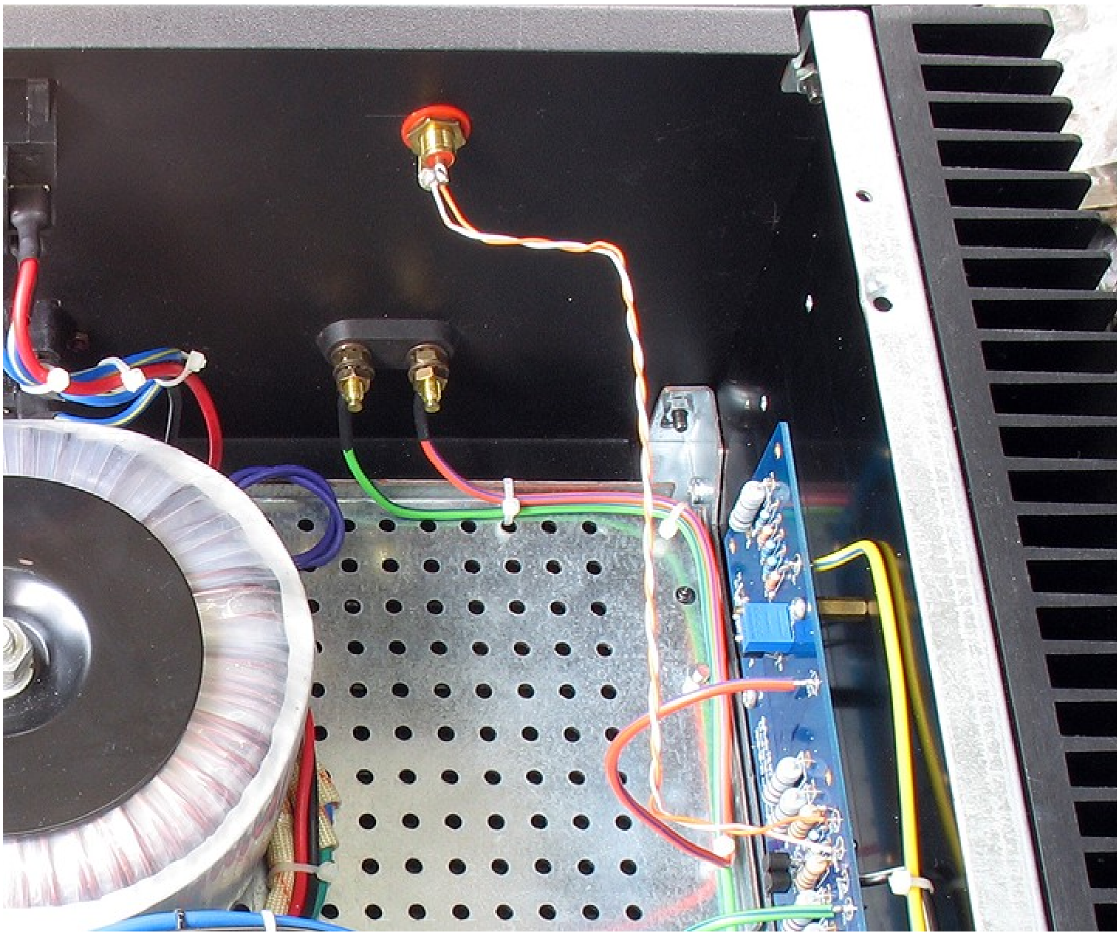
This photo above shows the speaker connection to the right channel wired to the speaker binding posts, and the power supply connection wiring. The power supply connection is actually not connected yet to the power supply board. Wiring is a bit of an art, and neatly bundled and routed wires not only look really cool, but also simplify troubleshooting and often help tame any potential hum or RFI interference. It's important to keep AC power wiring, high current wires such as to the speaker outputs, and low level signal input wiring, separate from each other.

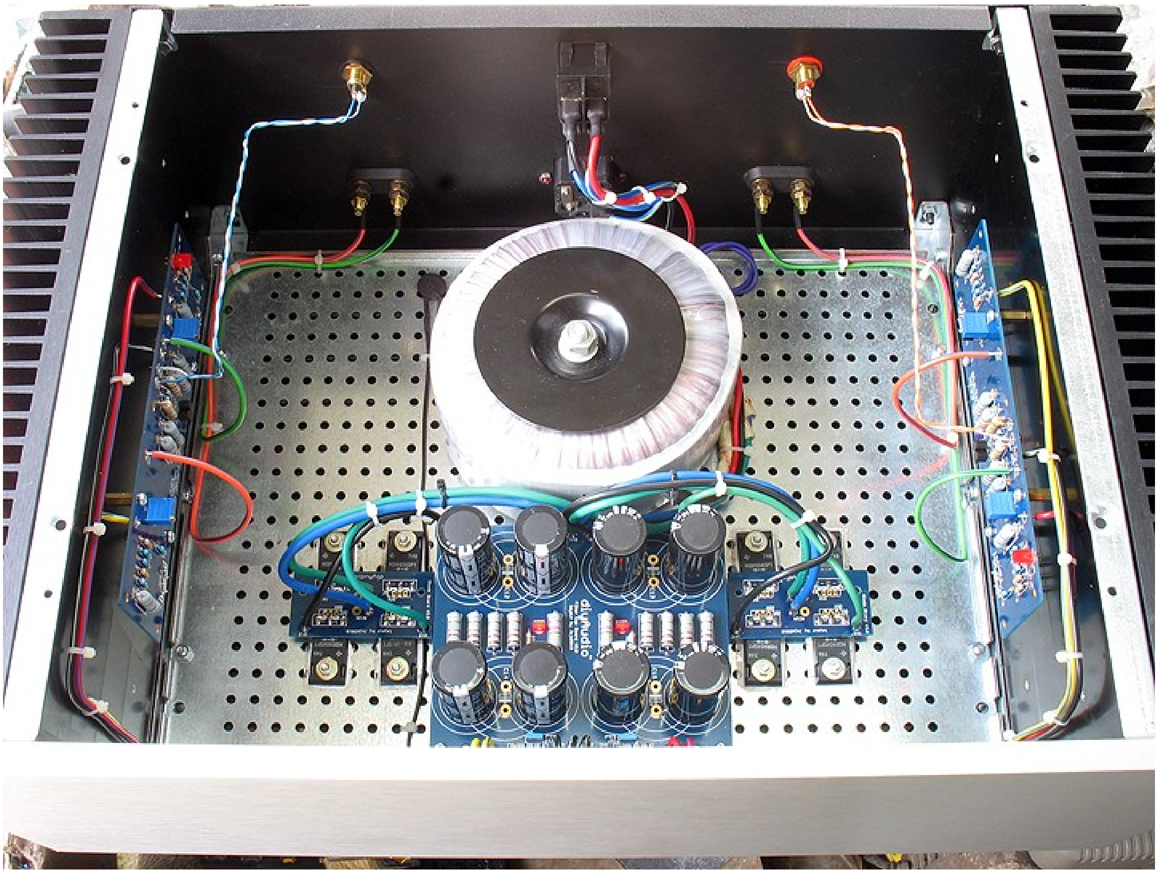
This photo shows the left channel with it's input wires connected to the RCA input jack.



This shows the right channel with it's input wires connected to the RCA input jack. Note how they are tightly twisted to limit interference or hum that low level signals are susceptible to.



Finally! All done!



Excellent job! All that's left now is connecting the power supply wires to the PSU board, but before we do that, it's wise to first test our power supply and confirm that it outputs the right voltage for our power amplifier to work properly.

And so, this officially concludes the Construction section. But before we move on to testing and calibrating our amplifier's bias, we need to check our work. Here's a standard list of very helpful reminders that I prepared for you.

Checking Your Work:

Building electronic stuff is fun and enjoyable, up to the point when you are about to power it on for the first time! To help in reducing the risk of failures and boost the builder's confidence, these are my usual procedures when checking a finished board.

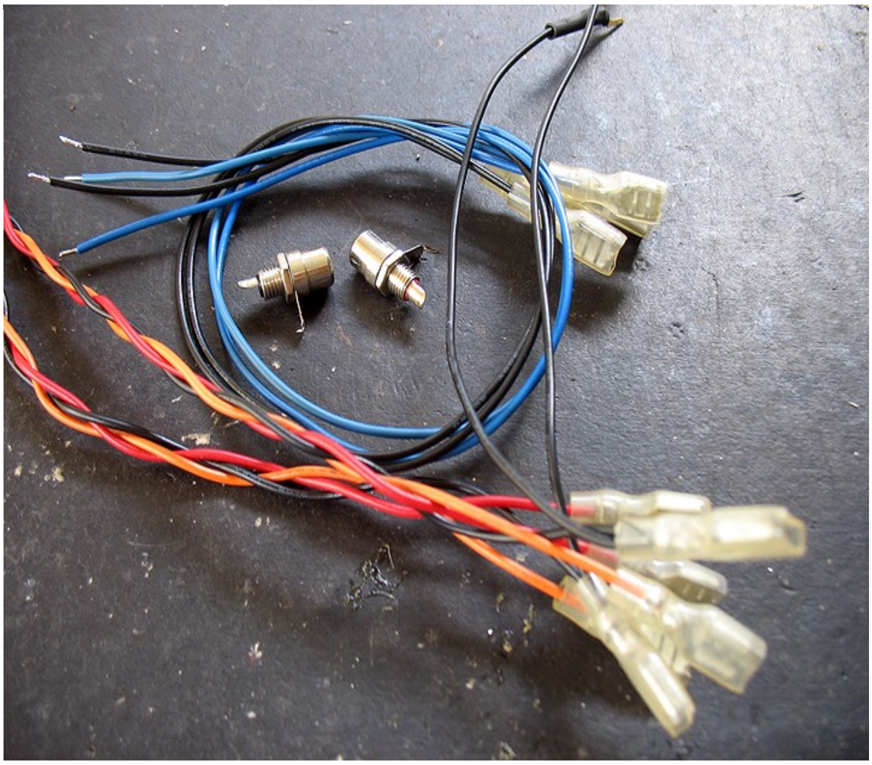
Resistors – Visually check each resistor, cross reference it with the BOM, and make sure that you placed the right value in the right spot.

Capacitors – Electrolytic capacitors are polarized so check and pay careful attention to their pin orientation. Make sure the markings on the capacitor match the polarity marked on the board.

Diodes – It is so easy to overlook the lead orientation of diodes, especially those two-leaded, small signal types and zener types. Check and make sure that their polarity matches the assigned polarity markings on the board. Usually the longer lead is positive.

Transistors – These devices have markings on their bodies that may require a magnifying glass to read. Make sure that every transistor is properly oriented on the board and that the particular transistor installed is indeed the type of transistor that is required in that position. Catastrophic failure may occur if you misplace or install a transistor the wrong way so take your time to check and recheck.

Wiring – it helps if the wires you use are of different colors. For example, all V+ wires are Red, Ground wires are Black, and V- wires are Orange. That way, there won’t be any confusion when doing tests and assembly of your amp. Also, make use of suitable thickness wires, but don't overdo it. Of course no one's stopping you from using those ultra high end cables for wiring the amp but remember too that it’s harder to dress a thick wire. Use at least AWG#16 stranded for hookup wires and shielded wires for all small signal carrying wires.



Testing and Calibration:

This is it. Just a few more steps and we'll be relaxing and listening to our F5 amplifier.

Things you’ll need:

1. Digital Multi-Meter (DMM). Two of these would come in handy. Three would be great. You can always borrow one from a friend ;)
2. A Variac could come in handy.
3. Trimmer adjustment tool. Those plastic ones will do well.

<u>First things first!!!</u>
Don't solder the power supply wiring of the amplifier yet, we must test the power supply and confirm it works before we connect it to our amplifier boards.

1. Turn all variable resistors, P1 and P2 (total of four variable resistors for a stereo setup) **fully counter-clockwise**. This can be verified by measuring the resistance between the outer leads of the variable resistors and it must read zero Ohms. This ensures that the bias is low, if not close to zero, once we power up the amplifiers.

Testing the Power Supply:

With a variac:

1. Make sure the Variac is powered off and that the dial is turned all the way down.
2. Connect our amplifier's power cord to the output of the Variac.
3. Connect a DMM's positive probe to the Power Supply board V+.
4. Connect the DMM's negative probe to the Power Supply board GND.
5. Set the DMM to read VDC.
6. Install a fuse in the PEM, proper value is indicated in the PSU schematic.
7. Switch the amplifier's power to on.
8. Power up the Variac and slowly turn the dial to increase the output.
9. Watch your DMM's reading, the output of the Power Supply should slowly increase.
10. With the Variac's output set at about 240V (or 120V in places with 120V mains), your Power Supply should output something close to 25V. Remove the positive probe of the DMM and clamp it to the Power Supply board V-.
11. Watch your DMM's reading, the output of the Power Supply board should be the same but with a negative, or minus marking (-).
12. Your Power Supply is now tested and ready! Switch off everything.

Without a variac:

1. Make sure the amplifier's power switch is set to off.
2. Make sure there is a properly sized fuse in the PEM, proper value is indicated in the PSU schematic.
3. Connect a DMM's positive probe to the Power Supply board V+.
4. Connect the DMM's negative probe to the Power Supply board GND.
5. Set the DMM to read VDC.
6. Plug the amplifier's power cord to a wall outlet.
7. While watching your DMM, briefly (for about a second or two) turn the power switch to on and you should see a reading of about 23V to 25V in the DMM.
8. With the amplifier turned off, remove the positive probe of the DMM and clamp it to the Power Supply board V-.
9. Again, briefly turn the power switch to On and you should see a negative reading (with a minus "-" sign) of about 23V to 25V in the DMM.
10. Smile, your Power Supply is now tested and ready! Switch off everything.

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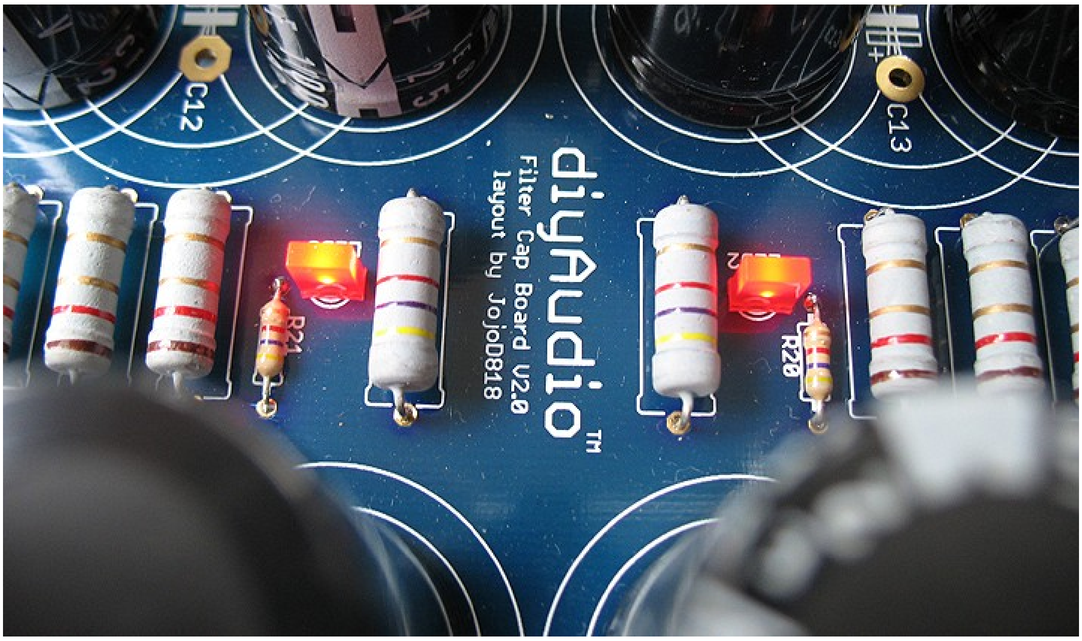
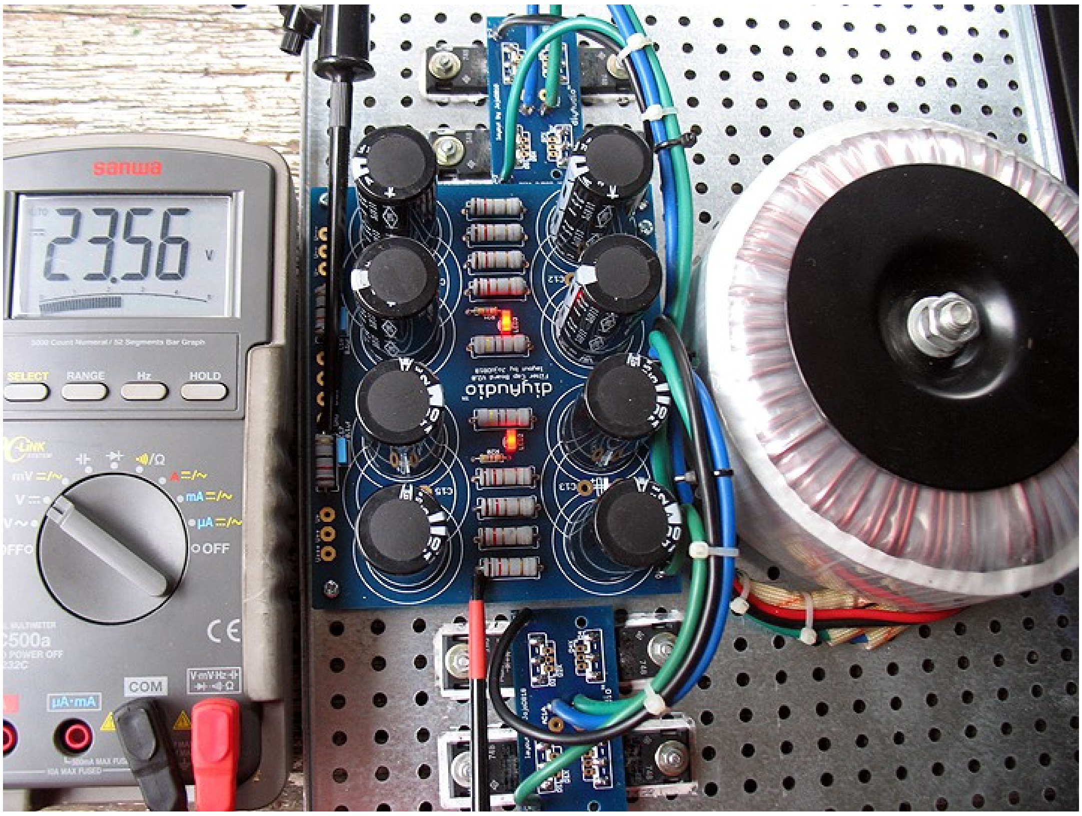


In both test cases, you should see the onboard LED of the Power Supply board light up when you turn the power on. Since there is no load yet, and there is a large amount of stored energy in the Power Supply board's capacitor bank, the LED will remain lit long after you have removed power. Don't worry, the Power Supply board has bleeder resistors that should discharge the stored energy safely in about 5 minutes or so.

Here's a photo showing a DMM connected to the Power Supply board. The negative probe is clamped to the GND while the positive probe is connected to one of the PI resistors which is effectively connected to V+.



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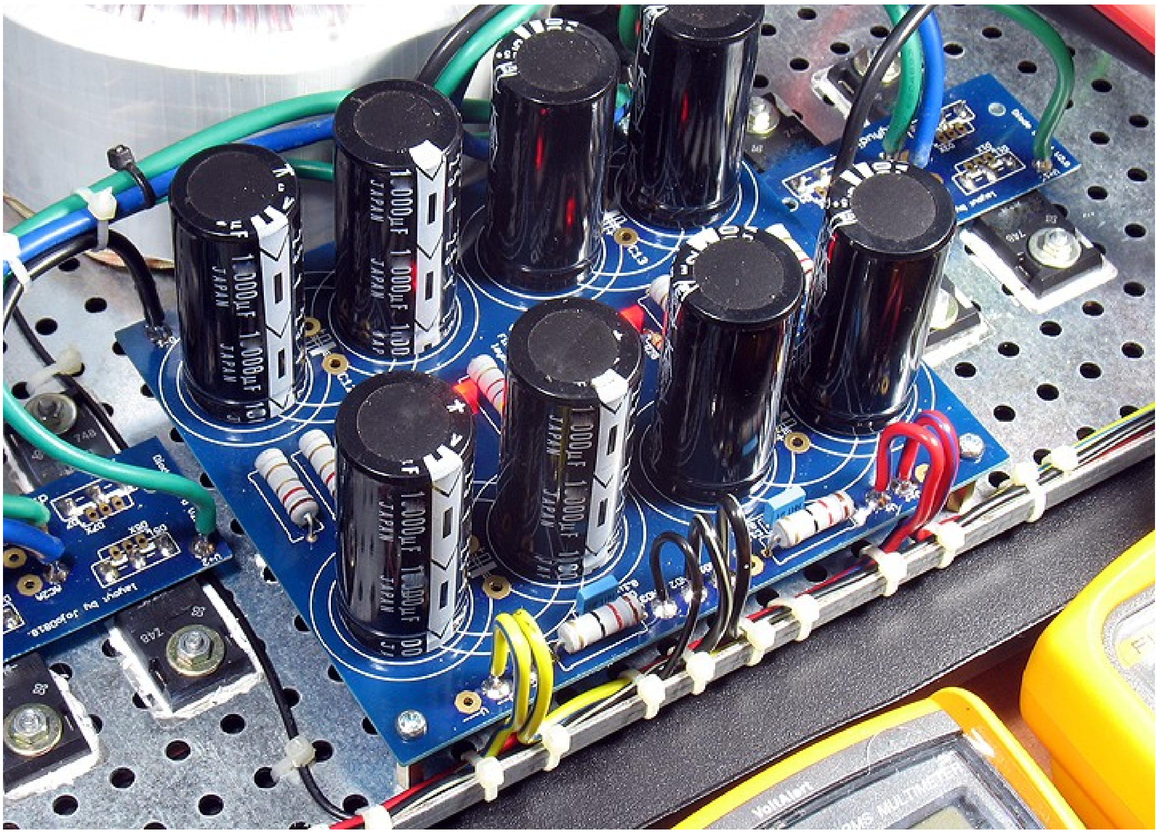
Once the Power supply board has fully discharged, you can start connecting the power supply wiring of your amplifier boards to the Power Supply board.



Powering the Amplifier for the first time:

- Please make absolutely sure that all variable resistors P1 and P2 are turned **fully counter-clockwise**.
- Connect a DMM's probes across R11, polarity is not an issue. Set it to read DC Volts.
- If you have another DMM, connect its probes across R12, polarity is not an issue. Set it to read DC Volts.
- If you were able to borrow a third DMM, connect its probe to the speaker binding post and set it to read DC Volts. **Do not connect a speaker load!** Just the DMM.
- Refer to the photos I prepared below this section for further details.
- With all 3 DMMs fired up and reading DC Volts, switch the power amplifier on. You should initially read 0 Volts on all 3 DMMs.
- Slowly turn P1 clockwise until you see your first few millivolts on the DMM connected across resistor R11.
- Now adjust P2 clockwise until you see your first few millivolts on the DMM connected across resistor R12.

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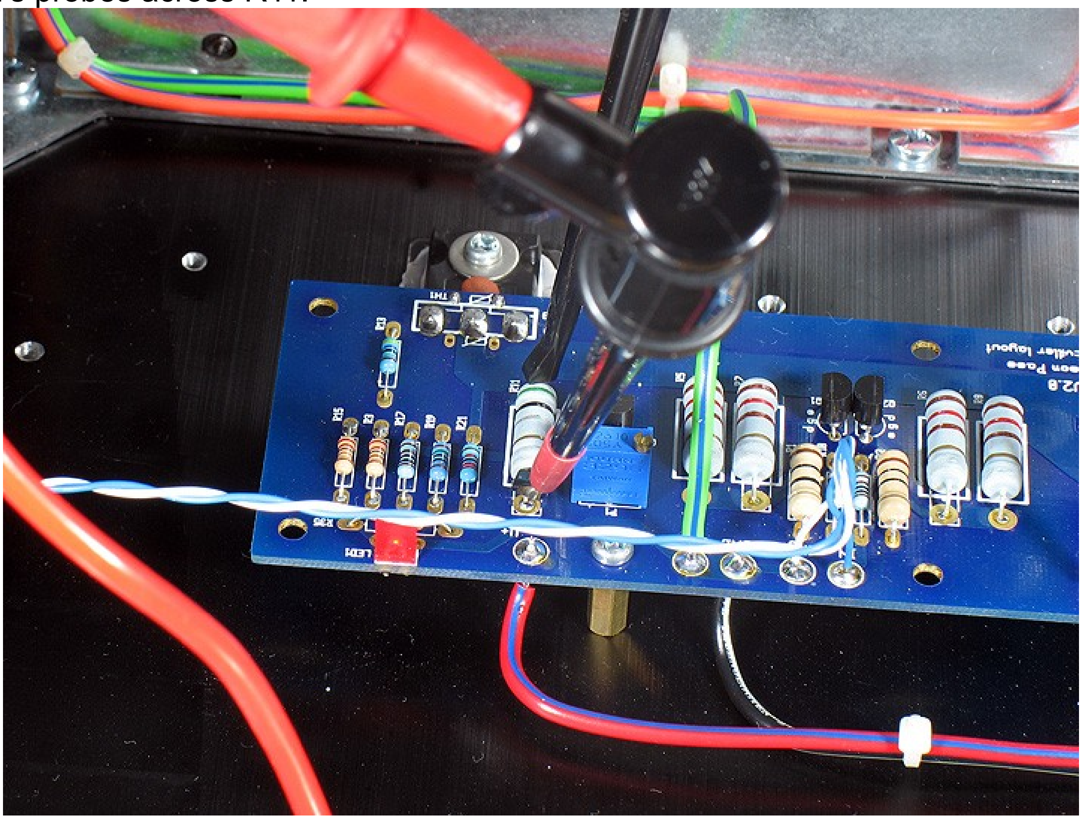
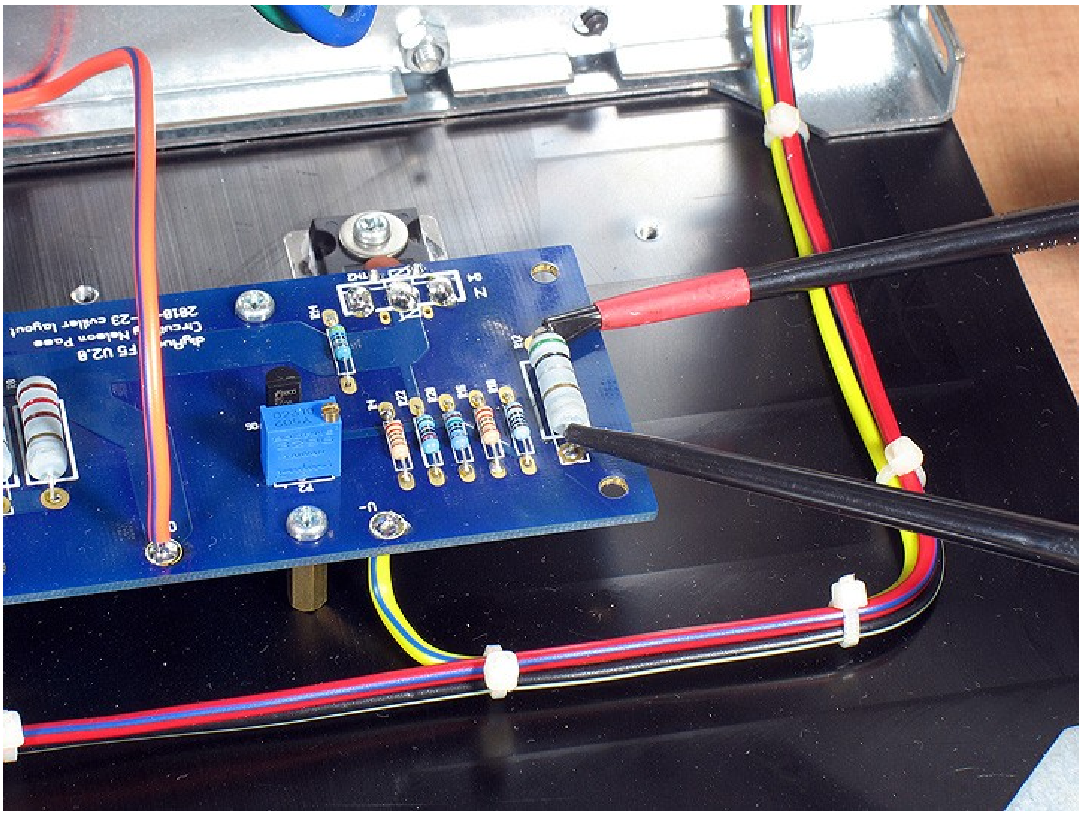
- Alternately adjust P1 and P2 until both DMMs connected across R11 and R12 read 0.4V. That should give us a bias of roughly about ~1A. Let's start low at the moment and let the amp warm up.
- As the power amplifier warms up, you will notice the readings start to decrease, so alternately adjust P1 and P2 again for a reading of 0.4V on both DMMs. You may notice that the DMM connected to the speaker binding posts will shift from positive to negative readings and can go as high as 0.1V during adjustment. This is completely normal and don't worry about it at the moment. Repeat adjusting P1 and P2 until the amplifier's temperature stabilizes.
- Once the power amplifier has completely warmed up, and the readings across R11 and R12 are still stable, you can now increase the bias to the target 0.59V across R11 and R12. Repeat alternately adjusting P1 and P2 until the readings are stable at 0.59V. Provided the amp was built with fairly good tolerance parts, you will notice that when the readings of the DMMs across R11 and R12 are equal, the DMM connected at the speaker binding posts will read 0V or very close to 0V. Getting a 0V reading is not impossible, refer to the following photos.
- Repeat the adjustment procedures for the other channel. Let the amp sit for an hour or two and then check biasing again.

Here are some photos of the testing procedures for your reference:

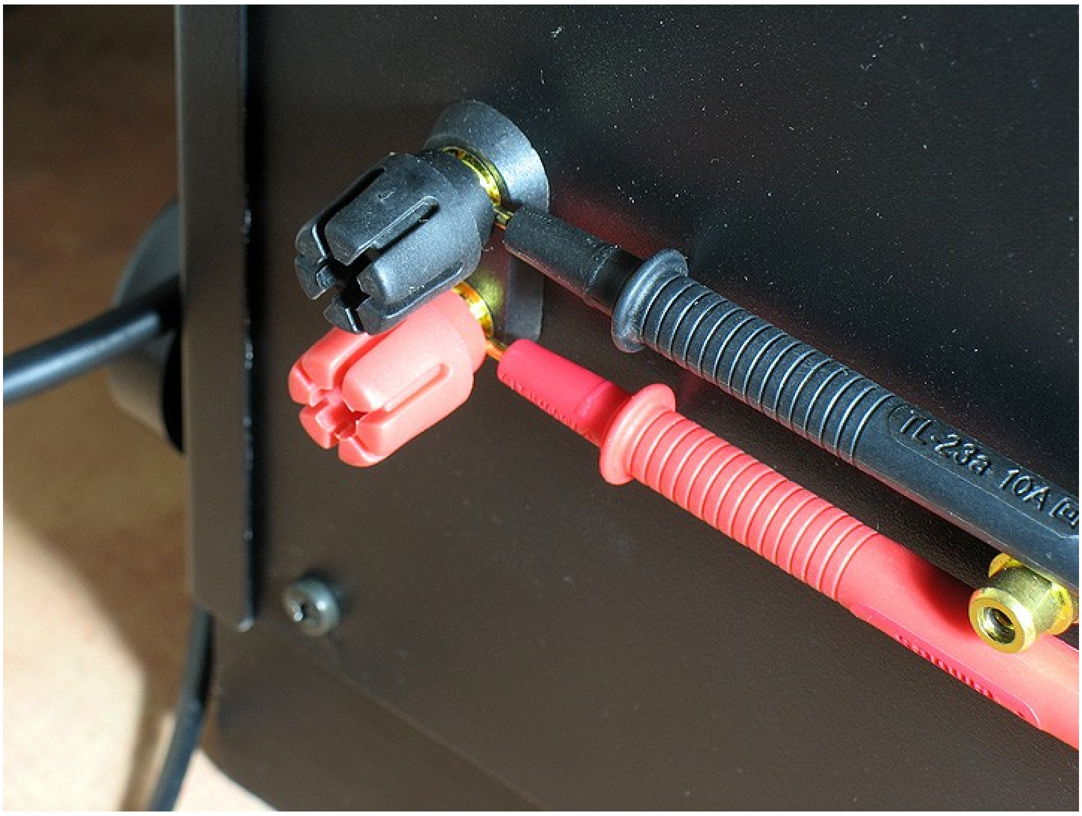
A DMM's probes across R11.



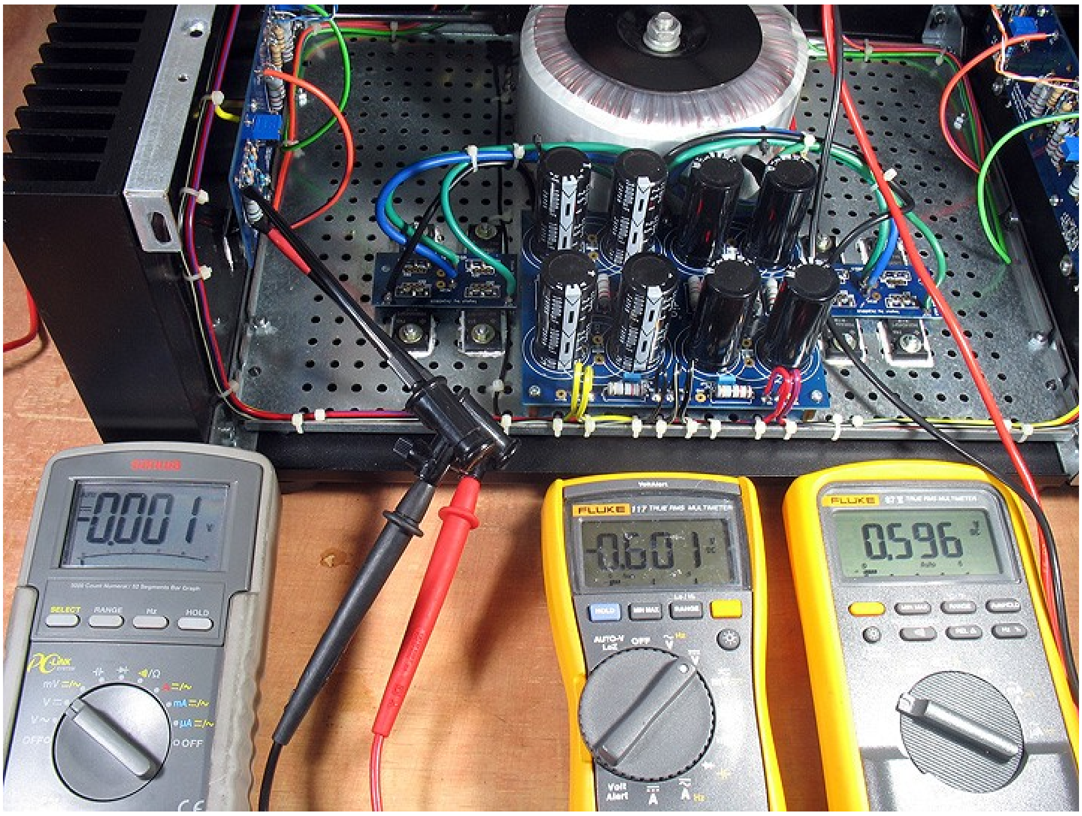
A DMM's probes across R12.



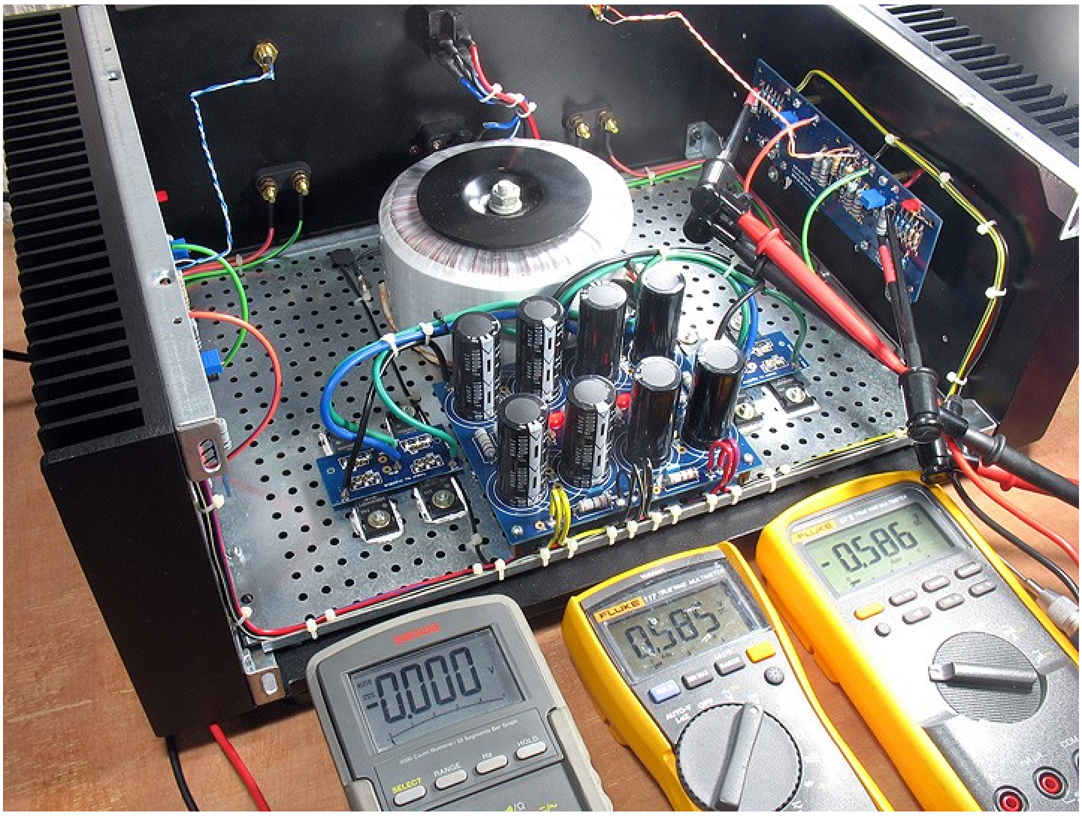
A third DMM is connected to the speaker binding posts to measure DC output offset.



The Sanwa PC500A reads the output offset, Fluke 117 reads the voltage across R12 and Fluke 87V reads the voltage across R11.



The DMM readings for the right channel. Did I say 0V output offset is not impossible? :D



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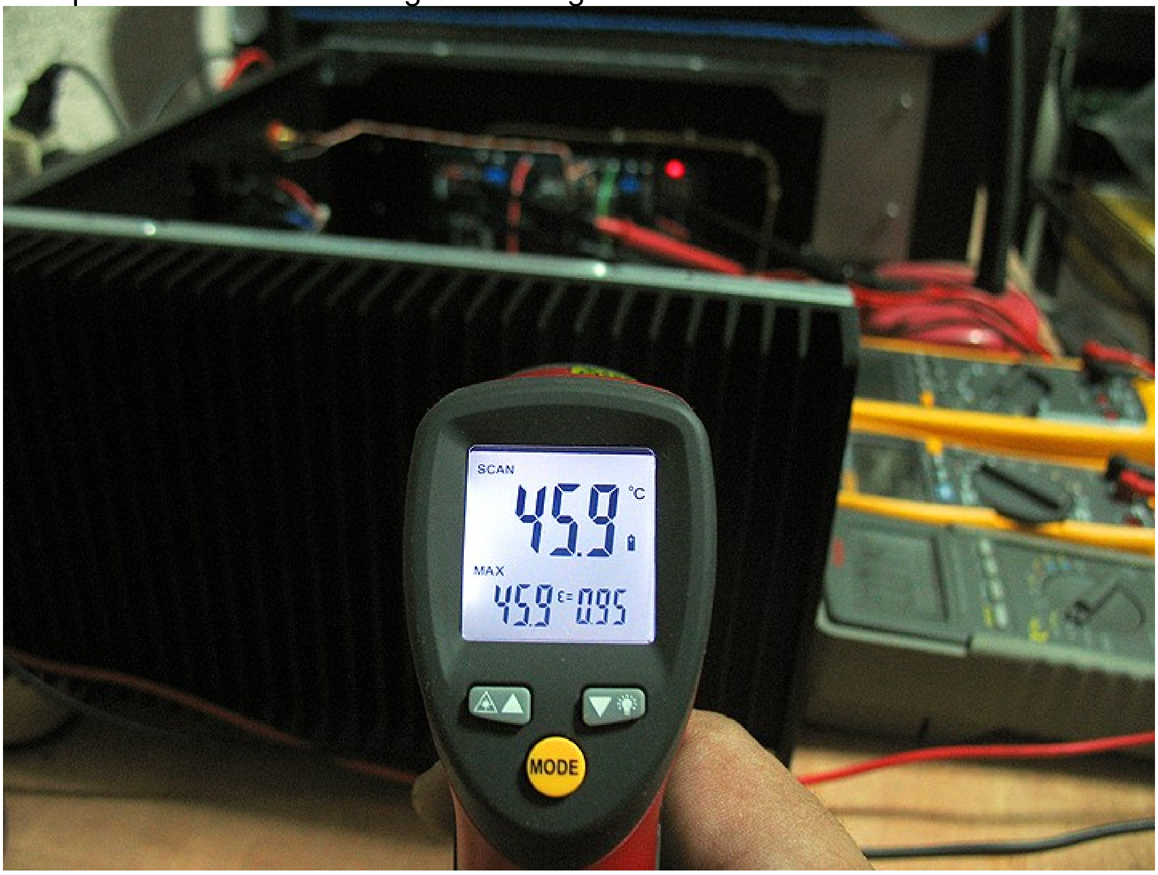
Here's the F-5 power amplifier warmed up and running for about 2 hours with an ambient room temperature of about 25 degrees Centigrade.



Congratulations!!!

You have just successfully built and calibrated your very own F-5 Class A Power Amplifier!!! 8)

Notes on biasing:

Why 0.59V across R11 and R12?

The designer of the F5, Nelson Pass, recommends that we operate the F5 with a bias of about 1.3A. If you used 0.47Ohm 3W resistors for the Source resistors then simple Ohm's Law would give you:

V = (1.3A) (0.47Ohms) = 0.6V

So a 0.59V reading would yield:

0.59V / 0.47Ohms = 1.255 Amperes or ~ 1.3A

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Listening Tests:

A few weeks back, I was invited to a friend's house for some R&R and of course, a listening session. Luckily, the F-5 prototype I built was finished, so I was happy to go and bring the newborn amp with me. We had a number of digital and analog sources, coupled to a luscious LS+Aikido Tube Preamp driving Living Voice Auditorium V2 speakers, a fairly high sensitivity speaker system. We also tried the F-5 amplifier with some of my other friend's speakers. Here you can see it playing with a wonderful pair of Harbeth Compact 7ES-3 speakers

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And with a big-sounding, small-sized speaker, the Epos ELS-3.

The F-5 behaved well with all these speakers, including exceptional behavior in handling loads of differing impedances. It sounded great, especially considering that it had just been finished. And as Nelson Pass said, it wouldn't burp! :D

I was so thankful I brought this heavy amp that day. I felt it was somewhat like a commencement day, the end of one thing, and the beginning of another. I am also very thankful to have friends who gave me the opportunity to share with them and try out the F-5 Class A Power Amplifier I had built.

Feedback and Final Notes:

The most common question I get when talking about Class A power amplifiers like the F5 is about thermal management. It's a reasonable concern of course, as any true Class A amp puts out a lot of heat. Thankfully, the 4U chassis that the diyAudio Store stocks handles the amplifier's thermal dissipation without any problems.

With too-small heatsinks the amplifier's temperature will keep rising until all hell breaks loose. But with the 4U's heatsinks, the amplifier's temperature stabilizes at just about 20 degrees Centigrade above ambient room temperature.

Another thing to note is the bias points. Nelson Pass recommends a bias setting of 0.59V across R11 and R12. This won't be a problem if the builder uses the same amplifier chassis as I did. However, Nelson also mentioned that we can also start low at about 0.4V

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which will definitely run the amplifier a lot cooler. I haven't tried it personally, but I think it would be worth trying to find out if there would be any huge difference in sonic characteristics. He also mentions that it can be biased higher if the heat dissipation can handle it, which would be interesting to try too.

Alas, this build guide comes to an end. It has been a wonderful experience building the amp and I definitely recommend it for those looking for an awesome sounding, Class A power amplifier of their own.

I hope that with this guide, I can pass on to you the knowledge, the excitement, and most of all, the confidence for you to build one for yourself.

If you would like to ask any questions, please visit the diyAudio Store F5 Build Guide thread.

Enjoy!

JD

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