



Project 101 Rev C - MOSFET Power Amplifier Assembly Instructions

Updated 12 May 2007

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Overview

This project board can be assembled by a reasonably experienced electronics hobbyist in about two hours or so (excluding case, heatsink and other hardware). The board is simple to build, relatively inexpensive considering the power output, and has outstanding performance.

Before you start construction, read all this information carefully.

Warning: The power supply voltage used for this amplifier is potentially lethal! With $\pm 70V$, the total voltage is 140V which can kill you! You must exercise extreme caution with any DC power supply, but this is much more important with an amplifier that uses supplies over $\pm 35V$. *Never* allow yourself to come into contact with the supply rails, and ensure power is turned off and filter capacitors are fully discharged before working on the circuit. Note that the highest voltage I recommend is $\pm 56V$, but $\pm 70V$ can be used for hi-fi applications where continuous high power is never needed.

To build this project you will need to follow the general recommendations in the [Guide to Components and Construction](#).

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Introduction

This is a high power amplifier, using premium Hitachi, Exicon or Alfet MOSFETs for the output stage. It is capable of peak powers of well over 300W into 4 ohms, and is suitable for hi-fi, subwoofers, bass guitar or PA use. Continuous high power operation should not be considered without forced cooling.

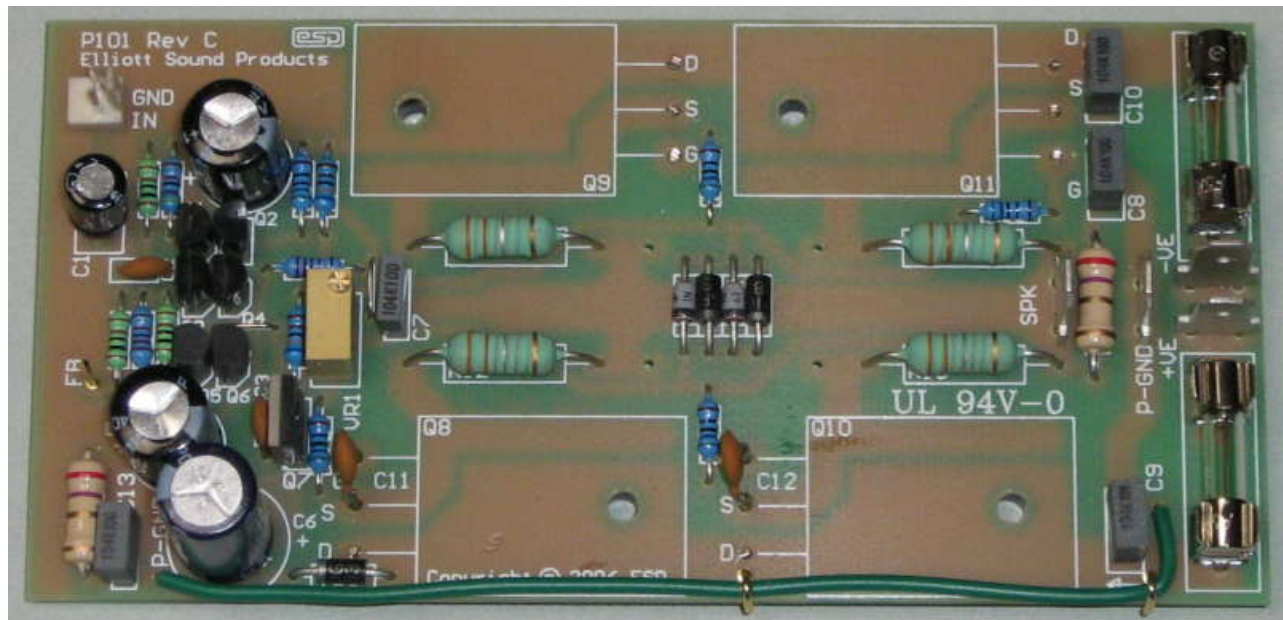


Photo of Completed Rev-C Board

A photo of the completed board is shown above. Construction is quite straightforward. Note the insulated green wire link along the closest edge - there is provision for PCB pins to act as guides to make this very neat. Fastening was done by simply bending the pins over and around the wire. This link *must not* be allowed to make electrical contact with any guide pin along its length - the pins are to guide the link, and nothing else!

Note that there is an extra terminal marked FB on the board. This is provided to allow current feedback. You can use current feedback as well if you want to - the main reason is to allow the output impedance of the amp to be set to a specific impedance - for example 4 ohms. This reduces damping factor dramatically, but is extremely useful in some cases. See [Project 56](#) for more details of reasons for, and implementation of, modified impedance. More info is available in the article [Effects Of Source Impedance on Loudspeakers](#), with specific examples, waveforms, etc. Most constructors will not use this, and it may safely be ignored.

Assembly

Assembly is best performed in steps. This ensures that a disciplined sequence is followed, and a sequence almost guarantees you get it right first time. Rework in electronics is nearly always costly, particularly if it results in destroying the ICs. Make sure you are comfortable, all tools are to hand, and ensure adequate lighting. If making multiple units, assemble one board at a time to avoid duplicating mistakes, and check each and every component carefully after you finish soldering it in. If it is incorrectly installed, remove it carefully, wait for it to cool, and then fit the component a second time – correctly.

Make sure that you keep the tip of the soldering iron clean. Before making solder joints, wipe the tip over the moist sponge to clean off burnt flux and solder residue. A clean tip is essential for good solder joints.

1 - Check Printed Circuit Board

Check the printed circuit board for damage in transit; cracks, bridged tracks or abrasive damage which might cause problems during assembly. All component positions are clearly marked on the board.

In some cases, the large copper section where the MOSFETs mount may have small bumps of solder, and these should be filed off before you start installing components. This surface must be perfectly flat so that the PCB is not distorted when the MOSFETs are bolted down to the heatsink.

2 - Fit Wire Links

There are three links on the PCB, one is situated between Q4 and Q6, and another to the right of R9. These are short, and easily installed. Carefully bend a short piece of wire to fit, and solder in position. The remaining link runs the length of the PCB, and must use insulated wire. There is provision for PCB pins to act as a guide for this link, which connects the power ground from one end of the PCB to the other.

For the low power version (as shown below), R12 and R13 can either be used as shown for the high power version, or

replaced with wire links.

3 - Fit PCB Pins, Input Connector, Fuse Clips, etc.

Insert 1mm diameter PCB pins for the DC power, inputs and outputs. Power and speaker positions may use 2 pins for each connection, allowing easy connection of thick wiring. If the pins are not desired, wiring can be connected through the holes in the PCB and soldered into position. This should be left until last.

As an alternative to using pins for power and speaker connections, you can enlarge the holes a little and use PCB mount Quick-connect lugs (also called "Faston" lugs). The Rev-C PCB has been laid out specifically to allow this.

Install the fuse clips in the positions shown. It is usually best if you install a fuse in the clips first, as this aligns the clips properly. Make sure the clips are pressed firmly onto the PCB, and solder generously.

4 - Fit resistors

Fit resistors. All resistors are on the component side of the board. Resistors may be 1/4W carbon or metal film (metal film recommended for lowest noise) except where indicated.

It is a good idea to actually measure each resistor with a multimeter prior to fitting. This guarantees you install the resistors correctly. See the [Guide to Components](#) for more information, colour code, etc.

Use the composite diagram to identify the board positions for the resistors.

Dress all leads so that they are bent neatly to line up with the holes in the board so they can then be fitted without stressing the leads. After soldering the resistor leads to the circuit board, trim them flush with the top of the solder surface using suitable flat side cutters.

Resistor orientation is not important; they may be inserted either way. Personally, I suggest that you orient them in the same direction - for example with the tolerance band at the bottom or to the right. This makes reading values much easier later on.

For the low power version (as noted above), R12 and R13 can either be used as shown for the high power version, or replaced with wire links. The resistors are mandatory for the high power version.

5 - Fit capacitors

Now fit all capacitors. All capacitors mount conventionally on the component side, with the exception of C11 and C12. These are soldered into position between the gate and source pins of Q8 and Q10 respectively, after the power transistors are installed. There is no specific footprint for these caps, as their leads commonly need to be spread to reach the MOSFET pins.

Electrolytic capacitors are polarised. This means that they have a positive and a negative terminal, and must be inserted properly into the board or serious damage may result when you first power up the circuit. Be warned: incorrect polarity on electrolytic capacitors can result in the device exploding.

The longer lead on electrolytic capacitors is positive, and the plastic outer sleeve is heavily marked with a negative (-) sign, clearly identifying polarity.

Double check each of these capacitors prior to soldering, because mistakes can be fiddly to correct. Avoid using excessive heat when soldering, and press the capacitor lightly towards the board with your fingers from the component side as you solder the leads. Try to fit each capacitor so that it stands upright, not tilted to one side or the other.

Polyester, bipolar electrolytics and ceramic capacitors are non-polarised, and may be inserted either way - their orientation is not important.

Once you have soldered in each capacitor, trim the leads on the copper side in the same way as the resistors.

6 - Install Semiconductors

Start with the diodes - there are 3 standard and 2 zener diodes - *do not get them mixed up!* Next, fit the small signal transistors (MPSA42 or MPSA06 and BC559, BC549). The body of the transistor should be oriented as shown on the overlay, and you need to kink the base lead out slightly to fit the hole pattern provided. Note that if you substitute different transistors, you must verify the pinouts - they may or may not match those specified.

Next, fit the driver transistor (MJE350) - make sure that it is located in the correct position! The metal face of this transistor must face towards the input section of the PCB.

Install the trimpot at this time. It should be oriented as shown. A small amount of adhesive will ensure that it cannot move on the board, however this is optional.

Now, fit the MOSFETs. Handle these devices with care, as static can damage the gate insulation of the MOSFET. With the metal surface facing down, carefully bend the leads up so that the leads and mounting holes on the PCB are perfectly aligned. The leads should be bent at close to a right angle, and there must be no strain on the component when it is mounted to the PCB with a 3mm screw and nut. Make sure that the MOSFET is in perfect contact with the PCB surface. Attach the MOSFETs firmly to the board with screws and nuts before you solder the leads - this ensures that the holes are in perfect alignment, and prevents the MOSFET from moving while it is soldered. Do not cut the leads on the component side just yet!

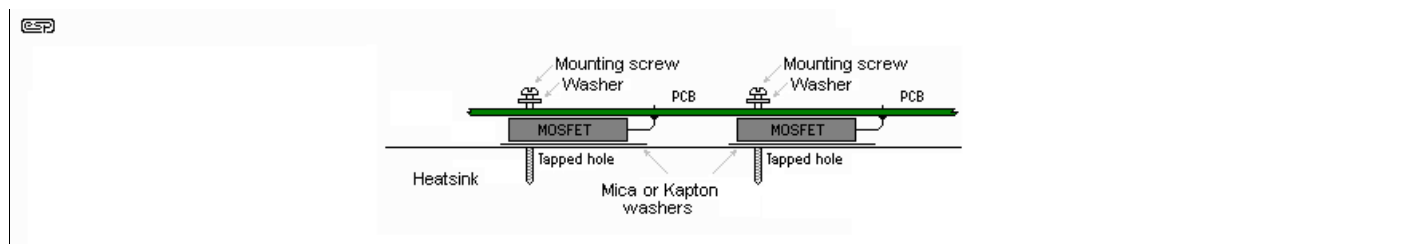


Suitable MOSFETs include the Hitachi 2SK1058 & 2SJ162, ECX10N16 and ECX10P16 or ECX10N20 / ECX10P20 (from Profusion PLC in the UK). ALF08N16V & ALF08P16V or the higher voltage versions ALF08N20V & ALF08P20V can also be used. Do *NOT* use vertical MOSFETs (HEXFETs or similar), as they will A) not work properly, and B) fail. They have a different pinout from the lateral MOSFETs so cannot be installed on the PCB.

After installation of the MOSFETs, C11 and C12 need to be attached between the Gate and Source pins of Q8 and Q10. These caps are attached directly to the pins as shown in the diagram below. Wrap the leads around the pins, then cut the MOSFET leads about 3mm above the PCB surface. Cut the capacitor leads close and neatly, then solder the connections.

7 - Install PCB on Heatsink

The entire PCB is held onto the heatsink via the MOSFET mounting screws, and no other form of mounting is necessary (even for the low powered version). See the diagram below for the basic arrangement suggested.



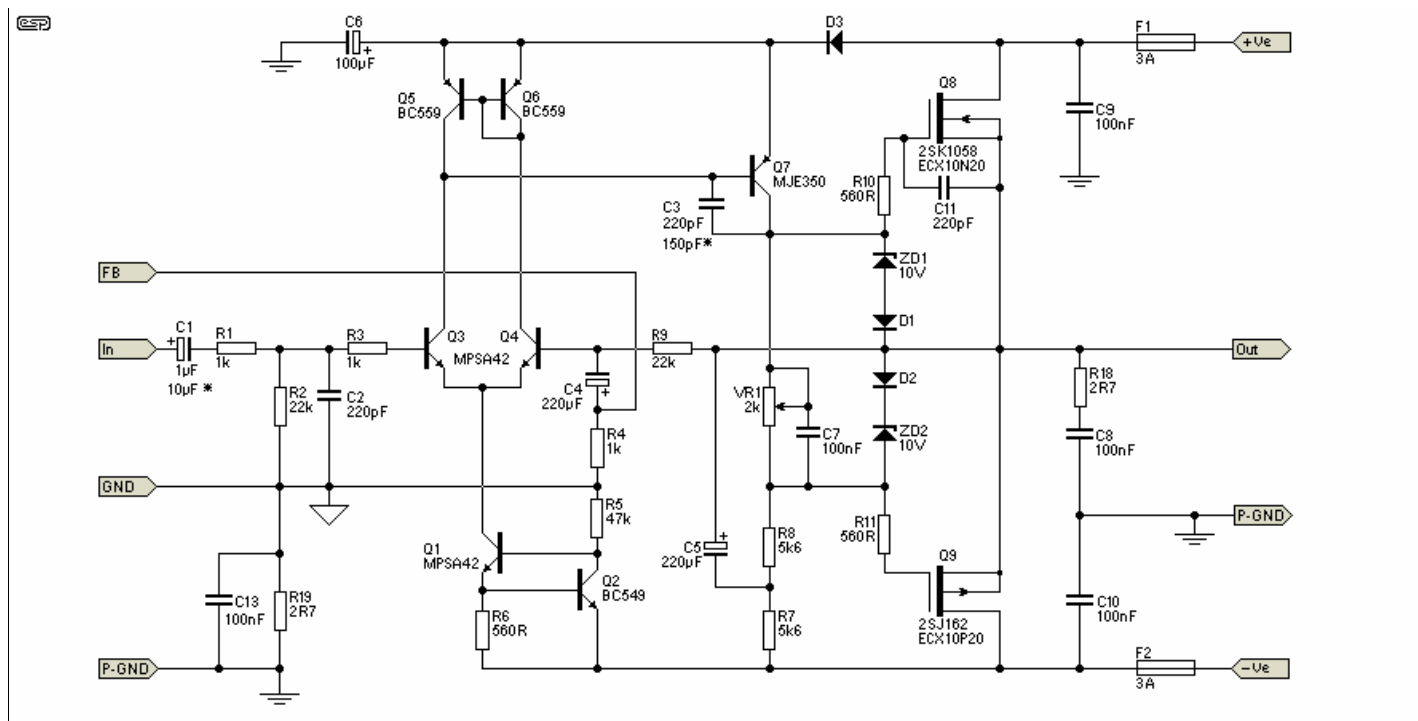
PCB Mounting Details

Attach the PCB to the heatsink as shown above, and make sure that the insulating washers are properly coated with heatsink compound on both sides. Remember that the metal face of the power MOSFETs *must* be facing away from the board. You can use either mica or Kapton to insulate the MOSFETs from the heatsink, but Sil-Pads are absolutely **not** recommended, as their thermal conductivity is simply too low. While convenient, from my own experiences I can tell you that they are generally utterly useless for dissipating more than a few Watts. Before applying power, check for shorts between the transistors and heatsink. The centre pin from the MOSFET is connected to the metal face - this makes the measurement easy.

The screws that hold the board and transistors down on the heatsink need to be metal thread screws, and the holes tapped for the size and thread used. This varies depending on what's available where you live - most constructors in Australia or Europe will use ISO Metric fasteners, but those in the US will most likely use a readily available US screw. After tapping, ensure that there are no burrs or metal shavings in or around the tapped hole. In some cases it will be possible to use screws that pass right through the heatsink, so you can use nuts rather than tapping threads into the heatsink.

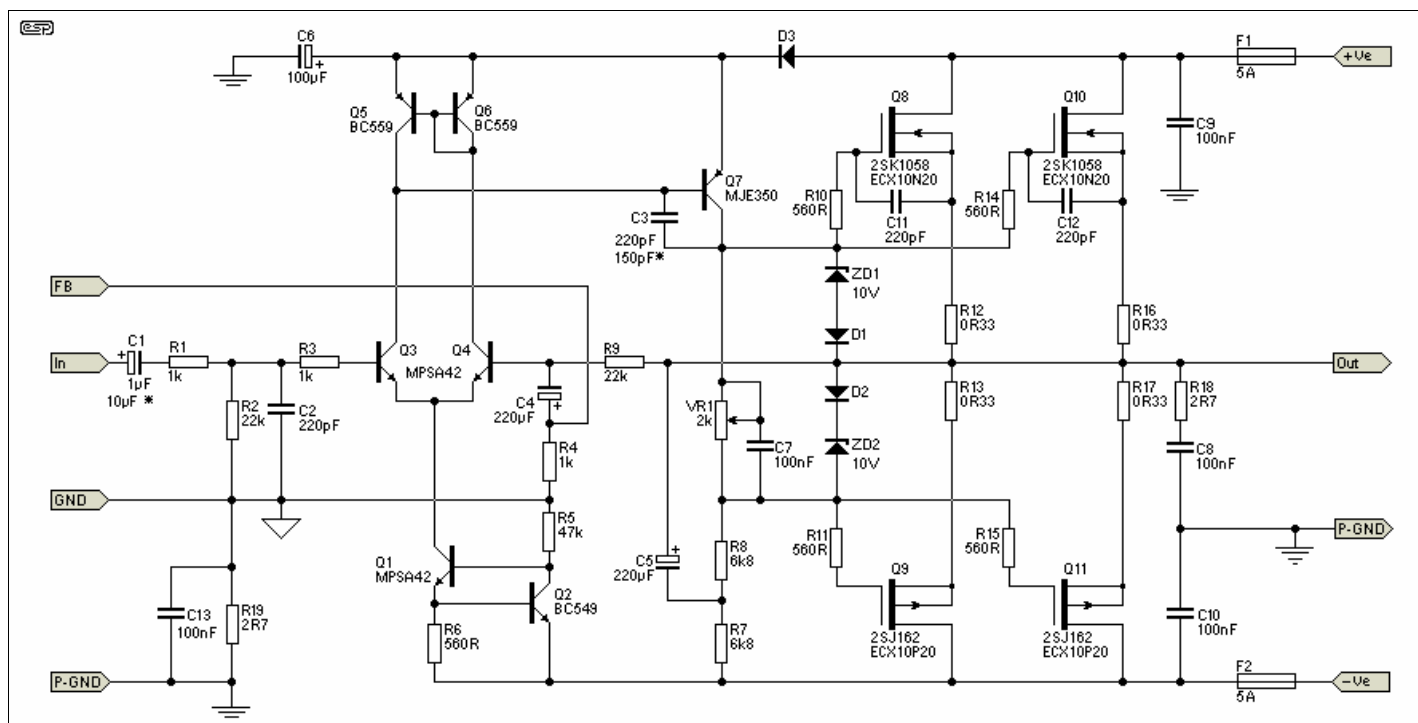
Once attached and the amp has been tested, seal the screws with Loktite or varnish (nail polish is a cheap alternative and works well). This prevents the screws from becoming loose over time.

Schematics



Complete Amplifier Schematic (Low Power Version)

The low power version will be suitable for a great many constructors, and will be powerful enough for most applications. The following high power version can be operated at up to $\pm 56V$ (higher voltages are possible but not really recommended), and will give a little more power than the low-power version - especially into 4 ohms.



Complete Amplifier Schematic (High Power Version)

It's worthwhile to consider that increasing the supply voltage from the recommended $\pm 56V$ to $\pm 70V$ gives a theoretical power increase of only 2dB, but stresses the components a great deal more. The amplifier is relatively conventional, and uses two pairs of lateral MOSFETs as the output devices. These are very rugged, and have excellent characteristics for audio. They are considerably more linear than switching MOSFETs used in many amps, and consequently have lower distortion.



For both circuit diagrams, the values of R7 and R8 change depending on supply voltage. For the low power version ($\pm 42V$, or the high power version operated at $\pm 56V$), use 5.6k. When operated at $\pm 70V$ (which isn't really recommended), use 6.8k. 5.6k resistors at 56V operate at 140mW each, and 6.8k

resistors at 70V operate at 180mW each.

Again, for both circuits, the component values marked * are optional variations. Using a 1uF input cap gives a low frequency -3dB frequency of 7Hz, and a 10uF electrolytic cap reduces this to 0.7Hz. While the difference is effectively inaudible, the higher value gives a lower phase shift which is preferred by some constructors. Using 150pF in the C3 location (Miller stabilisation capacitor) improves slew rate and extreme (supersonic) frequency response, but may make the amp more prone to oscillation. If you use the lower value, you do so at your own risk.

How it Works

The input stage is a conventional long-tailed pair (LTP), and uses a current source to supply the emitter current. The current is stabilised by Q2, and Q1 is a current sink for the long-tailed pair.

The collector load for the LTP is a current mirror. This increases the gain of the stage dramatically, and also helps ensure that the DC offset from the amplifier is less than 50mV (typical worst case - it will normally be considerably less than that). The current mirror helps to force the same current through each transistor in the LTP, and this also reduces distortion.

The Class-A amplifier stage uses a conventional Miller stabilisation capacitor, and this ensures that the amplifier is stable (i.e. does not oscillate). The voltage amplifier stage breaks with MOSFET amp tradition by using a single stage, with a bootstrapped load to create the current source. This operates at a higher current than is traditional with MOSFET amps, but the difference is actually quite minor.

Despite the lower gain of this stage compared to the more traditional driver stages, it has the advantage of being simpler and easier to stabilise, and there is no loss of performance. Stability is always a concern with any amplifier, and the higher the open-loop gain, the more likely it is that it will oscillate.

MOSFET bias is set by the trimpot (bypassed by a capacitor). While this does mean that bias changes slightly with the supply voltage, this has never caused a problem in the hundreds of P101 amps that have been built so far.

NOTE: - Make absolutely certain that the trimpot's resistance is set to minimum when it is installed. This sets minimum MOSFET bias. Failure to do so may cause the MOSFETs to fail on application of power!

The output stage consists of one or two pairs of power MOSFETs. The gates are isolated with resistors to prevent parasitic oscillation, and a resistor is used in the source of each MOSFET to help ensure current sharing. Although MOSFETs have a positive temperature coefficient and theoretically will current share properly without any resistance, it is common practice to use the resistors regardless.

The diode and zener combination in each gate drive circuit limits the maximum gate voltage and provides basic overload protection - although MOSFETs are much more tolerant of overload than bipolar transistors, operation into a short circuit is *not* recommended.

C11 and C12 are used to compensate for the fact that P-Channel MOSFETs have a different (higher) gate-source capacitance than do N-Channel devices. C11 and C12 equalise the capacitance. Do not attempt to operate the amplifier until these capacitors are fitted, as it will oscillate!

Finally, the output section uses a conventional Zobel network. If desired, this can be followed (right at the speaker terminals) by a small inductor with a paralleled resistor, and finally a second Zobel network at the output. This is intended to decouple the amplifier from highly capacitive loads and ensure stability under all normal operational conditions. The use of ultra-low inductance (very high capacitance) speaker leads is not recommended, although the additional output network described will prevent oscillation in most cases. The inductor can be quite small (around 5-10uH is about right), and must be shunted by a parallel resistance of between 2.2 and 10 ohms (10uH gives a -3dB frequency of 71kHz with an 8 ohm load).

The Bill Of Materials (BOM) is shown in the following tables and text. You will need to buy these parts to build the power amplifier.

Bill of Materials

Resistors

Component	Value	Component	Value	Component	Value
R1, R3, R4	1 k	R2, R9	22 k	R5	47 k
R6, 10, 11, 14, 15	560 ohm	R7, R8	6.8 k	R12, 13, 16, 17	0.33 ohm /2W
R18, R19	2.7 ohm /1W	VR1	2k /10 Turn		

Notes:

1. 1% tolerance metal film resistors are recommended for best noise performance and long term stability. If unavailable, 5% tolerance carbon resistors can be used with no ill effects (other than a slight increase in noise).
2. R12, R13, R16 and R17 may be replaced by 5W wirewound resistors, although care is needed that the leads do not touch each other or other components.

Capacitors

Component	Value	Component	Value	Component	Value
C1	1uF/63V (10uF/ 63V ¹)	C2, C11, C12	220pF /50V Ceramic	C3	220pF /500V Ceramic ²
C4	220uF /16V Electro	C5	220uF/63V Electro	C7, C8, C9, C10, C13	100nF /100V
C6	100uF /100V Electro				

Notes:

1. C1 can be a 1uF MKT polyester cap or a 10uF electro, as noted above.
2. Polystyrene or silvered mica may be used instead of the 500V ceramic. Although I am reluctant to do so, I must admit that 50V ceramics can also be used, even at much greater than 50V. I have tested them to 1kV without breakdown or failure of any kind, however you use them at your own risk.
3. Voltage ratings shown are the minimum recommended, Higher voltage capacitors may be used space permitting.
4. All unspecified caps are polyester, and are rated at 100V.

Semiconductors

Component	Value	Component	Value	Component	Value
Q1, Q3, Q4	MPSA42	Q2	BC549	Q5, Q6	BC559
Q7	MJE350	Q8, Q10	2SK1058 / ECX10N20	Q9, Q11	2SJ162 / ECX10P20
D1, D2, D3	1N4004	ZD1, ZD2	10V Zener (1N4740)		

Notes:

1. Q1, Q3 and Q4 may also be MPSA06.
2. Do not substitute MOSFETs - most alternative devices (e.g. switching MOSFETs) will not work properly (if at all) in this circuit. The ECX10N16 and ECX10P16 or ECX10N20 / ECX10P20 (from Profusion PLC in the UK) are at least as good as the originals - they may even be slightly better. ALF08N16V & ALF08P16V (or the higher voltage versions ALF08N20V & ALF08P20V can also be used)
3. The zener diodes (ZD1, ZD2) provide protection for the MOSFETs and also act as current limiters under fault conditions

Miscellaneous

Other parts and assorted items you will need to complete the assembly are as follows:

- Heatsink. Recommended minimum size is 0.6°C/W for each amplifier (high power version) - see below. The heatsink for the low power version of the amp should be a minimum of 1°C/W (each amp)
- M205 fuse clips (4 on each PCB), and ...
Fuses (2 needed): Low power version - **3A**, High power version: **5A**, fast blow.
- Mica or Kapton insulating washers for the power MOSFETs, thermal compound.
- A suitable transformer, filter capacitors and bridge rectifier (see below).
- Input and output connectors, mains connector and switch, plus other hardware
- A suitable case and assembly screws, nuts, washers etc.

You will also need insulated hook-up wire. This must be heavy duty for all power connections. Mains wiring must use cable with insulation rated for mains voltage. Audio signals should be in shielded cable for the inputs.

Always remember, there is no such thing as a heatsink that is too big. The recommendation above is the absolute minimum I suggest - in general, try to use a bigger heatsink if possible.

Testing

Warning: Remember, the power supply voltage used for this amplifier is potentially lethal. Normal usage will have $\pm 56V$ DC (112V total), but although not recommended it can use up to $\pm 70V$, the total voltage is 140V which can kill you! You must exercise extreme caution with any DC power supply, but this is much more important with an amplifier that uses supplies over $\pm 35V$. *Never* allow yourself to come into contact with the supply rails, and ensure power is turned off and filter capacitors are fully discharged before working on the circuit.

After assembly, the circuit must be tested to ensure that there are no wiring errors. The initial test may be done with no heatsink, if (and *only* if) you have a $\pm 15V$ (or thereabouts) supply. The supply does not need to be regulated, and any voltage from ± 10 to $\pm 25V$ is reasonably safe.

If you have a suitable bench power supply this can be used, but most builders will not have access to such equipment. If you

do not have a bench power supply, use the following method (using the low voltage supply described above).

For testing, you will need two 5W safety resistors (between 22 and 100 Ohms), and a signal source. Before power is first applied, temporarily install the 'safety resistor in series with each DC supply line to the board. You must also connect the power ground connection to each end of the PCB - there are two connections labelled P-GND, and both must be connected as shown below with an insulated wire link. Make sure that the bias pot is set to minimum resistance. Measure it with an ohmmeter to make sure that it really is at minimum.

Apply power at $\pm 15V$ from a suitable supply - *do not connect the amplifier directly to the main power supply for the initial test, and do not attach a speaker !*

The voltage across each safety resistor should be no more than about 2V (less for lower values), and the amplifier's output voltage should be close to zero volts. If these conditions are not met, then there is a fault in your assembly. If everything is ok, the safety resistors may be removed and you may connect a speaker and signal source, and verify that the amp works without distortion. Remember that there is no heatsink, so any signal test must be kept very brief, even with a low voltage.

Once you are satisfied that the amplifier works correctly, it may be bolted to the heatsink for a full voltage test. Remember to use the mica washers and heatsink compound, and screw down firmly - do not over tighten. Before applying voltage, check that the transistors are insulated from the heatsink. Use an ohm meter, and verify that there is no connection from the output pin to the heatsink. A short indicates that a mica/ Kapton washer is faulty - this is usually the result of a speck of metal having pierced the insulator. Repair as necessary.

Bias Setting Information

Before applying power, check the pot with an ohm-meter! It must be at the minimum resistance setting. Connect the amplifier directly to the main supply in the final wiring configuration. Do not connect a speaker or any other load! Connect a multimeter across one of the source resistor pairs (R12, R13 or R16, R17). Make sure that you connect to the MOSFET source end of the resistors! The points are shown as 'A' & 'B' in the layout drawing - connect to one set of 'A' and 'B' - *not both*.

Carefully advance VR1 - with 0.33 Ohm resistors, the total is 0.66 Ohm, and for 20mA bias, you will measure 13.2mV (14 - 20mV is fine) across each resistor pair. You may increase the bias current if it makes you feel better. I suggest a maximum of around 50mA per pair, or 33mV. When using $\pm 56V$ or less, you can increase the current to 100mA, but this will result in a total quiescent dissipation of up to 22.4W so the heatsink will get noticeably warm.

For the low power version (assuming you omitted the source resistors), you need to use the safety resistors to be able to set the current. With the resistors in circuit, set VR1 to zero Ohms and apply power at normal operating voltage. Measure the voltage across one of the safety resistors. Carefully advance the bias pot until the voltage across each 100 Ω resistor is 2V greater than your first measurement - this represents 20mA quiescent current in the MOSFET output stage.

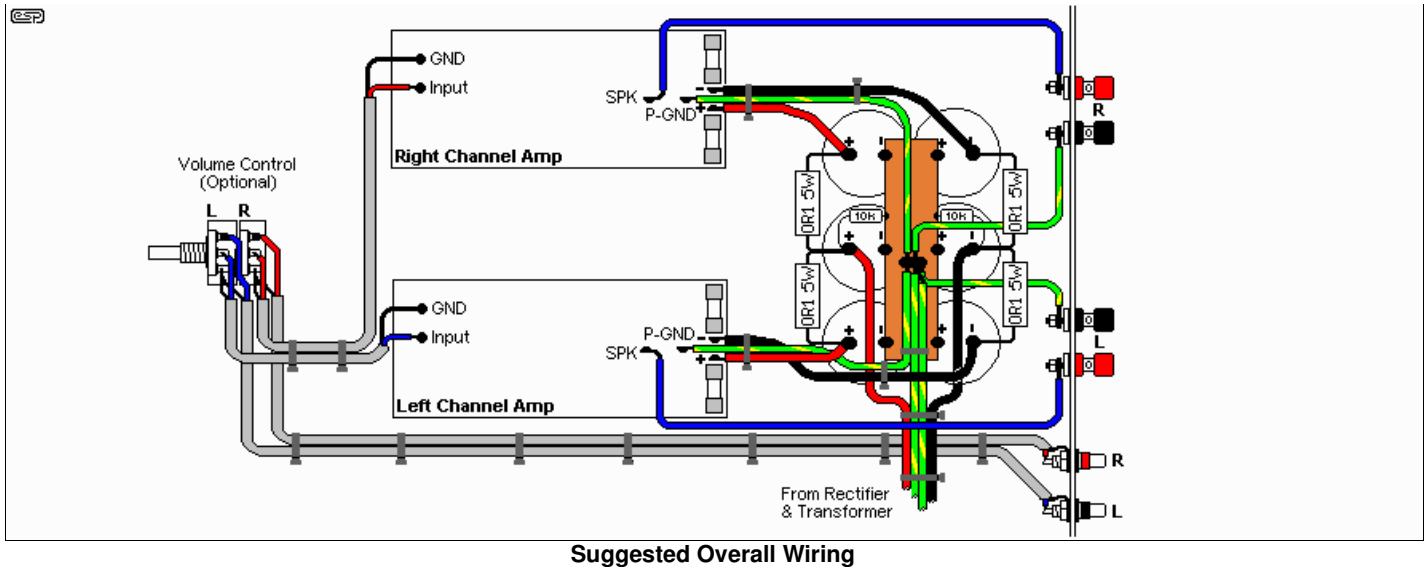
If everything is ok, remove power, and wait until the filter caps have discharged (this may take 30 seconds or more). Remove the 100 ohm safety resistors, and connect the amp directly to the power supply. Perform a check that the polarities are correct! When you are satisfied that everything is ok, you may apply full power without the safety resistors. Check that the output voltage is within $\pm 100mV$ of 0V - it will normally be around 20-30mV.

Connect a speaker and signal source, and enjoy.

Appendix

Overall Wiring

The diagram below shows the overall wiring scheme for a stereo P101 system. Note that all input and output connectors must be insulated from the chassis. Failure to observe this will result in a hum loop (best case) or a destroyed amplifier (worst case).

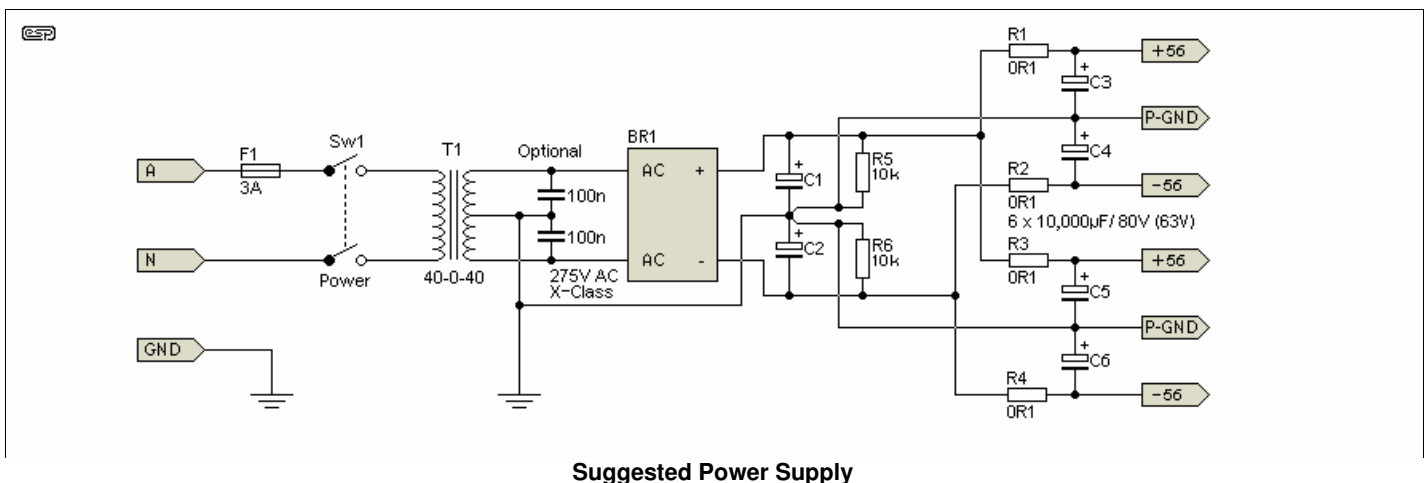


Note that the P-GND connection goes direct to the star earth point at the filter caps, and that the input GND connection is used *only* for the input wiring. This seems to cause some confusion. R19 and C13 are used to isolate the input from the main power ground - this is done to eliminate possible earth loops and hum when the amp is connected to an earthed source (preamp, etc).

Power Supply

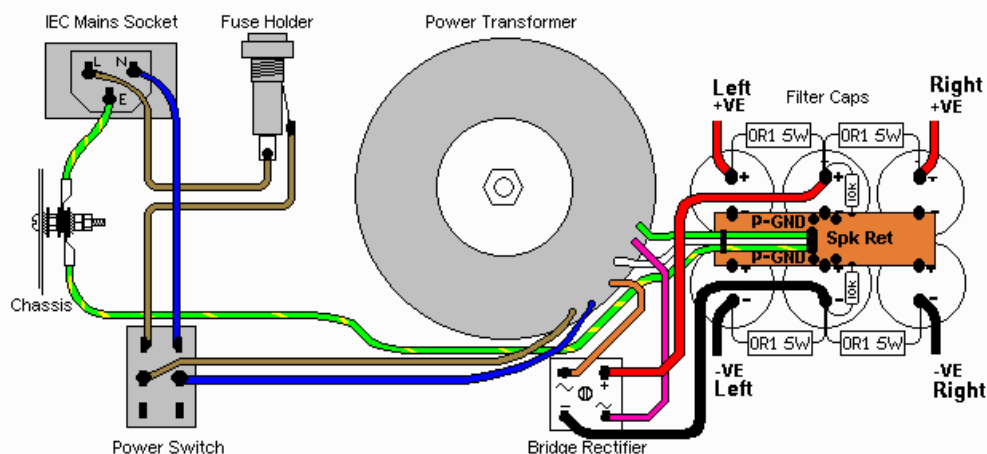
The power supply shown below is the recommended version. You may choose to construct a 'dual mono' supply, using two bridge rectifiers and 8 filter caps, but the performance gain will be minimal.

WARNING - This power supply is connected to the mains voltage, and requires mains wiring. In some countries it may be illegal to work on mains wiring unless suitably qualified - please check with the relevant authorities to determine the regulations in your location. Mains voltages are hazardous, and the reader accepts all responsibility for any injury or death (howsoever caused) that results from the application or misapplication of this project.



The addition of a few 0.1Ω resistors (which may be up to 0.22Ω if you want) may not look like it would do much, but the difference is very pronounced. High order harmonics from the rectifier and mains are reduced dramatically, and the DC waveform is much cleaner than with a conventional capacitor bank. Note that these resistors must be rated at 5W. Higher resistance (such as 0.22Ω - the recommended maximum) will result in slightly lower continuous power levels, but a cleaner supply voltage, but with music signals the power difference is marginal.

Remember that for any toroidal power transformer bigger than 300VA, a 'soft-start' circuit is highly recommended - see [Project 39](#) in the projects or construction index for details.



Suggested Power Supply Physical Layout

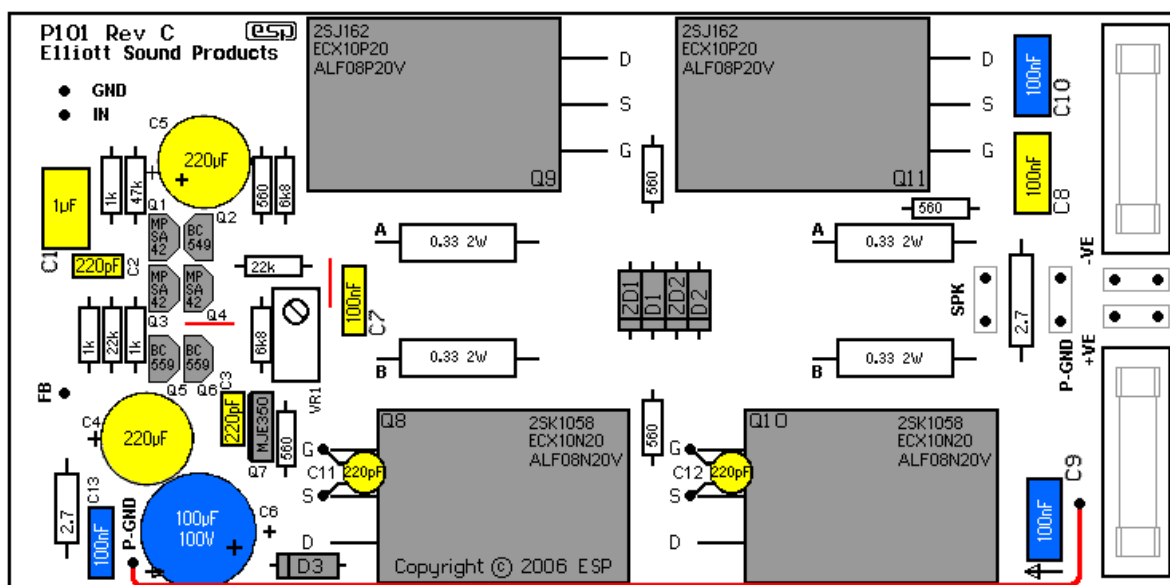
The layout above should help you to get the supply wired up with no difficulties. I suggest that the caps are soldered to a solid earth bus as shown, using a piece of thin copper plate or similar. Be warned that you will need a sturdy soldering iron, as the copper will just suck the heat from your iron, and may even cause the tip to become stuck to the plate (and yes, I am serious - it's happened to me). Bleeder resistors can be added between each supply and ground. These ensure that the supply caps discharge if there is no amplifier connected. 10k 1W resistors are suggested as shown. Not shown (but recommended regardless) is the soft-start circuit.

PCB Overlays

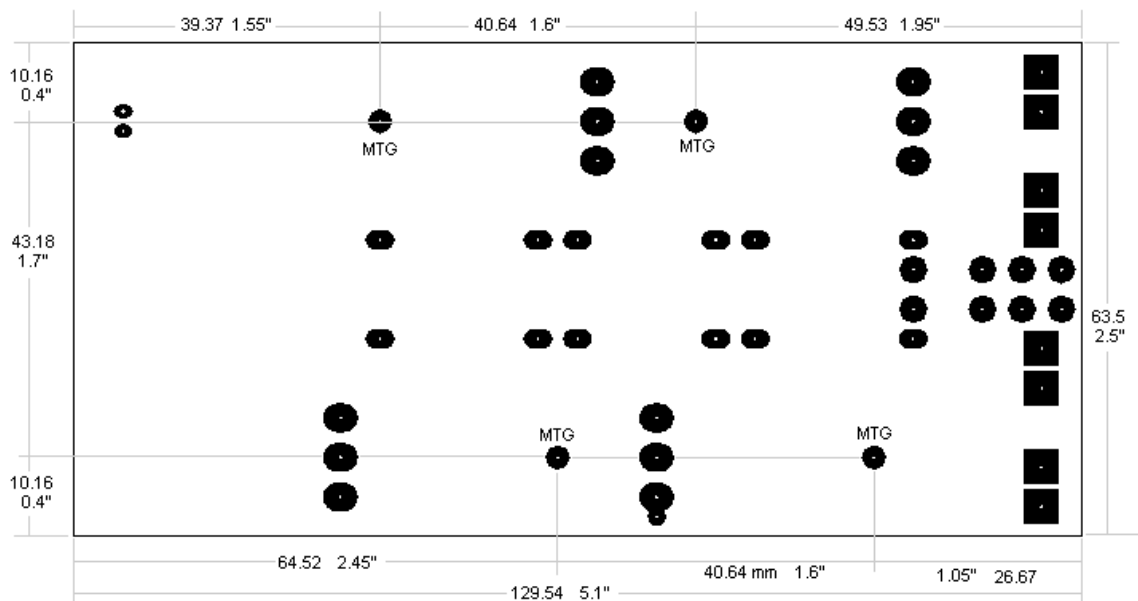
With a design such as this, there are very few (if any) changes that you will be likely to make. The configuration shown is standard, and will cover the requirements for the majority of constructors.

This is the standard layout as described in the BOM, and is the complete power Amplifier. Filter and bypass caps are shown in blue, and the signal caps in yellow. The links are shown in red, and semiconductors are in grey. Note the long link from the power supply end to the input end of the board. This link **must** be insulated - it connects to the end pins *only*! The other pins are used only to provide convenient attachment points for the wire so it looks neat.

The Rev-C board also allows the use of physically larger source resistors, since 2W resistors are not easy to obtain.



For those who want to start drilling heatsinks before the PCBs arrive, you can use the diagram below.



Power Amplifier Dimensions

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