Oakley Sound Systems

Power Supply Unit (PSU)

PCB Issue 4

Project Builder's Guide

V4.4

Tony Allgood
Oakley Sound Systems
CARLISLE
United Kingdom

Introduction

This is the Project Builder's Guide for issue 4 of the PSU circuit board from Oakley Sound. This document hopefully contains everything you need to know to build and install the Oakley power supply unit.

The PSU allows for various options in the installation. You can use the unit either in full wave rectification mode for connection to tapped linelumps or twin transformer secondaries, or in half wave rectification for single phase AC output wallwarts and linelumps. If all this sounds very confusing at the moment, do not worry, in this manual I will try to make it clearer so that you make the right decision about what power source you will need.

It is designed to be mounted onto a metal panel which is used as a heatsink for the two power devices used on the board. Mounting your power supply to a metal panel on the outside of your case helps keep your modular cool.

For general information regarding where to get parts and suggested part numbers please see our useful Parts Guide at http://www.oakleysound.com/parts.pdf.

For general information on how to build our modules, including circuit board population, mounting front panel components and making up board interconnects please see our Construction Guide at http://www.oakleysound.com/construct.pdf.

Safety Warning

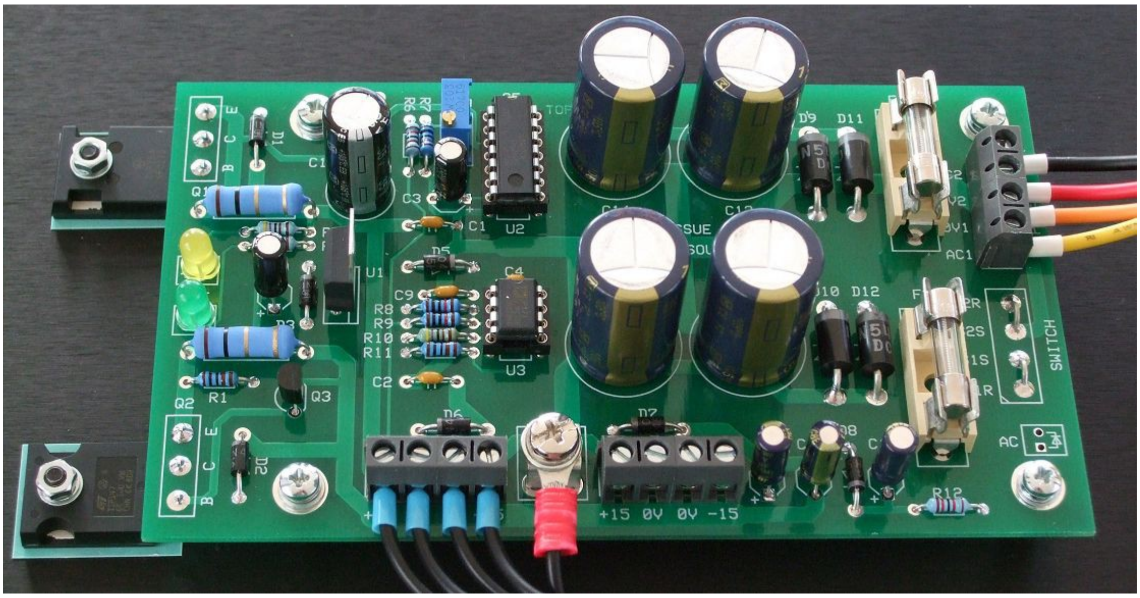
The PSU has been designed to work with isolated low voltage AC inputs. Connection to any other supply, such as an internally mounted mains transformer, is done at your own risk. Low voltage is classified as being less than 25V with respect to the ground potential. Voltages above this level can, and often are, lethal to living creatures.

Oakley Sound Systems will not advise on building or modifying this board to allow for direct connection to the mains, or other high voltage sources, further to what is provided in this document. Please do not ask me for any additional information pertaining to direct mains connections or using internally mounted transformers as I will not give it.

For safety and legal reasons I cannot recommend powering this board from any other supply than low voltage AC output mains adapters.

Oakley Sound Systems are not liable for any damages caused by the misuse of this product. It is your responsibility to use this product safely. If you have any doubt about installing a safe power supply, then please do not attempt to do so.

The Oakley Power Supply Board



The issue 4 PSU board from Oakley Sound Systems.

The power supply board will allow the conversion of a suitable low voltage alternating current (AC) to be rectified, smoothed and regulated for operation with the Oakley Modular. The module is designed to be fitted to a suitably large metal panel which functions as a heatsink for the series pass devices connected to the PSU circuit board. This metal panel should have adequate airflow around it. An example of such a panel is the 3U wide master panel which also contains a handy multiple and power switch. You can also use a 4U or 5U high 19” rack blank panel. These are particularly suitable if you are mounting your modular synth in a 19” rack. The greater surface area on the 19” blank panel allows you to mount not only the power supply module but also up to two Dizzy PCBs. And the greater surface area also allows the power supply's power devices to dissipate more heat safely and that means a greater current output should you need it.

The voltage output of the power supply module is a split rail or bipolar 15V supply. This means it generates both +15V and -15V. That is, two power rails, one of a positive voltage, the other a negative one. It's sometimes written as +/-15V. These voltages are measured with respect to a common ground which is normally connected, via your house's wiring, to the earth that you stand on. The voltage across both rails is 30V, with the common ground sitting exactly in the middle of this at 0V.

The output current capability is the maximum current you can draw out of the power supply. The current taken from the supply is, for the most part, determined by the amount and type of modules you are connecting to the power supply. However, the actual patch also has an effect on the current draw – the more outputs that are connected to inputs increases the current draw slightly. Also, some LEDs when lit may increase the current draw.

The Oakley PSU features current limiting. This sets the maximum current the power supply will actually provide. If you try to draw more than the limit the output voltage will fall to maintain the current at the limit value. The current limit is set by two resistors, R2 and R3, on the PSU board. It is essential that you make the current limit resistors suit your application. The next section, and also in the parts list of the Builder's Guide, will give details on what values to use.

I recommend that you use a Yamaha PA-20 or PA-30 power supply. These are neat tidy external power supplies that keep the dangerous mains voltage away from your modular. The PA-20 will allow a maximum current of 520mA (0.52A) to be drawn from each rail. While the PA-30 will allow up to 780mA (0.78A). Remember though you can't use a PA-30 with the 3U master panel and expect to draw 0.78A out of it without the panel getting too hot. If you are using the 3U master panel then you should draw no more than 0.52A per rail. Both the PA-20 and PA-30 are centre tapped AC supplies with three wires within their output cable and use a three pole connector.

Other power supplies are available and they come in lots of different variations. Other than AC output voltage the two key specifications are output current (please don't call it 'ampage'), and whether the output is centre tapped or single phase. In almost all cases the outputs of standard AC output power supplies are single phase. You can tell because they only have a cable with two wires inside which terminates in a two pole connector.

A single phase AC output supply will allow only you take not much more than a quarter of its rated current output. For example if you are using a 500mA (or 0.5A) AC wallwart* then the most current you can take from this power supply module is around 125mA from each rail. That is, take no more than 125mA from either the +15V supply and 125mA from the -15V supply.

Various companies make linelumps** with a greater capacity than 500mA. If you can get a single phase 1A output one than this will be able to drive up to 250mA per rail.

The Oakley PSU can be used with full wave or half wave rectification. The former allows it to utilise split AC outputs. With full rectification and using a centre tapped power supply the amount of current taken from each 15V rail can be up to just over half the rated current output of the power supply. The Yamaha PA-20 supply is rated to give an output voltage of 35Vac (with a centre tap) at a load of 0.94A. Once rectified and smoothed this means that a maximum current of 0.52A can be drawn from each rail.

Two sets of screw terminal blocks are provided for connecting the low voltage AC power source to the board and the optional power switch. If you are using a single phase wallwart to power the PSU module than you need only to use two terminals per terminal block.

The board has four mounting holes for stable placement onto your modular case. Care should be taken so that the board's various board mounted components do not come into contact with any part of your modular's enclosure. Use of 10mm hex spacers between the board's bottom surface and the panel is the preferred option.

The issue 4 PSU board utilises a different way of connecting 0V to the panel than previous issues. I recommend that the metal panel be securely connected to 0V. Provision on the PSU board of a chunky screw terminal allows a thick wire connection to be made to a suitable bonding point on the panel. This is essential if you are using an internal mains transformer but also has benefits even when you are using an external wallwart or linelump supply.

The power supply has two integral fuse holders in case of a problem with the power supply circuitry itself. Two fuses are needed if you are using full wave rectification, but only one, F2, is required for ordinary half wave rectification. The fuse type should be a slow blow or anti-surge type. The size is 20mm. It should be rated at between one and two times the maximum current of your wallwart. Thus a 500mA AC output mains adapter should have a fuse that is rated between 500mA and 1A, ideally 750mA. A 1A linelump should have a fuse that is between 1A and 2A, ideally 1.25A.

Three on-board LEDs, an orange one for +15V, a green one for -15V, and a red one for the AC input, provide a quick visual reference that all is well. All three LEDs could be fitted externally to the board and be mounted on a front panel. However, the recommended way is to mount only the AC indicator on the front of the synthesiser along with the AC power standby switch. The red LED comes on whenever AC power is applied to the unit.

As we have seen the standard circuit provides two outputs, one at +15V and one at -15V. Both output voltages can be finely adjusted with just one trimmer. The -15V will automatically track the output voltage on the +15V.

The output voltages are available from two screw terminal blocks. It is expected that each terminal block will be connected to one Dizzy board. However, you can with care connect more than one Dizzy board to each output block. Multiple Dizzy boards should never be connected in daisy chain fashion. That is, each Dizzy board should always go back to the PSU separately and with the shortest and thickness wire you can use.

* A wallwart is the vernacular term for a low voltage mains adapter that plugs directly into the wall. These take the form of a black plastic block that is shaped like an oversized mains plug. It is called a wart simply because its appearance is somewhat uglier than a normal slimline plug.

** A linelump does the same job as a wallwart but it generally can handle greater currents. Because of its increased size it cannot be made so that it will safely fit into a plug socket directly. Thus the adapter sits in a black plastic box and connects to the wall via a cable and traditional mains plug. It is therefore a black plastic lump connected to a line. The Yamaha PA-20 and PA-30 are such linelumps.

Our Recommended Power Supply

The safest available option is to use a ready made 'wallwart' or ‘line lump’ supply. As already mentioned one can use any 15V or 18V AC output wallwart of linelump you can source. The current capability of the mains adapter will be the chief limiting factor in determining the maximum current draw of your PSU. For a variety of reasons I recommend the Yamaha PA-20 and PA-30 supplies.

Yamaha PA-20

The European version of the PA-20. Other country's units are similar but will have the local mains connector fitted.

This is a linelump supply and features a fixed 17.5-0-17.5 volt AC output at 0.94A maximum. This means it gives us two AC outputs with a centre tap or mid point reference voltage. So unlike the single phase AC adapter output with two leads, this one has three. This means you need to use the Oakley PSU in full wave rectification mode.

The PA-20 is made for Yamaha products and they are available from Yamaha spares departments as well as many music shops, eg. Thomann. These are CE approved and connect to the mains via your local mains connector. They will be different types depending on the country you need them for. It comes with a handy three way plug at the low voltage end that you can use with an appropriate socket. If you wish you can ditch their connector and use your own. Oakley Sound sell a suitable three way connector to fit the Yamaha one perfectly.

In the UK the line lump’s part number is V9812300 and the total cost is around £30 including VAT and postage.

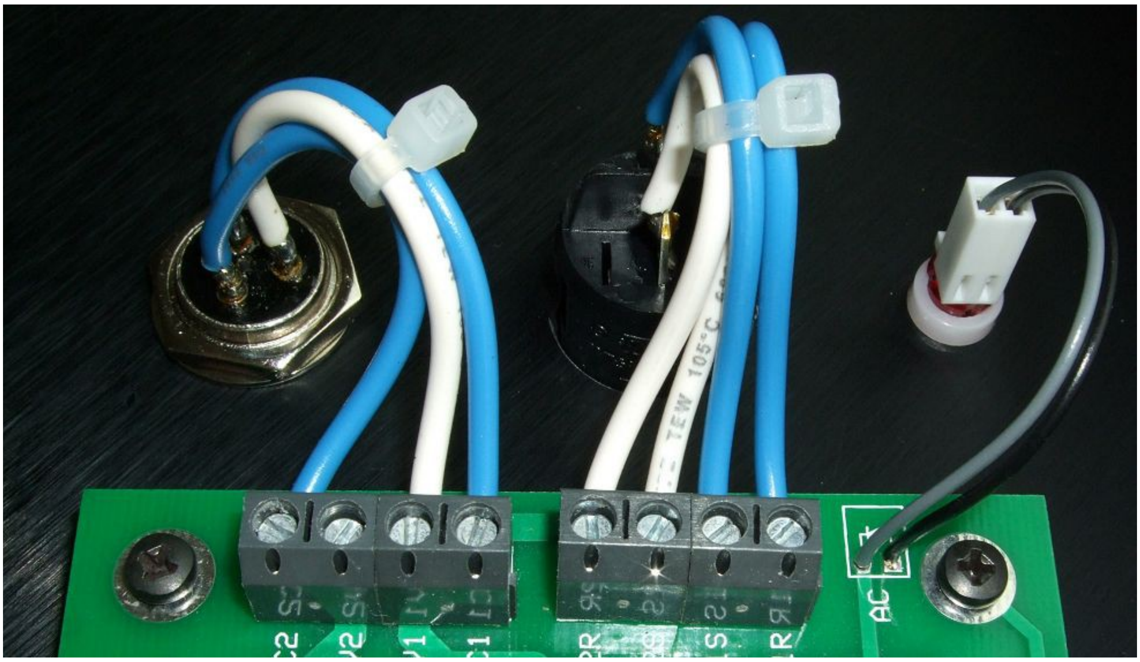
Once rectified, smoothed and regulated the Yamaha PA-20 can deliver up to 0.52A continuously into both 15V rails.

You should fit both fuses and both should be anti-surge types and rated at either 1A or 1.25A.

Yamaha PA-30

This is essentially a bigger version of the PA-20 as detailed above which supplies 18V-0-18V at 1.4A maximum. Once rectified, smoothed and regulated it can supply up to 0.78A continuously. You should again fit both fuses and both should be 2A anti-surge types.

If you have successfully used the Oakley PSU with any other types of power pack please do let people know via the Oakley Sound forum at www.muffwiggler.com



The input and switch wiring to suit a PA-20 power supply. The power inlet is on the left, the DPST switch in the middle and the power on LED to the right.

Note my method of mounting and connecting the off board LED. I use a two way 2.54mm Molex KK housing to hold crimped 7/0.2 wires. These simply slide onto the LED's leads and will stay in place until one needs to remove the connection by simply pulling on the housing. This 5mm red LED is held in place by a low profile red LED clip and mounting ring. The LED needs to be wired so that the anode is connected to the positive connection, ie. the square pad.

Which Power Devices?

The two recommanded power transistors are chunky devices in a TO-247 package. These are the TIP35C for the NPN, and the TIP145 or TIP147 for the Darlington PNP.

The TO-247 version of the TIP147. Note that the mounting hole is insulated from the metal parts of the case.

Although they are directly soldered onto the circuit board they are actually mounted onto the heatsink plate to which the whole power supply is attached. To prevent the metal part on the underside of the power device from making electrical contact with the heatsink you need to use an insulating pad. This allows the heat to travel through but not any electrical current. These will be sold as TO-247 (or TO-3P) insulating pads. You need one pad per transistor but it may be best to order a couple of extras since they can damaged if not handled carefully.

Obsolete versions of both power devices are still available in the older TO-218 package. This package is similar in appearance to a larger version of the popular TO-220 package with an all metal mounting tab. Try to avoid these in this project as they are more complex to mount onto the heatsink as the fixing screw, washer and nut need to be insulated from the metal tab. Special mounting kits are available for these older devices but they do take more time to assemble.

Circuit Description

The line lump outputs a two phase AC signal each one with a peak of nearly 25V with respect to its centre tap output. The difference between the two phases is that one is completely out of phase with the other. It's a bit like an audio balanced output in that respect. Both phases should be present for the power supply to work correctly.

Each phase is separately fused. Note that the fuses should be anti-surge, or ‘slo-blo’. The standard convention is for a ‘T’ in front of the value, where T is for time lag. For example, T2A would mean a two ampere anti-surge fuse. Anti-surge fuses have a higher thermal mass than fast blow fuses to prevent them blowing when they see a short burst of current. The inrush current when the supply is first switched can be very large and we don’t want our fuses blowing at that point.

D8, C12 and R12 provide a low current DC feed to a standby AC in LED. This lights up whenever the line lump is connected and powered up. It is wired in before the modular's power switch to remind you that the power on switch is actually a standby switch and does not switch the line lump off.

It is possible to run the Oakley PSU module on a single phase. This means that the unit could be connected to a single output AC adapter, ie. one with just two leads to pins 1 and 2. However, the regulators and the AC adapter will have to work harder in this application. It is therefore not recommended to run the PSU in single phase unless the output current is going to be less than 250mA or so.

The raw AC is fed to a bridge rectifier based around D9, D10, D11 and D12. This is the classic bridge rectifier circuit. Although it is drawn somewhat differently in the schematic than the usual ‘bridge’ style. If you think about a diode as passing current through it just one way, you should be able to work out why the voltage across C13 and C14 ends up as only positive, and across C7 and C8 as only negative.

I have used 1N5401 diodes in this place. These are 3A devices and are plenty large enough to cope with any abuse the power supply is given.

The outputs of the rectifiers supply current to the two smoothing capacitors. These act as reservoirs of charge when the AC voltage dips below its peak output. You can think about the rectifiers as merely topping up the reservoirs 100 times a second (120 times in North America), whilst the capacitors actually provide the energy to keep the modular powered.

The smoothing capacitors are generously rated both in terms of voltage and capacitance. It is essential that you use good quality components here and that they have sufficiently high ripple current rating. Since this PSU could possibly be supplying up to 1A per supply rail, a single smoothing capacitor could have nearly 2A running through it. The issue 4 Oakley PSU uses two smoothing capacitors in parallel per supply rail. The current through each capacitor is, therefore, roughly half that what it would be with just one larger smoothing capacitor per rail. This reduces the internal heating of the capacitor thus increasing longevity. Since the capacitors are in parallel the individual capacitance can be half of what is required for a single capacitor. This reduces the size, normally the height, of the capacitors used, making the whole PSU assembly physically less high.

The voltage across the smoothing capacitors is fairly constant but it is not stable enough to drive a modular synth. Modular synths need to have a regulated supply so that they stay in tune and behave in a predictable fashion whatever patches are selected. The regulators smooth out the voltage across the big capacitors even more and will produce a constant, low ripple +15V and -15V output.

Both of the regulators work in a similar way. You can think of them like a person controlling the speed of a water wheel. If the wheel runs too fast, the water flowing over the wheel is cut back by closing the sluice gate. If it runs too slowly, then the water flow is increased by opening the gate. The person uses his own eyes to monitor the speed of the wheel, and will make adjustments to the sluice accordingly. Now the wheel speed will depend on two things primarily, firstly the water rate, but also the load on the wheel itself. If the wheel needs to do more work it will slow down unless the water rate is increased.

The regulated power supply must also control its output with changes of load (ie. the number of synth modules in your system) and the input voltage (ie. fluctuations in the line lump's output).

Before we talk about the circuit in more detail, I ought to say why I haven't used the more common and I might add cheaper 7815 and 7915 regulators. The main reason is down to controllable current limiting. The 78XX and 79XX series do not feature this. In fact, if you were to short out a 7815 to ground, it would take around 1.7A from the supply and would heat up until the inbuilt thermal limiter kicked in. 1.7A may well be high enough to damage any connected transformer or line lump, to say nothing of the rectifiers and smoothing capacitors that would have to supply this current. By using the LM723 and a few external components we put the control back in the hands of the builders of the circuit.

Let us look at the positive regulator first since this actually also controls the negative rail too. The circuit is built around the venerable LM723 chip, U2. It contains pretty much everything you need to make a small regulator, including precision voltage reference, feedback control systems and a current limiter. However, it doesn't have a very big output current capacity so to use it for anything greater than 100mA, one needs to use an external pass transistor, Q1. The pass transistor is analogous to our sluice gate. The resistance of the pass transistor is effectively changed by the voltage at its base (pin 1). Decrease the voltage at its base with respect to its emitter (pin 3) and the transistor will increase its effective resistance and the output voltage of the PSU will drop.

The base voltage is controlled by the internal electronics of the LM723, but this in turn responds to the feedback from the output of the power supply. The feedback path is analogous to the sluice gate man's visual record of the water wheel's motion. In this case a fraction of the output signal is fed back into the LM723 at pin 4. The electronics will determine whether to make the base drive for Q1 higher or lower depending on what it 'sees'. The ADJ trimmer adjusts the fraction of the output voltage pin 4 will see and thus controls the overall output voltage.

R2 forms an important part of the current limiting circuit. When current travels through this resistor a voltage develops across it. When the voltage approaches 630mV, ie. 630mA through a 1R resistor, the internal electronics in the LM723 starts to pull down the base voltage on Q1. This effectively lowers the output voltage to make sure the current doesn't climb much above that value.

The value of R2 (and also R3) will determine the actual value of the current limit. For example, a 1R resistor will set the current limit to be around 630mA and a 0.82R resistor will make it around 770mA. The resistor value is chosen so that it will develop around 630mV across it when your chosen current limit would be going through it.

$$I_{limit} = 0.63V/R_{limit}$$

I_{limit} is the current limit value in amperes and the R_{limit} is the value in ohms of the resistor.

However, there are several things to be taken into consideration should you decide to increase the current limit above the values I have chosen.

Firstly, you need to ensure your transformer, internal or external, will be able to handle the additional current you are asking from it. The simple rule of thumb is:

$$I_{ac} = 1.8 \times I_{dc}.$$

Where I_{ac} is the steady state AC current in the transformer's secondary coil, and I_{dc} is the current taken by the load connected to the +15V and -15V rails. For example: The Yamaha PA-20 can supply 0.94A of alternating current into a simple resistive load from each of its two outputs. But by the time the output of the PSU has been rectified and smoothed the DC current taken should not exceed 0.52A on a continuous basis.

Secondly, the amount of current needed to drive the base of the pass transistors, Q1 and Q2, is directly related to the amount of current draw from the supply lines. Thus to ask for more from the supply would be to ask more from the 723 on the positive rail and the op-amp on the negative rail. The actual relationship between load current and drive current is related to hfe or the gain of the pass transistor. Choosing a pass transistor with too little gain will mean that you cannot obtain your required current. The recommended TIP35C and TIP145 devices have been tested to work with a mains transformer that can supply up to 1.1A into the output load. In this case the current limiting resistors, R2 and R3, would both be 0.56R.

Thirdly, the printed circuit board's copper tracks are not thick enough to pass huge amounts of current. The more current a track has to carry the greater the unwanted voltage drop across it and the hotter it becomes.

Fourthly, you need to consider how you are going to get rid of the extra heat the power devices will develop. The actual amount of heat dissipated by the power devices will increase with the more current you take from the supply. It is not quite as simple as a doubling of current will give twice the amount of heat given off, but it is not far off it. The amount of heat dissipated (in watts) will be equal to the voltage drop between the collector and emitter multiplied by the current running through it (the DC load). The temperature will rise with increased heat dissipation but a good heatsink will keep the temperature down to a safe level. If you can't comfortably touch a power device for more than ten seconds it is too hot.

The 3U wide 5U high panel design has only been tested to work with a maximum of 0.52A per rail when driven from a PA-20 or PA-30. A 4U or 5U high 19” panel is capable of considerably more – a 4U 19” panel has been tested successfully using a mains transformer with a 1A load and 25V across the smoothing capacitors. However, I would advise you to do your own experiments carefully otherwise you run the serious risk of overheating.

Finally, I think modular systems work better with a number of smaller power supplies rather than one big one. This is because as power is distributed around a large modular it gets 'corrupted' by the connected modules and the cabling. The cables have resistance and as current flows through the cables the voltage at the end of the cable gets reduced. The more current that flows and the longer the cable the worse the problem.

Having multiple power supplies does create the not insignificant question of what to do with the multiple grounds you will now have in your system. These can all be connected together and later in this document I will present one way of doing this.

Now let us look in more detail at the negative part of the power supply. The negative supply works in a similar way to the positive regulator but uses an op-amp, U3, and discrete components. The reference for the negative rails comes not from a precision reference but from the output of the +15V regulator. This means that the negative output voltage will track the positive one, but not vice versa I should add.

The op-amp is wired as a simple inverting amplifier although its difficult to see this at first glance. The input is via R9 which is connected to the +15V output. The feedback is provided via R8 which is connected to the negative supply output. The output of the op-amp drives the base of the pass transistor, Q2, via R11, which in turn controls the level of the negative output. Q2, a TIP145, is a PNP Darlington transistor. This is actually two transistors in one enclosure – but it can treated as one device with a larger than normal current gain (hfe) and twice than normal base-emitter voltage of 1.2V. Having a high gain requires only a small amount of drive current from the op-amp via R11 even when the load on the power supply is relatively high.

U3 will act so that its output will force all the current flowing through R9 to be passed onto R8. This is one of the op-amp golden rules; that is, no current shall flow into the input pins so long as feedback is maintained. To do this the op-amp must force the pass transistor to pass enough current though it to establish exactly -15V at the output.

Q3 and R3 form part of the current limit circuit. If the voltage across R3 exceeds 640mV then Q3 will turn on dragging current away from Q2’s base and thus lowering the output voltage of the negative rail accordingly.

The op-amp U3 derives its positive power from its own 5V supply based around a simple 7805 regulator chip. This allows the negative regulator to function correctly when the +15V rail is under stress and allows the negative rail to fall gracefully when the mains power is switched off.

D1, D7, D2 and D6 protect the +15V and -15V output rails from a variety of naughties. On power down any excess current left in the modular will be shunted to the smoothing caps and not damage the now unpowered power supply components. Also, they also prevent the negative rail from going positive should the negative rail die for some reason. And vice versa too.

Parts List

For general information regarding where to get parts and suggested part numbers please see our useful Parts Guide at the project webpage or http://www.oakleysound.com/parts.pdf.

The components are grouped into values, the order of the component names is of no particular consequence.

A quick note on European part descriptions:

For resistors: R is shorthand for ohm. K is shorthand for kilo-ohm. M is shorthand for mega-ohm

For capacitors: 1uF = 1,000nF = 1,000,000pF. Sometimes the F is not included on the circuit diagram to indicate a capacitor's value, ie. 100n = 100nF.

To prevent loss of the small '.'as the decimal point, a convention of inserting the unit in its place is used. eg. 4R7 is a 4.7 ohm, 4K7 is a 4700 ohm resistor, 4n7 is a 4.7 nF capacitor.

Resistors

5% 1/4W carbon or better (1/4W 1% metal film is recommended)

1K	R1, R11
4K7	R4, R5, R10

1% 1/4W metal film

10K	R7, R9, R8
12K	R6, R12

2W metal film or wirewound (5% or better)

For use with the Yamaha PA-20:

1R	R2, R3

For use with the Yamaha PA-30:

0R82	R2, R3

Capacitors

22pF low-K ceramic 2.5mm	C4
330p low-K ceramic 2.5mm	C5
100nF axial multilayer ceramic	C1, C2, C9
10uF, 35V electrolytic	C3, C6, C10, C11
22uF, 35V electrolytic	C12
470uF, 35V electrolytic	C15
1800uF, 35V electrolytic	C7, C8, C13, C14

Note: C7, C8, C13 and C14 are 105 degree Celsius radial types and have standard wire ended leads. Lead spacing is 7.5mm. I recommend Panasonic type EEUFC1V182 but any decent 105 degree part can be used that will fit on the board will do.

Alternatively, you can use two 3300uF, 35V instead. Fit these to positions C8 and C14 and leave C7 and C13 empty.

Integrated Circuits

7805 5V 1A regulator	U1
LM723CN 100mA voltage regulator	U2
OP177GPZ single precision op-amp	U3

Good quality DIL sockets are recommended. You need one 14-pin and one 8-pin.

Discrete Semiconductors

1N4004 rectifier diode	D1, D2, D3, D4, D5, D6, D7, D8
1N5401 rectifier diode	D9, D10, D11, D12
TIP35C NPN transistor	Q1
TIP145 or TIP147 PNP Darlington transistor	Q2
BC560 PNP transistor	Q3

Do not solder the Q1 or Q2 until the board is mounted on its panel

For D1 to D8 you can use any other 1N400X part such as 1N4001, 1N4002, etc.

D9 and D10 do not need to be fitted if you are using a single phase wall wart or line lump. However, for full wave rectification D9 and D10 are required. So if you are using a split output line lump, or an internal transformer with twin secondaries, D9 and D10 have to be fitted.

There are three LEDs that can be fitted to the board to indicate power status. All three can be fitted to any panel you are using if you wish. I typically fit the green and orange ones to the board and have only a red LED fitted to the panel to indicate that the AC input is active. The colours of the LEDs are not important and these are just suggestions.

Anodes are denoted by the square pad on the PCB. LEDs will not light up if fitted the wrong way.

5mm red LED	AC
5mm green LED	-VE
5mm orange LED	+VE

Trimmer

10K multiturn trimmer	ADJ

Miscellaneous

2A antisurge 20mm fuse	F1, F2
20mm fuseholder PC mount	F1, F2
4-way screw terminal 5mm	POWER, SWITCH, OP1, OP2
TO-247, TO-218 or TO-3P insulator pad.	Q1, Q2

Suitable power switch
Suitable power inlet socket

Keystone 8191 PCB terminal & screw	0V – fitted between OP1 & OP2
4mm 'banana' socket	Optional – fitted on panel. *
4mm ring terminals (crimp/solder)	For connection of 0V terminal to bond point. *

You will also need thick wire to connect between the power inlet, switch and any connected distribution boards. I recommend 24/0.2 (0.75 sq. mm) insulated wire.

If the standby LED is to be fitted then you will also need standard hook up wire – I use 7/0.2 for all my low current connections. The thicker 24/0.2 wire would be too thick for this.

For internal mains transformer (or any installation not requiring a standby switch) then you do not need to fit the screw terminal SWITCH.

F1 and its associating fuse does not need to be fitted if you are using a single phase wallwart or linelump.

* See sections on 'Fitting a Grounding Point' and 'Using an Internal Mains Transformer'.

Mounting hardware for Master Panel

M3 10mm countersunk screws	4 off	Panel front side
M3 6mm pan head screws	4 off	PCB top side
M3 20mm countersunk screws	2 off	For power devices
M3 hex threaded 10mm spacers	4 off	
M3 star washers	10 off	
M3 washers	6 off	For PCB and power devices
M3 hex nuts	2 off	For power devices

Mounting hardware for 19” rack panel

M3 6mm pan head screws	8 off	
M3 20mm pan head screws	2 off	For power devices
M3 hex threaded 10mm spacers	4 off	
M3 star washers	10 off	
M3 plain washers	6 off	For PCB and power devices
M3 hex nuts	2 off	For power devices
M4 16mm pan head screw	1 off	For 0V/Earth bond point
M4 washer	2 off	For 0V/Earth bond point
M4 star washer	2 off	For 0V/Earth bond point

And any mounting hardware for the Dizzy boards if needed.

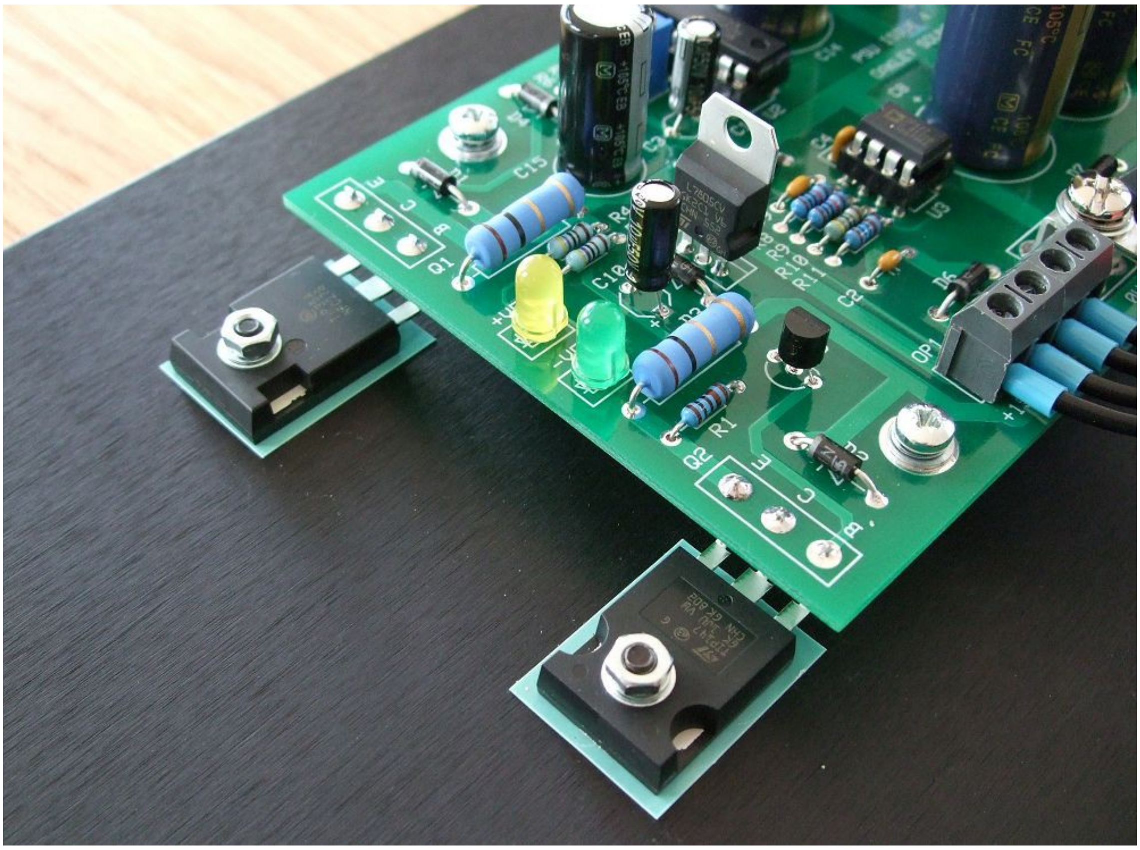
Master Panel - Jack Multiple, CV/gate and Attenuator Option

Switchcraft 1/4” sockets 112A	12 off
47K 5% or better, 0.25W resistors	1 off
4K7 5% or better, 0.25W resistors	1 off
20AWG tinned copper wire	Approx. 1m

For Oakley Bus:

3-way Molex/MTA housing	1 off – also Molex crimps if using a Molex housing.
A suitable length of hook up wire	

Attaching the Power Devices



The PSU board fitted to a 4U 19" rack panel. Note the blue TO-247 insulator pads underneath the two chunky power devices.

This section assumes you have purchased the 3U Schaeffer or FPE master panel or have a suitably drilled 5U high 19" rack panel onto which you will mount the power supply assembly.

For the four PCB mounting holes, insert a 6mm screw (10mm countersunk for the master panel design) through each of the four holes in the panel. Fit a star washer over the exposed thread on the inside of the panel. Now fit a hex spacer over the washer and tighten firmly. Check that the four holes in the PCB line up with the tops of the hex spacers but don't fit the PCB in just yet.

Now you need to prepare the leads on the two TO-247 power transistors. The three legs need to be bent upwards so that the PCB can be fitted over them. Note that the top surface of the device is marked with the name of the component and it is the flat side on the bottom of the device that will be in contact with the panel. You should be able to see that the leads have a thicker section close to the body of the device. Make a 90 degree bend upwards at a point 1mm away from this thicker section. Do this for all three legs of the device.

Take one of the insulating pads and place it against the rear of the TIP35C. Match up the hole in the pad with the hole in the power device. Now place the power device and pad flat against the inside of the panel aligning the holes of the transistor, pad and panel. Insert a 20mm M3 screw (countersunk for the master panel design) into the hole from the front, and fit a washer, star washer and nut onto the screw but keep it loose. Do the same for the TIP145.

Now if you have done all this correctly, you should find that the when the power supply PCB is aligned once more, you can coax the power devices' legs through the respective pads on the board. You will probably have to wiggle the power devices about a bit to get it to fit smoothly. Check that the transistors' leads have not been pushed downwards at all – they should not be touching the metal panel.

Place a star washer on a 6mm screw and a plain washer over that. Place into one of the PCB's mounting holes and screw into the hex spacer but do not tighten. Do this for the other three holes. Now secure the transistors in place by tightening the nuts. Do not overtighten. All you need to make sure is that the transistor sits firmly to the panel. If you tighten it too much the device will lift at one end and not sit flat against the insulating pad.

Then gently tighten the board's four screws. Again, all you need to do is secure the board.

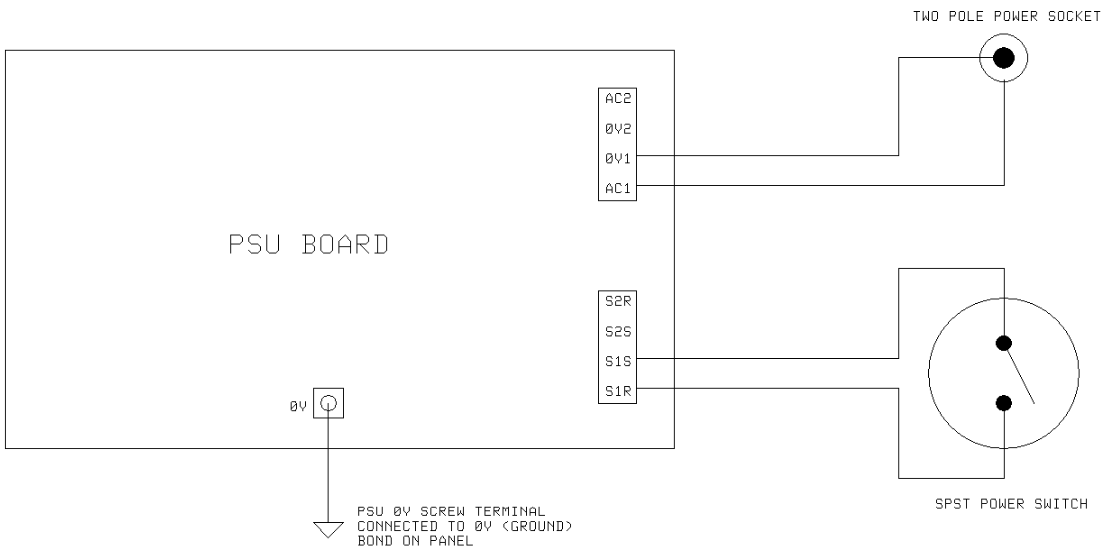
You can now solder the transistor leads from the top side of the board. Any excess lead lengths can be cut down as you would a normal component.

Linelumps and Wallwarts: Wiring Diagrams

Input wiring will depend on the type of wallwart or linelump you will be using.

Standard AC output wallwart

Single phase, two wire, wallwarts or linelumps need to use half wave rectification so the Oakley PSU can generate both positive and negative supplies simultaneously. They only need the terminal's AC1 and 0V1 wired to the power socket. AC2 and 0V2 are left unused.



Wallwart with single phase AC output.

The front panel switch is a single pole single throw (SPST) switch which simply connects S1R and S1S together when switched on. You can replace the switch with a simple wire link, but I do recommend that a switch be fitted so the socket doesn't have to take the full surge current when you insert it with the wallwart powered up.

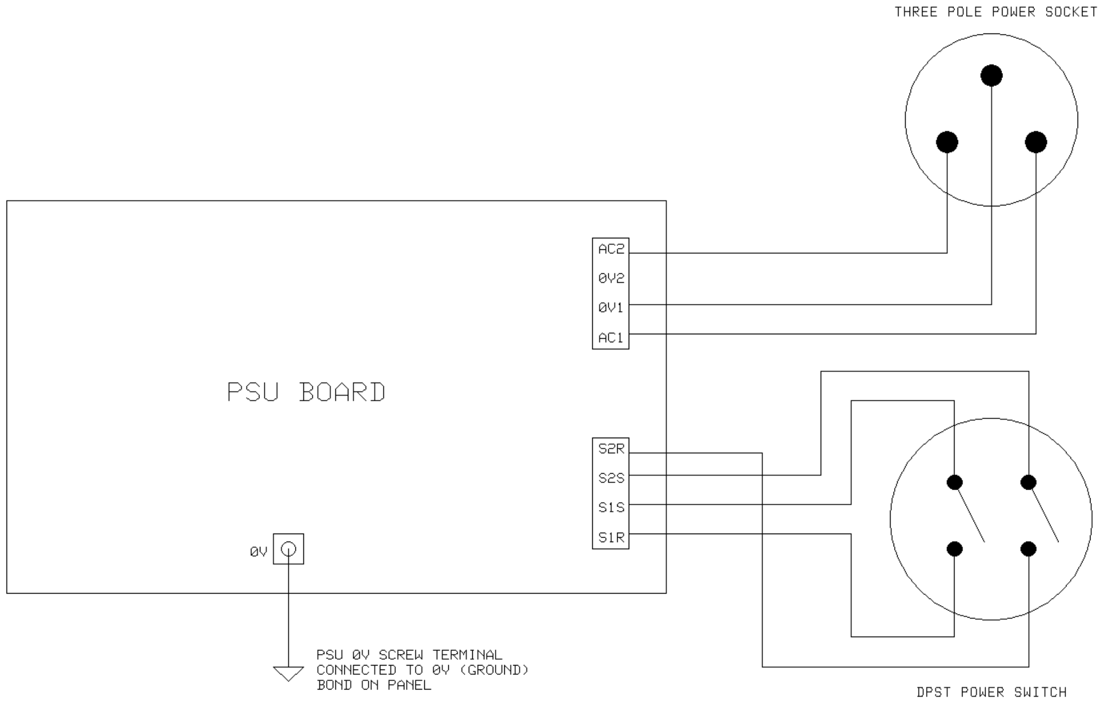
I also recommend fitting the AC indicator LED too. This is so you know the wallwart or linelump is on. The AC indicator is designed to indicate the status of incoming power and is not determined by the position of the standby switch.

The standby switch should not be used to turn the unit off permanently. This should be done by either switching the adapter off at the mains socket, or by pulling the adapter's plug out of the mains socket.

An optional 0V or grounding connection can be made. See later for more details.

Recommended Option: Centre tapped wallwarts and linelumps

Centre tapped linelumps like the Yamaha PA-20 will have three wires coming from their connector. It will have two AC outputs and one 0V. Take one of the AC outputs to terminal AC1 and the other AC output to terminal AC2. It should not matter which AC output goes to AC1 or AC2. The 0V should go to the 0V1 terminal. The 0V2 terminal is left unused.



Linelump wiring with centre tapped output, eg. Yamaha PA-20

The front panel switch is a double pole single throw (DPST) switch which connects S2R and S2S together, and S1R and S1S together, when switched on. You can replace the switch with two wire links, but I do recommend that a switch be fitted so the socket doesn't have to take the full surge current when you insert it if the linelump is powered up.

I also recommend fitting the AC indicator LED too. This is so you know the linelump is on. The AC indicator is designed to indicate the status of incoming power and is not determined by the position of the standby switch.

The standby switch should not be used to turn the unit off permanently. This should be done by either switching the adapter off at the mains socket, or by pulling the adapter's plug out of the mains socket.

An optional earth or grounding connection can be made. See next section for more details.

Fitting a Grounding Point and Grounding the Panel

Using double insulated wallwarts and linelumps mean that you do not have to have a mains safety earth fitted to your modular. However, if your modular is to talk to the rest of the studio you need to make sure that the modular's 0V is tied to earth somewhere in your system. The most usual way of doing this is via the connecting cable's shield or screen connection. Your mixing desk or monitoring equipment will be earthed and simply connecting a cable to any module within your modular will tie the modular's ground to the other equipment's earth. This seems pretty straightforward and it is so long as you have a small system and only have one or two interconnecting cables in use.

However, a larger more complex system will have perhaps more than one modular, more than one mixing desk and perhaps a heap of other outboard equipment. This is when it makes sense to look at grounding your modular cases together.

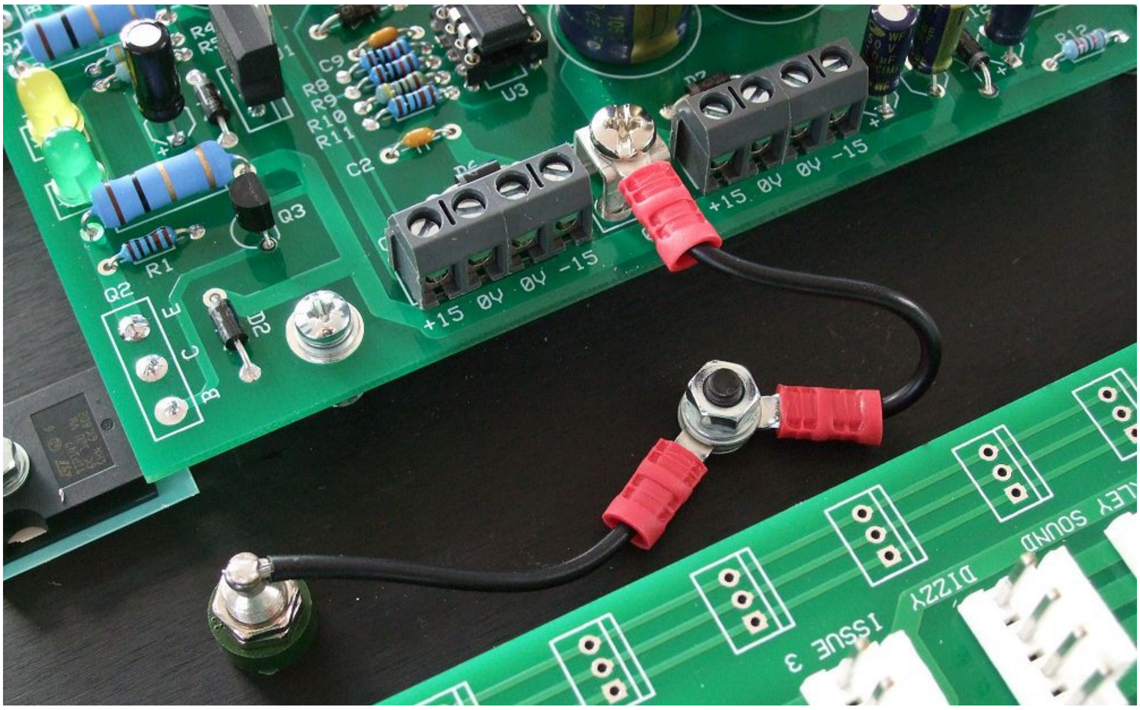
The additional 4mm socket to the right of the power inlet provides a way of connecting the 0V lines between cases

Let us consider a more simpler scenario for the moment. Say we have built ourselves two modular cases and we would like to connect the modules in them together to form an awesome monster patch. Each case has its own PSU and each one is powered by a Yamaha PA-20. It is useful in this situation to ensure that both PSUs are grounded together. In other words, the two 0V lines from each power supply are electrically connected together. Although this will be done the moment that one patch lead goes from one case to the other it is beneficial to do this with a dedicated thick bonding wire. The thicker the wire the lower the resistance which reduces any unwanted voltage drops as return currents travel through the wiring.

This can be done in a variety of ways but one useful and simple method involves having a 4mm banana socket mounted near each power supply. The banana socket is then connected to 0V, using the dedicated 0V screw terminal, on the PSU board. Use at least 24/0.2 wire to make this connection.

If both the power supplies have a banana socket then it is a simple matter of patching the two modular cases together with a banana patch lead. The great thing about bananas is that they are stackable so it's easy even if you have more than two cases to connect up.

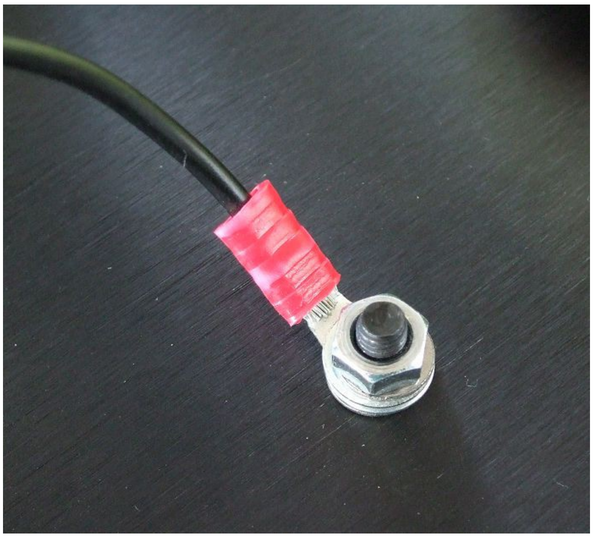
I recommend that you use thick multistrand cable to make your grounding leads and that you use good quality 4mm banana sockets and plugs.



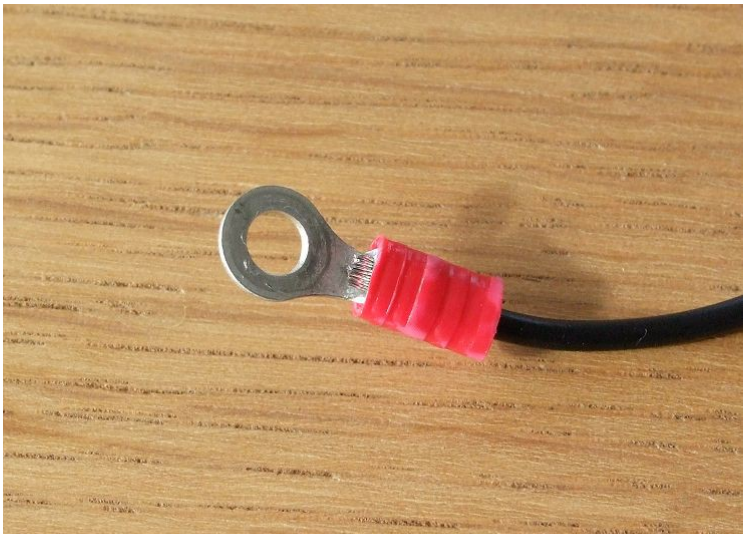
The dedicated 0V screw terminal on the PSU board has been connected first to a bonding point which grounds the panel. The bonding point then connects to a 4mm banana socket on the left. Thus both the metal panel and the banana socket have a good connection to the PSU's 0V.

To reduce electrical noise it is wise to ground the panel on which the power supply is mounted. In Oakley PSU versions prior to issue 4 the lower left mounting hole of the PCB was connected to 0V. Simply mounting the board to the panel with metal screws would connect the PSU's 0V to the panel. Recently I learnt it was necessary to make this connection more robust and with a lower overall resistance. Thus the issue 4 board removes the grounded mounting hole and adds the solid screw terminal that connects directly to the 0V close to the output terminals of the PSU.

To make a bonding point is straightforward. Simply drill a 4mm hole in your panel. Scrape back around the hole any finish on the inside surface, such as paint or anodising, to reveal the shiny metal underneath. Fit an M4 screw from the front and pop on a toothed star washer and flat washer on the rear. Fit your ring terminal (or terminals) onto the screw, place another flat washer and star washer on top of that. Secure tightly with an M4 nut. This should ensure that the panel is robustly connected to 0V.



An single M4 crimped ring terminal secured to a panel bonding point. A solder tag with a 4mm hole could also be used but for thicker wires, like this 24/0.2 wire, crimping offers better performance and is simpler.



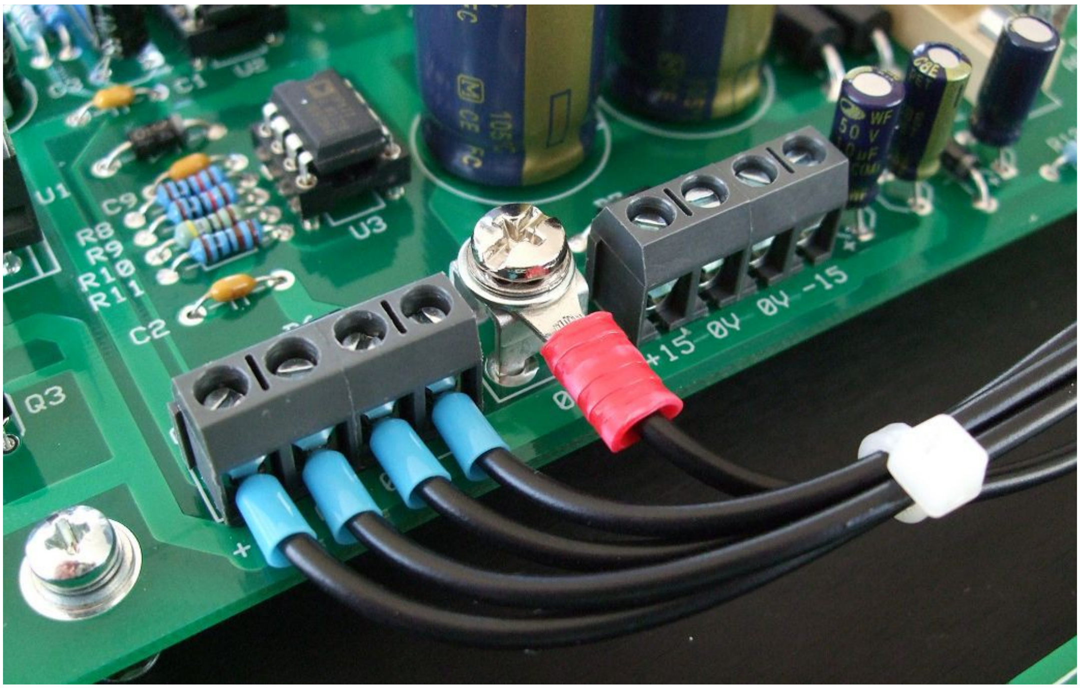
An M4 ring terminal crimped to 24/0.2 insulated wire. This sort of connector is suitable for both the panel ground bonding point and attaching to the dedicated 0V screw terminal on the PSU board.

Personal Note...

One has to a little careful when using the word 'ground'. I sometimes talk about local ground and 0V as being the same thing. This is technically incorrect but it is used a lot. I worked at Marconi in the 80s and Soundcraft in the early 90s, and ground and 0V were used interchangeably even by seasoned engineers. We'd talk about chassis ground, dirty ground, signal ground and clean ground. They'd all be connected to 0V somewhere in the system but the term ground was in common usage.

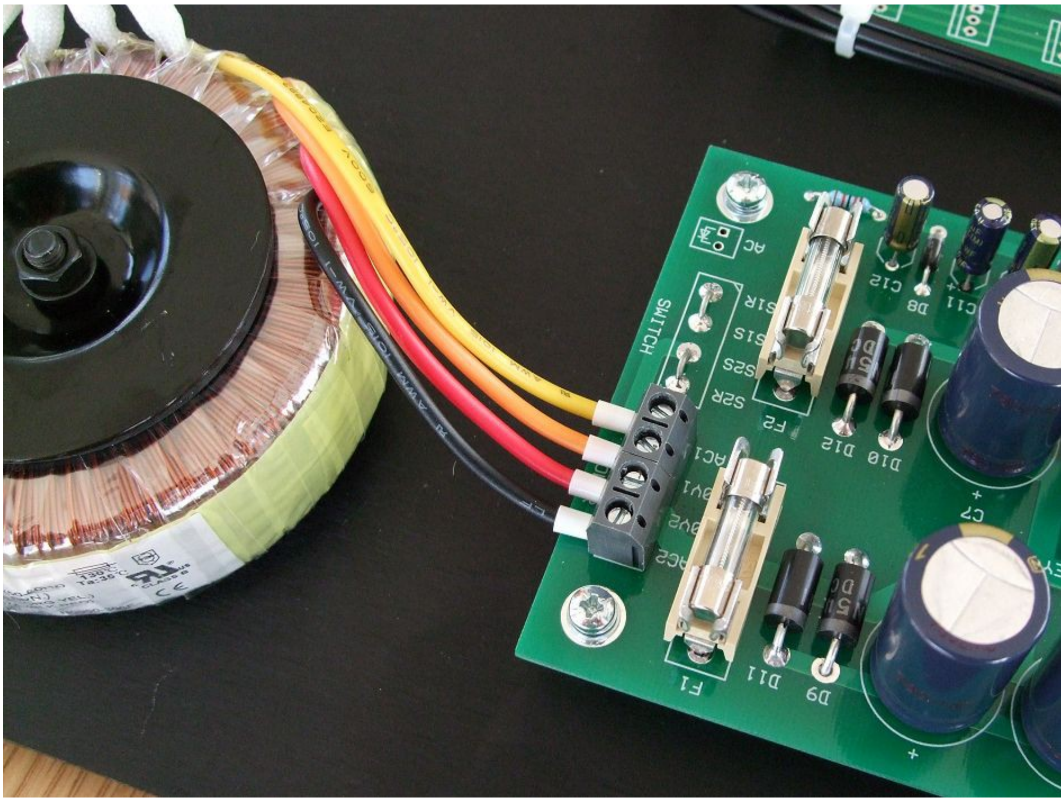
Ground, when used in this way, is then a local common reference connection tied to the 0V of the unit's power supply. It is not the same as mains earth. Indeed, it may not even be tied to mains earth in the unit in question.

Strictly speaking, electrical ground is mains earth and historically it was solely referred to as that, but usage, incorrect or not, has meant a shift in the meaning. Ideally, we should call our common reference connection within our unit as 0V and not use the term ground.



The connection on the dedicated 0V screw terminal (Keystone part no. 8191) using a crimped 4mm ring terminal. The four wires going into the power outlet terminal are fitted with crimped blue 'boot lace' ferules. These are a great way of making all the strands in the wires stay together when inserting them into the terminals.

Using an Internal Mains transformer



A 50VA toroidal transformer powering an Oakley PSU designed to deliver up to 750mA per rail. Note the wire loops fitted to the pads where normally the terminal block for the standby switch goes. The AC power indicator has not been fitted in this particular build.

Be afraid, be very afraid...

Some of you old hands will laugh about the level of hysteria that surrounds direct mains connection to DIY projects. However, this fear is more to do with our litigious society than the real danger to the builder. Even so, I have had more than my fair share of high voltage shocks over the years and it is not something I would want any builder to have to experience. It has been purely luck that has saved me in several of those cases.

So I will say again – do not attempt to build a mains transformer into your modular case, or any other project, without realising that to do so carries a risk of death to either you, or to the person who may inadvertently put their fingers into your half built construction. Furthermore, it is up to you as the builder of such an item to make sure, that once built, the item is safe to use and meets all current safety legislation.

This is not a complete set of instructions on how to fit a transformer into a piece of electronic equipment. This information is offered only as a guide and should not be considered as your only source of information. No further information, other than that included here, will be provided by me regarding the construction of mains powered items.

The mains transformer's secondaries should be rated:

18-0, 18-0 (twin secondaries) or 18-0-18 (centre tapped)

80VA

This will give you a power supply that should be theoretically capable of just over 1A each rail assuming your heatsink and smoothing capacitors are up to the job. In this case you should make both R2 and R3 0R56 2W resistors.

Take note that the 5U high 3U wide front Master Panel design is insufficient to carry away the heat safely when continuously supplying over 520mA per rail. A different method of mounting the power devices must be found unless you limit the maximum current to less than 520mA.

The 4U 19” panel detailed earlier may well be adequate for a 1A supply but remember that the secondary voltage will affect just how much heat needs to be dissipated. It is up to you to verify that your chosen panel is up to the job of keeping those power devices cool. Remember that air flow to the panel is essential so make sure any tests you do are representative of the situation your heatsink will eventually be fitted to.

The transformer secondary voltage is suggested to be 18V. Slightly higher transformer secondary voltages can also be tolerated although you need to consider three things:

1. You may need a physically larger transformer for the same output power.

2. The power supply's components, including the smoothing capacitors, should be rated at a high enough working voltage to handle the increased voltage across them.

3. The heatsink will need to dissipate even more energy because of the greater voltage drop across the regulators.

In the wiring diagram shown I have included a suggested wiring method for connecting up a mains transformer. Not all mains transformers are the same, some have additional windings, others have tapped windings. I have simply used a single primary, double secondary type for example only.

For the mains fuse you should use a 500mA anti-surge type. All wiring at mains potential should be adequately insulated and protected from straying fingers.

There is no need to fit an AC standby switch since you will be fitting a proper mains power on switch in series with the transformer primary coil. So you should link S1A to S1R, and S2S to S2S, on the PCB.

Earthing

Remember it is up to you, the builder of the equipment, to make sure that your item is safe and is built to the required safety standard in your country. These notes are only a guidance and it is up to the reader to establish the exact obligations required in their own country.

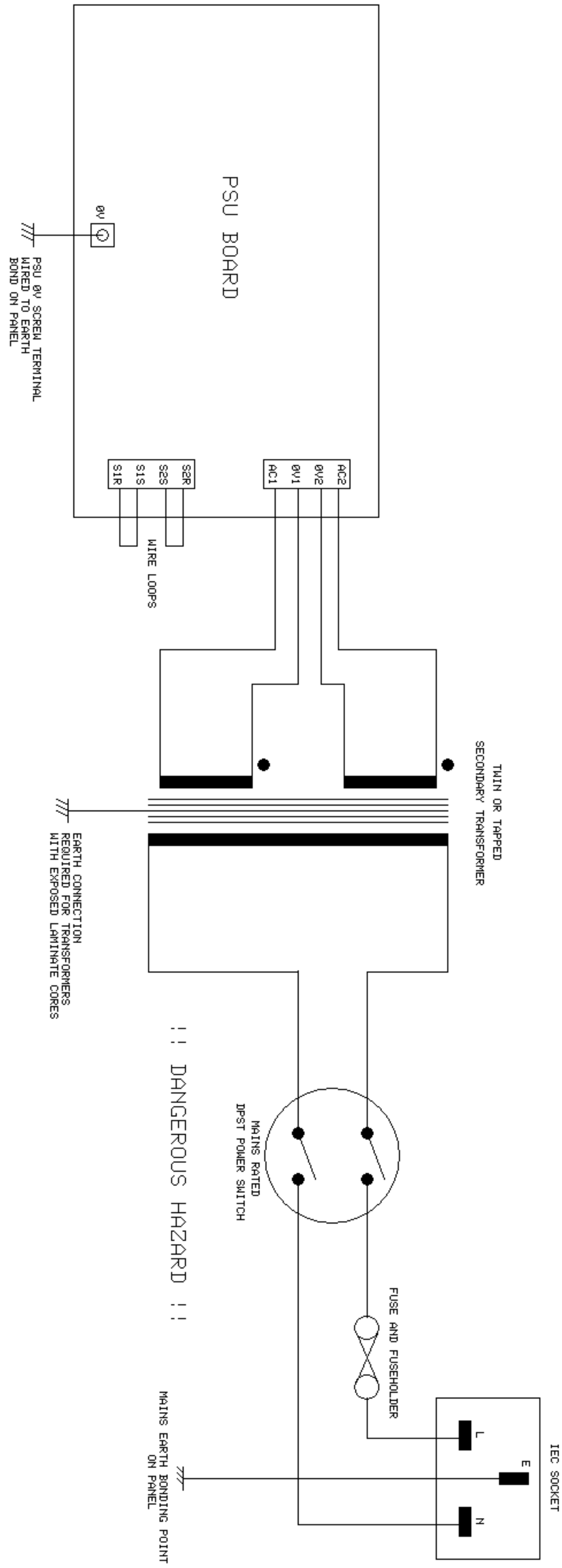
It is essential that everything you build, that has both live mains inside and a metal case or panels, has a safety earth fitted. UK legislation says that any metal panelling should be adequately insulated, ie. double insulated, or connected to earth. Since making a double insulated case is not practical you should ensure that any exposed metal parts be properly earthed.

Firstly you need to ensure that the heatsink panel is earthed. Given its size and required air flow this will certainly be an exposed piece of metal and thus should be earthed well. It should be bonded to earth via a short thick piece of wire back to the earth tang of the IEC mains inlet socket.

The PSU board should be securely mounted (using all four mounting holes) onto the earthed heatsink using appropriate screws and star or spring washers. Connect the dedicated 0V screw terminal on the PSU board back to the panel's earth bonding point using at least 24/0.2 wire. It may be useful to make a two bonding points on the panel. One solely for the mains earth which can be located near the mains IEC inlet socket. And another, located next to the PSU, for the PSU 0V and optional 4mm banana socket connections. The panel serves as a low resistance connection between the two – although you must ensure that any paint or anodising is scraped off around the bonding hardware. By using two bonding points in this way keeps the 0V wiring as short as possible and reduces the risk of the grounding wires coupling with the transformer and introducing mains hum on the local 0V.

None of this, however, may be sufficient for a solid safety earth bond as required by your local regulations. Ideally all modular panels should be earthed directly, either with their own direct connection to the earth bond near the power inlet, or via the modular's earthed metal mounting rails and suitable toothed washer and screw. This isn't always practical though so is not often done.

You will also need to provide earthing to any exposed transformer core. This does not apply normally to toroidal types but EI types should have their metal frame earthed.



Mains wiring diagram. For experienced builders only!

The Oakley Power Bus

In an ideal world I wanted the Oakley power bus to be based on a five way 0.156” MTA or Molex connector. This would contain +15V, -15V and three 0V or grounds. One ground would be the safety ground; this would be connected to the power supply's 0V, the modules' front panels and to the mains earth. The second would be a clean ground for all the analogue modules to take their supply reference, the true zero volt line, ie. 0V. The third would be a dirty ground. This would be the ground reference for things like the noisy digital circuitry and LED switching. All three would be connected together but only at the power supply. However, this system would be incompatible with the MOTM modular which only has a four way connector for its analogue modules. So the question now remained, how could I make my system work with MOTM, yet still retain some of the features I needed.

The chosen Oakley power bus comprises of +15V and -15V lines with two separate 0V connections. These 0V are not connected together in each module as they are in MOTM modules. They are joined only at the power supply in a wholly Oakley Modular.

In an Oakley modular one of the grounds, pin 2, is solely used for the electronics in the module. I call this module ground or module 0V, it's the reference point for all the circuitry used in a module. Unfortunately, it is also the dumping point for some hefty current but I try to reduce this to a minimum by certain design choices in the modules.

The second ground is on pin 3. This is also connected to the power supply’s 0V output. This ground is connected only to the metal lugs of the sockets on each module, and therefore the panel itself, and nothing else on the module. This way it is impossible for any signal return currents to travel down the inserted patch cords since the panel is isolated from the system ground except at one point, the PSU.

MOTM modules can be modified to allow full Oakley compatibility although this should be done as you are building the module. Modifying a completed MOTM module is possible, but the reverse side of the PCB must be accessed so that you can cut the required tracks.

However, note that the MOTM and Oakley power systems are still compatible. Any Oakley module will work in a MOTM system. And MOTM modules will work in a mostly Oakley system – the only downside being that some of the benefits of a two ground system are increasingly lost as you add more MOTM modules to the mix.

Master Module: Jack Multiple and Attenuator Option

Fit twelve Switchcraft sockets into the spaces on the Master Panel. Align them so that the bevel faces to the top right as you look at the back of the unit. With a single piece of 20SWG tinned solid core wire connect all the ground lugs together on the right hand column. Now do the same on the left hand column. Solder another piece of solid core wire across the two vertical pieces so that it connects both columns together. Make this 'bridge' just below the top eight sockets, that is, between the fourth and fifth socket down. Now with insulated wire connect this wire frame back to the dedicated 0V screw terminal on the PSU board.

Now connect all the signal lugs, marked as T on the body of the socket, on the first four of the right hand column of sockets. Then do the same on the left hand row.

You should now have four vertical wires, two running down the top four sockets, and two running down over six. Your multiples are now complete.

The KEY CV and GATE sockets now need to be connected to the Oakley Dizzy buss. Use a three way 0.1” Molex or MTA100, as described in the Dizzy User Guide, to connect the signal lugs on these two sockets to the CV and Gate buss.

The 10:1 attenuator is simply made. Connect the signal lug on the right hand socket (IN) to the signal lug of the left hand socket (OUT) with a 47K resistor. Then solder a 4K7 resistor from the signal lug of the left hand socket to the ground lug of the same socket. And that's it!

Testing and Calibration

Note all testing must be done with the heatsink or panel attached to the power devices.

After wiring the unit according to the instructions given in the Users Manual you should apply power to the unit. Check that no device is running hot. Any sign of smoke or strange smells turn off the power immediately and recheck the all the external wiring first, and then the components on the board. Both the +VE and -VE LEDs should be lit and neither should be too bright or too dim.

With a multimeter, check the DC voltage across the +15V and -15V output terminals. You should get around 30V or so. Adjust the trimmer so that you get exactly 30.00V. Now measure the voltage across the +15V and one of the 0V terminals. This should read 15.0V or very close to it. Check that the voltage across -15V and 0V is -15.0V. It is advisable that the +VE and -VE LEDs are fitted for this adjustment, or that at least one Oakley or MOTM module is connected up to the power supply board. This is to ensure that there is some current running through the series pass devices (Q1 & Q2) which allows them to work properly.

If all is well, then it is time to check the current limit. Put your multimeter into current mode. Use the 2A or 10A setting. Now put your probes across the +15V and 0V terminals. The meter should read approximately 630mA (for current limit resistors of 1R) or approximately 780mA (for current limit resistors of 0R82). The orange and green LEDs should both go out when the probes are in place. There is a problem if either of the LEDs do not come on again when the probes are removed.

Now do the same for the -15V and 0V terminals. This time we should get a slightly higher reading of around 730mA. (for 1R resistors) or around 870mA (for 0R82 resistors). This time only the green LED should go out when the probes are in place.

The current readings you have just taken may be slightly different from what is given here. It will depend on the ambient temperature, the accuracy of the power resistors and the accuracy of your ammeter. Expect the actual value to be different by about +/-10%. If it is significantly different, like 1000mA instead of the expected 630mA, then check your build. While doing the current limit check you may notice the power devices getting warm. This is perfectly normal.

If all is well, everything is probably working and you can now connect your new supply up to your modules.

The output voltages will vary a little with load. That is, it will change marginally depending on how many modules you connect up to the power supply board. Feel free to re-adjust the trimmer when you add more modules to your system.

Final Comments

I hope that the Oakley PSU lives up to your expectations and provides you with a reliable source of power for your modular system.

If you have any questions about the module, an excellent source of support is the Oakley Sound Forum at Muffwiggler.com. I am on this group, as well as many other users and builders of Oakley modules.

If you have a comment about this builder's guide, or have a found a mistake in it, then please do let me know. But please do not contact me directly with questions about sourcing components or general fault finding. Honestly, I would love to help but I do not have the time to help everyone individually by e-mail.

Last but not least, can I say a big thank you to all of you who have helped and inspired me over the years. Thanks especially to all those nice people at Muff's and the Synth-DIY and Analogue Heaven mailing lists.

Tony Allgood at Oakley Sound

Cumbria, UK