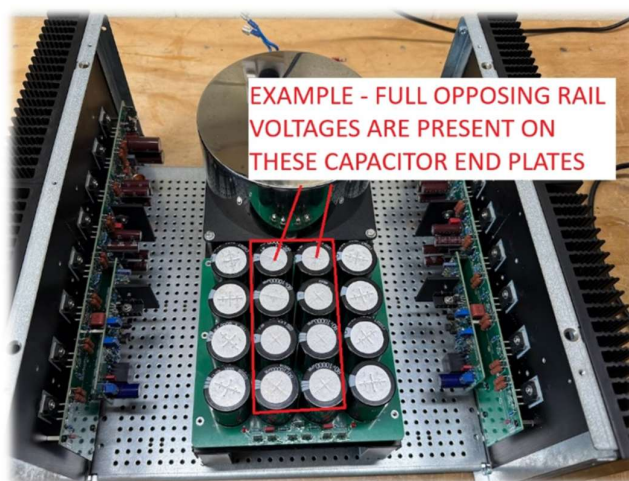


Foreword About Safety

Please ensure you are aware of and fully understand the following.

The Wolverine can operate with potentially dangerous high DC voltages up to 170VDC (-85V to +85V). These voltages can cause severe injury, permanent damage, or be fatal if mishandled. Care is taken in design so that these voltages are not located in finger proximity however there is always the possibility that two opposing sides of the amplifiers power supply somehow encounter a stray steel tool or hand. (Not Wolverine PCB related but with all Class AB amplifiers a common source of these two voltages being present is the uninsulated plates of the main filter capacitors in the case of a snap-in PCB see - below example PSU capacitor bank)

Mains voltages are even more dangerous due to their earth potential, even though this guide does not pertain directly to mains household voltages, it is likely that the builder will be performing some form of mains appliance wiring to run this amplifier. Therefore, it must be said that you must be familiar with and abide by your countries local wiring regulations. Remember that if someone is injured because of your work, you may be held liable for ensuing damages.



Your (and others) safety is top priority. Before continuing this build:

- Make absolutely sure you understand the risks involved in working with any household mains and power amplifier circuits.
- If you're not already experienced with safe handling of mains electricity and high-voltage DC, now is a good time to consult with a qualified electrician or technician who can familiarise you with the regulations and risks.
- Always disconnect the amplifier from the mains before removing any covers and test the power supply rails with an appropriately rated multimeter, before touching or modifying any internal wiring or components.
- Capacitors may store a **lethal charge** even after power is removed, yes this is applicable to both Linear power supplies and Switch Mode power supplies! Ensure they are fully discharged before proceeding. As above test the rails with a multimeter and use an appropriate capacitor discharge tool if your power supply does not have rail bleeding capacitors, or the connected amplifier does not drain the voltage through its internal bias circuitry (typically this will fail after a fault event so you must check the rails with a multimeter and not assume the amplifier has drained the capacitors.)
- Practice common safe working procedures for handling electrical appliances see here:
[Electrical Safety Requirements](http://www.sound-au.com/articles/mains-safety.htm) – www.sound-au.com/articles/mains-safety.htm
[Power Supply Wiring Guidelines](http://www.sound-au.com/psu-wiring.htm) – www.sound-au.com/psu-wiring.htm
- Do not attempt assembly, testing or fault finding when you are impaired, tired, distracted, or unsure about any step.
- Ensure that when testing, if you have long hair that it is tied back or up and if you have any pets, children or infirm persons, they are not near the amplifier when you have the lid off. Keep them isolated in other rooms and NEVER leave an amplifier unattended with covers off or in an incomplete state.

2.1 Power Supply Selection

2.1.1 Linear power supply (LPS)

The conventional way to power a class AB amplifier. In its simplest form, it requires a large transformer, one or multiple full bridge rectifiers and two or more large bulk smoothing capacitors. The transformer sizes typically used for Wolverine also necessitate the use of a *Soft Start*. Bulk capacitance recommended for wolverine is 20,000uF per channel. Refer BOM sheet 2 for transformer sizing.

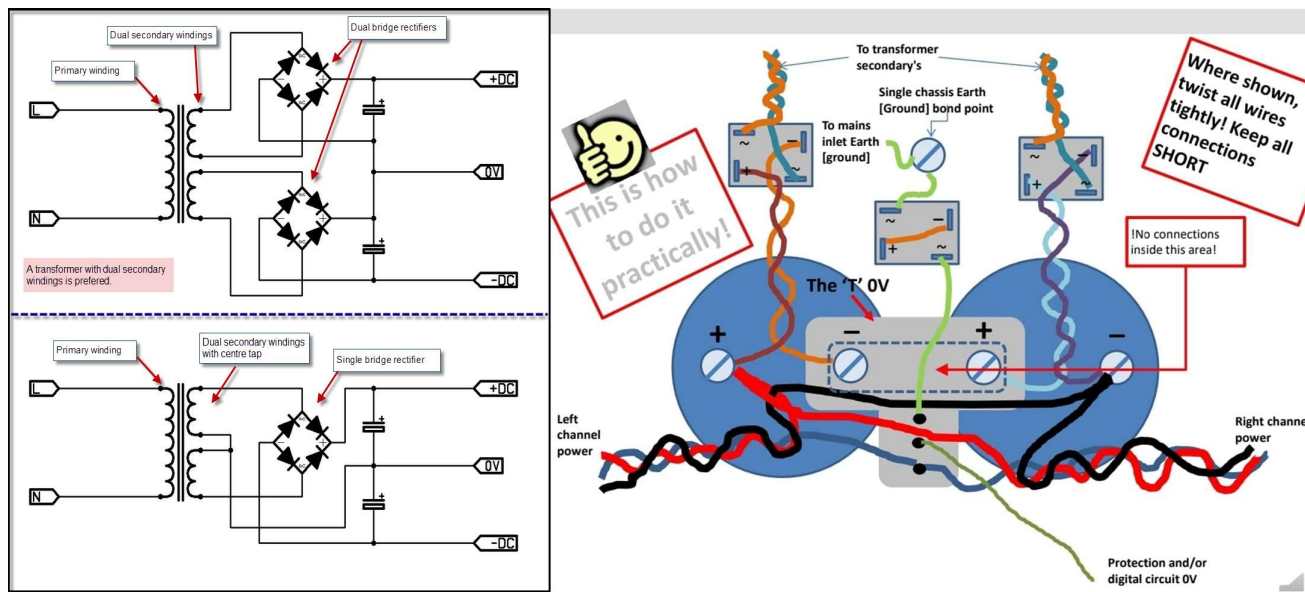
There are two types of transformers typically used to power audio amplifiers, the Toroidal transformer and the E-I transformer. Either can work fine for running a class AB amplifier, most builders swing toward toroidal transformers due to generally smaller weight per VA and small radiated magnetic fields.

There are two secondary-winding wiring configurations to choose from. One configuration uses a center tap, which is the midpoint (“center tap”) connection of one large or two series-joined secondary windings to get the dual rail supply. These typically cannot be separated or changed. The result is 3 wires for each secondary winding of the transformer. You can get transformers with two or more center tapped secondaries, resulting in 6 wires and so on, for dual mono builds etc.

The other configuration has two or more unconnected separate secondary windings. The result is 2 wires per secondary winding, and these can be configured as below to achieve dual rail supply. If you have the choice – *this is the preferred option due slightly to lower noise on the PSU ground*. The choice between dual secondary windings and four secondary windings depends on the number of power supplies being used in your chassis. Dual secondary windings are used for a single power supply (typical configuration where one or more channels take supply from one rectifier + capacitor-bank arrangement), while four secondary windings are used where two power supplies are used (this would be typical of a “dual mono” arrangement where each channel takes supply from its own capacitor bank and rectifiers).

Below left are the two LPS examples in their simplest form – we will not cover the optional additional components that can be added to an LPS for “improvements” in this guide, these are the basics you will need for a dual rail supply for Wolverine. Also not covered here but must be a consideration, is auxiliary windings for smaller “housekeeping” supplies. You may need one or two small auxiliary windings, say 10-20VA 9-12VAC to get a ~10W 12-15V DC supply to power things like speaker protection boards, control boards, status LEDs, standby switches, VU meters, buffers the list goes on.

Left – Center tapped, and dual secondary winding arrangements. Right – A practical example of the dual rectifier (from a dual secondary transformer) arrangement feeding 2x amplifier channels



2.1.2 Switch Mode Power Supplies (SMPS)

Switch mode power supplies have been a topic for contention amongst audiophiles and even amplifier engineers whose (now somewhat dated) writings can be found online or in texts shunning the use of switch mode power supplies in anything audio. We won't go into the arguments as to why here, but the simple fact of the matter is that modern competently designed SMPS with dual opposing rails are just as suitable as an LPS for use with any class of amplifier.

The main thing to be aware of is that many SMPS, due to design, can hold rail voltages higher during heavy loads (i.e. less "rail sag" - regulated OR unregulated SMPS) and this means that outputs and drivers must be rated and selected accordingly (traditionally class AB amplifiers are designed assuming the rails will sag under heavy load due to the assumption that they are powered by a LPS). See sheet 2 of the Wolverine BOM which has a section of max rail voltages for both LPS and SMPS for each output and driver.

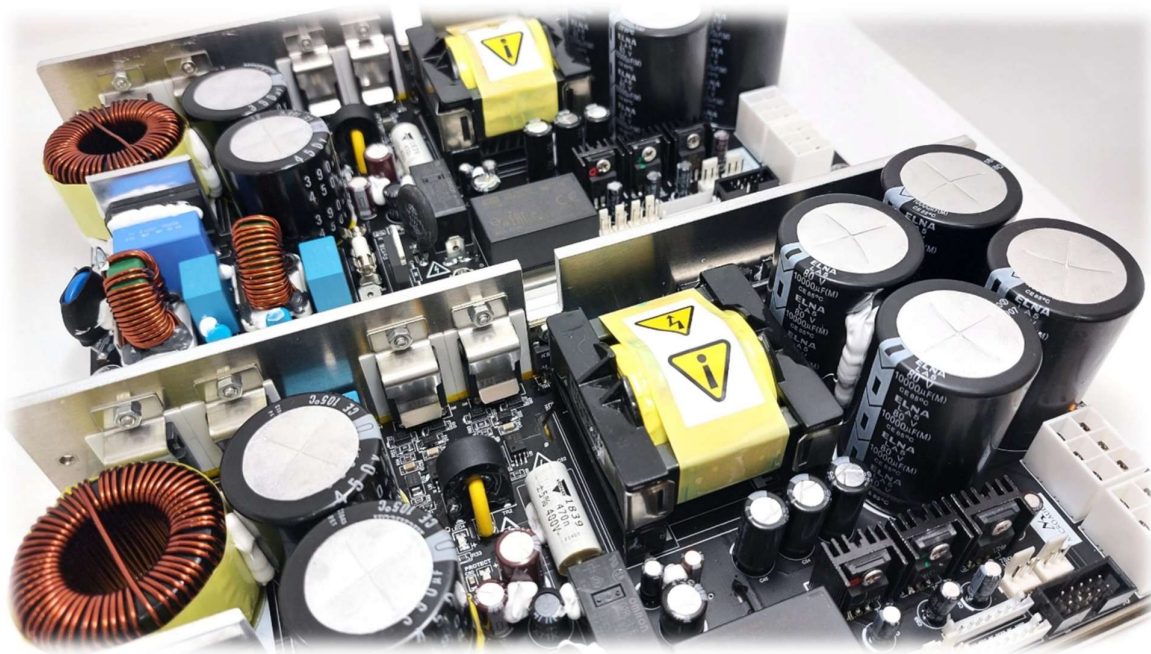
There are many types of SMPS, but so long as the SMPS you choose is designed for use with audio it should have; the appropriate certifications, low EMI, low emitted magnetic field, and its DC rails will have an inherent switching noise that is so far out of human hearing range (~65-140kHz) and so low in level (~80-120dB) that it will have no effect on the amplifier, speakers or sound and will not result in any rail ripple intermodulation into the audio band at moderate to high load.

Some examples of Switch Mode Power Supplies that have dual rail outputs, are designed for audio use and should be suitable for any class AB amplifier are:

- Micro Audio Cobra, or SMPS1K Series (1200~1900W)
- Hypex SMPS1200A400 (1200W)
- Connex SMPS2000RxE. (2000W)

These SMPS have an advantage that some also have an auxiliary 12VDC output for housekeeping, they also have a terminal for a front power switch and trigger inputs etc. (check documentation for your unit before ordering). SMPS also need no soft start module between their mains input and the mains line.

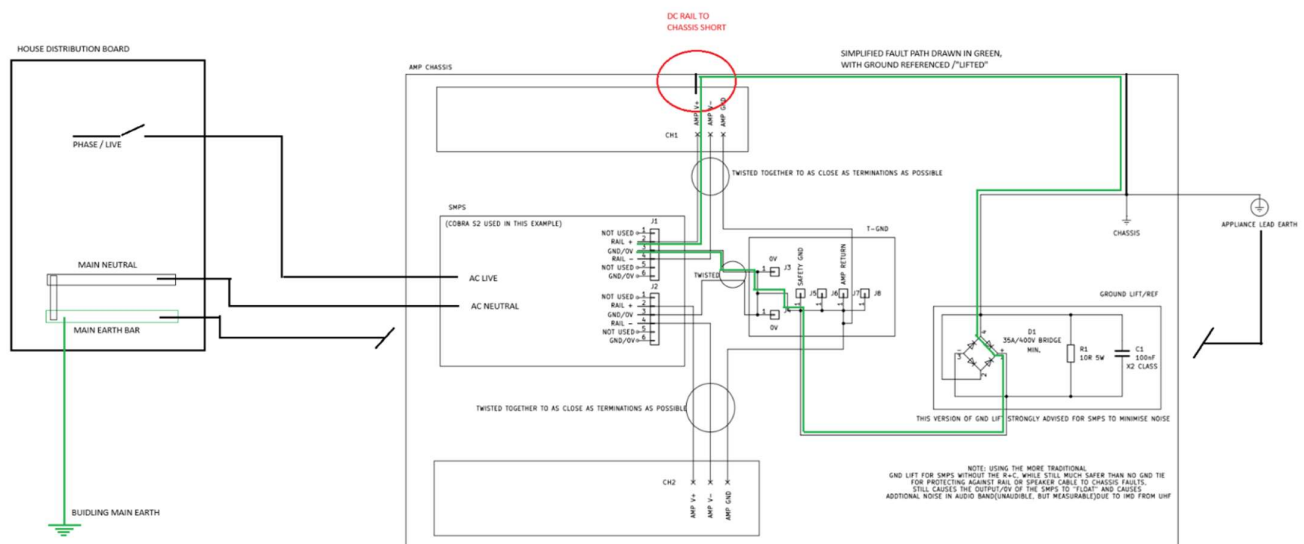
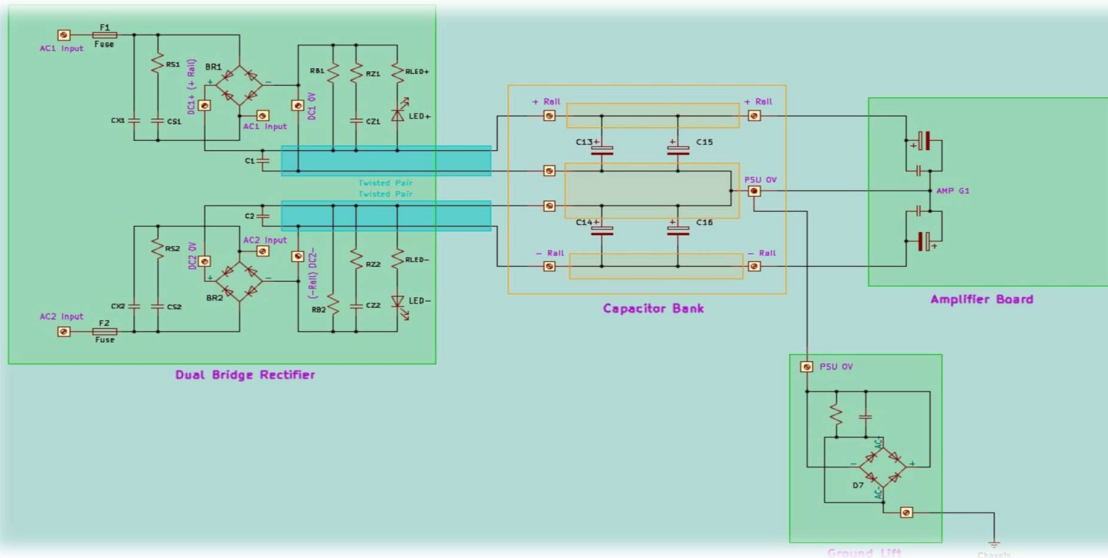
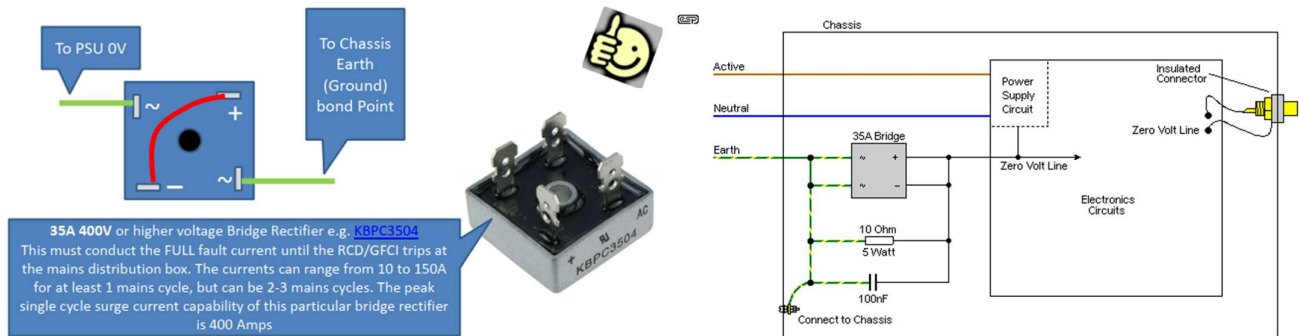
Please keep in mind that SMPS capacitors on both the mains line and amplifier load side will hold a voltage after shutting down just like an LPS. For Wolverine, "cheap" AliExpress/Temu/Ebay SMPS have not been tested and therefore cannot be recommended for use at this time. Also, the use of any 2x single rail SMPS wired in series to create a center tap dual rail is also untested and not advised.

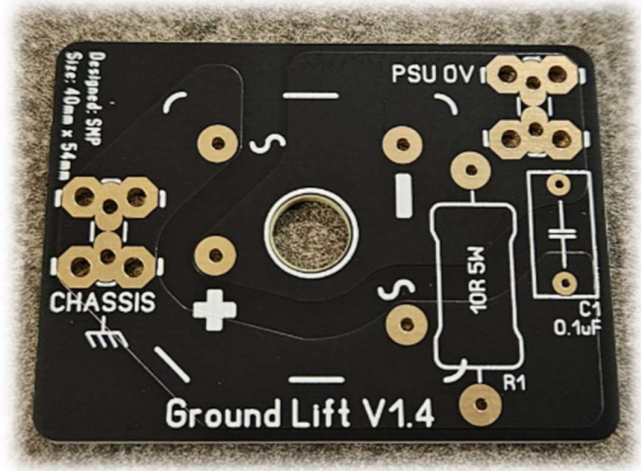
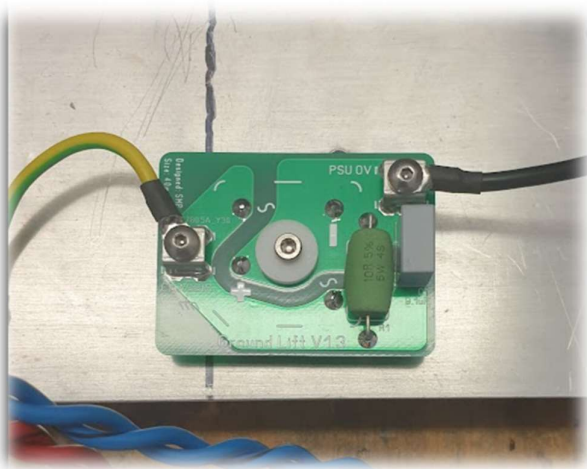


Pictured: Cobra S2

2.1.3 Ground Lifts – For yours and your Amplifiers safety

Ideally the '0V' GND side of your power supplies output would be floating from the chassis earth to keep ground loop hum to a minimum, however *it would be unsafe* to leave such a high voltage output "floating". So, to avoid ground loops by connecting the power supply 0V point directly to the chassis (which is the *minimum requirement*), the solution to this is to use a ground "lift". This allows the PSUs 0V line a reference to chassis earth in the event of a rail voltage fault somewhere else in the chassis and fast activation of protective devices. Shown below the many examples (one from hifisonix.com "how to wire an audio amplifier – also included with this guide) or see here for more information [Earthing \(Grounding\) Your Hi-Fi – Tricks and Techniques](http://www.sound-au.com/earthing.htm) – www.sound-au.com/earthing.htm

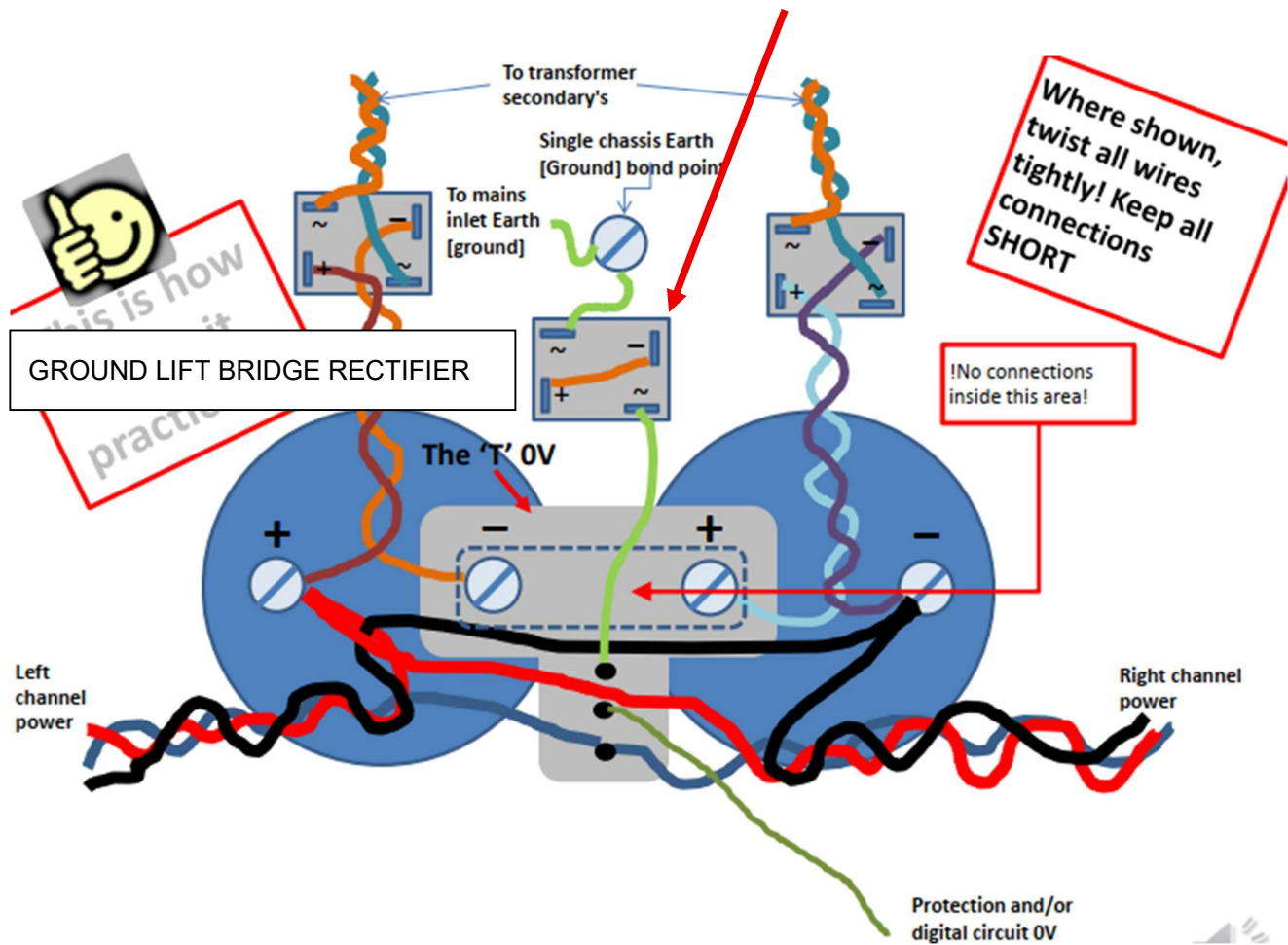




Above – Ground Lift PCBs offered with the Wolverine PCB group buy

Below – PSU practical arrangement showing the GROUND LIFT bridge rectifier.

“How to wire an Audio Amplifier” (Also provided with Wolverine documentation, thank you Andrew of Hifisonix)



2.2 Input Impedance Selection

The input impedance can be chosen before building the amplifier. 10k Ohm is the standard option but the design allows 22k Ohm with some additional changes. Modern hi-fi sources should be able to easily drive 10k, but tube preamps, older devices, portable sources or consumer gear may perform better with the higher 22k input impedance. However, this comes at a cost of ~3db higher noise, so it is not the default.

The wolverine BOM has parts listed to assemble for a 10k or 22kOhm input impedance. Please ensure you use applicable Input Stage parts for your build and do not mix and match.

2.3 Rail voltages

The BOM contains different parts to use at R23, R24, and Rled's 1 & 2 – make sure these parts align with the voltages you plan to use for your power supply and target rail voltages V DC. If your rail voltages don't match or your power supply is custom, just pick the nearest part rounded up i.e. ~62V power supply use the ~64V parts.

2.4 Driver Compensation

The BOM contains options (IPS – C4, C5, R20) for TMC depending on what drivers (OPS – Q107, Q108) you choose to use – make sure your part selection here matches your drivers accordingly. Keep this in mind if you do multiple output stages with different drivers not to mix up your IPS boards with OPS boards.

2.5 Parallel or Perpendicular Mounting

2.5.1 Bias Circuit - Q103 mounting position

The BOM contains options to configure the Vbe Bias circuit (R105, R106, R107, R108) depending on whether the drivers (Q107, 108) are mounted on the main or an auxiliary heatsink to allow you to mount a Wolverine PCB parallel with or perpendicular to the main output heatsink.

EF3-3 – The drivers are always mounted on an auxiliary heatsink, so the above can be ignored and the BOM parts are fixed. Q103 *must be soldered to fly leads* to extend over to mount to the main heatsink, either between a pair of output BJTs (recommended Q111 & Q113, or Q111 & Q114) or mounted on top of an output BJT under the same screw as Q111 or Q113. This way the EF3-3 can be either mounted parallel or perpendicular.

EF3-4 – when parallel mounted to the main heatsink, it is recommended that the drivers are mounted to the main heatsink using the holes provided in the PCB for access to the mounting screws. This means that Q103 is also mounted to the main heatsink between the drivers to monitor the bias temperature. Be sure to select the appropriate bias BOM parts (R105, 106, 107, 108) for the parallel mount arrangement.

EF3-4 – if opting to mount perpendicular to the main heatsink, the appropriate parts must be selected as per the BOM to suit this arrangement. The drivers Q107 and Q108 will be mounted to an auxiliary cooling heatsink. Q103 *must be soldered to fly leads* to extend over to mount to the main heatsink, either between a pair of output BJTs (recommended Q115 & Q116, or Q111 & Q116) or mounted on top of an output BJT under the same screw as Q111 or Q116.

EF3-5 – This board is not designed for a perpendicular mounting arrangement. Therefore, the drivers are always mounted to the main heatsink just as an EF3-4 parallel arrangement. The drivers are mounted to the main heatsink using the holes provided in the PCB for access to the mounting screws. Q103 is also mounted to the main heatsink between the drivers to monitor the bias.

The Q103 & Q104 mounting is explained with pictures in detail, [section 14.2](#).

2.5.2 Trim Pots

The BOM contains options for R25, R11 and R109 to make it easier to adjust the DC offset, CCS1 current and Output transistor bias current depending on whether you mount your boards parallel or perpendicular – Side adjustment screw or top adjustment screw.

2.5.3 Driver Bias Resistors

Not applicable to EF3-3 or perpendicular mounted EF3-4. The BOM contains an option for decreasing bias current resistors R111a and R111b *only for MJE drivers that are mounted on the main output heatsink*, for a slight performance improvement. This is not applicable to any 2SCxxxx/2SAxxxx driver and may result in damage.

2.6 Output transistors

Without going into detail here on the differences in performance between different parts, this is just a note to make sure you refer to sheet 2 of the BOM and ensure your drivers + output transistors can handle the rail voltage you are targeting with your PSU.

TO3P transistors are the “standard” 15x20mm (3/5” by 3/4”) output and are compatible with UMS (google: DIYaudio UMS) where applicable. TO264 output transistors are larger 20x25mm (3/4”x1”) packages and will require additional drilling and tapping to a UMS heatsink, or custom ordered heatsinks/chassis from modushop. TO264 typically, but not always, have better power handling.

For builders with an existing classic UMS chassis that do not wish to drill and tap heatsinks:

For a fully classic UMS compatible wolverine build that requires no drilling/tapping you are restricted to an EF3-3 output stage with 64VDC max. rail voltage, and TO3P outputs, (onsemi 200W NJW3281/1302 if you are going to use 64V rails). This configuration is also compatible if you are replacing or upgrading from the Honey Badger board. See Wolverine EF3-3 BOM sheet 2 for more information.

2.7 PSU Sizing / Power Output Target

Transformer for 2 Ch at 4ohms*				Expected Continous Power Out		Rail Fuses F1 & F2	
Typical	VA	AC	DC	8ohms	4ohms	Min Per Rail	Max Per Rail
	500	35	49	100	170	4A	10A
	600	38	54	120	200	4A	10A
	700	40	57	150	250	5A	10A
	800	42	59	160	270	5A	10A
	900	45	64	180	300	5A	10A
	1000	50	71	200	330	6A	10A
	1200	55	78	250	400	7A	10A
	1500	60	85	300	500	8A	10A
78-85V builds are strongly discouraged for novice builders							
Oversized	600	35	49	120	220	4A	10A
	700	38	54	150	270	5A	10A
	800	40	57	160	290	5A	10A
	900	42	59	180	320	5A	10A
	1000	45	64	200	360	6A	10A
	1200	50	71	220	400	6A	10A
	1500	55	78	270	500	7A	10A
	2000	60	85	330	600	8A	10A

The above chart taken from the BOM sheet 2 shows the expected approximate output power for a stereo build for a given Transformer (LPS) size. SMPS users should imagine a step above “oversized” due to minimal rail sag (e.g. 1200W PSU - 64VDC rails - 230W 8R 400W 4R max output). We will not discuss the headroom of LPS vs SMPS here. Refer BOM sheet 2 for outputs and drivers compatible with SMPS rail voltages.

As mentioned earlier, if using a Linear Power supply, the loose rule of thumb is 6,800 - 10,000uF of bulk PSU capacitance per 100W of output per channel. So, if you are targeting 64V DC rails it is recommended to use around 40,000uF in a single power supply feeding a stereo build. There is no harm in going larger than this, but you ideally wouldn’t go lower than ~27,000uF for such a build.

Keep in mind that the typical home user, even at loud levels, is likely to never need more than 100W per channel. It is estimated that most listening is done around 1-5W of output. A spreadsheet is provided with the build documentation that will help you decide on how much output power you may need “SPL and Rail Voltage Calculator”. If this is too difficult to get your head around, 60-64V DC rails and 180-200W of output power per channel is more power than anyone should ever need for a home hi-fi amplifier. This is also the sweet spot for lowest distortion levels and what the Wolverine “reference” build used.

Note: Emitter resistors values are increased for EF3-5 71V+ builds to bring down idle heat.

High VDC Builds (~78V to 85V) are not for new or novice builders, are only applicable to the EF3-5 output stage, are expensive and thus given a separate HIGH VDC BOM. Please do not build these unless you are experienced in amplifier construction. This is Public Address levels of output power and heat you will never need at home. You have been warned.

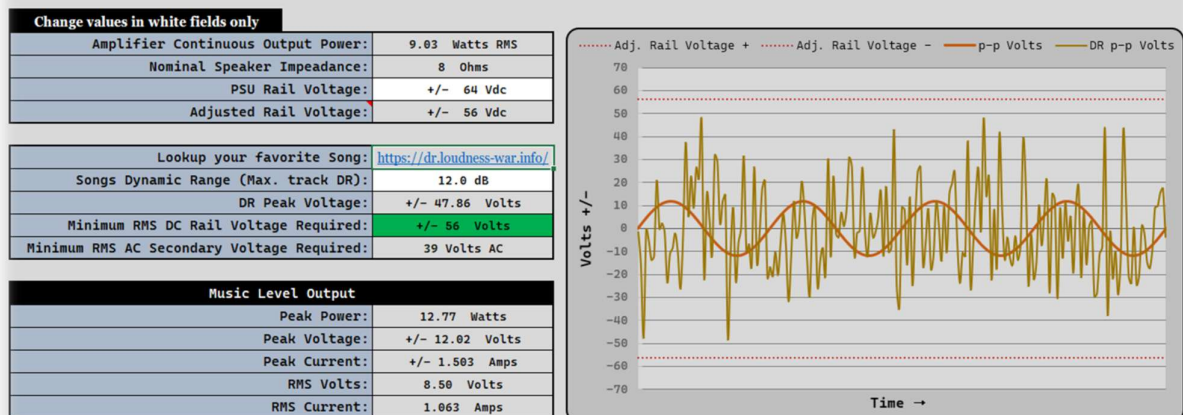
Here is an example of how to use the SPL and Rail Voltage Calculator. First, you can try a quick test with a phone and an app called "Decibel X" available for iPhone and Android to check what level you currently listen to your music at, to give you a rough indication of quiet, moderate and loud levels of SPL. You will find that 90dB at seated position is *plenty* loud. This spreadsheet will factor in musical dynamic transients and advise if your amplifier will hit rail clipping during such tracks. Taking our loud target 90dB at the listening position and a slightly below average speaker sensitivity of 87dB, we can see if our amplifier rails will clip with a slightly higher than average dynamic range of a 12dB music track (typically 6-10dB, only classical music tends to have higher dynamic range toward up to 20dB). Using the earlier recommendation, we can see that a 64VDC rail amplifier will handle dynamic range *above* the 90dB target level at seating position with plenty to spare (i.e. hitting 102dB peaks at the listening position).

Change values in white fields only			
RMS Output Voltage of Amplifier:	8.5	V	
Speaker Sensitivity:	87	dB/W	
Nominal Speaker Impedance:	8	Ω	
Distance to Seating Position:	3	M	
Number of Speaker Channels (2 for Stereo):	2	Speakers	
Amplifier THD:	-120	dBr	
THD	-120 dBr	0.0001%	1 PPM
Amplifier Continuous Output Power	9.03125	W RMS	
RMS SPL @ 3M	90.02	dB	
THD @ 3M	-29.98	dB	
SPL = S + 10LOG (P) - 20LOG(D) S=Sensitivity P=Power D=Distance			

Instructions:
Enter values in Column E, Rows 4 through 8. Units for voltage, distance, and THD can be selected from the dropdown lists in Column F.

This calculator can be used to determine SPL at the listening position and how much voltage/power is required. It can also be used to determine if the idle noise and THD can be heard at the listening position, but one must take note of their noise floor in room for this to be of any use, as well most loudspeakers will have more audible distortion anyhow.

Will my amplifier clip playing my favorite song?



No Clipping Detected

Another way of looking at this is to remove the musical dynamic range, and just imagine we are sitting there listening to nothing but a sine wave and wish to destroy our ear drums. Here is what the same 64V amplifier is capable of, at the listening position. Keep in mind that the speakers at this level would be at ~112db at 1m and would probably burn out instantly.

Change values in white fields only			
RMS Output Voltage of Amplifier:	36	V	
Speaker Sensitivity:	87	dB/W	
Nominal Speaker Impedance:	8	Ω	
Distance to Seating Position:	3	M	
Number of Speaker Channels (2 for Stereo):	2	Speakers	
Amplifier THD:	-120	dB	
THD	-120 dB	0.0001%	1 PPM
Amplifier Continuous Output Power	162	W RMS	
RMS SPL @ 3M	102.55	dB	
THD @ 3M	-17.45	dB	
SPL = S + 10LOG (P) - 20LOG(D) S=Sensitivity P=Power D=Distance			

Instructions:
Enter values in Column E, Rows 4 through 8. Units for voltage, distance, and THD can be selected from the dropdown lists in Column F.

This calculator can be used to determine SPL at the listening position and how much voltage/power is required. It can also be used to determine if the idle noise and THD can be heard at the listening position, but one must take note of their noise floor in room for this to be of any use, as well most loudspeakers will have more audible distortion anyhow.

Will my amplifier clip playing my favorite song?

Change values in white fields only	
Amplifier Continuous Output Power:	162.00 Watts RMS
Nominal Speaker Impedance:	8 Ohms
PSU Rail Voltage:	+/- 64 Vdc
Adjusted Rail Voltage:	+/- 56 Vdc

Lookup your favorite Song:	https://dr.loudness-war.info/
Songs Dynamic Range (Max. track DR):	.0 dB
DR Peak Voltage:	+/- 50.91 Volts
Minimum RMS DC Rail Voltage Required:	+/- 59 Volts
Minimum RMS AC Secondary Voltage Required:	41 Volts AC

Music Level Output	
Peak Power:	229.10 Watts
Peak Voltage:	+/- 50.91 Volts
Peak Current:	+/- 6.364 Amps
RMS Volts:	36.00 Volts
RMS Current:	4.5 Amps

Volts +/-

Time ->

No Clipping Detected

And the amplifier still has headroom.

Please don't try and listen to music at these levels and keep a "level-headed" approach to how much amplifier power you really need – excess rail voltage is just wasted in idle consumption power and build cost.