WARNING / DISCLAIMER

PLEASE READ THE FOLLOWING BEFORE PURCHASING OR BUILDING THIS PROJECT!

1. NO DIRECT TECHNICAL SUPPORT: This project has been verified to be working, and I have done my best to provide extremely thorough documentation, including information to help you troubleshoot. But on a project this size, I have to reiterate that **Aion Electronics cannot provide direct technical support for this project** or others. I love helping people bring these circuits to life, but my availability is very limited. If you post your question on one of the DIY forums and send me a link, I will do my best to chime in. Just know before purchasing this PCB that **there is no implied guarantee of the final product**, because the biggest factor is outside my control: **you!** Your experience and your attention to detail are the most important ingredients in making sure this works. My role is to provide the recipe and some cooking utensils.

2. IT WILL TAKE AWHILE: Be prepared to invest some hours into putting this together. You'll want to be doubly careful when populating the board since it'll be much more difficult to track down a problem if you were to make even the most basic of mistakes (for instance, accidentally using a 10k resistor somewhere instead of a 100k). **You can't be too cautious.** I'd recommend measuring each resistor with a multimeter before putting it into place. Triple-check your wiring. The more time you spend on the initial build, the less time you'll have to spend troubleshooting.

3. IT'S COMPLICATED: As of this writing, this is the largest PCB in the DIY guitar pedal scene. While it is not a technologically complex circuit—no BBDs, clocks or LFOs like in vintage EHX modulation effects—there are still a lot of things that can go wrong. Hopefully it goes without saying, but **if you've never built a guitar pedal before, this shouldn't be your first**. If you haven't successfully built at least ten, including drilling the enclosure accurately with a template, you may not be ready for this one yet.

4. YOU'VE GOT TO BUILD IT AS IT WAS INTENDED: I approached the project as though I was designing a completed product for market. Everything has been designed to be built using methods you'd see in a high-end pedal (for instance, PCB-mounted pots & switches and components with specific sizes and characteristics) and a full bill of materials has been provided so it's very easy to order all the parts from Mouser. We all build pedals in our own style, but with this one, if you try to "freestyle" by doing your own enclosure layout or using parts other than the ones specified, you might back yourself into a corner. Please do things my way—you'll end up with a very professional and durable end product and you might even learn a few things in the process!

5. IT'S NOT CHEAP: Between the PCB, enclosure, hardware, potentiometers, and the on-board components, expect to spend a minimum of **$100 USD** and probably closer to $125. Please don't try to cut corners on the parts selection by using poor-quality components or by substituting "close enough" components that you have laying around. You're putting a lot of time and effort into this build, so it's worth a few extra dollars to use the right parts. Expect to order from more than one web store to get everything you need.

6. IT USES A NON-STANDARD ADAPTER: This pedal requires an adapter that puts out **9V AC**, not DC. This is the same type of power supply used by Line 6 for their large digital modeling pedals such as the DL-4, and they are readily available from Line 6 or from other manufacturers who advertise Line 6 compatibility. Just know that **this adapter will destroy any pedal that is not designed for AC power**. By having an AC-output adapter laying around, you run a very high risk of this adapter getting plugged into a non-AC pedal, either by you or someone else, since it says on the label that it's a 9 volt adapter and the "AC" part is easy to overlook. I recommend using some colored heat shrink or electrical tape near the barrel tip of the adapter as a reminder that it's different.

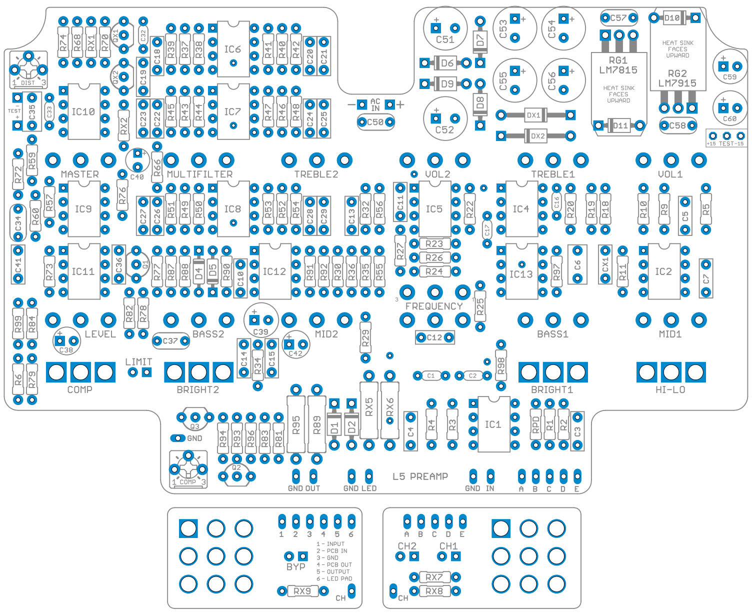
Now that you've been properly warned: on to the fun stuff!

L5 Preamp

Preamp, Overdrive & Limiter

Overview

L5 Preamp Project Link



See pg. 14 for a larger image of the PCB layout.

This is a pedal conversion of the preamp of the Lab Series L5, a Moog-designed solid-state amplifier from the late 1970s that is widely considered the best and most tube-like solid-state amplifier ever made. It has two channels which are both fed into a shared distortion/master volume circuit as well as a compressor/limiter.

The original amps had the preamp integrated with the power amp. By splitting out the preamp, we can use this either as a normal pedal in a chain (e.g. tuner → overdrive → L5 Preamp → modulation / delay → amp input) or as a true preamp by plugging its output straight into a power amp (either a dedicated power amp or the “return” jack of an amp with an effects loop). The main difference will be the volume you run it at. This thing is capable of enormous volume, far more than any stompbox, so if you are using it like a pedal, don’t feel like you are doing something wrong by keeping the master volume down really low!

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Differences from the original circuit

I kept it faithful to the original Lab Series L5/7/9/11 circuit, only changing the following things.

- The power supply—more on this later.
- Channel switching: the original had two channels with separate jacks for each. The only way to switch between them was to unplug from one and plug into the other, or use an external A/B box. I combined the channel inputs so that it has a single input jack and a footswitch to change between the channels.
- Master bypass so it can be turned on/off like a normal pedal.
- Hi/Lo inputs: the original units had two jacks per channel with different gain levels to allow it to be used with different types of instruments. I made this gain boost selectable with a toggle switch.
- I substituted the CA3094 for a 3080 and added external transistors. The CA3094 is identical to the 3080 except for having an integrated buffer tacked onto the end. Since the 3094 is difficult to find, I elected to convert the circuit to use the more common CA3080/LM3080. The 3080s are still very easy to obtain.

Usage

Channel 1 is a simple Fender/Marshall/Vox passive tonestack with treble, midrange and bass controls. Since this portion of the circuit operates at very low impedances only achievable with op-amps (and certainly much lower than a tube amp), the resistors and pot values are around 20% what you'd see in a F/M/V tonestack while the capacitors are multiplied by five to compensate. The tone controls are identical to the classic setup in frequency and behavior.

Channel 2 is a little more complex, with a Baxandall active tone control for treble and bass, a parametric midrange (which actually extends well into the bass and treble frequencies), and something called a multifilter, which is a patented Moog invention that uses a set of six fixed-frequency resonant filters to add a very unique quality to an instrument signal that is unlike any other guitar effect, sometimes described by Lab Series owners as making their electric guitar sound more like an acoustic. (Look up patent #4117413 to read more about it.)

A word of advice: don't neglect channel 1 if you're looking for overdrive! Channel 1 is incredibly touch-sensitive and it reacts fantastically well to your playing dynamics. It's like a classic Fender tube amp, but you can tune the amount of crunch yourself instead of having to maintain a specific volume level. You'll be tempted to think of the channels as "clean" and "drive", but that's a mistake.

One of my favorite tones through the amp is achieved by hitting the first channel with a Boss GE-7 EQ arranged in a "mid-hump" and boosted to +10dB. The distortion/overdrive circuit is located after both channels have been mixed together, so the same clipping happens to both channels. You just have to crank the first channel a little louder to trigger the overdrive, and a boost pedal in front will be very useful.

The **master volume** applies to both channels. With the channel volume essentially controlling the amount of overdrive, the master volume allows you to tailor the final volume to taste. By leaving the channel volume low and turning up the master volume, you can get a super-clean sound favored by jazz guitarists. By turning the channel volume all the way up and backing off the master volume, you can get an overdriven tone with the same overall volume level.

The **compressor** is a basic limiter that comes after the master volume. It has just an on/off switch and a threshold control to set the maximum signal level. Everything over that level will be squashed back down. At higher threshold levels, it simulates light tube compression, but turn it down and you can get all of the higher-gain tones without the high volume.

Mouser parts spreadsheet

Since this is such a complicated build, I created a spreadsheet of parts that can be imported directly to Mouser. Over 95% of the parts can be obtained from Mouser and their prices are great. I spent a great deal of time selecting the parts, and the PCB layout is designed around them, especially the boxed film & electrolytic capacitors, so by using this spreadsheet to order, you know you are getting the best possible result.

For international DIYers, Mouser recently upgraded their international shipping options, so it's very likely that you will be able to get free shipping with a project this size. Their prices are very competitive as well.

The BOM does assume you have zero parts on your bench, so you may be able to save a few dollars by comparing the spreadsheet with what you've got already and removing what you don't need, especially hardware like the power jack, input/output jacks, and IC sockets. But again, I would strongly recommend using at least **the exact capacitors from the spreadsheet** to ensure they fit. And while you could save a bit of money by using your own resistors, I guarantee it will save a lot of potential mistakes to receive them all in labeled bags!

However, with that said, I have to give the disclaimer that **this spreadsheet is being provided only as a convenience**. You are responsible for checking through the parts to make sure they are the ones you want, and Mouser is responsible for sending you the correct parts. I tried to pick high-availability components from well-known manufacturers that are stocked in large quantities, but with 75 different parts, it's likely that one or two of them will be out of stock at any given time. You will have to find your own replacements if that happens.

Checklist

I have tried to be as thorough as possible in this documentation, but the upshot is that by providing so much information, you may miss some of the most important details. Here are the high-level things to make sure of before turning it on for the first time:

- I am using an adapter that produces 9V AC, not DC.
- I have marked this adapter in some way so it's not going to be accidentally plugged into another pedal.
- I have triple-checked the wiring against the provided wiring diagram.
- I have ensured that the wiring is neat and that the wires are as far away from each other as possible.
- I have ensured that all of the potentiometers have some sort of insulation protecting them from the board, especially the 100kC dual pot (which doesn't work with the standard Alpha pot covers or the "pot condoms" sold by some distributors).
- I double-checked the orientation of the LEDs before soldering them in place.
- I compared my populated PCB with the photo on the project page (including jumpering CX1, the capacitor in the tone stack of channel 1).

Parts

Resistors

R1	280k [1]
R2	1M [1]
R3	4M7
R4	1k
R5	22k
R6	33k
R9	220k
R10	10k
R11	18k
R18	27k
R19	27k
R20	18k
R22	18k
R23	18k
R24	18k
R25	18k
R26	1k5
R27	1k5
R29	2k2
R30	2k2
R32	24k
R34	22k
R35	2k2
R36	100k
R37	22k
R38	270k
R39	390R
R40	22k
R41	300k
R42	430R
R43	22k
R44	240k
R45	390R
R46	22k
R47	300k
R48	560R
R49	22k
R50	220k
R51	390R
R52	22k
R53	150k
R54	300R

Resistors

R55	6k8
R56	39k
R57	10k
R59	15k
R60	1k
R66	18k
R68	330R
R70	470k
R72	220R
R73	10k
R74	3k3
R76	100k
R77	15k
R78	220R
R79	220R
R81	10M
R82	820R
R83	22k
R84	6k8
R87	22k
R88	3k3
R89	2k7 1/2W
R90	33k
R91	10k
R92	10k
R93	47k
R94	47k
R95	680R 1/2W
R96	100k
R97	10k
R98	1k5
R99	6k8
RX1	2k
RX2	47k
RX5	680R 1/2W
RX6	680R 1/2W
RX7	100k [2]
RX8	100k [2]
RX9	100k [2]
RPD	1M to 2M2

Capacitors

C1	10n
C2	10n
C3	8n2
C4	10n
C5	1n2
C6	220n
C7	47n
C10	4n7
C11	4n7
C12	68n
C13	2n2
C14	68n
C15	68n
C16	10n
C17	10n
C18	15n
C19	15n
C20	10n
C21	10n
C22	8n2
C23	8n2
C24	4n7
C25	4n7
C26	4n7
C27	4n7
C28	4n7
C29	4n7
C32	10n
C33	10n
C34	220pF MLCC
C35	330n
C36	68n
C37	100pF MLCC
C38	2u2 electro
C39	10uF electro
C40	2u7 tantalum
C41	10n
C42	4u7 electro

Parts

Capacitors, cont.

C50	100n MLCC
C51	220uF/35V
C52	220uF/35V
C53	220uF/35V
C54	220uF/35V
C55	220uF/35V
C56	220uF/35V
C57	100n MLCC
C58	100n MLCC
C59	22uF/25V
C60	22uF/25V
CX1	jumper [3]

Semiconductors

Q1	2N5457
Q2	2N3906
Q3	MPSA13
QX1, QX2	2N5088
D1–2, D6–11	1N4004
D4, D5	1N914
DX1, DX2	1N4004
CH1, CH2	5MM LED
BYPASS	5MM LED
COMP	5MM LED

Potentiometers

Vol 1	2.5kA [4]
Bass 1	50kA
Mid 1	2.5kA [4]
Treble 1	50kA
Vol 2	25kA
Bass 2	25kB
Mid 2	25kB
Mid Freq	100kC dual
Treble 2	25kB
Multifilter	25kA
Comp Level	50kC
Master	25kA
Comp Trim	20k (3362P)
Dist Trim	20k (3362P)

Switches

Hi/Lo	SPDT
Bright 1	SPDT
Bright 2	SPDT
Comp	SPDT

ICs

IC1	LF356N [5]
IC2	LM741P
IC4	RC4558P [6]
IC5	RC4558P
IC6	RC4558P
IC7	RC4558P
IC8	RC4558P
IC9	RC4558P
IC10	CA3080
IC11	CA3080
IC12	RC4558P
IC13	LM741P
RG1	MC7815
RG2	MC7915

[1] **Tweaked value:** The original amps had two input jacks per channel, one for each of the “Lo” and “Hi” settings. I combined these into one switch using parallel resistors, so the values have been modified but it is electrically identical.

[2] **Optional.** I included these three resistors as an experiment to see if the inevitable LED switch noise could be cut down by leaving a large resistor in place so there is a small but constant current going through it. It might not have much effect but you can try it if you want.

[3] **Tonestack experimentation:** I included this capacitor in case you wanted to experiment with modifying the tonestack. In a standard F/M/V tonestack, there’s a cap here, but since the values have a changed by a factor of five, the cap is no longer necessary. For a stock unit, you’ll want to jumper this.

[4] **Alternate value:** 2.5kA pots are very difficult to find. 2k will work fine here as an alternate value.

[5] **Substitute single op-amp:** The LF356N was the quietest single op-amp available in 1978, but there are much better ones available today. You might experiment with an OPA134, the single version of the OPA2134.

[6] **Substitute dual op-amp:** The RC4558 is a fine op amp, but again, there are much better ones available today. Tou could substitute it with a lower-noise dual op amp such as the NJM2068, NE5532 or OPA2134.

Adjustments & Calibration

The L5 Preamp has two different calibration trimmers: one that sets the range for the compressor circuit threshold knob, and one that sets the level at which the overdrive kicks in. Fortunately, both of these factory adjustment procedures are well-documented and they do not require any special equipment.

For these, all you will need is a **multimeter** and a **signal generator**, and there are a few free smartphone apps that will work for a signal generator. Turn both trimmers all the way down to start with. Note that for both of these trimmers, we are calibrating the audio signal level, so **you will use the AC setting on your multimeter**.

Distortion trimmer

The distortion trimmer should be set first. The procedure calls for a **1kHz 30mV sine wave** to be inserted onto pin 2 of our IC10, and for the trimmer to be adjusted until you measure 4.4V AC on pin 6 of IC10. For convenience, there is a pair of pads marked “TEST” in the top right corner of the board where you can insert your signal. The “+” pad connects to pin 2 of IC10 and the other is connected to ground. I would solder short pins to these pads (about 1/2” in length) to act as ‘posts’ for alligator clips to attach to. (The clipped leads from a 1N4004 diode would be perfect for this.)

For the signal generator, I used a free iPhone app called “Signal Gen”. The advantage to this one was that it lets you specify a gain in decibels. Even though the dB level is nowhere near accurate (it doesn’t even take into effect the headphone/speaker volume!), it’s at least useful for making fine adjustments to the level and for giving you a number to remember.

I hooked up a 3.5mm male-to-male headphone cable and turned up the phone volume to maximum, then set the frequency to 1kHz and the gain to -29.6dB, which is the dB level specified in the Lab Series service manual. I then measured the voltage of the output with a multimeter (black lead to the sleeve, red lead to the tip). The measurement was around 20mV AC. I ended up at the -23.4dB setting in the app to get 30mV. This probably varies widely depending on the phone, so measure yours to make sure you are getting the right signal level before using it to calibrate the distortion trimmer. (Also make sure the headphone volume on your phone is all the way up!)

Compressor/limiter trimmer

For the compressor/limiter trimmer, with the 30mV sine wave signal still inserted into pin 2 of IC10, turn the master volume up all the way and turn the compressor on. Then turn the compressor knob up to about the 2:00 position (⅔ of the way up) and touch your probe to the “PCB OUT” pad, the output of the circuit. Turn the trimmer until you measure 1.17V AC.

A note about the compressor trimmer: I found that when using the L5 preamp as a pedal, the minimum signal level to trigger the compressor was too high, even on the compressor’s lowest setting. I ended up dropping the compressor trimmer to zero to make the minimum setting as low as possible, and this felt much more usable to me. You’d never turn this knob anywhere near all the way up anyway.

CA3080

The original factory schematic for some of the Lab Series amps specify a “custom 3080” for the compressor circuit. While there is no way of knowing what this “custom” designation referred to, it’s likely that they were simply selected by the manufacturer to ensure they met a minimum performance requirement in certain areas. It’s definitely not referring to the actual silicon being customized by the manufacturer to Moog’s request.

Silicon manufacturing processes have come a long way since 1977, and newer devices are much more consistent than they were when they were first developed. It is most likely the case that the later improvements in the 3080 manufacturing process would have made the “custom” selection unnecessary. So unless you are using a chip that’s actually from the 1970s, it’s probably okay to just use what you can find without any regard for its specifications.

Power supply notes

Adapter

As mentioned on the first page, **this pedal requires 9V AC, not DC**. These adapters are not difficult to find, but you may want to look outside the normal audio gear websites. I actually would not recommend the Line 6 adapter, which is the easiest one to find—it's twice the price of most of the others and it's not very well-built based on the reviews. Here are a few others that should work besides the Line 6 adapter. Just make sure you get one with a 2.1mm barrel tip.

I will repeat the danger of having one of these laying around with the rest of your gear, since **it will almost certainly destroy a non-AC pedal if plugged in**. In addition to the heat shrink or color coding mentioned earlier, you could go a step farther and choose an adapter with a different type of connector or barrel (e.g. 2.5mm) and then use a matching DC jack on the pedal. That way it can't be mistakenly plugged in at all.

PSU design

The power supply is not the same as the one in the original Lab Series amps. It was adapted from an arrangement that was commonly used in Rane and Alesis rack units. It uses an AC voltage multiplier trick to get approximately +/- 25VDC from a single 9VAC source. This is then regulated down to +/-15V using positive and negative regulators. Visit this link for more information on the voltage multiplier concept.

Two **load resistors** have also been added. Many regulators, including the 7815 and 7915 used here, require a minimum current in order to begin regulating. These resistors will provide a constant 10mA load on both rails which is enough current to ensure that any brand of 7815 and 7915 will regulate without issue. These resistors are not strictly necessary in a complete working circuit because it'll always draw far more than 10mA, but they are required if you want to test out the power section before inserting the ICs and transistors, which is a good idea—and they barely draw any power so you may as well leave them in place after the circuit is working.

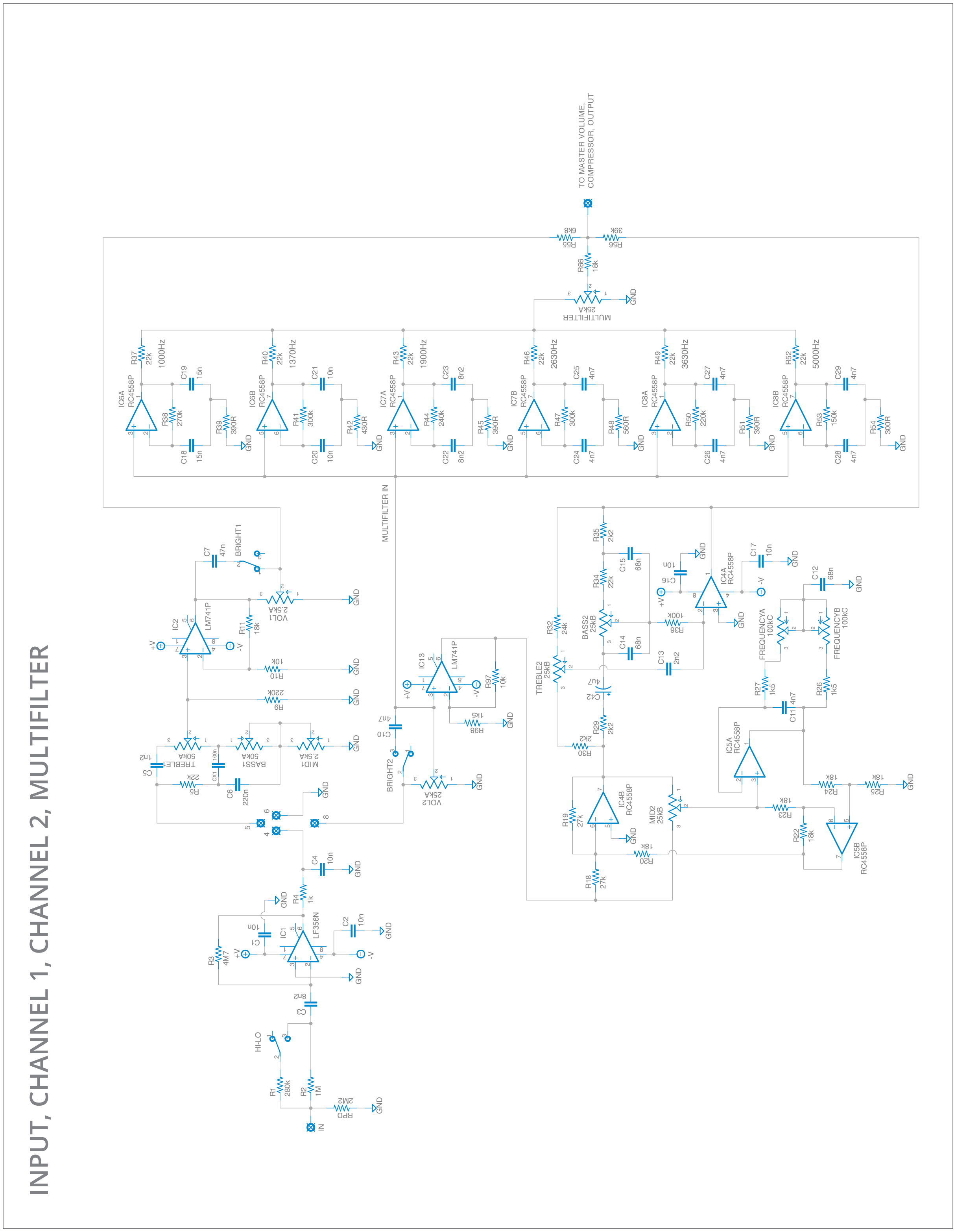
The regulators both have **reverse-polarity protection diodes** in case the power is cut off abruptly. Without these diodes, the capacitors could send a charge backwards through the regulator which risks damaging it.

The regulators are very tall and cannot stand straight up due to the height of the enclosure. They must be folded over with their heatsinks facing upwards. (See the photo of the populated PCB on the project page.) Make sure that the heatsinks do not touch anything metal such as the enclosure or other components or it will cause issues. There will be one diode underneath the metal fin of each of the folded-over regulators, but you should have plenty of clearance for this. Make sure to fold the legs down close to the body or RG2 might touch the edge of the enclosure.

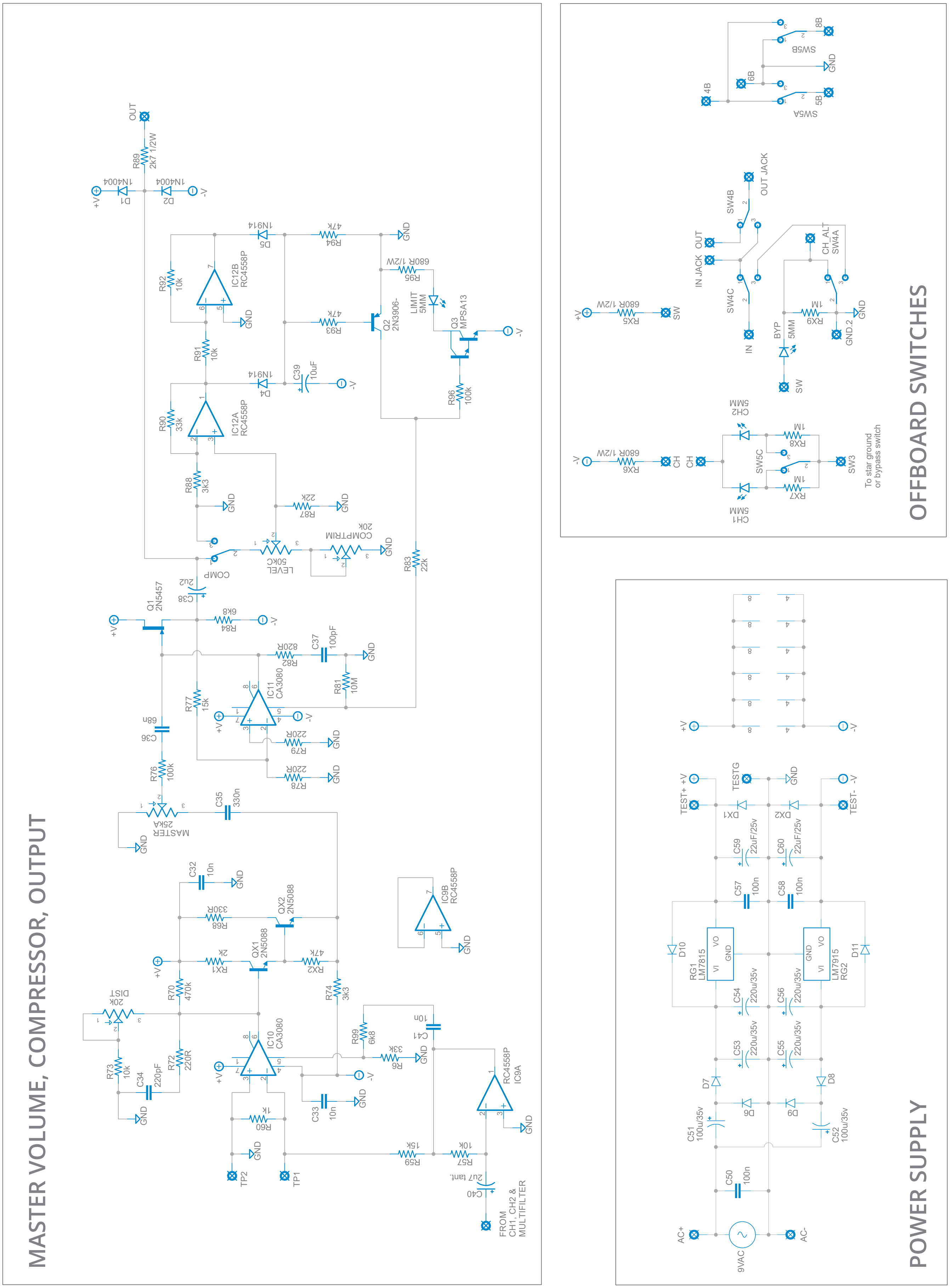
Capacitor choice

(You can ignore this section if you're ordering the parts from Mouser, unless you're curious.) There isn't enough space in the enclosure to use gigantic filter and booster capacitors in the power supply, so it's very important that you choose the power supply capacitors carefully. The booster caps and filter caps should be rated for as high of a ripple current as you can find. Ripple current is the maximum amount of current that can flow through the cap before it overheats and fails, and if you run a capacitor at close to its maximum ripple current then you shorten its life. None of these caps will see more than 120mA in practice, but the higher the ripple current rating, the cooler a cap will stay, which greatly extends its life. Anything above 600mA max ripple current should be fine, but higher is better. I found some that were 1600mA! Oftentimes these are categorized by the manufacturer as "low ESR" or "low impedance" capacitors.

Schematic (1/2)

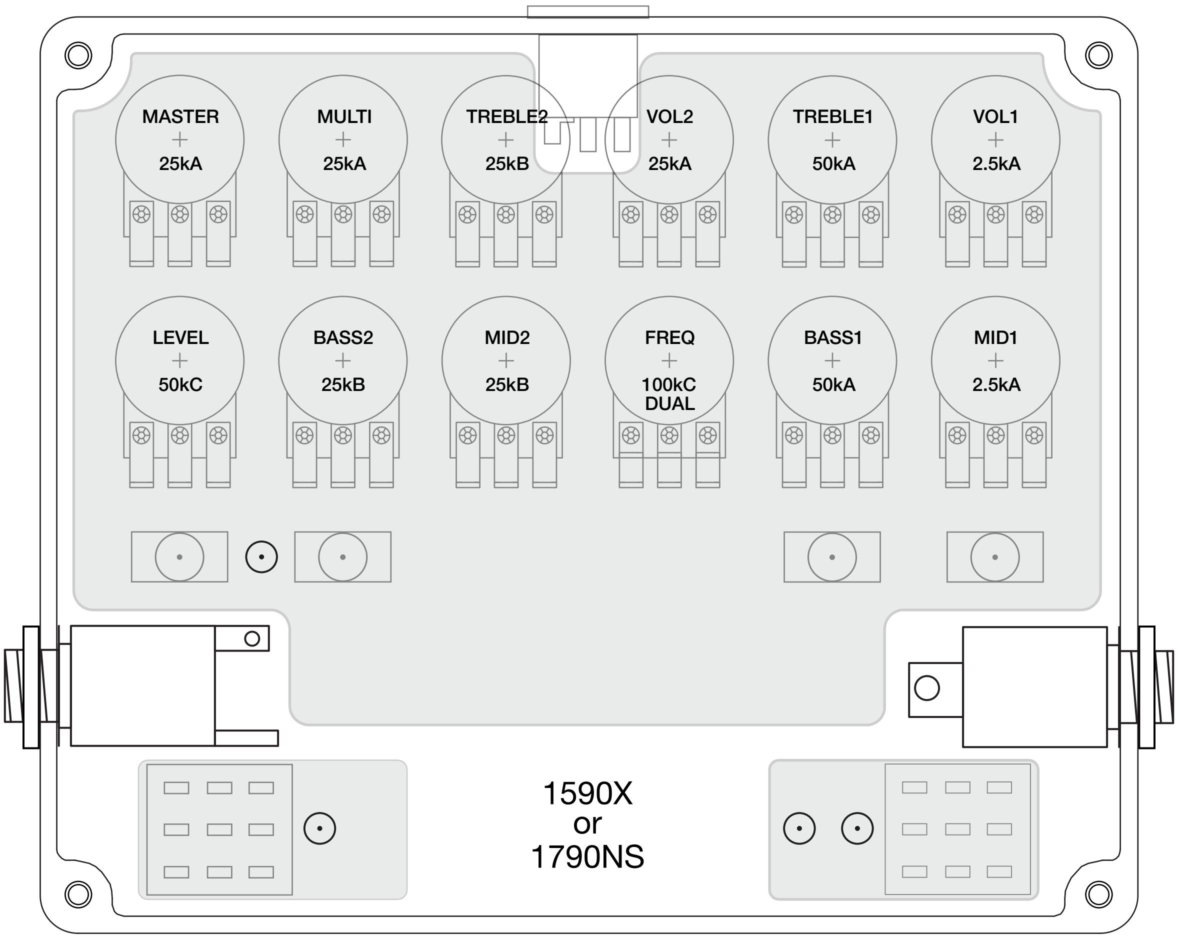


Schematic (2/2)

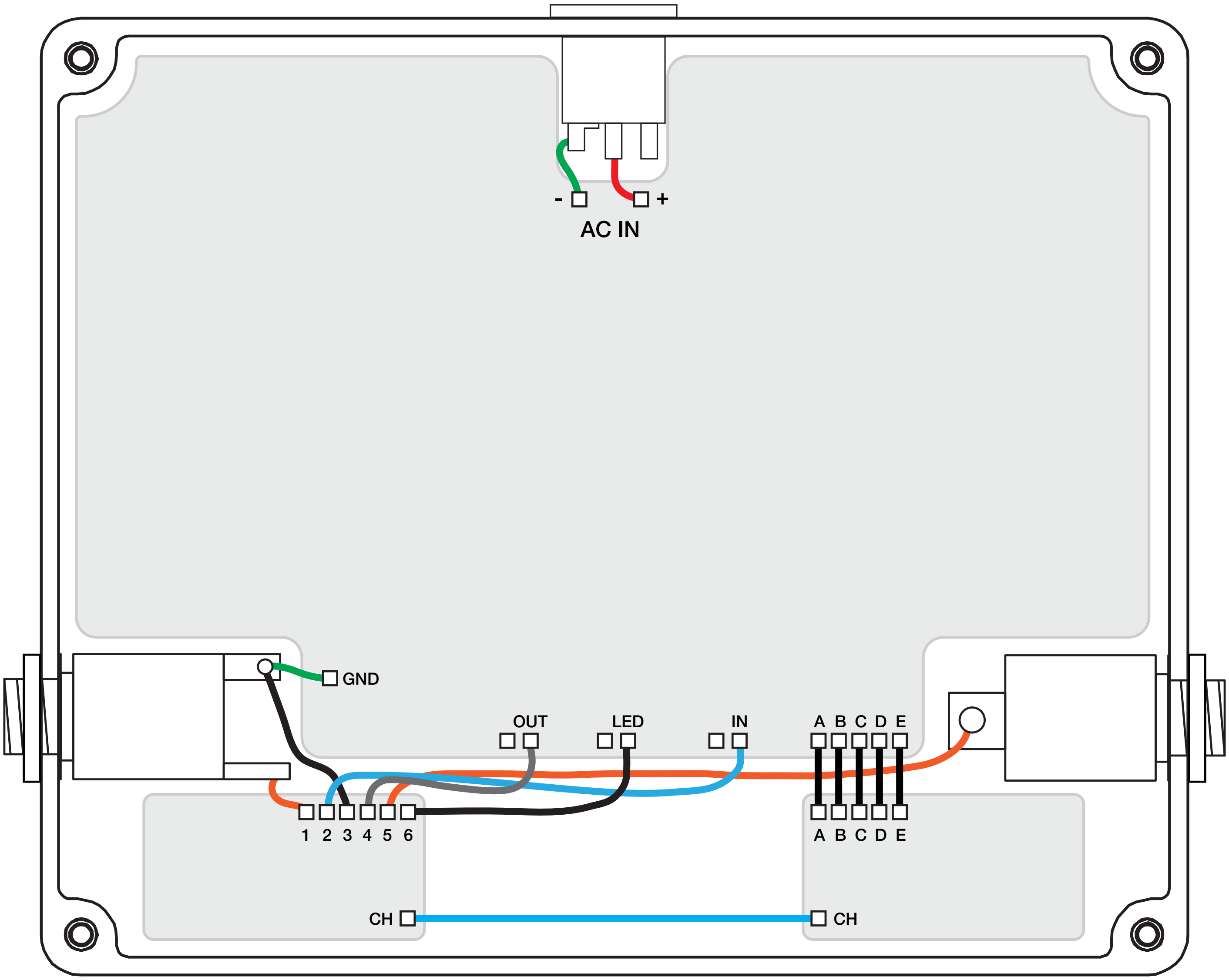


Enclosure Parts Placement / Layout

This shows the placement of the pots, switches, and other hardware inside the enclosure, looking in from the bottom.



Wiring Diagram



Shielded wire: Additional ground pads are provided next to the In, Out and LED pads in case you want to use shielded wire, in which case this ground pad would connect to the shield (leave the other side unconnected to prevent ground loops). This is not strictly required, but in a high-gain circuit like this, it's probably a good idea.

Channel LEDs: For the channel LEDs, you've got two options: always on, or tied to the bypass state. You might expect that all LEDs are off when the unit is bypassed, or you might expect to be able to see which channel is selected even in bypass mode. Both are perfectly reasonable, so do whichever you think is best.

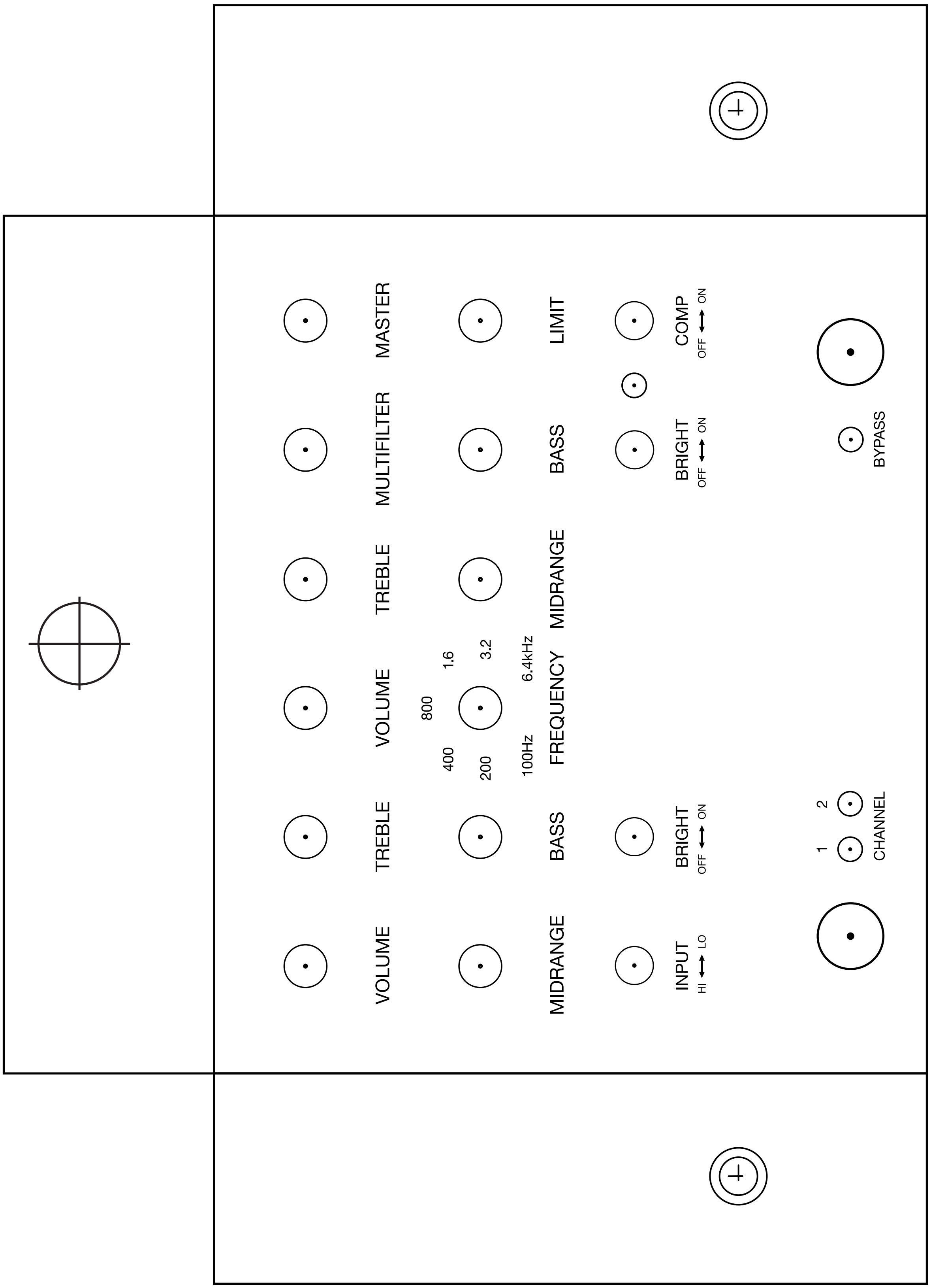
For **always-on** LED operation, run a wire from the "CH" pad on the channel-switching board (the one on the right-hand side in the diagram above, looking from the rear) to the star ground point, which should be the input jack on the far left-hand side. The channel LEDs will indicate the active channel regardless of bypass state.

For **bypass-off** LED operation, run a wire straight between the two "CH" pads, as seen in the diagram above. The channel LEDs will turn off when the pedal is in bypass mode.

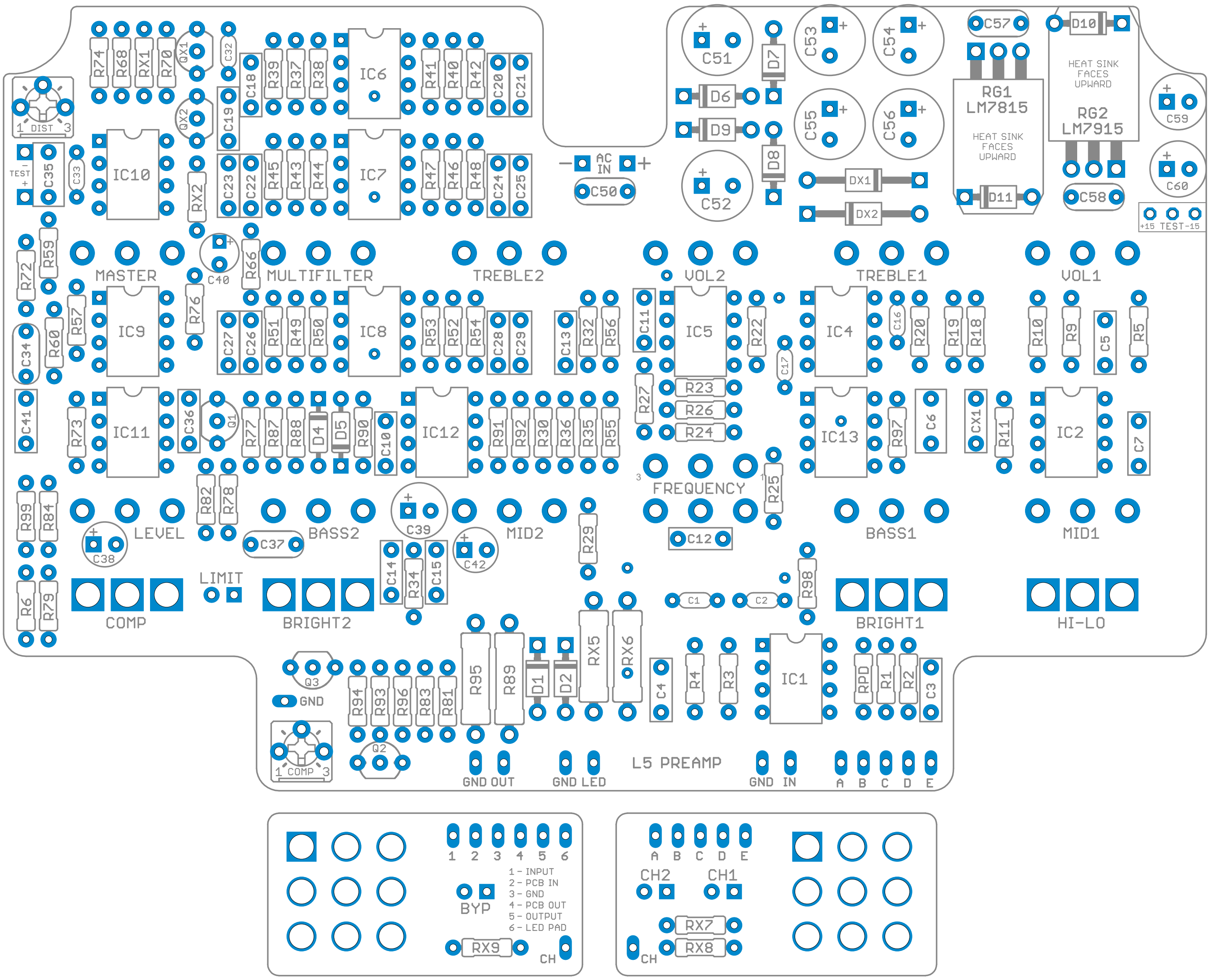
If using a painted or powdercoated enclosure, **make sure both jacks have solid contact with bare aluminum** for grounding purposes. You may need to sand off some of the paint or powdercoat on the inside in order to make this happen.

Drill Template

Print this page and cut out the drilling template below. Tape it to the enclosure to secure it while drilling. Note that the holes are shown slightly smaller than they need to be, so drill out the holes as shown and then step up until they are the correct size for the components. There are a lot of PCB-mounted pots and switches, so take your time and make sure to drill very accurately!



PCB Layout



This is about 50% bigger than life size. The main PCB measures 5.35" x 3.5". The smaller PCB on the left is the master bypass and the one on the right is the channel switching. These both inclode on-board LEDs.

General Build Instructions

Build Order

When putting together the PCB, it's recommended that you do not yet solder any of the enclosure-mounted control components (pots and switches) to the board. Instead, follow this build order:

1. Attach the **audio jacks**, **DC jack** and **footswitch** to the enclosure.
2. Firmly attach the **pots** and **switches** to the enclosure, taking care that they are aligned and straight.
3. Push the **LEDs**[1] into the hole in the enclosure with the leads sticking straight up, ensuring that the flat side is oriented according to the silkscreen on the PCB.
4. Fit the **PCB** onto all the control components, including the leads of the LED. If it doesn't fit, or if you need to bend things more than you think you should, double-check the alignment of the pots and switches.
5. Once you feel good about everything, **solder them from the top**[2] as the last step before wiring. This way there is no stress on the solder joints from slight misalignments that do not fit the drilled holes. You can still take it out easily if the build needs to be debugged, but now the PCB is "custom-fit" to that particular enclosure.
6. Wire everything according to the wiring diagram on the last page.

[1] **For the LEDs**: You can use a bezel if you'd like, but generally it's easier just to drill the proper size of hole and push the LED through so it fits snugly. If you solder it directly to the PCB, it'll stay put even if the hole is slightly too big. Make absolutely sure the LED is oriented correctly (the flat side matches the silk screen) before soldering, as it'll be a pain to fix later! After it's soldered, clip off the excess length of the leads.

[2] **Note on soldering the toggle switch(es):** It will require a good amount of solder to fill the pads. Try to be as quick as possible to avoid melting the lugs, and be prepared to feed a lot of solder as soon as the solder starts to melt. I recommend waiting 20-30 seconds between soldering each lug to give it time to cool down.

Sockets

Since double-sided boards can be very frustrating to desolder, especially components with more than 2 leads, it is recommended to use sockets for all transistors and ICs. It may save you a lot of headaches later on.

License / Usage

No direct support is offered for these PCBs beyond the provided documentation. It is assumed that you have at least some experience building pedals before starting one of these. Replacements and refunds will not be offered unless it can be shown that the circuit or documentation are in error. I have in good faith tested all of these circuits. However, I have not necessarily tested every listed modification or variation. These are offered only as suggestions based on the experience and opinions of others.

Projects may be used for commercial endeavors in any quantity unless specifically noted. No bulk pricing or discounting is offered. No attribution is necessary, though a link back is always greatly appreciated. The only usage restrictions are that **(1) you cannot resell the PCB as part of a kit**, and **(2) you cannot "goop" the circuit, scratch off the screenprint, or otherwise obfuscate the circuit to disguise its source**. (In other words: you don't have to go out of your way to advertise the fact that you use these PCBs, but please don't go out of your way to hide it. The guitar effects pedal industry needs more transparency, not less!)