Tips for Building Low-Noise Tube Amps

Basics

Preliminaries

WARNING! A tube amplifier chassis contains lethal high voltage even when unplugged - sometimes over 700 volts AC and 500 volts DC. These tips are intended for experienced amp builders. If you have not been trained to work with high voltage, please have an amp technician service your amp. Never touch the amplifier chassis with one hand while probing with the other hand; a lethal shock can run between your arms through your heart. *Use just one hand when working on a powered amp*. Learn how to drain the filter capacitors here. See more tube amplifier safety info here.

Basic understanding of:

- Reading electronic schematic diagrams
- Tube amplifier layout documents.
- Electrical engineering principles - *especially grounding*.
- Ohms Law and voltage dividers
- How guitar amplifier tubes work
    - Rectifiers and rectifier tubes - directly and indirectly heated.
    - Triode preamp tubes
    - Pentode power tubes
- AC to DC conversion - power transformers and DC ripple filtering
- Output transformers and speaker impedance
- Lead dress, crosstalk, and shielded cables

Premise

Noise in tube amps is cumulative. Sometimes one change won't make or break, but all of these changes put together can make an amp that is virtually free of extraneous noise. Just say no to hiss and hum!

Grounding

A proper grounding scheme is the starting point for a low-noise tube amp. Hum is caused by *ground loops*, where a single circuit has multiple ground points. *These are to be avoided!* The definitive tube amplifier grounding document (PDF) can be found here. For low-Wattage or lower gain amps, the aim is only three ground points on the amplifier. A Fender Deluxe Reverb type of amp can often have two dozen or more!

- Preamp section ground
- Power section ground
- AC Power ground

Inputs

Fender created the industry-standard High/Low input jacks used on most tube amps. Even so, the implementation is not ideal, due to multiple grounding points. Optimally, the preamp ground will be at or near the primary input. The best way to accomplish this is by isolating the input jacks from the chassis. For Switchcraft jacks, shoulder isolation washers are available for this purpose. Cliff-type jacks, such as are used on many Marshall amplifiers, are isolated from the chassis by design. Once the inputs are isolated, then a single-ground point for the preamp can either be on the primary input jack (not isolated - Cliff jacks have grounding washers) for this purpose, or even better, at a point on the chassis between the primary input jack and the first stage preamp filter ground. This is accomplished with a short wire between the primary input jack and a grounding lug or solder joint on the chassis and a corresponding wire from the first stage preamp filter ground. A long wire will act as a noise antenna, so it should be short or direct, and next to the steel chassis, marked "Chassis" in figure 1. To prevent radio frequency interference (RFI), some builders use isolated input jacks and put a 0.01µF capacitor from the *ground* side of the jack directly to the chassis at the closest point, such as on a ring terminal mounted behind a switch, or a on a pot or something. This will kill RFI in most cases.

Shielding

Chassis shielding. Presuming that the amp chassis is a metal box, electrically conductive, we want to add shielding to the part of the amp that the open side of the chassis bolts to, which is either the top inside, the bottom inside, or back panel. Aluminum shielding tape or shielding paint are the most common, but a metal panel of mesh screen may be used. The important thing is to ensure that the chassis, grounding to the building ground when plugged in, contact the shielding on the inside of the amp to create a Faraday cage to shield the amp from noisy electromagnetic and radio frequency interference . In some cases I use a flexible ground wire bolted the chassis and the shielded interior of the amp to guarantee electrical connectivity.

Signal shielding. Inside the amp itself, there can also be quite a bit of interference between components. This is why Lead Dress is so important (see below). Sensitive signal wires inside the amp should be replaced with shielded cables. Here are some suggestions on where to use shielded cable - depending upon the amp design:

From the input jacks to the first preamp tube.

- From the preamp volume pat to the next preamp tube.
- From a Master Volume to the phase splitter input coupling cap

The longer the wire run, the more benefit from using shielded cable. Being a MIL-Spec guy, I usually use RG-174, but there are other high-quality single conductor shielded cable options.. Only ground one end of any coax cable in an amp, preferably the signal input end, to keep from forming a ground loop.

Preamp grounds

In theory, each ground point in the circuit should connect to the negative terminal of the filter cap that supplies the B+ high voltage for that section. Sometimes, this can be hard to determine, so we use basic principles. Industry-standard schematics, such as those from Fender, typically read as a left-to-right guitar signal flow logic, and a right-to-left high voltage supply flow. Use the schematic to determine which high voltage filter cap supplies any part of the circuit, and ground that circuit at or near that filter cap. See Figure 1.

Notice the volume control in Figure 1, between the first and second triodes. Often, there is also a tone stack or tone control before the volume control. These controls should be part of the local star, and not separately grounded to their own case, i.e. the chassis, as indicated in the drawing.

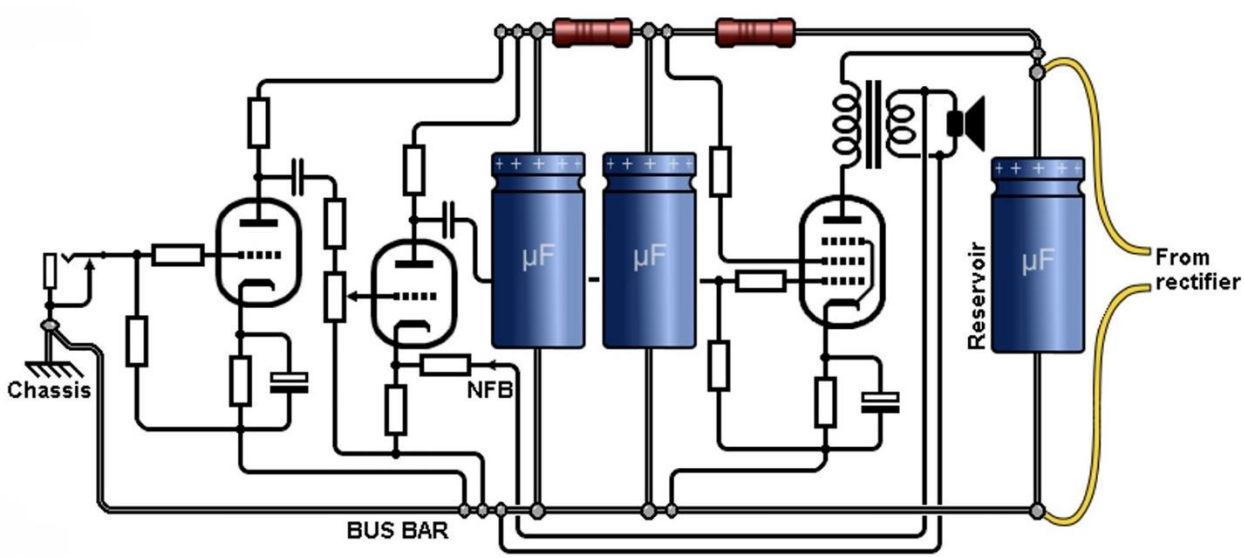

Figure 1 - modified buss ground

Power Amp Output Section Grounding

In this simplified drawing (figure 1) of a single-ended tube amp - similar to a Fender Champ - the right-to-left grounding logic is: The reservoir cap (A node), the power tube cathode ground, the screen grid supply filter ground (B node), the preamp supply filter ground (C node), the two preamps and volume control ground, and the input jack/chassis ground. Notice the ground points are close to the supply filter grounds, and the speaker grounds to the global negative feedback (NFB) circuit. In practice, these would either be tied directly to the supply capacitor ground (figure 2) using a local star ground, and the negative poles of the supply capacitors daisy-chained instead of using a buss bar (see figure 2).

All amps are not equal! I prefer ground the power transformer high voltage secondary center tap wire to the ground of the reservoir cap and ground it to the chassis within an inch or two of the AC earth ground. Then, the end point of the rest of the power ground can connect to that point.

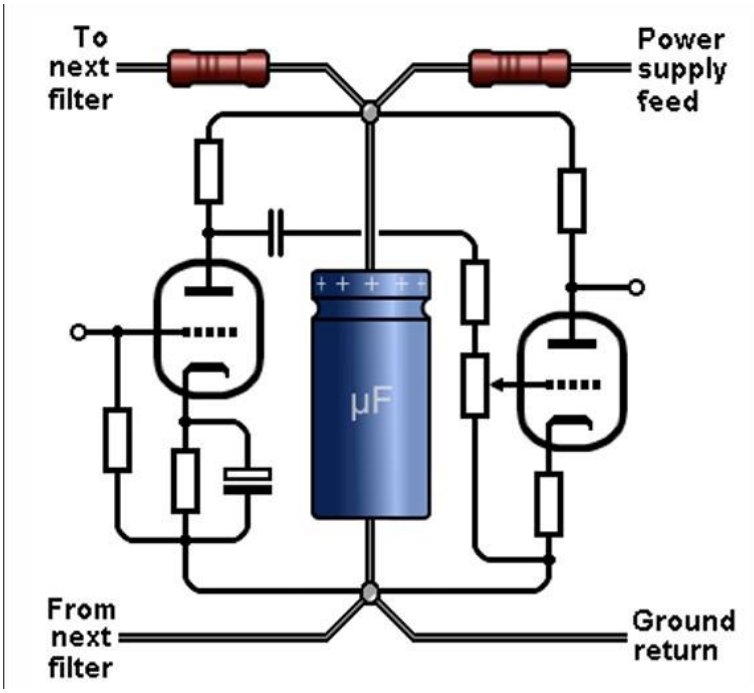

Figure 2 - local star buss ground

Look at Figure 3 of a simplified push/pull fixed bias amp. The output tube cathode grounds, the screen grid supply (B node), and the bias circuit all ground to one point - The Local Star, which also grounds the main reservoir capacitor (A node). For tube amps without NFB, such as the one shown in figure 3, notice that the speaker negative connection should go to chassis ground, close to the earth ground - less than 2-inches away. (Amps with NPB ground differently.)

However, most amps of 20-Watts a larger use NFB. In this case, the speaker negative connection is best run to the local star where the feedback is applied, most commonly the long-tail phase inverter (LTPI), which is commonly the C node. The phase splitter is grounded with the preamp ground because it is not referenced to the OT's ground, but part of the preamp supply. See figure 4.

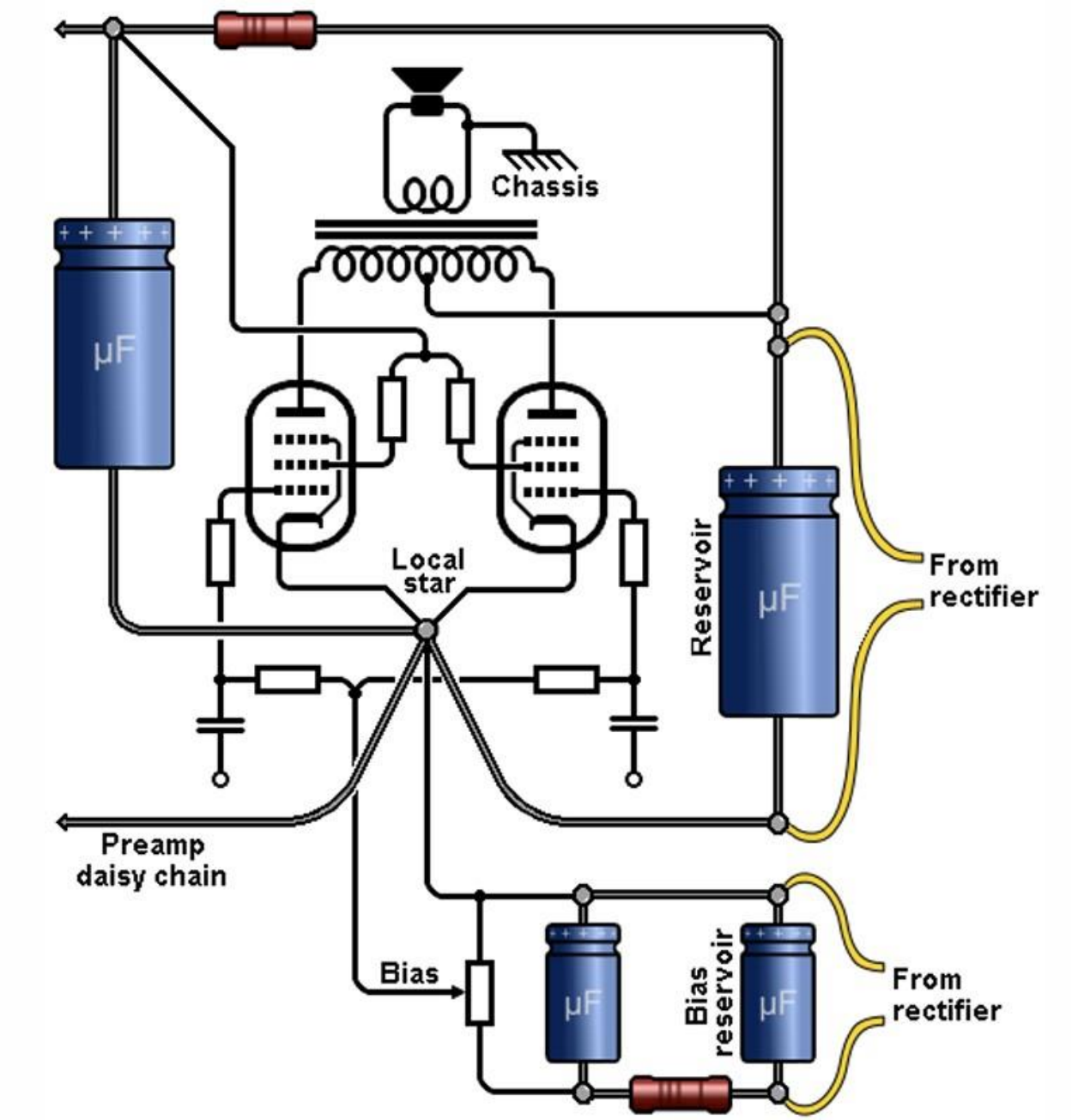

Figure 3 - output section grounding

Complications and Caveats

Many amps are more complicated than these simplified drawings. In those cases, find out which filter cap supplies the tube, and then you'll know which local star to ground to. Some famous amps have mixed grounding, e.g. in the famous AB763, the Reverb circuit shares a supply cap with the power tube screens, and yet grounds to one of several preamp ground points, sharing a ground with the Vibrato channel preamp tube. Not really a great idea.

Multi-Section can capacitors. These contain two to four capacitors with a single, shared negative terminal. They are convenient since they save space and presumably money, but by having only one negative terminal they force us to create a ground star that might be inconvenient. At the very least, try to use a single capacitor for the reservoir, then use the can-cap for later smoothing stages. However, most

amps that use *can-caps* have the reservoir and B Node in the same can. In those cases, the can-cap must be tied to the output power section ground. Another issue associated with can-caps is long wire leads from the can-cap to the relevant circuit. See "Lead Dress" below

Fender-style "doghouse" capacitor boards present another problem. However, the logic will stay the same. On the board you have the reservoir, the B-Node screen grid supply, and then the LTPI and preamp filters. The important note is to separate the power supply cap grounds from the preamp supply cap grounds, bearing in mind the LTPI and NFB info from "Power Amp Output Section Grounding" above.

AC Power Grounding

The AC power - 120VAC 60Hz in the USA - is the starting point, and the earth ground is of vital importance. This should have its own dedicated ground point, either solidly soldered to the chassis or with a dedicated bolt using lock washers and thread-lock, to ensure that it never comes loose! Do not stack this on other grounds. For amps with an IEC C14 type connector, the ground wire should be as short as possible. For vintage-style amps with bare wires inside the amp, the earth ground wire should be the longest of the three (hot, neutral, ground) because in event of the wires pulling loose, the earth ground will be the last to go. A proper strain relief or cable gland is vital.

The reservoir cap, or power circuit star, should be grounded near to the chassis earth safety ground, less than 2-inches away, for noise rejection, using a dedicated locked down solder lug or soldered directly to the chassis.

Tube Heater Circuit Grounding

The 6.3VAC heater wiring found in most tube amps is a noisemaker, so take steps to mitigate this. The pair should be tightly twisted to cancel induced noise. Leads should be away from all signal wires - you see this in the flying leads on most Fender style amps and chassis corner leads in most Marshall style amps. Power transformers typically have either a single pair, or a 3-wire center tap secondary.

On amps with a single pair, make sure they're tightly twisted and avoid all signal wires. Industry-standard practice is to use two 100Ω or 330Ω resistors to ground, one from each wire, or a 100Ω hum balance pot across the two. When using power transformers with center tapped heater string, the center tap is the ground. However, some builders like to tie off the center tap and substitute the resistors. Regardless of which you choose, take a further step and elevate the ground instead of referencing to chassis "ground" which is 0 Volts. This is easily accomplished on cathode biased amps, such as Fender Champ of tweed Deluxe or similar, by soldering the center tap or resistor pair to the hot side of the cathode resistor, which runs at an elevated voltage, e.g. 27VDC. Alternatively, and on fixed bias amps, a voltage divider circuit with a filter capacitor can provide elevated DC ground reference voltage. This goes a long way towards reducing noise in tube amp.

Higher Wattage and High-Gain Amplifiers

In the case of more powerful or high gain amplifier, separating the preamp ground from the power section ground will help reduce noise. In this case, we find the dividing line between the Preamp and Power sections, which is determined by the presence and location of NFB and the LTPI supply node.

If the amp has NFB applied to the LTPI, then you ground the LTPI supply cap with the power amp ground. This is because the LTPI is now referenced to the OT's ground which is grounded with the power amp ground (See Power Amp Output Section Grounding, paragraph 2 and Figure 4). In this case, the reservoir cap (A node), the screen grid cap (B node) and the LTPI cap (C Node) all become part of the power amp ground, which terminates at the reservoir cap ground. The preamp (which should be on the D Node, is grounded at or near the primary input jack/preamp ground.

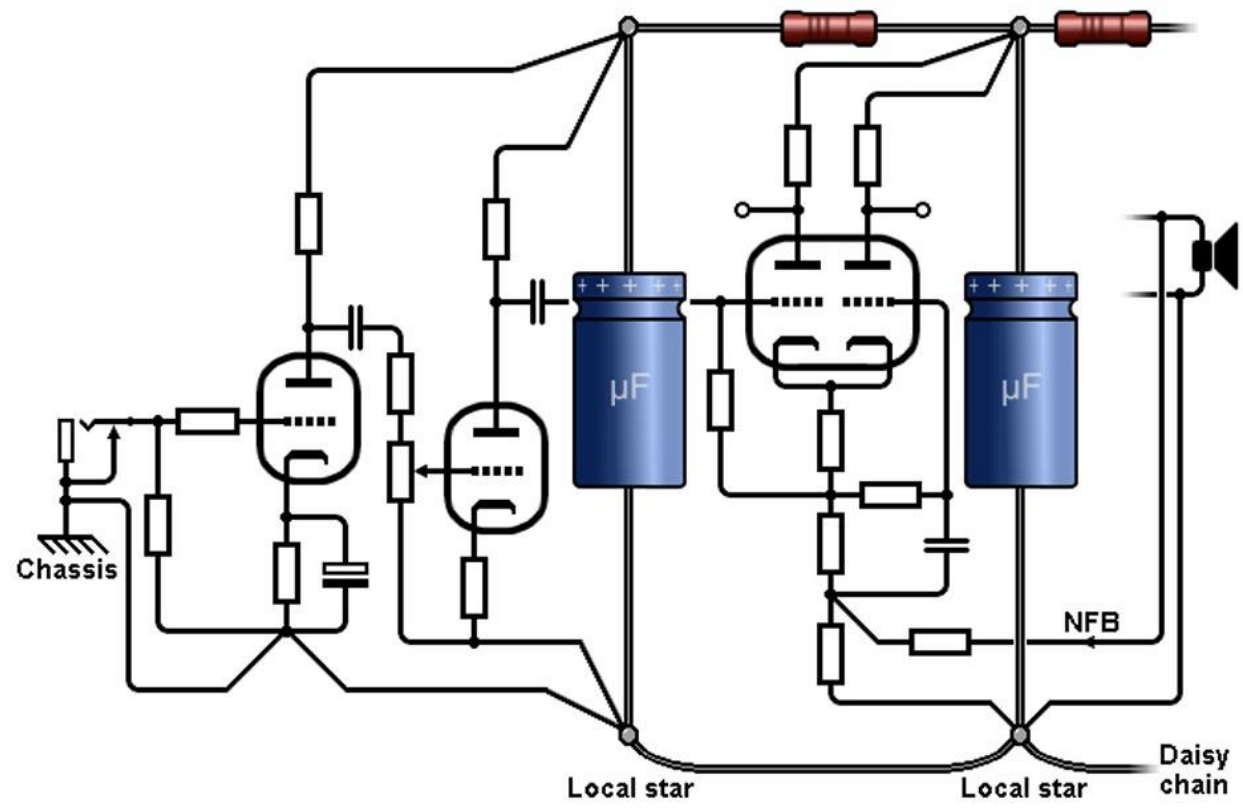

Figure 4 - output section grounding

Other Grounds

What about other grounds, such as the high voltage center tap? Make sure the center tap of the HV goes directly to the first filter cap ground. There is a lot of high-current noise traveling in this wire. Some power transformers have a separate wire for an internal screen between the primary and secondary coils to reduce stray capacitance between the two. This screen should also be connected to reservoir cap ground. (See Power Supply Grounding paragraph 2.) The same goes for the heater supply center tap, artifice center tap, or voltage divider ground.

Bottom Line

1. Each portion of the circuit grounds to its supply capacitor.
2. Only one ground point per circuit section.
3. Local star at each supply capacitor.
4. Smaller and lower gain amps have two ground points - Earth safety ground and circuit ground, near the input jack.
5. Higher Wattage and high gain amps have separate power and preamp grounds in addition to the Earth safety ground.

Two examples

- 5E3 Deluxe simplified grounding scheme as in item 4 above.
- 5E3 Deluxe split power and preamp grounding scheme, as in item 5 above.

Lead Dress

Proper lead dress is vital for a low noise tube amp.

When CBS bought Fender in 1965, to speed up production to meet a backlog of amp orders, they scrapped the Quality Incentive Program set up by Fender's VP & GM, Forrest White, whereby employees were generously rewarded for 100% quality work. This sped-up production resulted in sloppy wiring and wire routing. Sloppy wire routing led to excess noise and unwanted oscillations. Rather than correct the sloppy wire routing, CBS made circuit changes to add extra capacitors and the like to eliminate the noise and oscillations. This resulted in worse sounding amps, leading many guitarists and amp technicians to "Black face" their silver faced amps, along with the phrase, "Pre-CBS" to indicate higher quality amps. (CBS also mucked up their guitars, but that's another story).

Figure A. Proper heater wiring.

- Upper: Poor heater wiring with many potential sources of hum.
- Lower: Good heater wiring keeps the twisting tight, avoids hum loops, and keeps the wiring pushed against the chassis far from any signal wires.

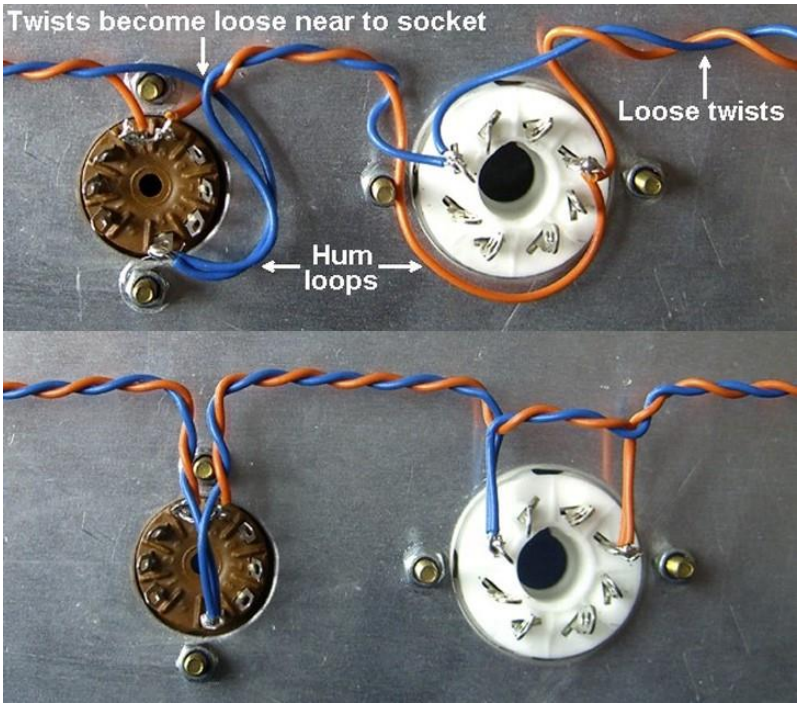

Figure A - Heater wiring.

Figure B. Proper triode wiring. Note the color coding. I like to use EIA industry-standard wire coding: BLU for plates, GRN for control grids, and YEL for cathodes. Twisting the anode and grid wires does increase Miller capacitance, but this is seldom a problem in a guitar amp. I call it "Builder's choice".

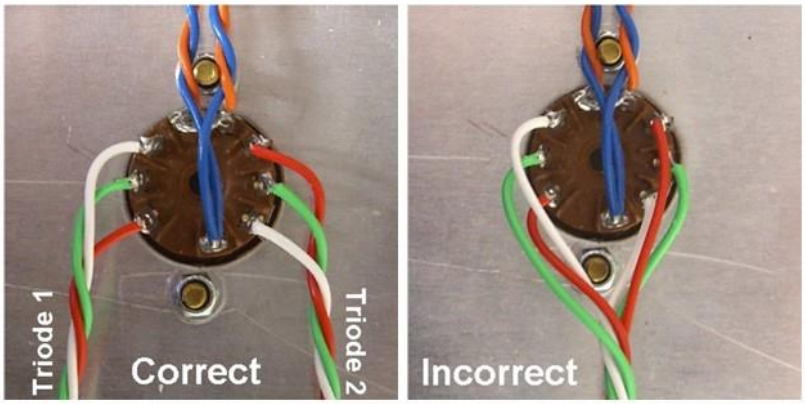

Figure B - triode wiring

- Left: The wires leading to different triodes should be kept separate.
- Right: Grouping all the wires together will inevitably lead to problems.

Component Selection

There is much Internet chatter and urban myth about tube amps components - especially resistor and capacitor types - and their contributions to the "sound" of an amp. I will attempt to point out lowest noise options without arguing which type is "better".

Resistors

For the purpose of hiss reduction, resistors in tube amps can be separated into two broad categories - in the signal path and not in the signal path. Example of resistors in the signal path are input grid stopper resistors, tone circuit resistors, and all other grid stoppers. Resistors not in the signal path are every other resistor - volage dropping, load (anode) and cathode resistors, grid leak and bias resistors.

The best place to reduce hiss is at the input, which is the most sensitive part of the circuit. (See the "Inputs" section near the top of the page.) In this case, metal film resistors have only 10% of the noise of carbon composition resistors, and therefore I recommend them for all input resistors when building or modifying an amp for lowest noise. This means the industry-standard 1M and 68k input jack resistors. If lowest noise is the goal, then you may want to use metal film for all signal path resistors except for power tube grid stoppers, which are best serviced with modern wirewound low mass cement resistors mounted directly on the power tube sockets.

B+ voltage dropping resistors are best serviced by metal oxide (MOx) for stability and long life. Carbon comps are too much affected by heat to be effective in that position. For plate load resistors, cathodyne or cathode follower load resistors, the choice is more personal. Bear in mind two things: 1) 1 Watt resistors have lower noise than 1/2-Watts, and 2-Watts have lower noise than 1-Watts, and 2) Some resistors carry more load, especially the cathode-follower and cathodyne plate and load resistors, and can benefit from a higher-Wattage upgrade.

Capacitors

I have no interest in debating capacitor types. For less noise, do two things:

- Orient tone and coupling caps for lowest noise.
- Don't cheap out on caps. Cheap caps are noisier and fail more often and more quickly.

Example of Fender Bassman capacitor orientation, with the outer foil marked with an "0", and a split power and .

Tubes

Good tubes are worth the money. Get and use good ones. Unless you are able to buy in bulk and test and discard, buy pre-tested tubes. At least one tube supplier will test tubes for low noise and microphonics, charging extra, which is fine. However, if the tube doesn't meet the criteria, they put it back on the shelf and sell it to the next guy. Don't be the next guy. Save yourself time and trouble. For the critical first preamp tube, only use a low noise, low microphonic tube (I like the JJ E83CC). In combo amps, I like to shock mount the V1 tube socket using MIL-Spec high temperature grommets.

Different tubes for different functions. There are several different types of ubiquitous 12AX7 tubes. Besides the standard 12AX7/ECC83, there are long plate, frame grid, and spiral element options, 7025, etc. Some work better in 1st stage preamp, and some are better for the LTPI, or the cathode follower or cathodyne phase splitter. I choose for low noise and may roll tubes to find the best at each position. It can make a big difference in noise and tone. You may want to compare.

Only use high quality tube sockets. They are not prone to failure, and tube sockets are a pain to replace.

Transformers

All transformers should be tested for hum prior to installation. I've seen brand-new power transformers that hum like crazy. Mount them solidly using lock washers and medium-strength thread-lock, as the mounting nuts have a tendency to loosen. For this reason, **never connect grounds to transformer mounting bolts!**

Conclusion

If low noise is your goal, if you want to hear your guitar and not extraneous noise - especially in studio applications, using the steps above can help you make your amp have the lowest possible noise floor. I make "Studio Series" amps that you would never know it was on until you either look at the pilot light or play your guitar through it. Happy amp-building!

Author: Bruce Blumentritt, amp designer at Texas Tone® Amps, known for their low noise floor - "the real deal. No hum and so touch sensitive and dynamic."

References and thanks to:

- Merlin Blencowe: The Valve Wizard.
- Rob Robinette: How Amps Work.

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