How to Drain the Filter Caps

Disclaimer

It is important to realize that these instructions were written exclusively for the Fender Hot Rod Deluxe and Deville. The location, appearance, and ease of access to filter caps will vary from amp to amp. **If you're not totally comfortable with working on amplifiers, take it to a qualified tech! If you're ever uncertain about something, take it to a qualified tech! Your ineptitude could mean your life at worst, and a more expensive trip to the tech at best!** Saving a few dollars isn't worth losing your life over. By proceeding you agree that I take no responsibility for any damage done to yourself or your amp.

So you want to work on guitar amps?

If you want to learn how to work on guitar amplifiers you need to crawl before you walk, and walk before you run. I'd start by building a volume box. Maybe then try rewiring a guitar. Once you're comfortable with that you should buy some good books and read some good websites. Taking a few classes at your local technical school won't hurt either! Working on guitar amplifiers is something we need to build up to. My advice? Read everything you can get your hands on! It may take years to become really good at this stuff, but even the most skilled tech started at the same skill level as you and I.

There's recently been an explosion of books that deal specifically with guitar amplifiers, you can find a few of these at your local Barnes and Noble—most are good. If you're interested in tube amp design/operation you'll be stunned the first time you compare an old radio circuit with a guitar amp circuit. Take away the demodulator and it looks just like an old Fender amp circuit! For this reason you'll find a lot of useful info in old radio books from the 50s and 60s. Some of my favorites include:

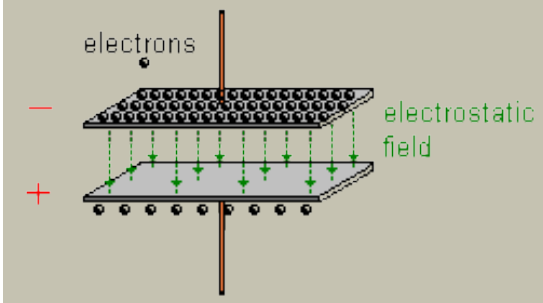
- F. Langford-Smith (ed.) Radiotron Designer's Handbook, 4th Edition, Wireless Press 1953.
  A solid and extremely detailed reference. It's sometimes called the "Tube Amp Guru's Bible," though you'll find it more useful if you have a background in engineering or higher-level math like calculus.
- Patrick, D., and Steven Fardo. Electricity and Electronics: A Survey, Prentice-Hall 2001.
  Written by a few professors at my University. An easy-to-read reference for everyday electronic theory, though very little when it comes to tube circuitry. Good explanations of solid state though.
- O'Connor, Kevin. The Ultimate Tone: Modifying and Custom Building Tube Guitar Amps, Power Press 1995.
  A good reference book that deals specifically with tube guitar amps. I was a little disappointed with how he flies through theory, and how unclear some of his writing was, but the later chapters are priceless—particularly the channel switching chapter. A good book, but not written for beginners.
- RCA Receiving Tube Manual, RCA 1973.
  Has a lot of clearly written explanations of tubes, how they operator, and LOTS of spec sheets. A nice book for beginners.
- Marcus, Abraham. Radio Servicing: Theory and Practice, Prentice-Hall 1960.
  A good book with nicely executed pictures that help the student visualize what's happening in the circuit. More than just a servicing reference, this book has lots of theory. What makes it so special of course, are the service notes included at the end of each chapter.

Most of these books can be found at Antique Electronic Supply or Amazon.

Why Drain the Caps? | Printer Friendly version

It is absolutely vital that we drain the filter caps in the DC power supply before working on ANY guitar amplifier. These often hold a charge of several hundred volts, which is potentially deadly. **Caps can hold their charge for weeks or longer, even with the power off AND the amp unplugged.** It's very important that we learn to properly "drain" this residual voltage so that we may safely work on the inside of our amplifier.

How Capacitors Work



A capacitor consists of two metal plates which are separated by some type of insulator, often called a "dielectric." This insulator can be paper, air, or anything that does not conduct electricity. When a DC voltage, like that of a battery, is hooked to the cap electrons will leave the positive side and build up on the negative side. Note no electrons actually flow through the capacitor due to the insulator. If our cap is unhooked from the battery, the electrons that were forced to go to the negative side remain there. We now have more electrons on one side than on the other. A "potential" has formed. Naturally, the visiting electrons want to go back home to the positive side. This attraction to the positive side is called the electrostatic field. If the two plates are ever reconnected so that electrons can flow, the visiting electrons will immediately return to the positive plate. We call this "draining the caps."

Very good cap info!

1. What We Need

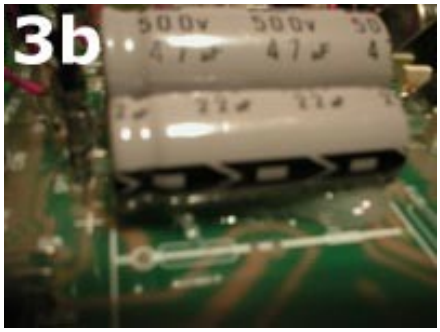
1. Safety goggles.
2. (1) digital multimeter capable of reading 500 volts DC. Don't have one? The best deal I've found was at AES, search for part S-Z3220. Great bang-for-buck. The Extech at Radioshack is good, though Flukes are the best general purpose.
3. (1) Xicon 25K 10W Cement Power Resistor for draining residual voltage.
4. (1) pair of pliers with an insulated handle for holding the resistor
5. (1) philips screwdriver to remove the back panel.

2. If you're not addressing a problem that requires the amp to be on, ALWAYS unplug it from the wall. Unplugging from the wall will not drain the filter caps, it actually won't make a bit of difference, but again this is for our own safety. We unplug to keep the amp from accidently turning on while our hand is inside the amp. Don't assume anything's impossible, as that's how people die. Unplugging is the equivalent to "locking out" before working on a downed machine.

Turn the power switch OFF, and place the standby switch in the ON position. Note: This isn't the same as having your amp "on standby." (see picture 2 for clarity) We're hoping the filter caps will drain down some with the standby switch closed.

3. Place the amp on a sturdy table in a well lit room. Be sure to wear rubber soled shoes, and if you have a properly insulated floor mat (made of rubber) standing on it can help prevent the likelihood of electrocution. Remove the back panel of the amp. Once it's gone look around the inside of the metal enclosure, but don't touch anything. **(a)** See those big grey things with 500V printed on them? (500V and 350V in the Deville) These are the filter caps, and what we need to watch out for. NOTE: There are more filter caps than what are pictured.

Because filter caps are almost always of the electrolytic type, they're "polarized" and therefore have a positive and negative end. **(b)** We can identify the positive or negative ends by looking for the "polarity indicator" printed on the cap's side. Assuming Fender is still using the same Illinois Capacitors, the line will be black and it'll have arrows pointing toward the negative side. On the cap the positive side will not be marked, though you'll find a "+" printed on the PCB indicating the positive side.



For filter caps the negative side is wired to ground, which is the amp's metal enclosure or "chassis." Caps will only drain when their leads are connected with a resistor or shorted together with anything that conducts electricity—including human flesh. This means touching the chassis with one hand, and touching anywhere that's wired to the cap's positive plate with your other hand, will make your body a path for the caps to drain. Immediately it will discharge several hundred volts which will pass through your heart. If you live then consider yourself lucky. The ground you're standing on may be at the same electrical "potential" as the chassis—especially if you're in the basement or outside. So you could still be electrocuted even if only one hand is working inside the amp! **Remember: what makes working on power supplies so dangerous is that you don't even have to come close to the filter caps to be killed.**

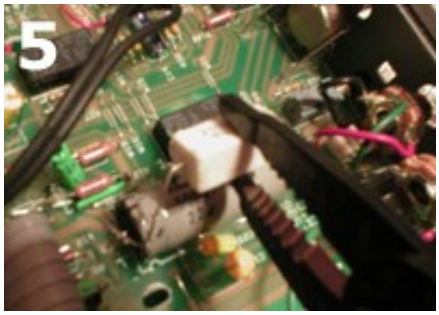
4. You should have on your safety goggles by now. Inspect your multimeter's black and red probes for frayed or broken insulation (the part you hold). If you find that the insulation is in questionable shape DO NOT use them. Throw them away and go to the hardware store and buy a new pair.

Our first objective is to check for residual voltage with a multimeter. In some cases most of the voltage may already been drained, but **NEVER EVER assume the caps have been drained to a safe level without checking with a reliable multimeter.** There are many ways to measure the residual voltage contained in the filter caps, but below are the most common. Note that these are also equally valid for draining the caps.

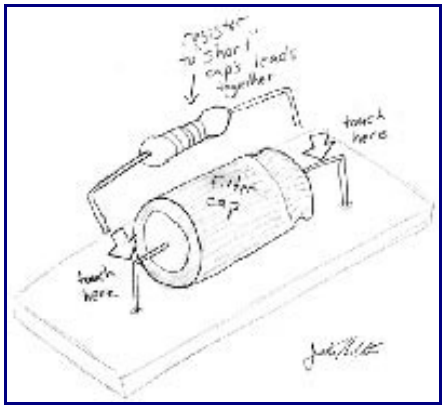
1. **Across the cap.** (pictured) This is my preferred method, but only if the filter caps are easily accessed.
2. **From the positive side of the cap to the chassis.** - This is essentially the same as draining "across" the caps since the negative side is at the same electrical potential as the chassis.
3. **From the chassis to a pin.** This can be done at pin 3 of any power tube, or pins 1 or 6 of any preamp tube. Sometimes, usually in larger vintage amps, the filter caps are located inside a small pan—often called the "dog house." This is fastened to the chassis, and access is normally limited. Often several clothed wires protrude from a hole in the pan, and these are connected to the positive side of the filter caps, or the negative side of the bias cap (if included). The negative leads are usually securely soldered through small holes in the pan. The dog house will be mounted on the same side as the transformers and choke. This method is often used for draining the caps when immediate access is not safely available, or if a proper resistor can not be found. By shorting the chassis to the correct pin the caps will be forced to drain through the plate load of that tube. This prevents sparking from high current. Once your meter indicates that the caps are drained you may unscrew the dog house and check each cap individually if needed.

Set your multimeter to read DC voltage. Adjust the meter's range so that it's above 500 volts. **Using only one hand, with the other hand far from the chassis (preferably in a pocket)**, measure the DC voltage across one of the big grey caps. Working with C36, which is behind the input jacks, seems to be the safest choice. You can adjust the meter's range down if you can not get a clear reading. What number did you get? Any DC voltage reading that's less than 10 volts is harmless, so the amp can be safely worked on. If not we must drain off the residual voltage with a resistor until it is safe.

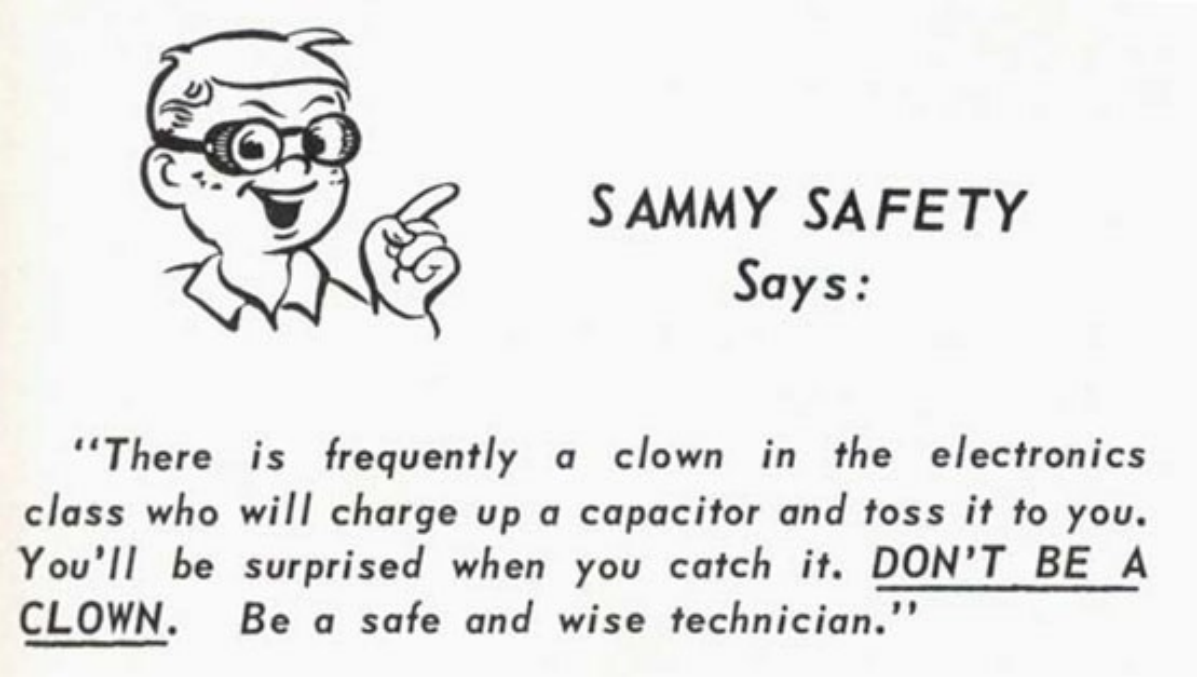
5. In old electronics books this is usually where they tell you to use a screw driver with an insulated handle to short out the caps. "Shorting" with a screwdriver will almost instantly drain the caps to zero volts, causing sparks from high current. This is acceptable if you know the handle is well insulated (think rubber), you're wearing eye protection, and you don't care about leaving marks on the chassis. If there's several hundred volts stored in the caps be prepared for a nice little spark. It'll most likely leave a black mark on the chassis, and in extreme cases partially weld the screwdriver to the chassis. When draining an industrial power supply, which may use very high capacitance and voltage, never use a screwdriver as the charge can blow a chunk out of it and make it into a projectile. Always use safety goggles, even if you think you look nerdy with them on. Trust me, no one cares.



If you find that you have several hundred volts in your caps you must be extra careful when draining them. Take your power resistor and bend the leads so that you can easily touch a filter cap's leads. Once again, C36 seems to be the safest choice. Use a pair of pliers to hold the power resistor for safety. Always hold the actual body of the resistor and NEVER the metal leads protruding from it (see picture). With your free hand in your pocket, choose a filter cap and touch the capacitor's leads with the resistor's leads (see drawing for clarity). Hold it there for 20 to 25 seconds.



Filter caps are wired in parallel, so draining one should drain them all, but never assume. **Always recheck for residual voltage in every filter cap until there's absolutely no doubt in your mind that all are drained.** Anything less than 10 volts is safe, but I prefer to drain mine to 1 volt for peace of mind. (I've been hit with 420VDC before!) Don't be surprised if you find the caps slowly recharging themselves afterward. This phenomena is known as *dielectric absorption* and is quite normal in electrolytic caps. Rest easy, for the filter caps will not recharge to a lethal level. Once you're certain the amp is safe, I'd like to wish you good luck on your mod or repair!



Sammy Safety, still giving the class clown "ideas" 40 years later! =D

Thoughts on Filter Caps

Calculating Drain Time

So did I pull 20 to 25 seconds out of my ass? No. A capacitor will discharge 63% of its original voltage in one *time constant*. What's a time constant? We'll define that in a moment. For example, if you have 100 volts in your caps they'll discharge by 63 volts in one time constant. So now there's 37 volts in your caps, and they'll discharge 63% of 37V in the following time constant. So now you have 13.7 volts left in your caps, and so on. It takes five time constants to fully drain a capacitor.

One Time Constant is equal to the product of Resistance and Capacitance.

$$T = R * C$$

T is the duration of one time constant in seconds
R is the resistance of the resistor in ohms
C is the capacitance of the capacitor in farads

Time needed to fully drain a capacitor in seconds = T * 5

The total capacitance of the Hot Rod's filter circuit is around 113µF. Our resistor is 25K, but you must also take in consideration the remaining series resistors in the filter circuit itself. This bumps our total resistance up to around 40K.

40,000 ohms * .000113 farads = 4.52 seconds (time constant)

4.52 seconds * 5 = **22.6 seconds** to fully drain the filter caps

If your caps do NOT have a dangerously high voltage, say around 30 volts, feel free to use a smaller 1K 1W resistor. This will shave the drain time down to around 8.5 seconds.

If you're familiar with calculus you'll realize that the voltage of a capacitor approaches zero as it's drained, but because it's logarithmic in nature it will never actually reach zero. This means a capacitor will never fully drain its entire charge even if a resistor is held there for a billion years! Of course the residual voltage will eventually get so small that it will become undetectable, but there will always be some charge left in the cap. Inversely, a capacitor will never fully charge to its source voltage, but after a certain point the difference will become unnoticeable.

Using "Clip On" Resistors

Some people like to solder alligator clip ends to their resistor so they can "clip it and forget it" while they work on the amp. I don't recommend you do this, not because it's useless but because 1.) the alligator clips must be well insulated and 2.) it's so easy to forget about it. If the clip ends are not well insulated you could be electrocuted. If you forget about it you could cause some damage to the power supply. For example, if you hear a terrible sound and smell something burning after a mod, you may have forgotten to unclip your resistor. Which is what happened to me, and I was using a smaller 1K resistor at the time. This allowed pulsating DC to bypass the capacitor, which was amplified when it hit the plates. It also caused R74 and R75 to draw more current and run out of spec. Luckily I had appropriate replacements on hand.

Caps and Death

As an interesting side note, high voltage does not kill you. It's current that puts us in our grave, but current is dependent on voltage AND resistance. So decreasing the voltage (or increasing the resistance) will lower the current. If you use a resistor to drain the caps, a larger resistor will be safer, but it will take longer for the cap to drain as we shown with the time constant equation. If you use too small a resistor, or especially no resistor, you will get sparks from too high current. Even with a small voltage, no resistance will result in VERY HIGH current. Luckily our bodies have a natural resistance, and can lower SOME current. But if the voltage is high enough the current will also be high enough to kill us. If you hit the gym you'll be happy to know that muscle has more resistance than fat.

Other Methods of Draining Caps

It seems to be widely believed that you can drain the filter caps by turning your amp off while strumming your guitar. I agree that it *sounds* like they're draining, but I've found that it does not make any difference. If you've visited here in the past you know that I included this method in my old instructions. It was posted here simply because I was told that's the way to do it. I've since separated fact from fiction.

FACT: This method can not guaranty that the filter caps have drained to a safe level, therefore it can not guaranty your safety. The only way to know if you're safe is by checking each filter cap with a reliable multimeter.

What's Capacitance?

Some people may also be wondering what 22µF and 47µF means? Of course we know it's the capacitor's "capacitance," but what does it REALLY mean? We could read all the technical definitions to our heart's desire, but if we can not visualize it then what's the point? Think of capacitance this way: If you charge up two caps (a 22µF and a 47µF) with the same voltage, and discharged them with the same resistor, the one with the larger capacitance will take slightly longer to drain. The one with the larger capacitance would be 47µF of course. This can be proven mathematically using the time constant formula given earlier.

Exploding Caps

A unique characteristic of electrolytic caps is if they're put in backwards, or if their maximum rated voltage is exceeded, they will explode. I've never exploded one myself, but I've heard it's quite loud and dangerous. Even though most electrolytic caps are polarized, I've seen some newer ones which aren't. Be sure to check for polarity, but if you can not find any indication on the cap it may not be polarized.

If you ever find yourself replacing a bad electrolytic cap, or recapping a vintage amplifier, be sure to observe polarity. The negative side of the cap should always be on the *most negative* side of the power supply. This is usually ground, but it doesn't have to be. For instance, an exception commonly seen in tube amps is in the "fixed" bias supply.

This bias supply creates a negative DC voltage, usually around -35V, that's applied to the power tube's control grid. The "classic" Fender bias cap is usually 100µF and rated at 100V. Its purpose is to smooth out AC ripples in the DC bias voltage, which prevents hum. Bias caps have their *positive* side hooked to ground. Why? Because the bias supply is creating a *negative* voltage. DC ground has no charge and is at zero (0) volts, but our negative voltage has a negative charge at about -35V. It should become obvious that the voltage created by the bias supply is *more* negative than ground. Similarly, ground is *more* positive than the bias voltage, even though it technically has no charge. For this reason the positive plate of the capacitor is hooked to ground. I'll restate that the negative plate of a electrolytic cap should always be hooked to the side of the power supply that's the *most negative*. If you're still a little confused don't worry. This isn't an easy concept for a beginner to grasp, I know. If you understand it give yourself a pat on the back!

By Justin Holton