Thoughts on Biasing

This section is for the more advanced users, and was written because of the many questions being posted on the FDP concerning the details of biasing these amps. If you're unfamiliar with electronics this part probably won't make much sense to you, so feel free to ignore it as it's not a required reading.

mV vs mA: Which is Correct?

Biasing in mV or mA has been a great source of confusion to many new Hot Rod owners. Some tech snobs gasp in horror when they read that people have been biasing in.. (organ crescendo) mill-eee-volts! After all when we bias an amp we're setting the *idle current*. Q: So why the heck did we use voltage in the "Biasing for Dummies" section?! A: Because measuring voltage across a cathode resistor is safer and can be successfully done with sub par test equipment, that's why.

How so? Current must be read in SERIES. This requires unhooking some wires, which always have a chance of shorting on something that they're not supposed to (i.e. you). Voltage, on the other hand, must be measured in PARALLEL and doesn't require removing any wires. The "Biasing for Dummies" method uses a 1 ohm (Ω) resistor between the cathode and ground. Believe it or not, this is called the *Cathode-Resistor Method* of biasing! To understand why this works we'll need to know Ohm's Law and some very simple math.

FACT: When measuring a voltage across a 1Ω resistor, voltage will be equal to current.

Ohm's Law states "voltage divided by resistance equals current" or .. V / Ω = A V = Voltage (in volts) Ω = Resistance (in ohms) A = Current (in amps)

So if you're biasing to 68mV..

$$68mV / 1\Omega = 68mA$$

That's why we can bias using voltage instead of current. When we measure the voltage across the 1Ω resistor we're measuring voltage in parallel. This is a lot safer (not to mention easier) than wiring your multimeter between the cathode and ground. It's not 100% accurate for reasons we'll learn about later, but it is perfectly valid—no matter who tells you otherwise. I chose the *Cathode-Resistor Method* because it's easy to do, and it's recommended by Fender on the Hot Rod's schematic (see Note 5).

Did you know that bias probes like the Weber Bias Rite and Bias King also use the *Cathode-Resistor Method*? A 1Ω resistor is placed inside a piece of piping which bridges pin 8 of the adapter's base and socket. These are preferred for valuable vintage amps that don't have cathode resistors, since installing one may damage the amp's value.

As you may know, the Fender Hot Rod Deluxe and Deville have a *common* cathode resistor. When we take a voltage reading at the *bias test point* we're reading the combined cathode current—or, in other words, we're reading the biasing numbers for both tubes at the same time! It is not unusual for owners to post what they've read at the bias test point on usenet forums (i.e. 72mV), only to baffle and concern techs who expect to see something closer to 36mA.

A bias probe is useful if you'd like to know the cathode current for each individual tube. If you're handy here's a page that explains how to construct your own bias probe, though instead of using a

1Ω resistor it wires pins 8 and in series. For the Hoffman probe we'd set our multimeter to measure current instead of voltage. The only draw backs to this design is that your meter must measure current (some don't), and it takes a good multimeter to measure current accurately.

Plate Diss-a-what?

Plate dissipation is what dictates how "hot" we can bias before the tube becomes too hot and is permanently damageed. Plate dissipation is measured in watts, and is literally the amount of heat given off (or dissipated) as a result of electron bombardment. The electrons are attracted from the cathode to the plate, because it's positively charged, and if the tube is biased "hot" more electrons will be attracted. When we say we're biasing "hot" this means we're increasing plate dissipation, so the tube will literally be giving off more heat! Plate dissipation is closely related to the physical size of the plates, which are easily visible inside the glass envelope. A tube with a larger plate will generally have a better plate dissipation—this is why power tubes need to be a lot larger than preamp tubes, more watts are required and therefore a better plate dissipation.

Plate dissipation is easily calculated by multiplying *plate current* and *plate voltage*. Measuring plate current is trivial since we'd have to install a very large 1Ω power resistor, or use a different method called the *Output Transformer Shunt Method*. (I'll discuss it later.) Since it's futile for the beginner to measure plate current we'll measure the next best thing—cathode current! As you may know, cathode current is what we read at the bias test point, so it's easily measured. After current leaves the cathode it travels to the plate, though a little is attracted to the screen grid. For this reason cathode current is mostly plate current with a little screen current. (Plate Current + Screen Current = Cathode Current) Since screen current is small when compared to plate current, we can ignore it for our plate dissipation calculations. We, like most people, will calculate plate dissipation by multiplying cathode current by plate voltage simply because it's convenient.

There are two types of plate dissipation that we must make ourselves familiar with. The first is *maximum* plate dissipation. This is what we'll always be given by a tube's spec sheet. This is the maximum amount of heat a tube can possibly dissipate before the plate becomes too hot and the tube is destroyed. When the maximum plate dissipation is exceeded, part of the plate will start glowing the proverbial "cherry red" color. Within a few minutes the tube will be ruined.

It is important to realize that plate dissipation will increase when we play our guitar, so we can not bias the tubes so that the plate dissipation sits at the rated maximum plate dissipation at idle. Once we plug in we'll surely exceed the max. (Note: this only applied to Class AB amps.) For this reason we must set the actual plate dissipation far lower than the maximum rated. The plate dissipation that we measure, which is with no signal applied, is *static* plate dissipation—sometimes called *idle* plate dissipation. This is the second type that we need to know. It's agreed that in our Class AB amp we should set the static plate dissipation to no more than 70% of the rated maximum plate dissipation. The 30% difference will compensate for the increase while we're playing our guitar. This number wasn't randomly pulled from the air, and Randall Aiken does a good job explaining why 70% is used on his website.

How Hot is "Too Hot?"

This is a great question! This depends on the plate dissipation of the tube, and the plate voltage of the amp. For *true* 6L6GCs (i.e. mostly NOS/Vintage tubes) the maximum plate dissipation is always 30 watts. Newer production 6L6GC tubes usually don't meet the requirements of the original 6L6GC. For example, Groove Tubes copy of GE's 6L6GC, the GT-6L6GE, is only rated at 25W plate dissipation. To read more about this refer to the section on which tubes to use.

The plate voltage of the Hot Rod Deluxe is about 420V ± 10V, while the Deville's is around 475V ± 10V. Say we bias our Deluxe to 68mV at the bias test point. We then measure a plate voltage of 420V at pin 3 of a power tube. We then calculate the static plate dissipation by multiplying the cathode current (.068A) by the plate voltage (420V). If you don't have a calculator you can quickly calculate plate dissipation by using my Biasing Calculator.

.068 amps * 420 volts = 28.56 watts

Remember: the cathode current, which is what we read at the bias test point, is the combined cathode current of both power tubes. When beginners tell their tech they've been biasing to around 70mA the tech usually flips out, not realizing that the numbers are actually the current flowing through both tubes. If the plate current was 70mA for each individual tube you'd likely witness a reenactment of Chernobyl via your power tubes!

Also, this does not mean our amp is putting out 28.56 watts, or even close to that. Plate dissipation has nothing to do with the actual output wattage of our amp. It is simply a measure of DC power, and since DC can not be converted into acoustic energy by the loudspeaker, it must be dissipated in the form of heat. The actual output of our amp is in AC power and is only truly measurable with an oscilloscope, a function generator, a power resistor, and a trained eye.

All I did next was take 28.56 and divide it by two. This is our "ideal" static plate dissipation for both tubes.

28.56 watts / 2 = 14.28 watts each

In truth this number would only be correct if both tubes were perfectly matched. Since this is rarely true our 14.28W is only theoretical, but it's usually close enough. If you'd like to read the cathode current for each individual tube pick up a bias probe. I recommend the Weber BR-AH, and at US$30 it's a great deal! You do not need any bells or whistles with it. We can easily measure plate voltage on our own, and getting the one that switches to pin 5 is useless for our amp. The adapter is simply placed between a power tube and its socket. If you measure the cathode current for one tube, the cathode current for the other would be the voltage read at the bias test point minus the voltage read with the Bias Rite. Remember, combined cathode current is read at the bias test point—okay, okay, I'm sure you're getting sick of hearing me say that!

The highest value we should set the static plate dissipation to is 70% of 30 watts, which is 21 watts. I recommend that you do not bias to 70%, and to a more modest number such as 50% or 60%. (NOTE: If you're using a slightly different variation of this tube [ex. Sovtek's 6L6WGB], then this number could be a little different. In that case check the manufacturer's website for appropriate spec sheets.) Note that 14.28 watts is less than 21 watts, so our tubes are operating at a point that's comfortable for them. At 100mV the static plate dissipation would calculate to be 21 watts, a perfect 70% of the maximum plate dissipation, though there are a few reasons why we should not bias this hot.

First and most importantly, our amp wasn't designed to run this hot! One question is "what are the transformers rated at?" The answer? I, nor anyone outside of Fender's engineering department, knows for sure. Fender will not release the specs. What is known is that because the Hot Rod uses a bridge rectifier instead of a full-wave tube rectifier, Fender can get away with using less copper in their transformers. This translates into lower thermal tolerance, and means the transformer is prone to overheating if the specs are exceeded, even by a narrow margin. When the power tubes are biased hotter the power transformer must supply more current and, as a result, both the power and output transformer physically run hotter from increased current draw! Skimpy transformers do not dissipate heat well, and when biased in "High AB" (ex. 100mV at bias test point) the transformer(s) may croak. The power transformer will probably go before the output transformer. Heat is not good for electronics, and be assured biasing hotter will affect transformer longevity. Unfortunately, the transformers are also some of the most expensive parts to replace.

It is not important what the speaker is rated at, because of the plate voltage the power tubes are ran at. The plate voltage plays a key role in how many watts an amp can put out. A lower plate voltage means a narrower range to amplify our guitar's signal. So the tubes will be driven into cut off earlier. This is why the Hot Rod Deluxe can only put out 40W, according to Fender, while the Deville can put out 60W. Even if we increase the bias so that the tubes are dissipating the maximum 30W each, we will never get every available watt out of 6L6GCs in the Deluxe. To get more watts we will need to raise the plate voltage in the power amp. Some amp designers lower the plate voltage way down—called "starving" the tubes—to get a distortion sound earlier. Eddie Van Halen lowered the plate voltage of his Marshalls with a Variac (a variable AC power supply), but because the amps were designed to run at a specific voltage ended up killing many good amps.

Since we're biasing hot our power tubes will "clip," or saturate, or distort earlier. When tubes are driven into saturation the output signal is distorted when compared to the input signal. Usually the peak of one alternation of the AC waveform is shortened, or "clipped." This is called amplitude distortion, but it also creates *harmonic* distortion, or THD (total harmonic distortion). A typical amp might be rated at 50 watts RMS with an 8 ohm load at 5% THD. The problem is that guitar amps are routinely overdriven way passed 5% THD. What happens is the clipped sine wave starts turning into a "square wave." The average power level of a square wave is 30% higher than a sine wave because the signal remains at maximum power for a longer period of time. As the power amp is pushed harder the percentage of THD increases, and as a result the effective output of the amp increases. I've heard of this getting to over 100W with two 6L6GCs! Yikes! I seriously doubt the Hot Rod amps have enough gain for that to happen though. The increase in odd and high order harmonics would become so great the amp would sound terrible, and it would be noisy as hell.

Fortunately, and unfortunately, the human ear loves the sound of harmonic distortion solely because of the increase in even-order harmonics. Harmonic distortion will always increase in order as output power is increased, which will be the 2nd, 3rd, 4th, 5th, 6th, and so on harmonics. If the fundamental frequency was a "C" this would be C, G, C, E, and G respectively. On the "natural scale" these are all even-order, but most of the harmonics after the 6th will be dissonant. Generally, the ear favors even order harmonics (2, 4, 6, 8) over odd order harmonics (3, 5, 7, 9), and lower order harmonics (2, 3, 4) over higher order harmonics (6, 9, 10, etc.). The ear can usually detect even tiny amounts of high and odd order harmonics, and is annoyed by them. So biasing hot to increase harmonic distortion may only sound good *to a certain point*. This point is often called the "sweet spot" by musicians and audiophiles. Heavily overdriven Class AB amps are laden with odd-order harmonics, which the human ear does not like. Class A amps are smoother when extremely overdriven, as they don't produce odd-order harmonics like Class AB does, but they're terribly inefficent, they murder your power tubes, and they require tougher and more expensive transformers. In my opinion, if Class A is not played in extreme overdrive the whole time you may as well use a Class AB power amp. Also, take note that 90% of the amps out there that claim to be Class A really aren't, and are usually refered to as "High AB" *coughVoxAC30cough*; the class of operation only refers to the power amp (every guitar amp I've seen has a Class A preamp); and all the highly collectable and sought after guitar amps I know of are Class AB. In other words, Class A is used as a gimmick 95% of the time.

If we bias cold enough so that there's cross-over distortion there'll also be an increase in odd-order harmonics. This is why many people describe coldly biased tubes as "sterile." Also, increasing negative feedback decreases harmonic distortion. Early solid state amps used a lot of negative feedback, which made them sound inferior to tubes. This is how they got their bad reputation, though today many solid state amps can accurately mimic how a tube saturates. A <u>good</u> solid state amp can hold its own with most tube amps, but most people only have experience with the extremely low quality "practice amps." Play a *nice* solid state amp and you'll see what I mean.

The second reason to bias modestly has to do with the power tubes themselves. If we biased right at 70%, when we played through our amp 30 watts would be dissipated at the AC peak of the signal for each tube. This means the maximum plate dissipation would be reached many times within the fraction of a second. We must also consider that, even though the tubes are matched, one will probably drift more than the other. We will not be able to detect this at the bias test point. Again, this is why I recommend biasing at a more modest number, and why I recommended absolutely no more than 80mV for either amp.

> "It is important that matched valves should never be run, even momentarily, at dissipations or ratings in excess of those recommended by the valve manufacturers as such treatment will render the valves unstable and destroy the

matching."

- F. Langford-Smith, ed. "Audio Frequency Power Amplifiers: Push-Pull Triodes Class A, AB1: V. Matching and the Effects of Mismatching." Radiotron Designer's Handbook. Fourth Edition. pg 580, paragraph 9. Wireless Press, 1953.

If you own a Deville, your tubes are tightly matched, and you choose to bias close to 70% be sure to check the bias quite often. It will very likely drift, and could easily exceed the rated maximum plate dissipation. A great idea is to purchase a small fan and blow it onto your power tubes at gigs.

Of course this is all said for the sake of longevity and avoiding unwanted repair costs. In the case that you care about neither, you can always set the dissipation as far passed 70% as you'd like. Heck, setting the static dissipation to 100% might even put you into the sacred-mother-land of "Class A"—which has been a laughable manufacturer's buzzword for decades, in my opinion.

What's the Correct Way to Bias?

There's been quite a bit of arguing over the "correct" way to bias a tube amplifier. Do we check for crossover distortion using the crossover-notch method? How about biasing to [insert number]mA, or using the Output Transformer Shunt method to measure plate current? What about using a 1 ohm Cathode-Resistor? Which is the most accurate, which isn't?

The one and only way to correctly bias any tube amp is **by ear**—afterwards always checking that the static plate dissipation. It should be absolutely no more than 70% of the tube's rated maximum plate dissipation in a Class AB amp, and preferably less. Looking for crossover distortion on an oscilloscope, or biasing to a certain number all have their drawbacks, which I'll let the others argue over. Scopes and function generators are expensive and at best unreliable to the inexperienced techie. The fact is: if your amp sounds good to you, and your calculations indicate that your tubes are operating safely, then you've correctly biased your amp—congratulations.

Measuring plate current using the output transformer shunt method may give a more accurate number when calculating plate dissipation, but it isn't necessarily a "better" method for some people. First of all, you need nice equipment to use the OT shunt method—think Fluke. Second, nay-sayers argue that cathode current is plate and screen current combined, therefore the plate dissipation is inaccurate. This is true, though the screen current is only a few milliamps. Calculating plate dissipation with cathode current (measured at the bias test point) will result in a slightly hotter number than we'd get by measuring the actual plate current. This is perfectly okay as actual plate dissipation will be slightly cooler than calculated.

If you're really anal, and want to know the exact plate current, you could always measure the voltage drop across the screen resistors, calculate the total screen current, then subtract that number from what you've read at the bias test point. You'd then know the exact plate current. I've included this in my Bias Calculator, but left it as "optional." (I ignore it because, as far as I'm concerned, we're biasing a guitar amplifier, not landing on the moon.) Third, using the OT shunt method requires the user to expose themselves directly to the B+, which is well over 400 volts. Don't slip or you could be in for trouble! As you may have guessed, the accuracy of the cathode current reading is dependent on the tolerance of the resistor being used. I therefore recommend a 1W 1% metal film resistor because of their stability and extremely low drift.

Why 68mV?

You'll often hear people recommend you bias to 68mV for the Hot Rod Deluxe/Deville. Around this point is where the Hot Rod Deluxe is putting out 40W clean RMS power, which is the industry standard for amplifier power rating. Believe it or not, it's not unusual to find a Deville only putting out a few more watts than the Deluxe! The truth is, I've heard of techs finding Devilles that spec out around 40W, nowhere near 60W, while the Deluxes tend to spec out at from 20W to 40W on the nose—but this is a whole other discussion.

At 68mV it's safe to assume your Hot Rod Deluxe/Deville won't be running too hot or too cold, and many people feel around this point is where their HRDx sounds its best. Again, I think if you bias to 68mV ± 5mV, you'll be absolutely fine. Biasing hotter will increase the wattage of your amp, but only to a point. Biasing hotter will always decrease clean headroom and increase THD. As I pointed out earlier, consider 68mV a "starting point," and use your ear to tweak it where you like it—some people like the sound of their amp biased on the cold side. The "sweet spot" of any amp is totally subjective. The only way to determine what sounds best to you is by experimenting.

Hot Rod Devilles are engineered a lot tougher with larger transformers, and can therefore take more abuse. Only Devilles should be biased anywhere near 70% plate dissipation, and preferably not right at it. To find where 70% is plug your own values into my Biasing Calculator.

Why does Fender recommend 60mV? Don't the recommend 5881s in the old manual?

60mV = 60mA (at the bias test point)

60mA / 2 = 30mA (per power tube)

30mA * 420V = 12.6W (heat dissipated by tubes at idle)

12.6W * 1.414 = 17.8W (heat dissipated by tubes at maximum output)

So if you bias to Fender's recommended setting the power tubes will be dissipating between 17.8W of heat (at their peak output), and 12.6W of heat (at idle) at all times.

This will work with most 6L6 related tubes, including the weaker 6L6 types rated at 19W plate dissipation. If you bias at Fender's recommended setting for the Hot Rod Deluxe you're plate dissipation will be fine for all 6L6 type tubes. Furthermore, power tubes can more readily handle higher plate voltages than they can higher plate dissipation. Fender is notorious for working their power tubes up to their limit to squeeze every bit of clean headroom out of them. So it seems we should be able to use them, right?

Well, most people forget about screen dissipation--which is just as important. Note that a true 5881/6L6WGB is rated for 270V at 3 watts. We're putting 420V on the screens, which is quite a bit, and all we have protecting the screens are adequate 470 ohm screen resistors. What Fender is doing is taking the chance of working the tube passed its limit so to gain clean headroom--Fender was always trying to build the cleanest amps available. If we use 5881s, or other weaker 6L6 type tubes, we're going to be taking a risk. What often happens in old Fender amps is the screens get too hot and melt, causing a tube short which causes the screen resistors to burst into flames--any old amp tech can tell you about this! Screen resistor failure is a common problem in old (and new) Fender amps. Techs just replace the resistors and put in a new set of power tubes.

We don't need to beat up our power tubes for clean headroom.. we can use 6L6GCs which are built to easily handle everything the HRDx can put out. We don't need to take chances if we use the 6L6GC. As I said on the bias page, you could probably use 5881/6L6WGBs and get away with it.. but you're taking an unnecessary risk. That's why I said proceed with caution. I disagree with Fender's recommendation to use 5881s, for relability purposes. Moreover, new production tubes just aren't built as well as vintage American power tubes (RCA, GE, Tung Sol, etc).

Matched Tubes (or not)?

For almost a century people have been plugging in whatever was on hand, and because of this some otherwise reliable tubes have gone before their time. In our amp, the cathode current of both tubes is measured at the *bias test point*. For example, say our reading is 70mA. That could roughly be 35mA each, or with an unmatched set 50mA through V4 and 20mA through V5. The latter would appear to be operating safely, even after calculating static plate dissipation, but V4 would obviously be running much hotter than V5. Increasing the total bias could destroy the tube in V4, and such a large mismatch could cause long term damage to the output transformer. This is an extreme example, though possible.

One argument against matching tubes is that it is "unnecessary" because the phase inverter and output transformer are "unbalanced." This is true, though we're not trying to perfectly balance our poweramp; it's damn near impossible, not to mention counterproductive. Pretty much all Fender amps with an adjustable bias control—like our Hot Rod—have one bias pot that controls the current flow for <u>both</u> power tubes. Here, balancing the power amp really isn't even an issue.

The site goes on to discuss how even matched tubes will have a high likelihood of aging (or drifting) differently. While this may be true, his argument is illogical. They're basically saying matched tubes may one day become "unmatched" so don't bother buying them. What they don't tell us is how this makes using unmatched any better. The fact is, even if a matched pair does drift, it may never drift as far apart as two randomly chosen tubes. Ironically enough, they were raving about the "vast differences" and "poor quality control" of tubes just a few paragraphs earlier. Good distributors will "burn in" their tubes for a few days before matching them. This helps weed out bad tubes and greatly helps stabilize premature drifting. The Radiotron Designer's Handbook recommends that prior to matching, the tubes "be operated for at least 50 hours under similar conditions to those under which the valves are intended to be operated in the amplifier." (4th Ed. pg 580)

Originally matching was a "Hi-Fi" thing, along with "balanced" phase inverters and the such. In truth the phase inverters used in guitar amps will never be perfectly balanced because both split load and long-tail phase inverters are unbalanced by design. (Ignore the "balanced" phase inverter hype.) The idea of matching was to get the signal as clean and hum-free as possible. In push-pull amps the power tubes are ran 180° out of phase of each other by the aptly named *phase inverter*, sometimes called the *power inverter*. The power amp is set up like a humbucker, which cancels hum and noise but not the guitar's signal. A Class AB push-pull power amp is ideal for HI-FI because it's eliminates most of its second order harmonics, which affect the clarity of a audio recording. (Remember that Fender's goal was *very loud and clean*, which wasn't fully reached until the blackface Twin.)

What most people don't know is that asymmetrical output produced by mismatched tubes may actually be desirable in guitar amps. Classic vintage Fender amps did not use matched power tubes for economic purposes. Vintage gear has literally reached a religious status, and as a result some vintage enthusiasts assume "if Fender did it in the 50s and 60s it's right!" This is simply poorly reinforced conjecture. They know what works, but they don't know *why* it works. What most guitarists don't know is that mismatched tubes actually increase second harmonic distortion, which many find beneficial for tone creation but not tone *recreation*. In my opinion, the importance of matching "for a better tone" has been overemphasized by people who read vintage Hi-Fi! Great for your stereo, but not as important in your guitar amp unless you're trying to achieve the "cleanest" sound possible.

If a power amp is more "balanced" than not, even-order harmonics are cancelled out, which lowers THD (total harmonic distortion). It was, and is, important that vintage Hi-Fi receivers have less than 1% THD for the clearest sound reproduction possible; but, as I explained earlier, many guitarists prefer lower even order harmonics (2nd and 4th) as they add "life" to the tone. It's not at all unusual for a tube guitar amp to be routinely driven passed 10% THD.

Mismatched tubes may increase desirable second harmonic distortion, though at the expensive of increased 60-cycle hum. (I've heard some people describe mismatched tubes as sounding "fatter."} Also, in theory a large enough mismatch could damage the output transformer, though probably won't happen. It's safe to say that tubes drawing within 8mA of each other should be fine—anything greater could cause long term damage. I see nothing wrong with a little "controlled" mismatching if biased at 50-60% plate dissipation, though I'm against plugging in random tubes just because "Fender did it," or because "that's how we used to do it back in the day." All tubes should be burned in to help control drifting, but they do not need to be matched "perfectly" unless they're going inside your stereo.

Matched, mismatched? It's subjective. Which ever you choose just be sure not to exceed maximum plate dissipation. If you buy tubes that were purposely slightly mismatched be sure to pick up a

Weber Bias Rite, and keep an eye on them if you bias hot. Some find that slightly mismatched power tubes that are properly biased yield the greatest tonal results.

Go back to Biasing for Dummies..

By Justin Holton