The Last Word On Biasing

General

There are only two things to worry about in biasing a guitar amp. The first and foremost is not to set the bias current so high as to exceed plate dissipation at any portion of the tubes operation, as indicated by that nice warm red glow of melting plates and the sound of a cash register ringing up a new set of tubes. The second is to not set the bias current so low as to sound bad, which generally means approaching or exceeding class B operation as indicated by the onset of heavy crossover distortion. Any point in between these two is fair game and is subject to personal taste. There is no single "correct" bias point.

Biasing methods

The negative grid voltage method: This method involves measuring the DC voltage on the grid of the output tubes, and setting it to a recommended value. Biasing by negative grid voltage is highly inaccurate because the same grid voltage can produce drastically different plate currents in different tubes of the same type. This method should be avoided.

The crossover distortion method: Biasing by the crossover distortion method as indicated in the Pittman book and other literature is also extremely inaccurate because the point at which crossover distortion appears is very hard to detect and is subject to changes with load impedance, amount of negative feedback, and, in particular, with grid drive if the phase inverter is AC coupled to the output tube grids (as it is in almost all guitar amps). Following are additional reasons why this method should be avoided:

When driven into the positive grid region at clipping, the output tube grid acts as a forward biased diode and clamps the positive peaks of the grid waveform to a point slightly above the cathode voltage. As the input signal level is increased, the clamping action forces the average value of the grid waveform downward, effectively increasing the average negative grid bias. This results in more crossover distortion, even if the amp is biased higher into class AB. Because of this clamping effect, the amount of crossover distortion that you are trying to "bias out" will change depending upon how far into clipping you set the grid drive. If you keep trying to eliminate the "notch", you will bias the amplifier too hot, and your tubes will be destroyed.

This method gives no indication of the actual bias current or plate dissipation in the tubes, so you have no idea whether or not your amp is biased into a safe region of operation.

If you have two class AB amplifiers, one with a plate voltage of 350V, the other with a plate voltage of 550V, and set them both using this method, the amplifier with the 350V plate voltage may be biased too cold, while the amp with the 550V plate voltage may be biased too hot.

If you try to bias a push-pull class A amplifier using this method, you will end up biased right to the cold side of class AB operation, and you will no longer have a class A amplifier!

If you have a single-ended amplifier, there is no crossover notch to be seen, so this method is useless. In some cases, particularly with large amounts of negative feedback, the notch on a class AB amplifier cannot be seen, either.

Plate/cathode current method: The only truly accurate method of consistently setting the bias is to measure the quiescent plate current and set it to a point within the acceptable range for the plate voltage the tube is operating at and the desired class of operation. This can be done in one of several ways.

The plate current can be measured by inserting a DC ammeter in series with each plate lead, which allows a direct reading of the plate current. This method is not very practical because it requires desoldering the plate connections, and is dangerous due to the high voltages involved, and should be avoided. It can also cause error-inducing or potentially damaging oscillations if the meter leads get close to other parts of the circuitry. However, there is a commercially available device that uses this principle, the Allessandro Bias Meter. It has socket adapters and direct reading meters, so the user doesn't come in contact with the high voltages, and the socket adapters are on the other side of the chassis, so the wiring is somewhat isolated from the rest of the circuitry to help prevent oscillations. The plate current can also be measured by permanently installing a resistor in the plate lead of each output tube. The actual plate current can then be measured as the voltage drop across this resistor. If a 1 ohm resistor is used, the plate current in milliamps is equal to the voltage across the resistor in millivolts (50mV across the 1 ohm resistor indicates 50mA plate current). This method is practical, but can also be dangerous because of the high voltages on the plate.

The plate current can also be measured using the "shunt" approach, where an ammeter is paralleled across each side of the output transformer. Since the internal shunt resistance of the ammeter is usually small in comparison to the resistance of the primary winding of the output transformer, most of the current is diverted through the ammeter, giving a fairly accurate reading of the actual plate current. This can also be dangerous because of the high voltages involved. One slip of the probe, and your expensive output transformer primary is shorted to ground through the low resistance of your multimeter. At best, you will blow the fuse in the meter. At worst, the output transformer primary winding will burn out in order to protect the multimeter fuse. This method is also inaccurate to varying degrees depending upon the make/model of the meter used. Some digital multimeters have fairly high internal shunt resistances (particularly on the lower current ranges), which will result in a reading that is lower than the actual plate current. This can result in setting the actual bias current too high, which can cause premature tube failure. Note that the shunt current measured on each side of the output transformer will be the total current drawn by all the tubes on that side, so if there are two tubes on each side, you must divide the measured shunt current by two.

The plate current can also be measured by first measuring the resistance across each side of the output transformer primary (it will usually be different on each side) with the power off. Make a note of the resistance on each side, and then, with the amplifier on, measure the DC voltage drop across each side of the output transformer. Divide this number by the previously measured resistance, and you end up with the plate current for the tubes on that side. Again, if there is more than one tube on each side, you must divide the total current by the number of tubes. This method is extremely accurate, and much safer than the shunt current measurement method, because a slip of the probe won't short anything out due to the high resistance of the voltage measurement setting on the meter compared to the very low resistance of the current measurement setting. You can also make a safer measurement by clipping the negative side of the voltmeter on ground, and measuring the center-tap voltage of the output transformer and the voltage at the plate of each output tube. Subtract the plate voltage from the center-tap voltage and you have the voltage drop across each side, and can then use this to calculate the current in each tube, again dividing by the number of tubes on each side.

The plate current can be indirectly measured by determining the cathode current in the tube. Since no appreciable current flows in the control grid of the tube, all of the plate current must also flow in the cathode. The cathode current, however, will also have all of the screen grid current flowing in it as well, since the cathode current is the sum of the plate and screen currents. Typically, the screen current in most commonly used pentodes is around 5mA (this varies, of course, depending upon the class of operation, the bias point, and the type of tube used). The screen current can be accurately measured by determining the voltage drop across the screen resistor and dividing by it's value (for example, 5V across a 1K screen resistor indicates 5mA of screen current). If you install a 1 ohm resistor in the cathode lead of each output tube, you can measure the voltage drop across it to get the cathode current, as described above in the plate resistor measurement. The advantage of this method is that there are no high voltages involved, since there will only be a few millivolts difference between ground and the other side of the 1 ohm resistor. The disadvantage is that you must subtract the screen current in order to accurately determine the plate current. However, since the screen current is only a few mA, it can usually be ignored, and the error will be in the conservative direction, i.e., less plate current than expected, which is good for tube life. This method of biasing is the most highly recommended. There are a few bias meters on the market that use this method, including the SwAMProbe (it doesn't measure across a resistor, rather, it breaks the cathode circuit so you can insert a milliammeter for direct cathode current measurement), and the Bias King. These devices have socket adapters that go in between the tube and the socket to make it easy to measure the bias current on an amplifier without having to modify it.

How much current?

The other important factor in setting the bias is to know the acceptable range of currents at which the tube can be safely operated, known as the "safe operating area" of the tube. Unfortunately, without some technical knowledge, you cannot usually look at a schematic or tube type and tell what the correct bias current range is. The manufacturer should provide a recommended bias current or range of currents for each particular amplifier. Unfortunately, this is not usually the case, as most manufacturers want you to have to buy their tubes which have been specially "matched" to the amp in question, usually at a high markup. Other manufacturers are merely copying existing designs, repackaging them, and don't know the correct way to bias an amplifier.

Some "gurus" will tell you that an EL34, for example, needs around 40mA of bias. This is inaccurate information, because it doesn't take into account the class of operation, the output transformer primary impedance, or the plate voltages involved. For instance, an EL34, in class AB operation at 400V, with a 4K plate-to-plate primary impedance, would be biased at 40mA, while the same EL34 tube, used in a true class A circuit at 250V, might be biased at around 100mA.

A general rule of thumb is that class AB amplifiers are usually operated at no more than 70% of the maximum plate dissipation of the tube (to account for the higher dissipation that occurs under signal conditions), *while true class A amplifiers generally run right at the maximum plate dissipation (the dissipation at full power is lower than the dissipation at idle in a true class A amplifier). For example, the aforementioned EL34 tube has a plate dissipation of 25W, so at 400V class AB operation, it should be biased no higher than (0.7 * 25/400) = 44mA. This doesn't mean you should automatically bias all tubes to 70% of max dissipation! They can be biased at any lower current if desired, and many people prefer a point of around 50% to 60% of the max plate dissipation, which contributes to longer tube life. In addition, the "70% rule" falls apart as you use very high plate voltages, unless the primary impedance is increased accordingly. In some cases, if the voltage is high enough, there is no bias setting that will result in safe operation without exceeding the maximum plate dissipation of the tube. For example, in a 100W EL34 amp with 480V on the plates and a 1.7K primay impedance, there is no bias setting that will keep the output tubes from redplating at some point in the power curve, even if you bias the amp at 0mA! If you double the primary impedance to 3.4K, however, the amplifier will operate fine at all power levels, and you can bias it all the way up to 52mA without ever exceeding the plate dissipation at any point in the operating curves. This may sound odd, because the bias point is right at 100%, but it works because of the very high plate impedance load, which never allows the tube dissipation to increase above the idle level. It also may not sound as good, because the screen voltage should ideally be decreased so the loadline intersects the "knee" of the curves if not, the nonlinearity increases drastically. The bottom line is that you have to take into account not only the plate voltage and plate current, but also the primary impedance to find out the safe bias area.*

In true class A operation at 250V, it should be biased no higher than (25W/250V) = 100mA. Note that a class A amplifier does not necessarily have to be run at the maximum ratings. You could design a true class A amplifier at lower plate voltages and higher currents, but there is a limit to how high the plate voltage can be without exceeding dissipation ratings, or having to go to class AB. There is also a limit at how high the plate or cathode current can be for a particular tube. A class B amplifier should be biased right at cutoff, or perhaps a few mA standing current, to minimize crossover distortion. Class B amplifiers usually have extremely high plate voltages in order to maximize the output power, so they must be biased right at cutoff to prevent over-dissipation at full power. If in doubt about the actual operating conditions of the circuit, call the manufacturer or refer servicing to a qualified amp technician.

Note that what most manufacturers pass off as "true Class A" or "pure Class A" push-pull operation is, in reality, merely cathode-biased class AB push-pull operation. If you use the class A biasing rules for these amplifiers, you may burn up the tubes. These amplifiers should be biased according to the class AB rule of thumb, but can sometimes be *biased a bit hotter due to the larger voltage drop that occurs across the cathode resistor under full signal conditions. For example, if a push-pull amplifier using EL84 tubes is operated much above 250V, it is probably class AB, because you cannot get true class A operation at much higher plate voltages without exceeding the plate dissipation limits, unless you run a very high plate load impedance, which is not typically done. The operating point in a true class A amplifier is chosen to correspond to a point on the load line where the load line intersects the maximum plate dissipation curve in such a way as to provide relatively symmetrical swing at the output. This maximizes the output power before clipping and makes the amplifier relatively linear.*

If you run an EL84 at 300V, for instance, the 12W plate dissipation limit requires you to bias the tube at a point where it will be in cutoff for a significant portion of the input cycle, if the load line intersects at or near the "knee" of the zero bias plate curve as it should, unless you run a very high load impedance which results in a relatively flat load line that intersects the plate curves at a very low point far from the "knee". This results in highly nonlinear operation at lower grid bias voltages (for example, the separation of grid bias curves is smaller from 0 to -4V than it is from -4V to -8V).

After biasing an amplifier, be sure to carefully look at the plates of the output tubes for any signs of reddish-orange glow, usually in the center of the plate, which is the large grey metal piece surrounding the tube elements. Don't confuse this with the normal filament glow. If you see signs of plate glowing, you have biased the amplifier too hot, and you must reduce the plate current. In some cases, particularly with older high-power amplifiers, the tubes will run hot no matter what you do, and the tubes fail frequently, unless you bias the amp very cold. These amps generally have no series screen resistors on the output tubes. In these cases, you should add a 1K 5W resistor in series with the screen grid wire on each output tube. This resistor should be soldered directly to the pin of the socket, with short leads. Also, the wires going to the screen and plate pins should be kept well away from the wire going to the control grid pin.

What about screen voltage? Does it change the bias current?

*The screen has much more control over the plate current in a pentode than does the plate voltage. However, it does not have as much control as the grid voltage does. When biasing, what counts is *plate* dissipation, which is equal to plate current multiplied by plate voltage. However, you must take into account the duty cycle factor of the class of operation. For most guitar amplifiers, the screen voltage is the same as the plate voltage, and the amplifier is biased in a moderately hot class AB. As a side note, the screen grid has dissipation limits as well, and you must insure they are not exceeded. If you see the screens* *glowing brightly when you apply a signal, you are likely exceeding their dissipation ratings. A measurement of the voltage drop across the screen grid resistor under signal conditions will allow you to calculate the screen dissipation.*

In some amplifiers, the plate voltage is made very high, higher than the maximum allowable screen voltage, so the screen must be run at at lower voltage in order to avoid over-dissipation of the screen grid element, or internal arcing between elements.

In this case, the amplifier is usually biased in class B, or a very cold AB, in order to take advantage of the greater power output capability provided by the higher plate voltage.

*At first glance, you might assume that as long as you don't exceed the plate dissipation at idle, you can bias the tube at a current equal to the plate dissipation divided by the plate voltage. However, this will only work in a true class A amplifier, because in a class AB or class B amplifier, the average plate current *increases* above the idle value when amplifying a signal, so the plate dissipation is higher during some point in the output range than it is at idle. The maximum dissipation point does not necessarily occur at full power, typically it is closer to midscale. For further details, see this article - Idle Current Biasing - Why 70 percent?*

This is where the "70%" factor comes in when bias calculations are given. In a typical guitar amplifier running at moderate class AB duty cycles, the difference between idle and max power dissipation amounts to about a 30% increase, so as long as you don't set the idle current to a level that results in more than 70% of the maximum plate dissipation, you're okay.

As you can see, the screen voltage can affect the maximum allowable bias current, but it is dependent on the plate voltage and the class of operation. If you take a "standard" guitar amp and lower the screen voltage, you can raise the grid voltage (less negative) and bring the bias current right back up to where it was at the original screen voltage without overdissipating the plates at idle or under signal. In this case, since it takes a smaller negative grid voltage to attain the same plate current (because of the lower screen voltage), you will lose headroom. If you don't raise the grid voltage, you will simply have the amp biased more towards class B, with the resultant increase in crossover distortion.

What about cathode-biased amplifiers?

Do cathode-biased amplifiers need to be biased? The short answer is yes. The cathode biasing method is self-regulating, to an extent, because increases in cathode current create a larger voltage drop across the cathode resistor, which in turn, creates a larger negative grid-to-

cathode voltage, which counteracts the increase in current. The tube will reach a stable point of equilibrium and stay there. However, just as different tubes from different manufacturers will draw varying amounts of current in a fixed-bias amplifier, the same is true of a cathode-biased amplifier. For this reason, the bias should always be checked, even with cathode-biased amplifiers.

Checking the bias current in a cathode biased amplifier is easy, just measure the voltage across the cathode resistor and divide by the resistance value to obtain the cathode current. Note that if the output tubes share a common cathode resistor, you must divide the current reading by the number of tubes sharing the resistor. Note also that a common cathode resistor does not allow you to determine the individual currents of each tube, so if one tube is drawing more current than the other, you would not be able to determine which is causing the mismatch, and, in fact, you would not be able to tell there was a mismatch at all. You can add individual 1 ohm resistors from the cathode of each tube to the common bias resistor, but you must then measure across the 1 ohm resistors, not from the cathodes to ground, to determine the voltage drop, and thus the cathode current. You can also use individual cathode bias resistors on each tube. The value of the resistor will be double that of the common resistor if two tubes are used, or four times that of the common resistor if four tubes are used. Each resistor would also have to be bypassed with its own electrolytic bypass cap.

The difficulty with cathode-biased amplifiers is that the cathode resistor must be physically changed for another one of different value in order to change the bias current. Although it can be done, very few guitar amplifiers have adjustable cathode bias.

Cathode-biased class AB amps are usually exempt from the "70% rule", because their cathode voltage rises when a signal is applied, effectively reducing the bias, and shifting the amp further into class AB operation. This means you can bias them hotter than a normal fixed-bias class AB amp and the tubes will still survive. Having said that, you have to experimentally determine how hot you can bias them by finding out how far the bias shifts during signal flow.

If the cathode-biased amp is "true" class A, there will be no bias voltage shift seen on the cathode when signal is applied, so you can bias at max dissipation and not worry about it. If the amp is actually class AB, you might still be able to get away with biasing at max dissipation because of the large bias shift at full power that pushes the amp into the class AB region, but you should check the tube dissipation at all signal levels. Note that max dissipation may not occur at full power, rather at somewhere between idle and full power (usually around halfway), so you have to carefully determine the safest max idle current to avoid exceeding the dissipation at any point in the tube's operation.

Do I really need to bias my amplifier every time I change tubes?

You will occasionally hear guitarists say things like "In the old days, we just bought new tubes, stuck 'em in, and started playing", and "We didn't worry about biasing back then, and you don't need to now", or perhaps: "Biasing is a myth". In most cases, you don't have to bias your tubes when you change them. You can just plug a new set in and start playing, especially if you aren't too particular about setting up the amp for the absolute best tone. However, if the new tubes you have plugged in are different enough from the ones that were in there, with respect to current draw for a particular grid voltage, they may end up biased too hot for that particular amplifier. In this case, your new tubes will start to glow cherry red on the plates, either at idle or while playing, and they will soon be destroyed. In addition, the tube may short out and take out the output transformer in the process, leading to costly repairs. Tubes of the same type from different manufacturers will usually vary greatly in current draw at a particularly grid voltage, but even two different tubes of the same type from the same manufacturer can vary widely in their current draw. For these reasons, it is always best to check the bias after installing a set of tubes. If you are in an emergency situation, such as a blown tube in the middle of a gig, you can go ahead and stick in your spare tubes, but you should turn the amplifier on and look at the plates of the tubes (the large dark grey metal element) in the dark, both at idle and while playing, just to make sure they aren't glowing red. Often, when a tube fails, it will take out the screen grid resistor, and any new tube you plug in will glow red, or won't work at all. In this case, you have no choice but to repair the amplifier before using it.

How important are matched tubes?

Most tube resellers will offer "matched" pairs or quartets, usually at a higher price than unmatched tubes. Matching generally refers to tubes that have the same current draw for the same given negative grid voltage and the same transconductance, or amplification factor. However, many vendors don't match for both parameters, they often only match for one or the other. Some vendors claim proprietary matching techniques and won't disclose them. You should be wary of this, as the tubes you receive may not be matched at all, particularly if your amplifier is different from their test circuit! Although no resellers do it, the ideal method of tube matching is to use a curve tracer and match by characteristic curves.

Idle current matching is important for output transformer current balance. In a push-pull amplifier, the output tubes on each side of the output transformer primary draw DC current through the transformer in opposing directions. This causes a net DC current of zero, and thus, a net zero magnetization in the output transformer core. This is important because a push-pull transformer has no air gap to prevent core *saturation. If the offset DC current is great enough, the primary inductance will drop, and the amplifier's low frequency response will suffer. It doesn't take much offset DC to produce an unacceptable drop in primary inductance in most output transformers. Tubes must be matched at the idle current range to be used in the amplifier, as they may be matched at one particular grid voltage/plate current, but not at another point. As an alternative to idle current matching, individual bias pots, or a combination bias/balance arrangement, can be used for the output tubes, allowing perfect DC balance even with unmatched tubes.*

Transconductance matching is important for AC (signal) balance in the output stage. A push-pull amplifier has inherent power supply hum rejection and common-mode input rejection due to the symmetry of the output stage. If one side has a different amplification factor than the other, this symmetry is lost, and the amplifier won't be able to reject power supply hum and noise as well. However, there is another property of push-pull amplifiers that needs to be considered when discussing transconductance matching, and that is the cancellation of even-order harmonics. In a properly balanced push-pull amplifier, even-order harmonics generated in the output stage will be canceled out. Note that even-order harmonics generated in the preamp stages will not be canceled by the output stage, only those generated within the output stage itself will be canceled, otherwise the amplifier would not sound very good! Some will argue that unmatched tubes actually sound better because of the lack of even-harmonic cancellation. This is a matter subject to personal taste, so there is no one correct answer, but it does mean that of the two parameters, idle current matching, or DC balance achieved through the use of a bias balance arrangement, is the more important of the two. Note also that the transconductance varies with the DC bias point, so it is again important that transconductance matching is done at the DC bias range the tubes will be operated at in the amplifier, if truly matched tubes are desired. Generally, it is not that critical to get such absolute precision, but if the tubes were to be operated at true class A, for instance, at 250V/100mA per tube and they were matched for class AB operation at 450V/30mA per tube, they may not be as well matched as desired.

Note that tubes tend to drift with age, and a matched set of tubes will likely become unmatched after awhile. Typically, the most drift occurs in the first several hours of use. For this reason, you should always purchase tubes that have been burned in for several hours before the matching process. This will minimize the amount of drift later in the tube lifespan. Many resellers match tubes after only a short warm-up time, which means that they will likely not end up being matched after you install them in your amplifier and play for awhile. Be sure to inquire as to the burn-in time when purchasing matched tubes.

Disclaimer - READ THIS CAREFULLY:

Beware that tube amplifiers contain lethalvoltages. This is not something to be taken lightly. If you do not have experience in dealing with high voltage circuitry, do NOT attempt to bias your own tube amplifier, refer the job to a qualified technician. Even if you do have experience in dealing with high voltages, remember to always keep one hand in your pocket when probing around in a live amplifier. Remember to always unplug the amplifier before soldering or replacing parts. Also, remember that the large electrolytic capacitors in a tube guitar amplifier can hold a lethal charge for long periods of time after the amplifier has been turned off and unplugged. Always discharge the capacitors before working on an amplifier.

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