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BIAS-Setup

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Foreword

It cannot be repeated often enough: tube amps work with voltages which can be fatal. Even when they are unplugged, tube amps contain capacitors which are still charged with voltages high enough to cause painful and dangerous injury. In addition, the amp itself can be damaged by improper treatment.

Consequently, a detailed study of this document is suggested before beginning work. Afterwards, you should ask yourself, "Am I capable of making these adjustments myself, or would it be better to go to a technician?" Honesty is the best policy here; overestimating your abilities can have fatal consequences.

If you are uncertain, than it is better to err on the side of caution and go to a professional.

This document cannot answer all the questions which may arise in working with tube amps. Further questions can be posted in the Technical Forum on the homepage from www.tube-town.de. A glance in the forum - perhaps with the help of the search function - will certainly bring clarity, and if the question hasn't been answered yet, you are more than welcome to post it.

... and now, have fun in the world of tube electronics.

What is bias adjustment?

Tubes are components which are subject to a certain amount of wear and tear. They don't work forever at full power and 100% reliability; rather, they deteriorate with time. Because of the way they are constructed, they can fail completely; for example, due to a broken filament, internal short circuit, or loss of vacuum. If this happens, the tube has to be replaced.

Nevertheless, the vacuum tube has a great many advantages, the biggest being of course the sound itself. The sound of tubes is very pleasant to the human ear. Solid state technology can reproduce this sound only with great difficulty, if at all. Even simply swapping tubes can change the fundamental sound of an amplifier. This is possible only with extensive modifications in a transistor amplifier.

A tube amp has to be properly adjusted before it produces the sound that one expects from such a device; furthermore, proper adjustment is also necessary to maximize the tube's lifespan and ensure the amplifier is not damaged.

The bias controls the current that flows through the tube and defines the quiescent point of the tube, so that the tube reacts immediately to an input signal and so that it amplifies that signal accurately. A good analogy from the automotive world is the idle speed of a motor.

The value of the quiescent point and its adjustment is dependent on the amplifier type.

For the most part, only two basic types, or "classes," of audio amplifier are used for musical instrument, studio, hifi, and high end amplifiers: Class A and Class AB (also known as push-pull amplifiers). These amplifier types may be modified or expanded to varying degrees, but they are all based upon the same basic circuits.

In summary, the important point is that adjusting the bias changes the current flow through the tube, which in turn defines the tube's quiescent point. This guarantees reliable operation of the tube and an undistorted reproduction of the audio signal. An incorrectly set bias can result in increased hum, other undesirable noises, and a distorted output signal.

Preparation

Three parameters must be known before an amp can be properly adjusted:

- Amplifier class (A or AB)
- Plate voltage
- Type of tube

The type of tube determines the power dissipation, which is required to calculate the idle current. Normally, bias adjustment is required only for output tubes (that is, the tubes in the output or power stage of the amplifier); preamp tubes are usually biased automatically at a fixed point using cathode resistors. Adjustments must be made while the amplifier is under load - either a speaker, or a dummy load (power resistor). If the load is absent, the output transformer could be damaged or destroyed.

Safety Notice

Tube amplifiers work at very high voltages. Because the bias adjustment must be made on a "hot" amp (one which is turned on), a very real danger exists that improper handling CAN BE FATAL. Persons without experience in working with high voltages are better served by going to an expert.

Furthermore, use of an isolation transformer is recommended, which, although it does not guarantee 100% protection, at least provides separation from ground as well as the use of an FI (fault interrupter).

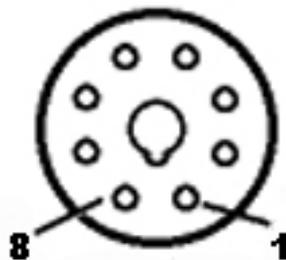
Plate voltage

It is best to measure the plate voltage directly on the socket of the output tube. On the common octal tubes, this can be measured with a voltmeter between pins 3 and 8. This ensures that the real plate voltage is determined, independent of any influence from other components.

The easiest method is to remove the tube and insert the meter probes in the socket. The meter should be set to measure DC voltages. In normal operations, with tubes, the real voltage under load will be somewhat less than at idle; if 450 volts unloaded is measured, as a rule the loaded voltage will be between 420 and 430 volts.

These values shouldn't be viewed as written in stone, as the voltage from the wall can vary from region to region and from day to day.

View from above:



Tube type

Determining the tube type is usually straightforward, since this is either documented or printed on the tube itself.

Amplifier class

On the other hand, determining the amplifier class can be a bit more complicated. Normally this should be stated in the handbook which accompanies the amp, or obtained directly from the manufacturer. Some manufacturers may give misleading or incorrect information, but this is the exception rather than the rule.

In general, higher-power amps are usually push-pull class AB circuits, while low-power amps are usually pure class A. Certain assumptions may be made as long as the power output of an amp is known:

A 50 watt amp with two 6L6 or EL34 tubes, or a 100 watt amp with four 6L6 or EL34s, is a push-pull amp. 100 watts with two KT88 is also push-pull. A small Fender amp with one 6V6 and 3 watts is operating in class A. Class A operation is often found in high-end audio, but less often in guitar and bass amplification. Today, class AB push-pull is usually used.

Determining the required value

At this point, we assume the amplifier to be adjusted is a class AB push-pull amp. Once the plate voltage and the tube type are known, the minimum and maximum values for idle current can be read from table 1. Naturally you can also calculate the values yourself. The formulas required are shown in the box further below.

Measuring the idle current

The idle current through the tube must be measured if the amplifier is to be properly adjusted. Since current is not as easy to measure as voltage, a variety of tricks are used to determine the value. These are explained below.

Resistor measurement

Usually, a resistor is used to simplify measuring the idle current. This 1-Ohm, 1/2 watt, low tolerance resistor is soldered directly in the cathode path. The voltage drop over this resistor is measured. Since the voltage drop is being measured over a 1-Ohm resistor, Ohm's Law shows that voltage drop in millivolts (mV) is equal to the current, in milliamps (mA).

A little theory

Ohm's Law states that

$$R = U/I \quad (R = \text{resistance, } U = \text{voltage, } I = \text{current})$$

from which the current can be derived:

$$I = U/R$$

Since the resistor being measured has a value of 1 Ohm, the voltage drop is equivalent to the current.

Practically, this means that a voltmeter is set to measure voltage (for example, 200 mV) and the probes are placed on either side of the 1 Ohm measurement resistor. If a value of (e.g.) 40 mV is measured, then, from Ohm's Law, we know that the current flowing is 40 mA.

If the measured value is outside of the permissible range, then the bias voltage must be adjusted until the idle current is correct. Normally this is achieved via a potentiometer included for this purpose.

If an amplifier does not have such a potentiometer, one can be added to the circuit.

Useful tools

If an amplifier does not have a measurement resistor in the cathode path, one can be added to the amp. This however can be difficult in amplifiers which are built on printed circuit boards.

As an alternative, an adapter can be used which does not require modifying the amplifier, but nevertheless yields the same value. A simple, but effective version of this adapter is shown in the photograph below left.



Such an adapter also measures the voltage (voltage drop over the measurement resistor) which is equivalent to the cathode current. In addition, there are adapters that measure the current directly. These adapters, however, can under certain circumstances cause problems, usually instability in the amplifier, and as such are not recommended.

Measuring idle current with the shunt method

It isn't always possible to measure the anode or cathode current with a measurement resistor or adapter. Furthermore, many amplifiers have no built-in measurement point, and may not be desirable or possible to add one if the amplifier is built on a printed circuit board, or if other arguments against such a modification exist.

In these cases the "shunt" method is available as an alternative method for the current measurements.

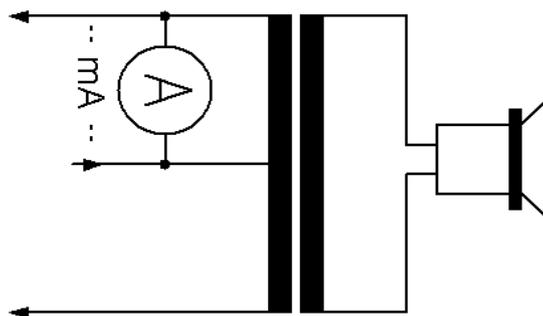
The ammeter used for this measurement must be of very high quality. The internal resistance of the meter should be nearly zero ohms, essentially a short circuit, so that one may make use of the fact that current always takes the path of least resistance. The current flow through the output transformer must be rerouted through the ammeter.

Important

This method should be used only by individuals with the necessary knowledge and experience in working with such currents and voltages, and in making such measurements, as a short circuit can quickly develop and damage the amplifier. Furthermore it is critical that the ammeter used is of very high quality, so that the measurements do not result in "garbage in, garbage out." Mathematically, one could say:

$$R_{\text{ammeter}} \ll R_{\text{output transformer}}$$

Back to the measurement setup:



The meter is set to the appropriate ampere scale (200mA), and the probes are connected parallel to one half of the output transformer - as a rule, the center lead and one of the side leads.

Some transformers have an additional lead, between the outer and middle leads, which is connected to the screen grid of the tube. This should be ignored.

When the meter is correctly connected, and the amp is turned on with standby off, the current flow through the output transformer is measured. The flow measured is the sum of the currents of all tubes connected to the measured side of the transformer.

However, the sum of all currents is not interesting; rather, the idle current through a single tube is needed for the calculations. If the class AB amplifier has a single pair of output tubes, then the current measured is the current flow through a single tube; however, if the output stage has more than two output tubes, then the value measured must be divided by the number of tubes per side. In the case of an amplifier with four output tubes (two per side), the measured value must be divided by two. If six tubes are used, the value must be divided by 3, for 8 tubes, divide by 4, and so on.

Disadvantages

At first glance, this method for measuring the idle current is simple and requires no additional hardware. However, it has certain disadvantages which do not particularly recommend its use.

First it must be emphasized that the meter used absolutely must be of very high quality. A simple multimeter from the clearance table in the corner of the hardware store is certainly the wrong meter. It may be difficult or impossible to fasten the probes to the output transformer, and they must be held there by hand. This of course increases the odds of slipping, leading to a blown fuse at best. If necessary, a couple of terminals to which the probes can be clipped can be soldered to the output transformer.

Finally, it should not be forgotten that total current is measured rather than the current of each tube individually. As a result, tubes whose values have changed, or which are defective, cannot be detected. For example, if you measure 80 mA, with two tubes per side, it is possible that 50 mA flows through one tube, and 30 mA through the other - there is no way to know with the shunt method. Nevertheless some people prefer the shunt method, and use it successfully. When in doubt, it is a matter of preference.

A further alternative to the shunt method

However, there is a second method, set up similar to the shunt method, but which measures voltage instead of current. After first shutting off the amplifier AND draining the filter capacitors, the DC resistance of one side of the output transformer is measured from the center tap to the start of the coil.

Next, the amplifier is turned on, and the voltage drop over the same half of the transformer is measured. The setup is exactly like that of the shunt method above, except that a volt meter is used rather than an ammeter.

Since the DC resistance of the transformer (which is constant) leads to a voltage drop, Ohm's Law can be used to calculate the current flowing through the transformer:

$$\text{Total Idle Current [I]} = \frac{\text{Voltage drop over the transformer [U]} / \text{DC resistance of the transformer [R]}}$$

As with the shunt method, the calculated current is the total current flow through all the tubes on the side of the output stage feeding the measured half of the output transformer, and it must be divided by the number of tubes per side, in order to obtain the current flow for a single tube. An alternative is to multiply the desired value for a single tube by the number of tubes and compare to the value measured, making adjustments as necessary.

Settings for class AB push-pull

Once a measurement method has been decided upon and everything has been prepared, all that remains is actually setting the bias. However, the most important parameter is missing: the value at which the idle current should be set. This can either simply be calculated, or read out of the table below.

Setting a tube to a value from the table guarantees that the tubes are working in a stable state. They will not be unnecessarily loaded, which contributes to a long usable lifespan. However, the tubes should be set to a number of values within the acceptable range, and the setting which produces the best tone should be used. The tonal variation when changing from cold to hot settings could be extreme, depending on the amplifier.

As can be seen from the formula, the maximum value is set to 70% of the maximum plate dissipation. This means that there is still a 30% reserve available. Experience has shown that the tone changes very slightly for settings above 70%; however, the lifespan of the tube is significantly reduced. This shouldn't stop you from trying an 80% or 90% setting to see how it sounds and decide yourself.

In the table entries, a single pair of values is given for each tube and plate voltage, showing the minimum and maximum settings for idle current.

For example: the amplifier has a plate voltage of 500 V and uses EL34 tubes. According to the table, the acceptable idle current range is 25 - 35 mA.

Formulars for push-pull amplifiers

Calculating the range for idle current is not black magic. It is really quite simple:

AV = plate dissipation in watts

AS = plate voltage in volts

Minimum value [mA] = (AV * 500) / AS

Maximum value [mA] = (AV * 700) / AS

Bias settings for push-pull class AB amplifiers

Plate voltage [U]	[mA]	250	300	350	400	450	500	550	600	MPI[W]
Typ										
6550 SED	Min.	70	58	50	44	39	35	32	29	35
	Max.	98	82	70	61	54	49	45	41	
6550 EH	Min.	84	70	60	53	47	42	38	35	42
	Max.	118	98	84	74	65	59	53	49	
EL34	Min.	50	42	36	31	28	25	23	21	25
	Max.	70	58	50	44	39	35	32	29	
KT77 JJ	Min.	50	42	36	31	28	25	23	21	25
	Max.	70	58	50	44	39	35	32	29	
6L6 25 W	Min.	50	42	36	31	28	25	23	21	25
	Max.	70	58	50	44	39	35	32	29	
6L6 GC 30 W	Min.	60	50	43	38	33	30	27	25	30
	Max.	84	70	60	53	47	42	38	35	
6V6 JJ	Min.	28	23	20	18	16	14	13	12	14
	Max.	39	33	28	25	22	20	18	16	
6V6	Min.	20	17	14	13	11	10	9	8	10
	Max.	28	23	20	18	16	14	13	12	
KT66	Min.	50	42	36	31	28	25	23	21	25
	Max.	70	58	50	44	39	35	32	29	
KT88 JJ	Min.	84	70	60	53	47	42	38	35	42
	Max.	118	98	84	74	65	59	53	49	
KT88	Min.	80	67	57	50	44	40	36	33	40
	Max.	112	93	80	70	62	56	51	47	
EL84	Min.	24	20	17	15	13	12	11	10	12
	Max.	34	28	24	21	19	17	15	14	

Hot and cold

One often hears the terms "hot" and "cold" in discussions of bias settings.

If an amplifier is to be biased "hot," then the idle current is set near the maximum of the permissible range. A "cold" setting is logically near the minimum value.

In certain circumstances, a "hot" setting produces excellent tone: the amp sounds fuller, more dynamic. However, a "hot" setting directly affects the life expectancy of a tube - it shortens it! A decision to operate tubes "hot" is also a decision to replace the tubes more often.

A "cold" setting has the opposite effect on tube life; however, it can happen that the amp sounds thin and lifeless. In the end, the decision to run an amp "hot" or "cold" is one of personal preference - and of the wallet.

Class A amplifier

Class A amplifiers are often used in audio and hi-end stereo. The proportion of pure class A guitar and bass amps is on the other hand low because they are, in comparison to class AB amps, relatively low power, and the effort required to create a high power class A amplifier is far greater than for a corresponding class AB amp.

In contrast to a class AB amp, the bias setting for a class A amplifier is calculated. This is related to the way the circuit functions.

The idle point is calculated with the formula:

$$\text{Maximum Plate Dissipation [W]} / \text{Plate voltage [V]} = \text{Current [A]}$$

Example: For a class A amplifier running an EL34 at 250V platevoltage, the maximum plate dissipation is 25 watts.

This results in:

$$25 \text{ W} / 250 \text{ V} = 0.1 \text{ A} = 100 \text{ mA}$$

The bias should thus be set at 100 mA. Measuring the idle current is done in the same way as for class AB amplifiers.

Stable settings

New tubes in particular require a certain amount of time – usually several hours - before they stabilize and the bias point stops drifting. When installing new tubes in an amp, it is best to wait a few hours so that an optimal and stable idle current can be set. Good practice is to set a rough point when the tubes are installed, and then play through the amp for half an hour or so (better yet, an hour).

This is followed by a second measurement and setting, again playing the amp for 1/2 to 1 hour afterwards. The final measurement and adjustment can then be made which should lead to a stable bias setting. As a final control, a last measurement can be made after the amp has been used for several hours.

If the bias doesn't stabilize after measuring and setting the bias several times, then it is possible that a tube is defective. This happens rarely, but it does happen.

It is good practice to check the bias regularly, even if the tubes have not been changed. With normal use, it should be checked once or twice per year. Doing so will not only improve your tone; it will also extend the life of your tubes.

Tube choice

Since most current (guitar and bass) amplifiers only have a single bias adjustment potentiometer, it is advisable to install only tubes which have been measured. These tubes have similar electrical characteristics and are usually sold as "matched" or "selected" sets.

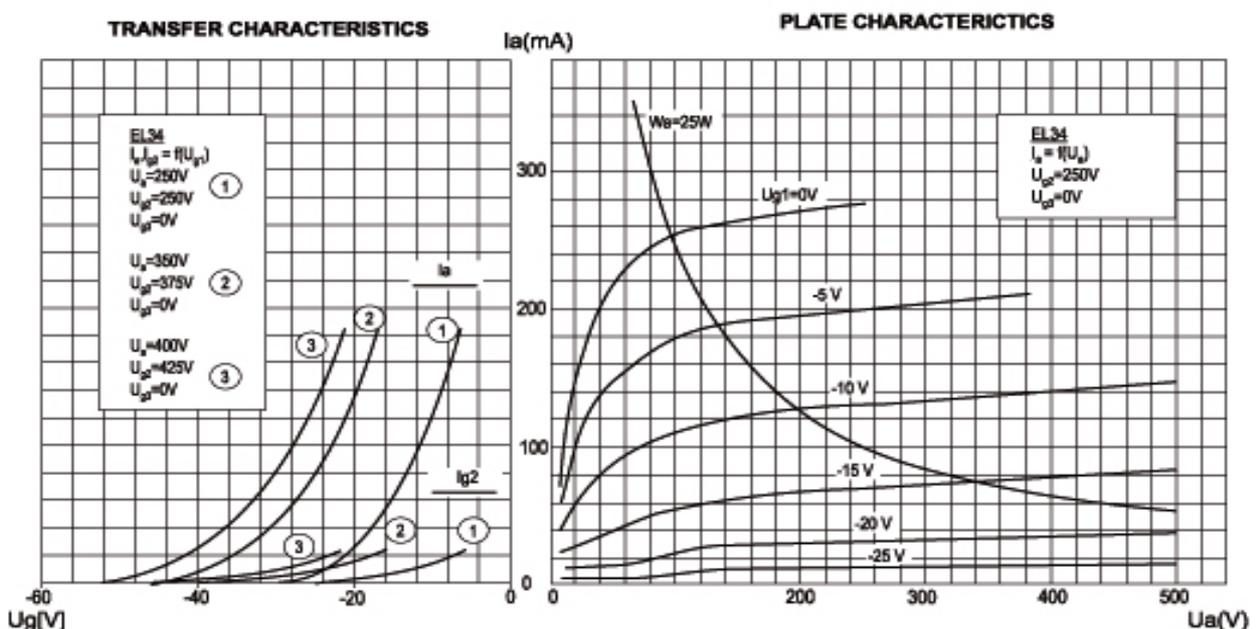
Owners of amplifiers with individual per-tube bias pots do not necessarily need to buy matched sets. Nevertheless, it is good practice to use tubes which do not differ too much from one another.

Important: in the case of a defective tube, all the tubes should be replaced. Otherwise, the chances for further damage to the amplifier are greatly increased!

A practical comment

As is so often the case in electricity and electronics, theory and practice are often widely separated. This is chiefly because individual components have widely varying tolerances and they never really work together "ideally" -- perfect components exist only on paper.

Vacuum tubes are no exception - just the opposite is true. A tube NEVER operates linearly, rather, it ALWAYS has greater or lesser curve in its characteristics, as can be seen in the data sheets (here for an EL34):



The interesting area is that in which the characteristic shows the least curvature and is most nearly linear without operating outside the tube's rated limits. In the right-hand diagram this is, for example, the area to the left of the 25 watt curve on the -15V line from about 120 V plate voltage. In comparison, the -5V line has a much stronger curvature in the permissible area, and is linear only beyond the 25 watt curve. The tube would be heavily overloaded under such operating conditions, and the plates would glow a bright red.

If that weren't enough, every tube, even of the same type and manufacturer, behaves differently than every other tube. The curves are always shifted a bit; as with fingerprints, there are never two exactly identical tubes.

Furthermore, the other components in the tube's signal path also affect its operation; for example, the output transformer, which exhibits DC resistance as well as inductivity. As with tubes, no two output transformers are identical. Even the two halves of the primary side of a push-pull transformer will differ in resistance and impedance.

Varying tolerances of the screen resistors can also influence the idle current, which is the sum of screen and plate current. When one tube draws 5 mA and the other 7 mA screen current at the same plate voltage, then there is already a discrepancy of 2 mA. The circle is now unbroken: in the real world, it is impossible to set the same idle current for all output tubes, regardless how well-matched they are, even with per-tube bias pots. What can be done?

If every tube has its own bias pot, the tubes can be set to nearly the same value, even if an absolutely identical setting is impossible, and although the value will change a bit due to progressive heat, load, and aging of the tube.

Amps with a single bias pot for all tubes are more of a problem. In this case, the best solution is to choose a setting which is the average of the settings of all the tubes. Larger deviations are the inevitable consequence of this value, but these deviations are unimportant, especially for guitar amplifiers.

Practically, the output tube idle current can differ by 5 mA without affecting the operation of the amplifier. Assuming the "best" range is between 35 - 40 mA, then the tubes should be biased so that the flow in each of the tubes lies within this range. It is more important to make sure that the maximum plate dissipation is not exceeded, as this is far more dangerous than a few mA deviation of idle current.

Another problem which arises often is that the tubes cannot be biased correctly because the potentiometer which sets the idle current does not have a broad enough range, and the tubes draw too much current. In this case, the current should be measured, and a decision made if the excess is acceptable. As mentioned earlier, the values cover 50% to 70% of the maximum dissipation, so a 30% reserve remains before the tube is 100% loaded. Even if the load is 80% to 90%, it is still within the maximum rated dissipation. It will, however, age and deteriorate more quickly.

If, on the other hand, the 100% limit is exceeded, either the tubes should be replaced with others which draw less current, or the bias pot (or the branch of the bias voltage supply) should be changed, so that a greater range is available. Often this requires nothing more than swapping the bias potentiometer and a resistor. The effort required is minimal and is in any case worth the effort.

Safety Information & Disclaimer

The devices and circuits described in this document use or generate potentially lethal electric voltages and currents and may cause lethal electrical shocks or serious injury! If you are not a legal adult (21 years old) or experienced working with dangerously high voltages, do not attempt to follow any of the guidelines or procedures outlined in this documentation without supervision from an adult expert.

If you are not experienced in the handling of electric devices you should always consult an experienced service technician.

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