TUBE AMP CLASSES

The Last Word on Class A

First of all, what is a class A amplifier?

A class A amplifier is defined as one which is biased to a point where plate current in all the output devices flows for the entire 360 degrees of an input cycle, at the full, unclipped output of the amplifier. Or, as stated in the RCA receiving tube manuals: "The classification depends primarily upon the fraction of input cycle during which plate current is expected to flow under rated full-load conditions". The key phrase being "under rated full-load condtions", which is a requirement for amplifier classifications to be meaningful.. This is typically done by biasing the output stage halfway between cutoff and saturation, with the plate load impedance to an appropriate value that gives maximum undistorted output power. This is the least efficient method of amplification, because the output devices are dissipating maximum power with no input signal.

For audio amplification, a class A amplifier can be either single-ended or push-pull. Now, you might be thinking, how can a push-pull amplifier be class A? Doesn't one side amplify half the waveform and the other side amplify the other half? Isn't this why we use a phase splitter? These are common misconceptions. You can, indeed have a true class A amplifier that operates in push-pull mode. Amplifier class has absolutely nothing to do with output stage topology. If the output tubes on either side of a push-pull pair are biased in class A (halfway between cutoff and saturation), then the current in each side will still flow for the full 360 degrees of the input cycle, just in opposing directions. As one tube's current increases from the midpoint, or idle, bias current, the other tube's current is decreasing by an equal amount. The output transformer sums these oppositely-phased currents to produce the output waveform in the secondary winding. As one side reaches saturation, the other side reaches cutoff, just as they would in a single-ended class A amplifier. Neither side cuts off at the full, unclipped output power of the amplifier. The output power of a push-pull class A amplifier is exactly twice the output power of a single-ended class A amplifier operating under the same conditions of plate voltage, bias, and effective load impedance.

Another misconception is that of cathode biasing. The method of biasing has nothing to do with the class of operation. You can have a fixed-bias class A amplifier or a cathode-biased class AB amplifier, or vice-versa. The presence of a cathode bias resistor and bypass capacitor is not an indication of class A operation.

There are several advantages to push-pull class A amplification. First, the bias current for each side is flowing in opposite directions in the primary of the output transformer, so they effectively cancel each other out. This lack of static, DC offset current in the output transformer means that the core can be made smaller, because it requires no air gap to prevent core saturation from the static DC offset current. A single-ended class A amplifier output transformer is huge compared to a push-pull class A amplifier of the same power level. The air gap required to prevent core saturation drastically reduces the primary inductance, so the transformer must have a larger core and more windings to achieve the same primary inductance and the same -3dB lower frequency cutoff point. Second, a push-pull class A amplifier output stage will have inherent rejection of power supply ripple and noise. This is because the power supply signal is "common-mode", i.e., it is amplified by each side equally, but since each side is out of phase, it cancels in the output.

The main disadvantage of push-pull class A amplification over single-ended class A, is the necessity for a phase splitter stage to generate the oppositely-phased drive signals. Another "disadvantage", in terms of guitar amplification, is that even-order harmonics generated in the output stage are canceled out in a push-pull output stage (hi-fi guys consider this a great advantage, by the way!). This does not mean that the push-pull amplifier generates no even order harmonics, however, because even-order harmonics generated in the preamp stages are amplified by the output stage and will pass right through to the output. Only those even-order harmonics generated in the output stage itself are canceled.

What is a class B amplifier?

A class B amplifier is one in which the grid bias in all output tubes is set at cutoff, i.e., no plate current flows in the absence of an input signal. Plate current only flows when a signal is present, and only flows for exactly half, or 180 degrees, of the input cycle.

For audio amplification purposes, a class B amplifier must operate in push-pull mode, because each output device only amplifies half the input signal, and the output would be fully clipped on one side if operated single-ended. The important thing to remember is that, even though the current in one side is fully off, or "clipped on one side", the output waveform is not clipped at all, because the other tube has taken over the job of reproducing it's half of the waveform. Clipping of the output stage only occurs when both tubes are at their respective, and opposite, limits of saturation and cutoff.

The advantage of class B operation is it's efficiency, which is far greater than class A, because the average dissipation of the output devices is much lower, because they are biased normally "off", and only dissipate power during half the input cycle. The limiting factor in output power is the average dissipation of the output devices. If the average dissipation can be decreased, more output power can be obtained. The disadvantage of class B operation is a large amount of "crossover distortion", which occurs when one tube of the push-pull pair cuts off and the other turns on. The characteristic curves of a tube are not perfectly linear and symmetrical, so the "handoff" between the two sides results in a short time at the zero crossing where there is distortion. This crossover distortion looks like a notch, or flat spot, in the sine wave as it crosses the zero axis.

How is class AB defined?

A class AB amplifier is one in which the grid bias is set so that plate current flows for more than half, but appreciably less that the full 360 degrees of the the input cycle, again measured at the full, unclipped output of the amplifier. This increase in idle bias current over class B operation keeps the tubes on a small amount at all times, resulting in reduced crossover distortion, because it keeps the tubes out of the highly nonlinear region near cutoff. Unless the idle bias is set too close to class A operation, efficiency gains similar to class B operation can be obtained, without the unwanted crossover distortion. This is the most popular class of operation for medium to high powered guitar amplifiers.

Finally, can a single-ended amplifier be class AB or class B? The simple answer is, yes. Many RF (radio-frequency) amplifiers are single-ended class B or class C (current flows for less than 180 degrees of an input cycle). However, for audio amplification, these are of little use. Technically speaking, you can have a a class AB single-ended amplifier, which was biased away from the linear portion of the curves, but that amplifier would (hopefully!) be rated at the unclipped output power, so plate current would be flowing at all times at the max undistorted output power. This would stretch the definition a bit, particularly since the amp would undoubtedly be able to be driven into asymmetrical cutoff (where us guitar players like to hang out!) which would effectively be class AB single-ended operation, because the amp is not biased in the middle of the transfer curves and is capable of being driven into cutoff for a portion of the input cycle. As long as the manufacturer isn't rating the amplifier for its output power in this clipped state, the amplifier would normally be called class A, single-ended.

What about class A2, AB2, and B2?

The numerical suffix appended to the class designation indicates whether or not grid current flows in any appreciable portion of the cycle. A "1" suffix indicates no grid current flows, while a "2" suffix indicates grid current flows for some part of the cycle. Class A2/AB2/or B2 requires a very low impedance, transformer-coupled or DC-coupled driver stage. The standard AC-coupled phase inverter or single-ended driver stages used in nearly all guitar amplifiers will not allow grid current flow, so they are class A1/AB1/B1 amplifiers.

The advantage of class A2, AB2, or B2 is the complete lack of "blocking distortion", or transient intermodulation distortion. The disadvantage is the extra complexity of the output stage required to source current to drive the output tube grids into the positive region.

Which is better, class A or class AB?

From a guitar amplification standpoint, neither class of operation is necessarily better, they are just different. You shouldn't get too hung up on the "class A" designation, because most of the push-pull amplifiers that are supposed to be class A aren't really class A at all, they are just cathode-biased, non-negative feedback class AB amplifiers. Operating class is not the reason for the tonal differences between these amplifiers.

The cathode biasing and lack of negative feedback is one of the main differences between the Vox clones and the Marshall/Fender style stuff. The typical Marshalls and Fenders used a fixed-bias output stage with negative feedback from the output back to the phase inverter input, while the Vox clones use a cathode-biased output stage and no global negative feedback. In addition, the output tubes and preamp stage/phase inverter configurations contribute greatly to the tonal signature of these amplifiers.

Cathode biasing vs. fixed biasing

In a cathode-biased amplifier, the bias voltage is developed across a cathode resistor that is bypassed with a big electrolytic capacitor. In a class AB amplifier, as the current through the tube increases, the average voltage across the cathode resistor changes, which modulates the plate current, creating a bit of "sag" and a dynamic change in the harmonic structure of the note that changes while playing. This occurs because the plate current in a class AB amplifier is not continuous for the entire AC cycle. The tube goes into cutoff for a portion of the cycle, which means that the average DC level of the signal on the cathode will shift, changing the operating point of the tube, with the resulting dynamic tonal changes. The average value of a sine wave is zero, but the average value of a clipped sine wave, such as occurs when the plate current is cut off for some percentage of time, is not zero. The current in a true class A amplifier is constant, so it doesn't exhibit this bias shift, unless driven to clipping, where all bets are off. This is why a cathode bypass cap is not necessary in a true class A push-pull output stage - the plate currents are equal and out of phase, unless there is an imbalance in the output transformer, the output tubes, or the drive signals (it is a good idea to use one anyway, for these reasons). The fixed-bias amplifier maintains the bias at a more constant level, so it doesn't have the constantly changing operating point that varies with the output level.

The effect of global negative feedback

The use of global negative feedback does several things: it flattens and extends the frequency response, it reduces distortion generated in the stages encompassed by the feedback loop, and it reduces the effective output impedance of the amplifier, which increases the damping factor. All of these things affect the tone in some manner.

The flattened, extended frequency response obviously changes the tonal character by removing "humps" in the output stage response and producing more high and low end frequencies. The distortion reduction makes the amp sound cleaner and more "hi-fi", up to the point of clipping. Perhaps the main difference for the "feel" is the increased damping factor produced by the negative feedback loop. The decreased effective output impedance causes the amp to react less to the speakers. A speaker impedance curve is far from flat; it rises very high at the resonant frequency, then falls to the nominal impedance around 1kHz, and again rises as the frequency increases. This changing "reactive" load causes the amp output level to change with frequency and changes in speaker impedance (a dynamic thing that changes as the speakers are driven harder). Global negative feedback generally reduces this greatly. This can be good or bad, depending upon what you are looking for.

Negative feedback makes the amp sound "tighter", particularly in the low end, where the speaker resonant hump has the most effect on amplifier output. This is better suited for pristine clean playing or a tight distorted tone, while a non-negative feedback amp has a "looser" feel, better suited to a bluesy, dynamic style of playing. The other disadvantage of a negative feedback amplifier is that the transition from clean to distorted is much more abrupt, because the negative feedback tends to keep the amp distortion to a minimum until the output stage clips, at which point there is no "excess gain" available to keep the feedback loop operating properly. At this point, the feedback loop is broken, and the amp transitions to the full non-feedback forward gain, which means that the clipping occurs very abruptly. The non-negative feedback amp transitions much more smoothly into distortion, making it better for players who like to use their volume control to change from a clean to a distorted tone.

There is an output stage topology that is kind of in between, called "ultralinear" operation. This uses local negative feedback to the screen grids of the output stage by means of a tapped output transformer primary. This increases the damping factor and makes the amp a bit tighter without the use of a global negative feedback loop (you can use global negative feedback with ultralinear output stages, but you may not like the tone as much). The Dr. Z Route 66 amplifier uses an ultralinear output stage. There is also a triode output stage, which has even higher damping factor than ultralinear, but some players feel that it sounds too "compressed" and midrangey, while others like it. Part of the reason for the midrange emphasis is the increased input capacitance of triode mode over pentode mode because of the Miller effect, which in effect, multiplies the grid to plate capacitance by the gain of the tube. This increased capacitance rolls off the high frequencies.

Does true class A operation require any particular current or bias point?

True class A operation does not have to be above any particular current rating or dissipation. It depends on the tube type, the power supply voltage, the reflected impedance, and the required operating point. However, in general, when a class A power amplifier is designed, the bias point is chosen to correspond with the spot on the plate curves at the intersection of the load line, the plate voltage, and the maximum dissipation curve that gives maximum symmetrical swing in both directions before clipping. This means that the tube is biased right at maximum plate dissipation, which is okay, because the dissipation is maximum at idle in a class A amplifier, and does not increase with applied signal, as it does in a class AB or class B amplifier (it actually decreases to a minimum at full power). This is not to say that that is the only current and voltage that will work. If you lower the plate voltage by 100V, you will find another "optimum" spot where these lines intersect. If you change the reflected load impedance, you will find yet another optimum spot. There is, however, an upper limit on the voltage that can be applied where you can no longer bias for symmetrical swing about the idle point without exceeding the plate dissipation ratings. This is the limiting voltage for that tube in true class A operation *at the max recommended tube ratings*. If you choose to run the tube over ratings, as is the case in some amplifiers, you can bias the tube to a point that is running class A, but is above the maximum dissipation curve. Although this seems to work with some tubes, it is not a recommended practice.

This holds true for both single-ended and push-pull designs. In push-pull class A, the bias point and plate supply voltage is the same as for single-ended, but there is a phase inverter and a center-tapped transformer, which are used to increase power and reduce distortion (even-order harmonics are canceled, and power supply hum is canceled in a balanced push-pull amp). Power is twice that of single ended (for a two-tube push-pull vs. a single tube single-ended, etc.).

To get a better feel for this, take a set of plate curves for a given tube, and draw a load line representing the reflected impedance (it has a slope corresponding to the negative reciprocal of the reflected load impedance, and passes through the intersection of the bias current and plate voltage lines), and draw a curve representing the plate dissipation (it will be a parabolic shape, with each point equal to the current that corresponds to the plate dissipation divided by the plate voltage). The load line should just touch the plate dissipation curve at the selected plate voltage (for max power out - if you want less than max power, it can be below the dissipation curve). The current corresponding to this point will be the required bias current, and the dissipation will be maximum at that point. All tube signal swings will occur on the load line (assuming a purely resistive load -

reactive loads generate elliptical load lines), so you can find the plate voltage swing for a given grid voltage swing, and you will see that you will have to either change the plate voltage or the reflected load impedance, or both, in order to get the optimum class A bias point. Don't forget that the actual plate voltage swings both above and below the supply voltage, and the center of the swing is the actual plate supply voltage. This is kind of confusing at first, because it isn't intuitive that you could get a 400V peak with only a 250V supply (i.e., a swing from 100V to 400V, centered around 250V). The "extra" voltage comes about because of the nature of how the output transformer works.

Does biasing at max dissipation guarantee class A operation?

Just because you are biased at max dissipation does not mean you are class A! You must be in the region where the voltage swing is symmetrical and biased in the center of the range, where plate current flows for all unclipped output. Biasing to a high voltage and low plate current whose product equals the maximum plate dissipation might not allow this, because, although you are at max plate dissipation, the bias point is such that plate current will flow for an appreciably less time on the negative signal swing (cutoff) than it will on the positive signal swing (saturation), and *no* load line can be found that will allow symmetrical swing, or it will be in such a non-linear portion of the curves as to be unusable. This is because the plate voltage is too high, and the max allowable current without exceeding dissipation limits is too low. The same thing can occur on the other end of the scale, where you can reduce the plate voltage to a point that the max dissipation current will exceed the maximum allowable plate or cathode current ratings of the tube. There is an optimum area of the curves that will become apparent when you start drawing load lines and picking bias points. It is a bit of an iterative process, so the tube manufacturers make it easy for you by listing typical class A operating conditions in the data sheets.

In theory, you can take a class AB push-pull amplifier and convert it to class A push-pull operation, *however*, you would, in nearly all cases, have to reduce the plate voltage to be able to bias the tubes into the class A region, because the whole reason for going to class AB is to get higher power, so the plate voltage is run higher and the idle current lower than what is allowed in class A. Once again, you have to look at the plate curves for the particular tube to determine where the allowable class A region is. If you simply bias a class AB amp to max dissipation at idle, you will find that as you apply a signal, the tubes will dissipate more power, and they will start to glow a lovely cherry red color, and something will croak. In addition, the power supply and/or output transformer may not be able to handle the extra current required for true class A operation, so, unless you know the ratings of the trannies, it is best not to attempt this, even if you lower the supply voltage.

Are those class A amplifiers I see advertised really class A?

There is much debate raging in the marketplace about "class A" amplifiers, and whether or not they are truly class A, or just class AB amplifiers unscrupulously marketed to the unsuspecting public as "class A". The truth is that most, if not all, are in reality cathode-biased, non-negative feedback class AB amplifiers, contrary to what the manufacturer's literature may say.

What is the difference, then, and why is it a problem for so many people?

The fundamental problem is in how class AB is defined, and how people interpret it. The people who say a class AB amp is "class A at lower volumes" are technically wrong, but for the right reasons. If you were to define class A as being only conduction for a full 360 degree phase angle, you would be correct. However, there is more to the definition of amplifier classes than that.

The defining factor in a determining whether or not an amplifier is class A, class AB, or class B *has* to be made at the full output before clipping, otherwise, the class definitions have no meaning whatsoever. It is indeed, a very black and white thing, and depends on the bias point on the characteristic curves, and the load line, among other things.

If, at the full undistorted output, the plate current flows in each tube for a full 360 degrees of the input conduction cycle, the amplifier is class A. However, if the amplifier is biased such that the plate current cuts off for an appreciable time during each cycle at this full undistorted output power, it is then a class AB amplifier. If it is biased such that each side is in cutoff for half the input cycle, it is a class B amplifier. Note that cutoff does not mean that the output of the amplifier is clipped, or distorting. Cutoff refers to plate current cutting off on one side of a push-pull pair for a portion of the cycle, while the other side continues to function. The output waveform is still a clean, unclipped sine wave, because the transformer sums the two "halves" of the input signal into one composite signal. Effectively, one tube amplifies the "upper half" and the other tube amplifies the "lower half". This is done to provide higher efficiency and greater output power. In a class AB amplifier each tube amplifies a bit more than half the signal, in order to reduce the distortion that occurs at the zero crossings of the waveform, which is called "crossover distortion".

Here is where the problem comes in: because a class AB amplifier is biased so that the plate current flows for the entire cycle at lower output levels (which is done to reduce crossover distortion), many people claim it is a "class A amplifier at lower volumes". This is simply not true. It is operating in conditions *similar* to class A, but is not a class A amplifier by any means. It is still a class AB amplifier, no matter what you choose to call it.

Now, what are the differences, you might ask? Well, for one, the Class AB amplifier is biased in a more non-linear portion of the characteristic curves, which means it has more distortion than a true class A amplifier. Also, the efficiency will be greater than is theoretically possible with a class A amplifier at these levels. There is a very real difference in tone and operating conditions between a true class A 10W amplifier running at say, 1W, and a 10W class AB amplifier running at 1W. Same output level, same overall power level, *but* a different class of operation, different amount of distortion, different efficiency, *and* a different tone, even though neither one of them is in cutoff for any portion of the output cycle at that low level. This is due to the bias point differences and load line differences. The differences become even more apparent when the amplifiers are run at their full undistorted output power. The true class A amplifier will have no crossover distortion, while the class AB amplifier will. The average plate current for the true class A amplifier will not change, or will change very little, from idle to full output power, while the average plate current in a class AB amplifier will increase dramatically. This will lead to "sag" in the power supply that doesn't exist in the true class A amplifier, which again results in a tonal change.

As you can see, there is indeed such a thing as a "true class AB" amplifier, just as there is a "true class A" amplifier, and the class definitions are not at all ambiguous, except to those who don't understand them, or choose to ignore them for marketing advantage.

One more thing: What if you push the class A or class AB amplifier into clipping? Does it then become a class AB/ B, C, or D amplifier? No, of course not. It is simply the same class amplifier it was to begin with, but driven into clipping. A class A amplifier driven to clipping is still a class A amplifier by definition. This is why amplifier classes are defined the way they are. Otherwise, the class designations would have no meaning. Any amplifier can be driven beyond it's limits into a fully-clipped square wave output (unless it is limited), but that doesn't make it a class D switching amplifier, now does it?

Which one to buy?

The bottom line is this: don't worry about whether an amp is "class A" or not. If you are interested in details, find out if it is cathode-biased or fixed-biased, and whether is uses global negative feedback or not, whether it uses a pentode, triode, or ultralinear output stage, and what type of output tubes are used. These parameters will give an idea of the "feel" of the amp, but in the end, you still must play the amp and use your ears to tell you which one is best suited for your playing style. Don't make a decision based on technical specs alone, you may miss out on a great-sounding amplifier!