Tubes
Mechanics & Mystique

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By R. Aspen Pittman

Guitarists both today and yesterday are linked in many cases by one piece of equipment: a tube amp. In fact, the tube amp is currently enjoying its greatest popularity with musician, even though there have been great strides in transistor amp technology over the past 20 years. Guitarists prefer tube amps.

Why do designs built around tubes sound different from those following the solid-state approach? Simply, tubes work differently. What follows, then, is an explanation of their construction, function, and applications.

Tube Construction and Operation

A tube is an electronic device consisting of a minimum of four active elements: a heater (filament), a cathode, a grid, and a plate. All of these are sealed in a glass enclosure with its air removed -a vacuum- to prevent the parts from burning. The filament is heated in order to warm the cathode. Once heated, the cathode begins to emit electrons, which flow from the cathode (which is negatively charge) toward the plate (which is positively charged).The grid's purpose is to control this flow. If the grid were absent, this movement of the electrons would be uncontrolled, much like water rushing from the faucet that's opened all the way.

Theory of Operation

When a small signal is applied to the grid, it causes a larger change in the current that flows between the cathode and plate accordingly. In effect, it acts as a valve. A portion of the amp's electronic circuitry, the *grid bias control* adjusts the proper voltage setting of the grid. The amount of bias varies from tube to tube, depending on its sensitivity, and it acts to keep the tube "idling". When the grid bias is properly set, the tube is balance to the circuit, and therefore produces a clean, powerful signal (proper biasing also extends the life of the tube).

For optimum performance, the bias setting should be checked whenever power tubes are changed-preferably by a qualified technician using an oscilloscope. A bias adjustment is a relatively simple operation, and can be performed for a minimal bench charge (typically $15.00 to $20.00).Some symptoms of improper bias setting include the amp running too hot, excessive hum after it's been on for a short while or distortion that just doesn't sound right. The amp doesn't necessarily have to

sound bad for its tubes to be incorrectly biases, and these symptoms may indicate other problems. However, if your amp is behaving in an extraordinary manner, a trip to the shop may head off damage to it, regardless of the cause.

Tube Functions in the Amp

Let's look at a common example of how a tube works in an amplifier. Imagine a small guitar amp with no volume or tone controls: just a guitar input, one tube, an output transformer, and a speaker. The guitar's pickup produces a small voltage, the result of the string vibrating in the pickup's magnetic field. In general, this signal is applied to the grid, which in turn causes a large current flow from the cathode to the plate. Thus, a correspondingly large voltage now appears at the plate. This plate is connected to an output transformer, which matches the tube's output impedance to that of the speaker. (Because there is a great disparity between the impedance of the tube amplification circuit and the speaker, the transformer must act as a buffer to interface the two components).Thus, a small, low-power signal from a guitar's pickup can produce a high-powered signal to drive the speakers.

Naturally, amps don't all sound alike. This is due to variations in the type of tube that is used, the quality of the tubes, and the specific circuit design of the amp. In other words, some tubes amplify more than other tubes under similar conditions. Also, the amount of gain a tube produces varies with the circuit design. This is why different makes of tube amps can sound very different, even though they use the same tube types. Additionally, certain amps use completely different types of tubes. A good example of this is the English-type Marshall using European EL-34 tubes in its power amp section, compared to the U.S. type, which employs American-made 6550 power tubes. The U.S. and English styles sound and play very differently, reflecting the character of their power tubes. That is, the English EL-34 tubes yield more distortion than their American counterparts, although they produce roughly the same amount of volume. With internal bias modification (which mostly involves changing some resistance values), any U.S. Marshall amp can use European EL-34s, and vice versa.

Multi-Stage Amps

Larger and more complex amps have many stages of tube amplification: preamp stages, signal-processing stages, and power amp stages.

The preamp: The preamp stage is much like a mixer in a PA system, which must amplify an incoming mike or guitar signal to *line-level* strength before the signal can be processed with effects for tonal shaping. Likewise, a tube amp must preamplify a guitar's signal so that it can be further processed. This is the first gain stage of the tube amp.

Signal-processing stages: An example of a signal-processing stage is the reverb section, where the signal is diverted through a reverb spring system and then returned by another gain stage, and finally blended with the original signal. Tone controls and second gain stages (often employed for an overdrive effect) are other examples of signal-processing stages.

Power amp stages: The power amp section takes the preamp's signal and amplifies it many times to a level that can drive the speakers. All tube amps with power rating of 10 watts or more employ a *push/pull* power amp. This means that the power tubes work as a team to amplify the signal and drive the speaker. (Practically all transistor amps employ a push/pull configuration as well.) The

output tubes all share in the sound, so for maximum efficiency it is desirable to use tubes that operate as similar as possible. Also, for efficiency use power tubes of the same make-manufacturers' specifications for tubes bearing the same stock number may vary over a broad range. And, if one power tube is bad, it is advisable to change *all* of them. Having one fresh, powerful tube and three old ones, for example, can create an imbalance in the push/pull effect, resulting in inefficient operation. The power amp section is only as strong as its weakest link. So, if one tube out of four is faulty or varies from the others in its performance character, the overall sound of the amp will be limited.

The process of output tube matching dates back almost as far as tube amps. The military began matching certain properties of tubes to produce longer field life and higher performance. Later, top audio companies such as McIntosh developed a system to match power tubes for use in their audio amps, and would guarantee performance specifications only when their matched tube sets were used. Unfortunately, it is impossible to specifically *manufacture* matched power tubes because of the mechanical nature of the device and the extreme operating temperatures that exist within the tube (around 700° F).However, once the tube is made, it can be performance tested for various parameters and matched into sets with identical characteristics.

Limitations

Since a tube is a mechanical assembly of parts that forms an electronic device, it is subject to some mechanical problems and limitations. Tubes wear out in direct proportion to how hard they are worked (due to the circuit design) and how often and loud you play your amp. Vibration and jarring shorten the useful life of the tube as well. Ideally, a tube could be built so that no vibration existed between its mechanical elements. However, adverse tube microphonics can be a big problem when the elements of the tube rattle or ring, producing a signal all by itself. A tube with this problem is unsuitable for use in music amps, much like a faulty guitar pickup or a bad microphone is undesirable for most musical purposes.

When to Replace Tubes

So, when should you change your tubes? Chances are, your *power* tubes are worn out when your amp starts sounding weak, lacks punch, makes funny noises, has its power fading up and down, or loses highs or lows. If your amp squeals, is excessively noisy, loses gain in one channel, hums, lacks sensitivity to touch, or generally feels as if it's working against you, a *preamp* tube could be malfunctioning, and is in need of replacement. In both cases, though, the tubes may not be at fault. Unless you are skilled in specific troubleshooting, regard the high-voltage circuits found in amplifiers as extremely dangerous. Take the amp to a professional for diagnosis and repair.

Unfortunately, you can't simply pull your tubes out and take them to the drugstore or local electronics outlet and evaluate them on one the tube-testing machines designed for TVs. This is because of the high voltage levels at which guitar amplifier tubes are driven. Amp tubes can be powered with 450 volts or more, whereas the testing machine provides only about 150 volts. This difference can completely foul up a diagnosis. Tube-for-tube replacement and a before-and-after comparison is often the most reliable test.

Good-sounding, non-microphonic preamp tubes are the exception, not the rule. Quality preamp tubes along with matched sets of power tubes are a little harder find, and you may par more when you do locate them. However, you can expect improved sound and longer life, so there is a payoff.

Tubes, Transistors, and Distortion

No tube primer would be complete without an explanation of how tubes distort in a way that is different from transistors. Tubes distort uniquely because as the signal emitting from the plate approaches its maximum potential, the tube gradually begins to react less and less to the original input signal. This results in a types of compression of the signal, and produces a soft clipping. Clipping occurs when the input signal increases but the maximum power has been reached. Thus the signal becomes cut off, or clipped. Transistors, on the other hand, react exactly the same to the input signals rights up to their maximum power; then they stop quickly, creating a sharp clipping. These different types of clipping produce different series of harmonics (overtones).When the transistor amp clips, it produces more odd-order harmonics (and in its worst case can sound hollow and dry), whereas tube distortion produces even-order harmonics. Tube distortion sounds warmer. It should be mentioned that various types of transistor and tube distortion are possible, depending the amp's design.

In the case of a tube amp, preamp and power amp tubes have different distortion characteristics due to the difference in both their tubes and their circuit design. For example, relying on a master volume distortion circuit by itself will yield less sensitivity to variations in a player's *touch* than if the amp is attenuated (has its volume limited) after its power stage (that is, with a power attenuator).This is due to the contribution of the output transformer to the sound of the amp and also to the difference in sonic qualities between different power tubes compared to preamp tubes. Leaving some of the distortion to the power amp section rather than relying mainly on the preamp section gives a broader range of sensitivity. In addition, the nature of the tube allows the player to vary his touch, producing different tonal responses from the amp according to the manner in which he plays.

There are many variables in tube amp design, and each has its characteristic sounds and quirks. Regardless of what type of amp you use, you will find that like strings on guitars or oil in an automobile, tube do wear out. Amps are not maintenance-free, and as they age, they undergo changes. The tubes are subjected to wear and tear, some of the electronic parts lose their initial properties, and pots and jacks get old. Bad tubes can cause premature failure of other parts, such as the output transformer, speaker, and other vital components. If your amp sound bad, weak, or otherwise not up to par, don't just hope the problem will go away. Get it fixed. Keep on top of the maintenance, replace the tube when necessary, and get the most form your amp.

Survival Tips for Tube Amps
by R. Aspen Pittman

Tube amps are simple, and so they are easy to keep running smoothly. However, if you neglect to follow a few simple rules, you can buy yourself some expensive trouble. What follows are some suggestions you can try that will put your amp in top condition and keep it there.

TIP #1
Speaker Impedance

The proper matching of the impedance between your tube amp and speaker is extremely important. Improper matching will cause severe tube wear and is a common cause of early tube failure. Some amplifiers are more sensitive to this than others . Among the most sensitive are Marshall amps. Pay attention that the Marshall's impedance selector is on 16 ohms when your running a common 16 ohm Marshall cabinet, and reduce it to 8 ohms when adding a second identical cabinet. Always check your cabinets by measuring with a volt meter on the ohms scale (these meters read low, i.e.: an 8 ohm cabinet might read 6 ohms while a 4 ohm cabinet could read 3 ohms).Another way to determine the impedance of your cabinet is to read the individual speaker impedance and note how they are wired. If there are two 8 ohm speakers wired in parallel (+ to both +'s and - to both -'s) then the cabinet will be a 4 ohm load. If the two speakers are wired in series (+ to spk #1 +, #1 - to #2 +, #2 - to -) then the cabinet will have a 16 ohm load. In other words, parallel wiring halves the impedance of the speakers while series wiring will double it.

Find out the specified output impedance of your amp by asking a service station or perhaps your local dealer. The common amps are: Marshall, variable 4, 8, and 16 ohms; Fender Deluxe and Princeton, 8 ohms; Fender Twins and Dual Showman,4 ohms; Fender Super/Reverbs and 4-10 amps, 2 ohms.

Beware the dangers of using a power attenuator with your Marshall as most power attenuators do not match impedance closely enough for these amps. Using a power attenuator might let your Marshall distort at lower levels, but at the expense of much more rapid output tube wear -- premature failure of the output tubes is common in Marshalls used with power attenuators. Fender amps are not as sensitive to power attenuators as Marshalls, because of differences in design in the output section. However, since the tubes are putting out full power into the attenuator, they will wear out quicker than if they were just coasting at a moderate output level. If you like the sound you get with the attenuator, be prepared to spend a little more on power tubes.

TIP #2
Power Tube Replacement

The regular replacement of power tubes is normal in amps with regular use. Just when to change them can vary with the type of use the amp gets and how often it's used. Most players should change their tubes once a year if they play moderately loud and fairly often. As the output tubes wear out, both the bass and treble responses of the amp will begin to suffer. This power loss from worn out tubes isn't always noticeable because it occurs gradually over time, and because power level differences aren't easily noticed. It takes twice the power for the ear to hear just 3 dB more, and

that's just barely audible! Worn tubes will usually have poor, mushy bass response. Regular power tube replacement will guarantee consistent and reliable performance. It's cheaper in the long run.

TIP #3
Drive Tube Replacement

The driver tube operates in conjunction with the power tubes to form the power-amplifier section of the amp. The best power tubes will sound bad with a weak driver tube, as this is the tube that controls the output tubes-- if it can not control the output tubes, the amp can't sound its best. This will show up particularly at higher power playing, or when playing the amp distorted. REPLACE THE DRIVE TUBE WHENEVER REPLACING THE OUTPUT TUBES! In most amps, the driver is the smaller tube (12AT7, 12AX7, 7025, 12AU7 or similar), which is adjacent to the output tubes.

TIP #4
Re-Tensioning Tube Sockets

NOTE: Because the tube sockets are connected to the very highest voltages in the amplifier, we suggest that the following work be done only be those having the proper knowledge of electrical safety.

When tubes are changed again and again over time, the sockets female parts begin to stretch and not make good tight contact with the tube pins. This can lead to arcing and intermittent connections between the tube and the amp. This condition can be aggravated by the vibration from your speakers and so may occur on certain notes on your guitar or keyboard. You can correct this by replacing the socket (last resort) or by re-tensioning the socket with a large safety pin, jeweler's screwdriver, or small ice pick. Use a tool with an insulated handle if at all possible.

First: disconnect the amp from the AC outlet and allow the amp to drain off any voltage by leaving your speakers hooked up to the amp with the standby "ON". This takes just a few minutes and could save an awful experience later. Now remove the tubes and notice the contacts located inside each pin hole of the socket. These contacts spread the pin hole -- do not push the contacts in so far that the tube will not re-insert. After you've re-tensioned all the contacts, replace the tubes and notice how much tighter the tubes are held.

You may also find corrosion on the contacts. Try spraying a little contact cleaner or WD-40 on a tube and inserting it into the socket a few times. This will improve the connection to the tube and prevent future corrosion.

TIP #5
Capacitors and Resistors

The most common problem we see in tube amps (other than tubes) is worn out capacitors and bad resistors. What follows are some common symptoms of bad resistors and capacitors, why they can go bad, and how to locate and fix the problem.

NOTE: Tube amplifiers contain high voltages which may be lethal, **even if the amp has been off for some time**. We do not recommend that you open your amp, or try to perform any repair operations unless you are properly trained in electronic servicing. Again, there are large voltages

present in your amplifier that can kill, even with your amp unplugged from the wall. Having said all that, you may now read on.

A common result of cheap tubes failing is that they will take out a screen grid resistor with them (usually located across the inside of the tube socket, or near by). These take the heat when the tube shorts and can fall out of specification easily. This will cause improper function of any power tube you place in the faulty socket -- if the resistor is open, the tube may as well not be in the socket! In any case, the amp will not be reliable until the screen grid resistor(s) have been replaced. Fender amps usually have a 1 watt 470 ohm screen grid resistor, while Marshalls generally use a 5 watt 1000 ohm resistor for this purpose. The screen grid resistors can be checked using an ohm-meter to measure their resistance. The measurement should be within 10% of it's marked value.

Another common source of poor sound quality would be worn-out filter capacitors in the output or supply stage of the amp. This is especially common in amps over ten years old. These are fairly large components and are often mistaken for "metal tubes" at first glance. The filter caps "filter out" the 60 cycle hum from the power source and through the years they dry out and filter less and less. As the 60 cycle hum is now present in your audio output, it will create an odd harmonic that will seem to follow your notes up and down the scale. It's almost like having somebody singing off-key all the time. In addition, since the amp is now producing sub-harmonic notes, the power is sapped and the overall response of the amp will become weak and sound mushy.

Inspection of filter caps can usually determine if they are bad. These large metal cylinders are easy to spot. Fender amps have them on the under side of the chassis, between the transformers, covered by a 4" X 6" metal pan. It is therefore not usually necessary to remove the amp chassis from the wood cabinet. Remove the pan and "drain" the capacitor by touching a screwdriver from the hot side of the caps to ground. Now inspect the top site (or positive) of the part, looking for a broken or swollen seal. This can look like a little bubble about to pop, or it could have already burst and have powder coming out. Capacitors have this relief seal to expose when they go faulty. Be sure to replace them with the same value (or greater value) and make sure they are placed with the proper polarity.

Marshalls have their filter capacitors placed upright on the chassis held at the base with a clamp. The chassis must be removed from the wood cabinet to inspect the filter caps. Observe the same procedure for inspection of the capacitors. It should be mentioned that if you replace your filter caps, you should connect your amp to a variac and power the amp up very slowly to allow the caps to charge and form properly.