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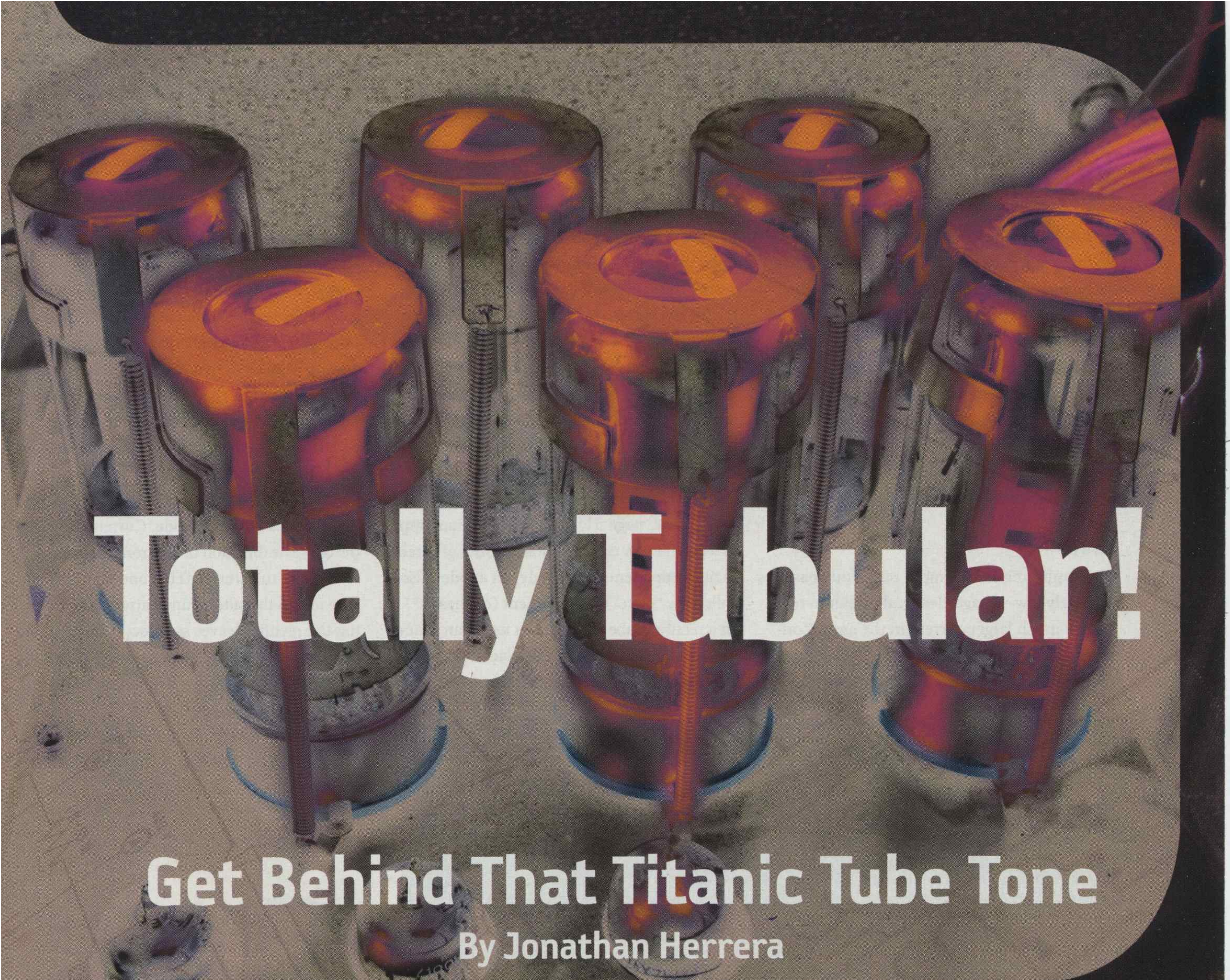
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DIG DEEPER



Totally Tubular!

Get Behind That Titanic Tube Tone

By Jonathan Herrera

MY FIRST ENCOUNTER WITH AN ALL-TUBE BASS AMP

was a big deal. I had only recently made my club debut, playing through a solid-state combo amp. Soon after, I played another gig, this time through an all-tube Ampeg SVT. My tone—strong, fat, and warm—forever changed my then-naïve notions of the bass. I didn't know it then, but it was the amp's soul, in the form of glowing glass bottles, that was the messenger of this revelation.

Solid-state technology is dominant for convincing reasons. It offers clean, high-volume tone that conveys low frequencies with authority and speed. Sophisticated solid-state amps are more flexible, portable, and potentially louder than most tube bass amps. They're also cheaper to own in the long run, as regular maintenance and shop costs like tube replacement and biasing are unnecessary. But the nature of tube circuits gives them a unique sonic signature that's difficult to duplicate with

transistors. Plus, because they're made from a limited number of discrete components, tube amps allow much more customization and post-purchase tweaking options. Solid-state amps use a lot of integrated circuits, which place all those individual electrical components on chips that you most definitely don't want to mess with.

Every player interested in sonic flexibility should consider owning both solid-state and tube amps. This article will explain what makes tube amps special, and what lies beneath their unique tone. (Many of these basic amplification concepts are applicable to understanding how a solid-state amp works.) Understanding the basic technical functions of our gear has musical benefits beyond mere personal edification. Knowing how gear works also makes you a savvy consumer. If you decide to buy a new tube amp, check out the buyer's guide to all-tube bass heads on page 54.

WHAT'S IN A TUBE AMP?

IF YOU HAVE NO BACKGROUND IN ELECTRICAL engineering, peeking inside a tube-amp chassis or peering at a schematic (the diagram that visually represents a circuit with symbols) will be utterly confusing. But amps are actually made up of a surprisingly limited amount of stuff, so understanding what's in them, and what that stuff does, is not as impossible as it may seem. Here is a guide to the basic electrical components used in a tube amp: tubes, resistors, capacitors, and transformers.

TUBES

An amplifying tube simply uses your bass's relatively low-voltage electrical output to regulate a much larger current in the amp. Consider a faucet. It takes very little effort to turn the knob and allow the high-pressure water

to flow. A small amount of energy is regulating a much larger amount of energy. A tube works the same way, except it regulates electricity, not water. In fact, tubes are still often called valves because of this similarity. All tubes, regardless of type, rely on the same basic principles and construction. Tubes in bass amps use a glass enclosure, which maintains a vacuum to prevent collisions between electrons and unwanted gas molecules.

The simplest tube is a **diode** (see What's In A Name, page 51), and is used in an amp as a **rectifier**. A rectifier tube consists of three main components: a **cathode**, an **anode** (also called the "plate"), and **filament** (or "heater"). In a rectifier tube the filament itself can function as a cathode or it can be placed very near the cathode. Either way, when low-voltage,

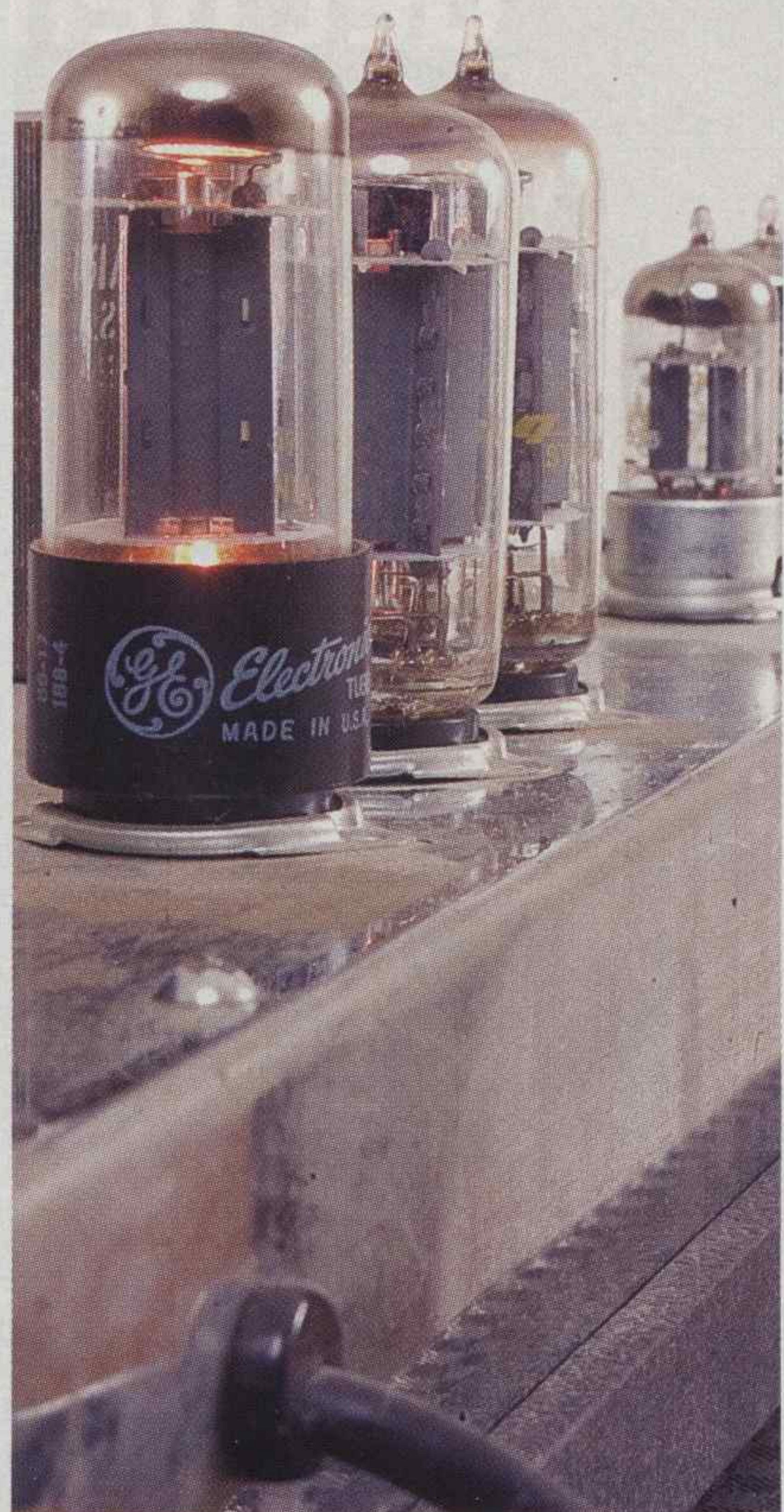
high-current electricity is applied to it, the filament and cathode get hot. The cathode is coated in a material that sheds electrons when heated. Remember from science class that electrons have a negative charge? The anode (from now on I'll call it the plate) has a positive charge. The difference in charge between the components causes the electrons from the cathode to be attracted to the plate, thus flowing across the tube's vacuum and on to the plate. Note that the electrons in a rectifier flow in only one direction: cathode to anode. Current flows in the opposite direction of electrons, in this case, from plate to cathode. This one-way current flow means that alternating current (AC) entering the rectifier leaves as direct current (DC). This process, called rectification, is essential for our amp to work. (More on that in Power Supply Basics, page 46.)

Amplification tubes, like **triodes**, **tetrodes**, and **pentodes**, add one or more additional

TUBE, SOLID-STATE, OR HYBRID?

WHEN IT COMES TO AMPLIFICATION, bass players have three basic options: all-tube, solid-state, or hybrid. The distinction refers to the amplification component used in a head's two primary stages, the preamp and power amp. The **preamp** raises a bass's relatively low-level output to make it strong enough for the myriad initial stages in the amp. The **power amp** does the heavy lifting, dramatically boosting the signal to drive a cabinet, transforming the tiny energy of a vibrating string into the force required to move speaker cones and bathe a room in bass. To achieve amplification, a solid-state head uses an electrical component made from a semiconductor, the transistor. Either on its own or incorporated into an "integrated circuit" (IC) chip, solid-state components are so called because electricity moves through solid material. Tube heads utilize vacuum tubes to achieve electrical amplification. By contrast to transistors, tubes send electricity through a vacuum. **Hybrid** heads combine solid-state and tube components, usually putting at least one tube in the preamp and relying on solid-state devices for the power amp. Though these components all achieve the same goal, transistors and tubes have a dissimilar influence on the amplified signal, which we hear as differences in tone.

Tubes sound different from transistors for several reasons. All output devices impart distortion on a signal, altering its waveform by creating overtones (or "harmonics") related to the frequency of the signal. When pushed to their operational limits, tubes tend to impart harmonics that are musically related to the fundamental in a way that's pleasing to the human ear. Though transistor circuits can be designed to closely emulate tube distortion, it's never quite identical. Tubes also move into the clipping range of operation (the point where the signal surpasses the capabilities of the device and begins to be cut off) more smoothly than transistors, which have an abrupt transition into clipping. Much of the difference in sound between tube and solid-state amps is that many typical tube bass amp circuits have stages that impart a distinctive sonic signature on a bass's tone—in this sense, they have lower fidelity than more contemporary solid-state devices. Since we're dealing with music, however, high fidelity does not necessarily equal good tone.



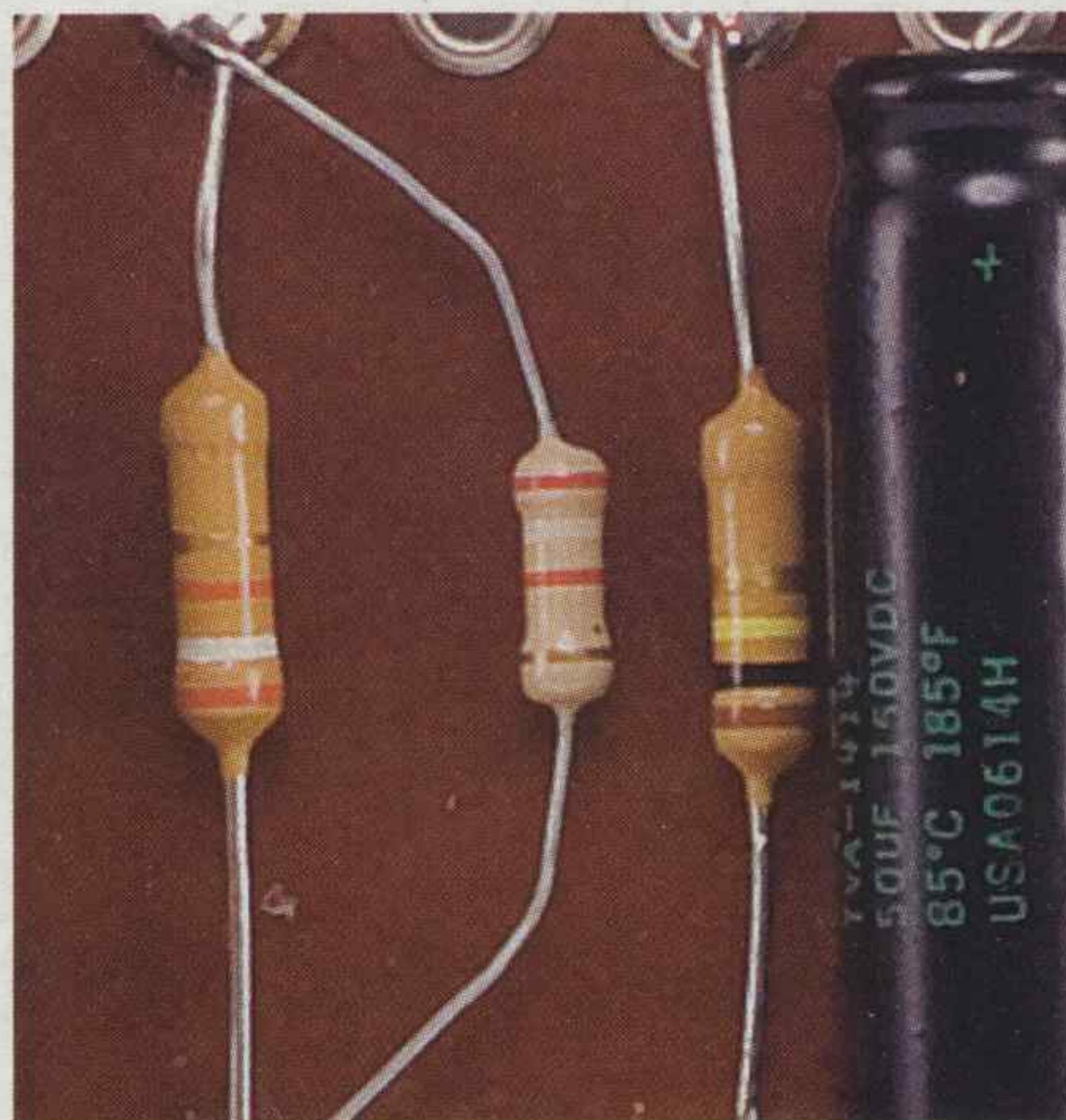
CLASS CONSCIOUSNESS

Someone will probably prove me wrong, but I'm not aware of a tube bass amp with anything other than a Class AB output section. Class AB is also called "push-pull." Push-pull amps split the audio signal into two out-of-phase twins, feed these into at least two power tubes (or two symmetrical banks of power tubes), and then sum them back together at the output transformer. Why? Efficiency. When the split-phase AC signal is fed into each side of our Class AB power section, one side of the power tube bank is "pushing" the signal while the other side is "pulling." In a sense, each bank of tubes is only working on half the incoming signal, allowing them to rest half the time. In reality, they're still drawing current even when they aren't amplifying, but still, they do cycle between full power and idle such that each bank of tubes works more efficiently. The advantage of this efficiency is more power and longer tube life.

active electrode, the **grid**. These more complex tubes are found in an amp's preamp and power amp, as the grid is the key to amplification. Like the valve in a faucet tap, the grid regulates the potential flow of electrons from the cathode to the plate. In a triode, a high-voltage DC current is applied to the plate, making it much more positive than the cathode, maximizing the flow of electrons between the heated cathode and the plate. When the grid is more negative than the cathode, it blocks some of the electrons coming from the cathode, preventing them from reaching the positively charged plate. As we change the voltage on the grid, we can influence the much larger current striving to flow between the cathode and plate. What's a perfect source of a small alternating signal to apply to our tube's grid? The output of your bass, which is a low-voltage AC signal.

RESISTORS

A **resistor** is an electrical component made from a material that has some resistance to electrical flow. The unit of measure for the amount of resistance is the ohm (Ω). Inside an amp, resistors are everywhere. They usually look like little grandma candies with multi-colored stripes on them. The stripes reference a standardized coding system for indicating a resistor's value. A potentiometer (or "pot"), like a volume knob, is a type of variable resistor. In tube



amps, resistors are used to regulate voltage and current, as well as frequency response when used in conjunction with capacitors. There are different types—*carbon comp*, *carbon film*, and *metal film*—and tube nuts argue over each type's effect on sound.

CAPACITORS

Capacitors are nifty. They exhibit "capacitance," the ability to store energy, which is measured in farads (F). They are also rated for the maximum voltage they can handle without breaking down. The capacitance and voltage rating are usually written on the capacitor, which can take a variety of shapes in an amp. Since the farad is a large unit, in the context

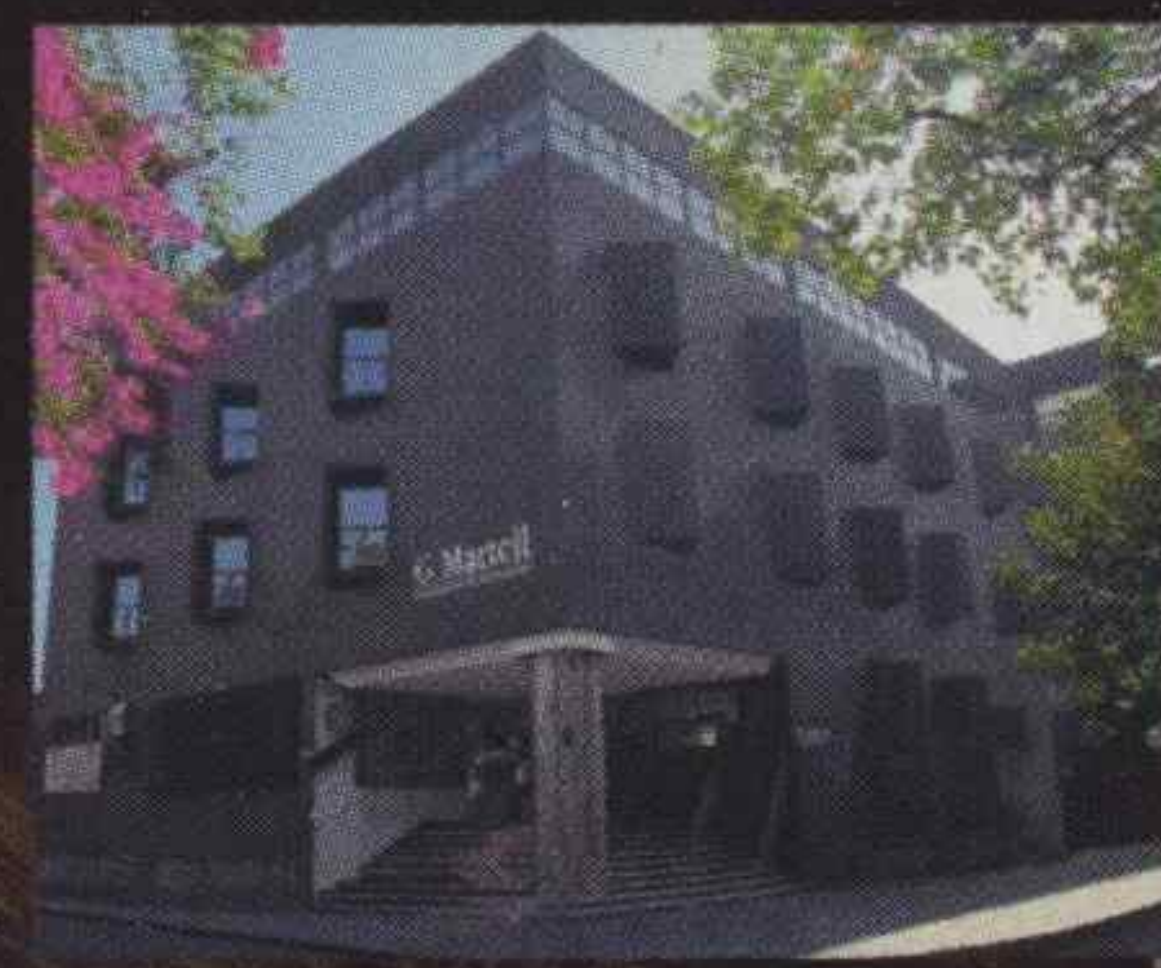
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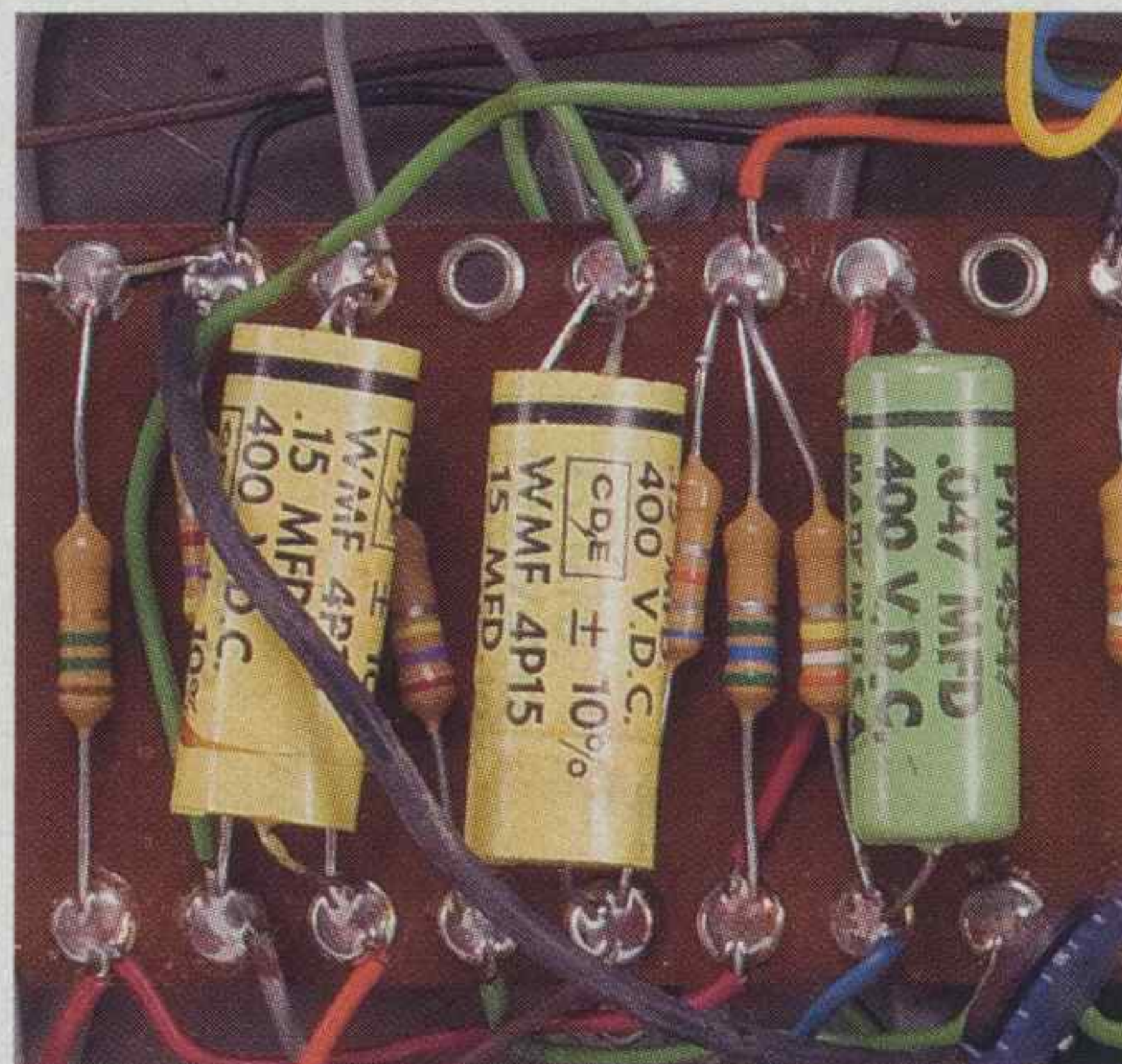
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of an amp we're usually dealing with microfarads. One microfarad (symbolized μF) equals 0.000001 farads.

A capacitor is made from two conductors (plates) separated by an insulator, or *dielectric*. How a capacitor stores energy is a bit complicated, but suffice it to say that sending electrons

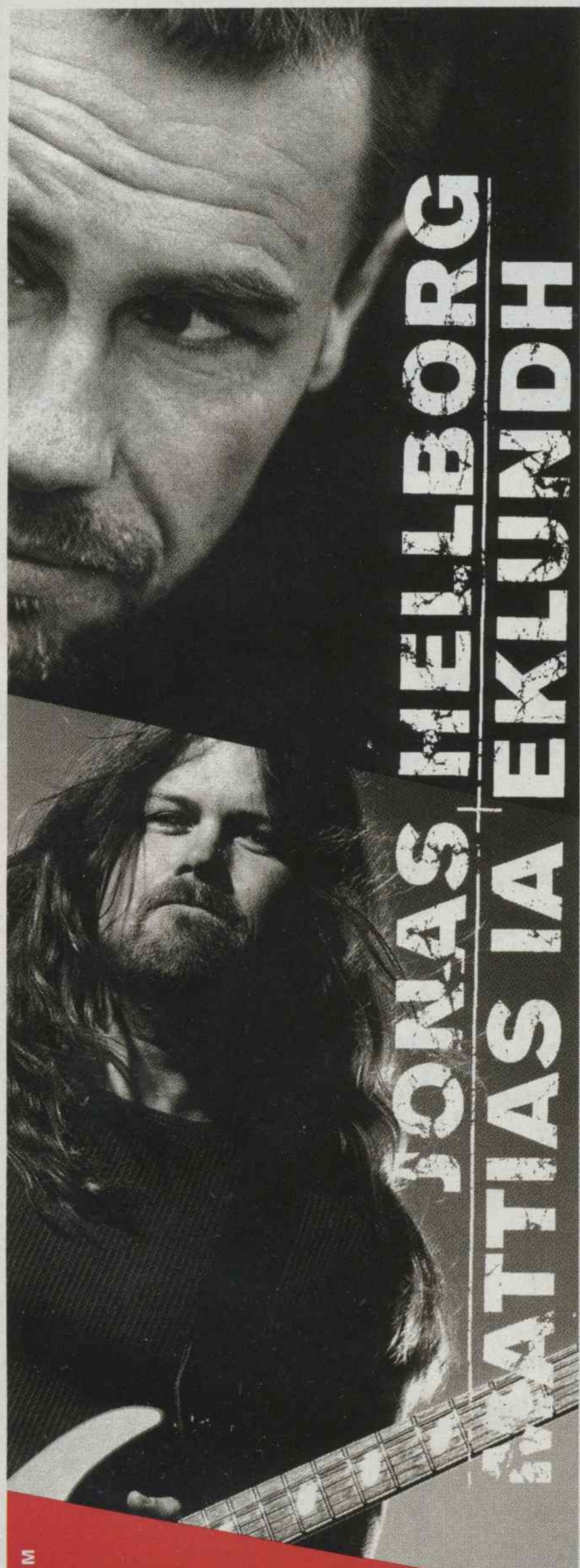


to one of the plates creates a difference in potential—one plate has more electrons than protons and the other has more protons than electrons—creating opposite areas of unbalanced charge. This has the effect of storing energy in the capacitor until it is discharged, allowing the potential difference to achieve equilibrium. The constant charging and discharging is achieved due to the nature of **alternating current (AC)**, which is constantly shifting polarity in a circuit. **Direct current (DC)**, which moves in only one direction, does not allow the capacitor to cycle through charge and discharge. The capacitor quickly charges, and then stays that way. As a result, when capacitors are wired in series, in a circuit they present infinite resistance to DC, effectively blocking it from moving down the circuit. This property is essential for coupling stages of a tube amp, where we want a bass's AC signal to pass through without the high-voltage DC from the power supply.

Capacitors also have another crucial characteristic: When wired in series with an AC signal, they block low frequencies and allow high frequencies to pass—they are highpass filters. This makes them key to tone shaping. The capacitance value determines the cutoff point for the highpass filtration—larger values allow more low frequencies to pass. Capacitors and resistors work together in resistor-capacitor (RC) circuits as frequency-selective filters for use in EQ circuits and to voice the various stages of a tube amp. There are two main types of capacitors: *non-polarized* and *electrolytic*. Electrolytic capacitors, which have a plus and

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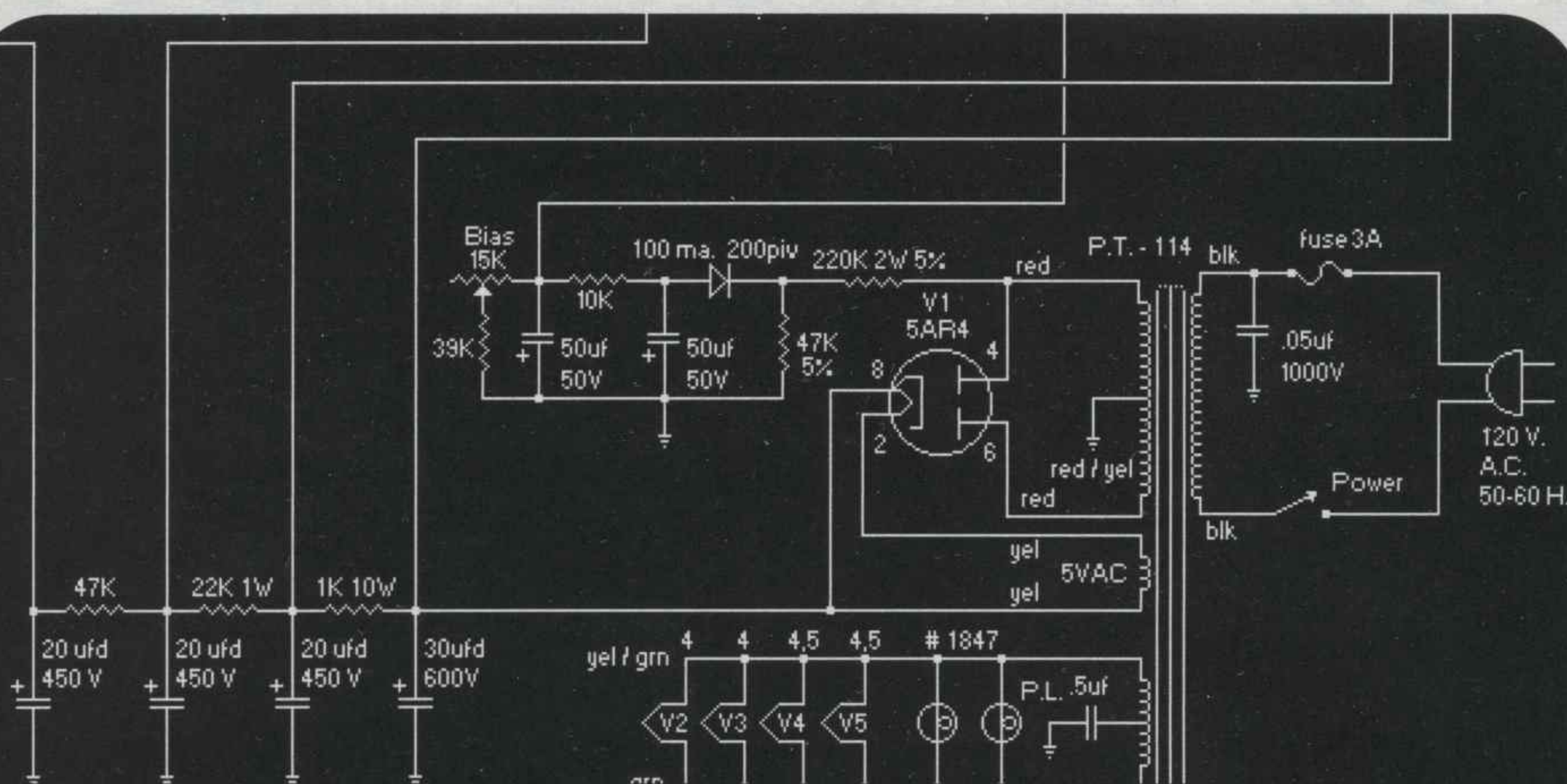
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POWER SUPPLY BASICS

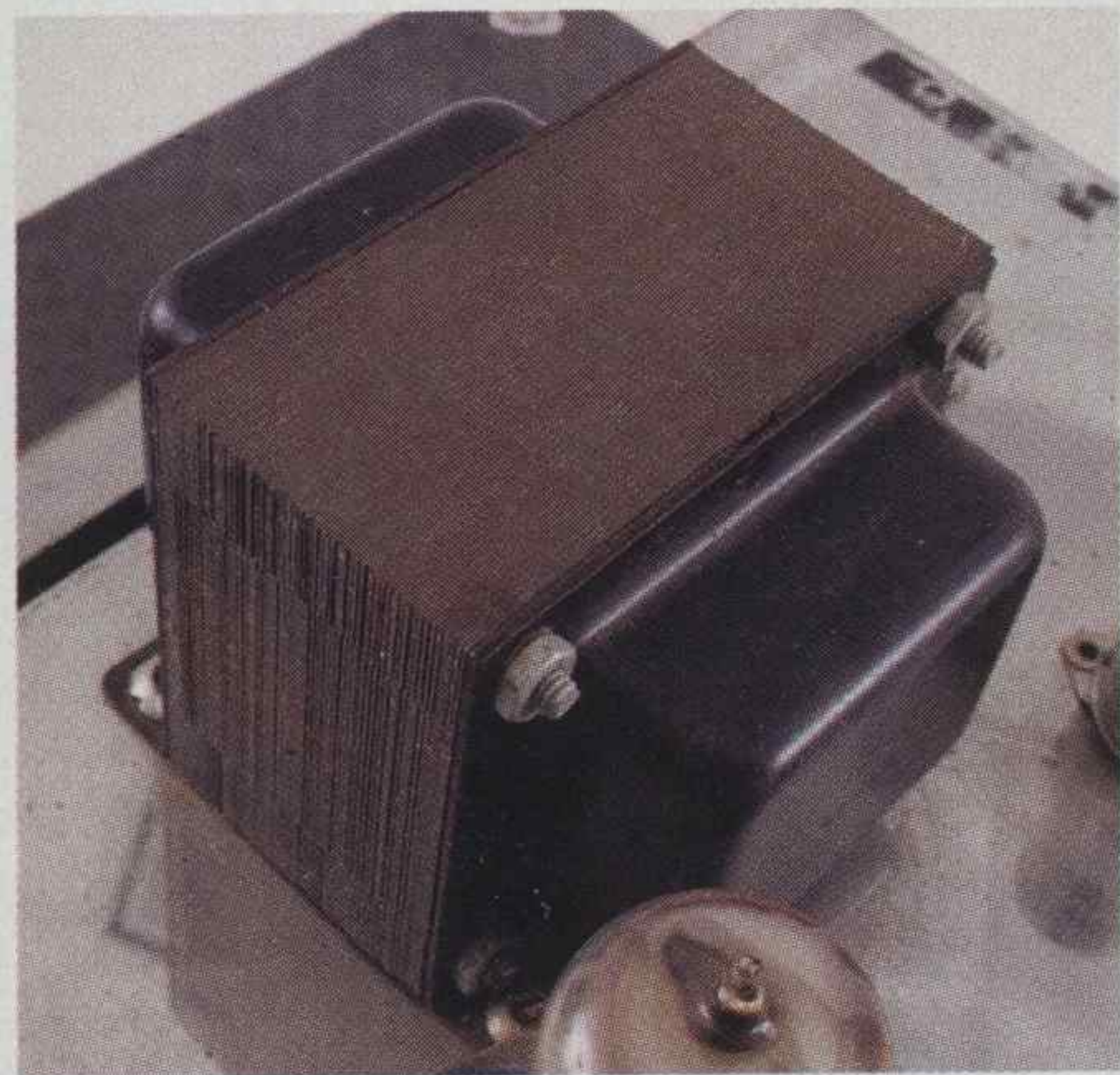
AN AMP USES TWO DIFFERENT TYPES OF ELECTRICITY that must coexist and move through the circuit: DC and AC. The AC is the bass's signal as it travels from the input to the speakers. The DC is the power source, moving from the power supply to tubes and other components. Many of an amp's circuits are designed to prevent DC from moving in the wrong direction (you don't want DC hitting the speaker or the tube grids) while allowing AC to pass through. It's important to understand that AC and DC can coexist on a wire.

The tubes in an amp require DC to operate, but the power from the wall socket is AC. To turn the AC into DC, amps use a rectifier. Rectifiers are tube or solid-state diodes that only let electricity move through them in one direction. Basically, AC goes in and DC comes out. In big bass amps, solid-state diodes are preferable, as they better cope with the big transient demands of the instrument's signal. Older tube bass amps, like the SB-12, often use tube diodes that perform the same function, but they sag a bit in their power delivery when asked to cope with a loud transient. This sag is audible as a compressed, lively dynamic response. Guitar players tend to dig it, but bass players may find it too squishy. If your amp has a tube rectifier and you want quicker power delivery, a solid-state diode retrofit is easy.

The rectifier turns the AC into DC, but the DC is lumpy; the waveform looks like a series of hills. To smooth it out, electrolytic filter capacitors are wired in parallel with the rectifier's output. The filters charge on the upswing of the lumpy DC input, but discharge much slower than the downward slope of the incoming DC. In this way, they smooth out the valleys in the DC, resulting in a DC signal that's essentially flat and smooth to send to our tubes.

The power supply handles another important task in our amp: **bias**. Bias describes the electrical relationship between a tube's control grid and its cathode. It's akin to a car's idle speed, except instead of engine RPM, we're dealing with current draw through the tube when we aren't playing. A properly set bias ensures that a tube is running at optimum condition, prepared to respond to changes in grid voltage in a linear way. In most all-tube bass amps, the power tubes are given a "fixed" bias. That means that a negative DC voltage is directly applied to the grids via a power supply circuit. The alternative, cathode biasing, works by making the cathode more positive than the grid, which is essentially the same as making the grids more negative than the cathode. Cathode biasing is self-adjusting; all preamp tubes are biased this way. But, since the power tube bias in a fixed-bias amp is adjustable (yes, the name is confusing), ensuring that it's appropriately set is an important aspect of tube-amp maintenance. It's a job best left to a qualified tech.

minus side, have much higher capacitance and voltage ratings than non-polarized capacitors, and are used in an amp's power supply to filter DC voltage.



OUTPUT TRANSFORMERS

Tube amps have a major component that distinguishes them from almost every solid-state amp: an **output transformer** (OT). Basically, an OT changes the high-voltage, low-current output of the power tubes to a low-voltage, high-current signal appropriate for speakers. It consists of two separate coils of wire (a primary and secondary) wrapped around an iron core. When an alternating current is applied to the primary, a magnetic field is created, which in turn induces a current in the secondary. If the secondary has a different number of wire turns, the AC will have different properties from the primary. Many tube amps let you change the output impedance of the transformer (by tapping off different places on the secondary winding) for proper matching with cabinets of different impedances. Transformers also block DC, protecting speakers from harmful DC spikes.

Since output transformers are the main interface between amp and speaker, differences in construction, like amount of iron or winding arrangement, have a large influence on sound. The details are intricate, but a good rule of thumb is that when it comes to bass-amp output transformers, bigger is usually better.

POWER TRANSFORMERS

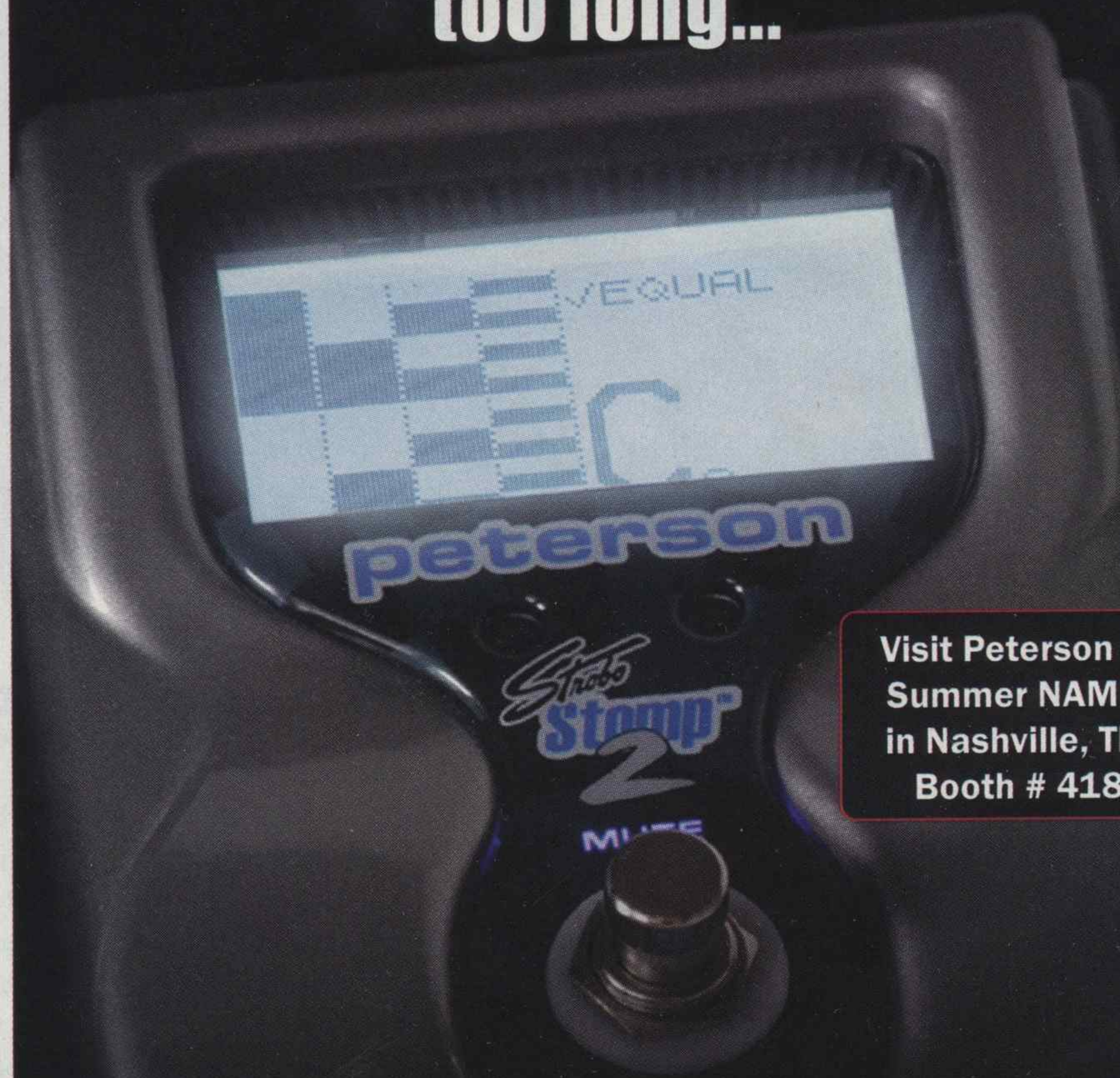
A power transformer looks similar to an output transformer, but in function, it's quite different. The power transformer is the interface between the amp and the electricity coming from the wall outlet. The power transformer changes the AC voltage coming from the outlet—in the U.S. this is about 120 volts at 60Hz—

into the various voltages required by the amp. It does this by means of a variety of secondary windings, each with the required number of wire turns to step down or up the voltage for the components down the line.

The preamp and power amp tubes require high voltage on their plates. The heaters in the tubes require a low voltage to heat up (6.3 volts, to be precise). A tube rectifier needs 5 volts to heat up. The transformer turns that 120-volt wall power into voltages that are workable in our tube amp.



You've been kept in the dark too long...

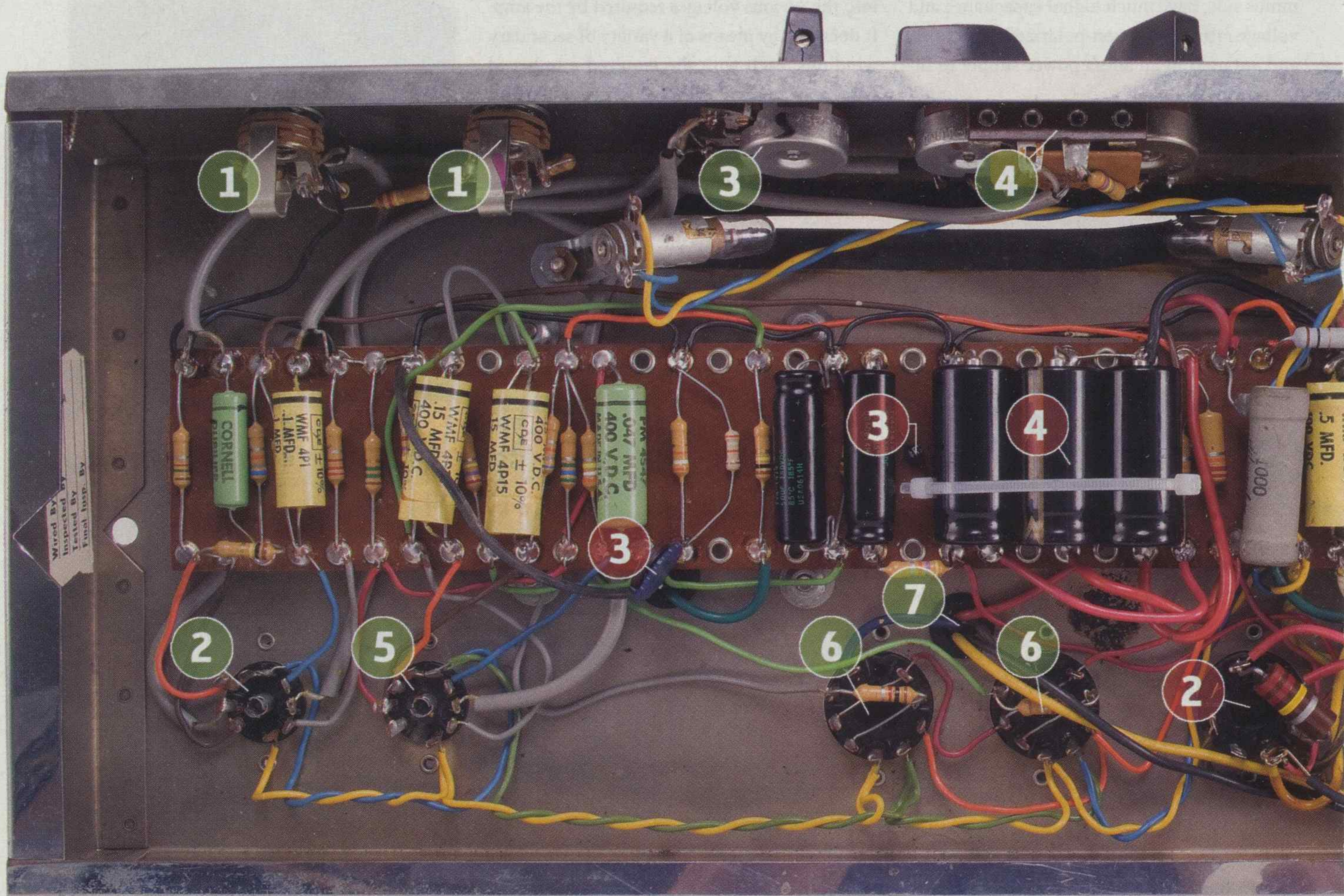


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AN ALL-TUBE CLASSIC, STAGE-BY-STAGE

NOW THAT YOU KNOW THE BASIC COMPONENTS OF A TUBE

amp, let's look at how they work together to produce sound. A tube bass head is best thought of as a series of stages. As the signal from your bass travels down the cord and into the amp, each of these stages has a different role in accomplishing the amp's goal. Take a look at the picture above. It's the interior of an Ampeg SB-12, specifically a 1966 model owned by Associate Editor Brian Fox. The SB-12 was originally designed for use with the Baby Bass (hence the prefix "SB" for "string bass"), but it's a mighty fine-sounding small amp for all-around recording and general tube-y goodness. It's also a simple circuit, thus making it a good example for understanding the underlying principles of tube amps. Brian's amp has had a "cap job" (replacement of all electrolytic capacitors, which can fail over time), so some of the components are not original, but the basic circuit has been preserved. (Had I chosen an Ampeg SVT, which is one of the most complicated tube amps ever built, we'd need quite a few more pages).

BASS SIGNAL PATH

1 INPUT JACKS

The SB-12 has two 1/4" input jacks, labeled BASS and INSTRUMENT. They're essentially the same.

2 PREAMP TUBE SOCKET

From the input jack, the bass's signal flows into the grid of the preamp tube, a 12AX7, which sits in this socket on the other side. The pins of the socket correspond to the different electrodes in the tube.

3 VOLUME POT

The output coming off the plate of the first stage of the 12AX7 goes through a capacitor to block the high DC voltage (but allow our bass's now-amplified AC signal to pass). Then it goes to a volume potentiometer, which controls the gain of the bass signal as it enters the grid of the "second" tube (really the other half of the 12AX7 dual triode).

4 TONE STACK

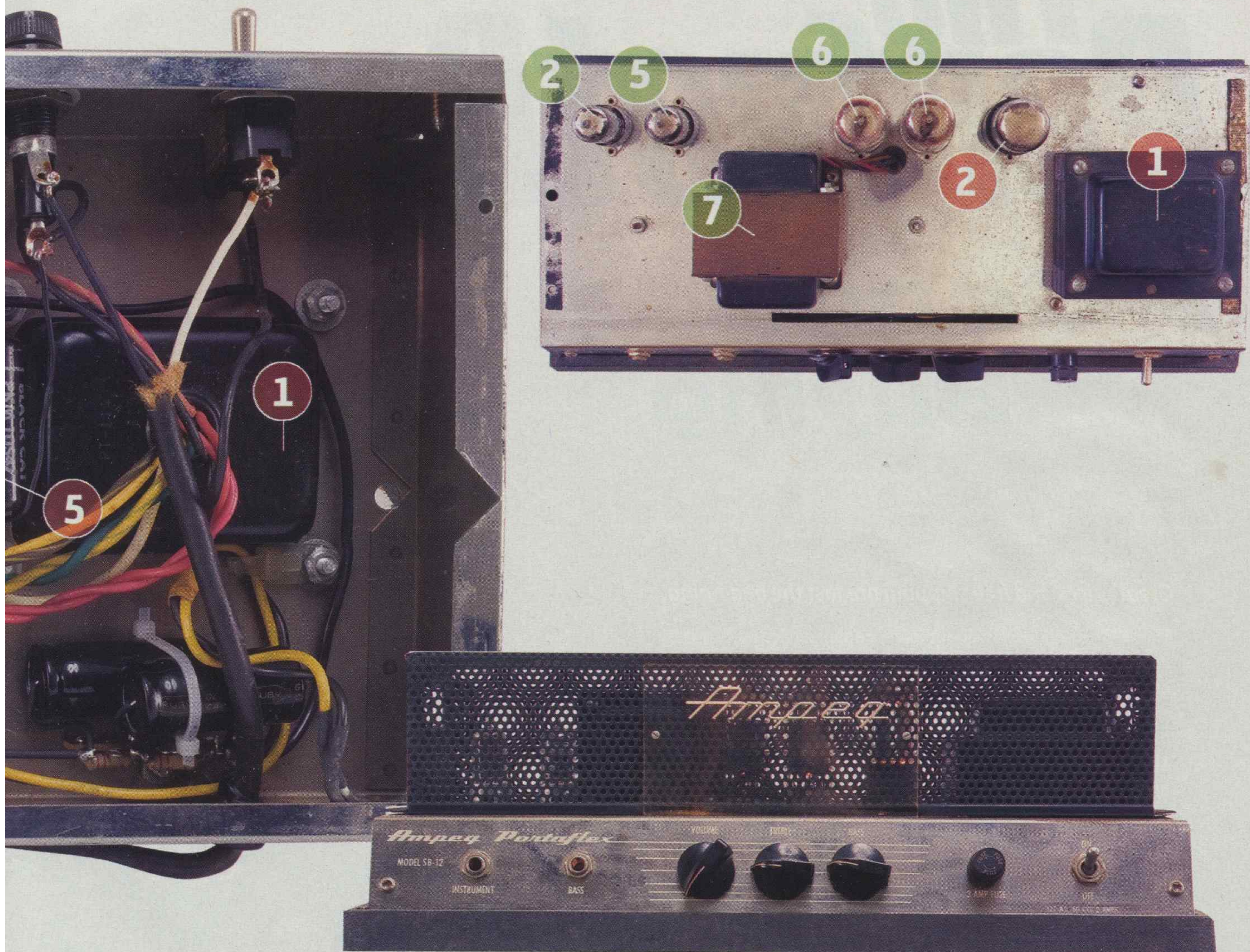
A bass's signal leaves the

plate of the 12AX7 and hits the SB-12's "tone stack."

Governed by the BASS and TREBLE knobs, the tone stack is a relatively complicated collection of pots, resistors, and capacitors that work together to shape the frequency contour of the bass signal.

5 PHASE INVERTER

The other 12AX7 in the SB-12 is a phase inverter (PI) tube. In a Class AB amp like this (see Class Consciousness, page 43), two AC sig-



nals of equal power but opposite phase are required to feed into the power tubes. This tube accomplishes that goal, and it also boosts the power from the first tube to produce the current necessary to drive the power tubes.

6 POWER TUBES

The SB-12 uses a couple of semi-rare 7868 tetrodes in the power amp.

7 OUTPUT TRANSFORMER

The plates of the power tubes

are connected to the output transformer. Originally, the flip-top SB-12 made its speaker connection through the latches attaching the head to the cabinet. Weird. Brian's has been updated with a speaker cable, which begins with the yellow and brown wires seen here.

POWER SUPPLY

1 POWER TRANSFORMER

The SB-12's power transformer is connected to wall power via the POWER switch and a 3A fuse. The wires exiting the

hole at the transformer's base are headed in numerous directions to provide power to the amp's components.

2 TUBE RECTIFIER

The SB-12 utilizes a 5AR4 tube rectifier. The red wires are connected to the 5AR4's two plates. The yellow and yellow/brown wires send 5-volt AC to the tube's heater for operation.

3 BIAS SUPPLY AND DIODE

This diode takes DC current

from the rectifier and flips its polarity to provide a negative DC voltage to the grids of the power tubes. This trim pot is for bias adjustment. The bias current is filtered courtesy of the two smaller black electrolytic capacitors.

4 TUBE DC PLATE SUPPLY

The bank of black electrolytic capacitors smoothes the high-voltage DC coming from the rectifier. The power is then sent to the plates of all the amp's tubes, either

directly in the preamp, or via the output transformer in the power amp.

5 FILAMENT SUPPLY

The yellow/green and green wires coming from the transformer are providing 6.3Vac to the pilot lights and to the heaters of all the amp's tubes except the rectifier. Check out the two pilot lights beneath the slit in the amp. These light up the SB-12's trademark Plexiglas logo.

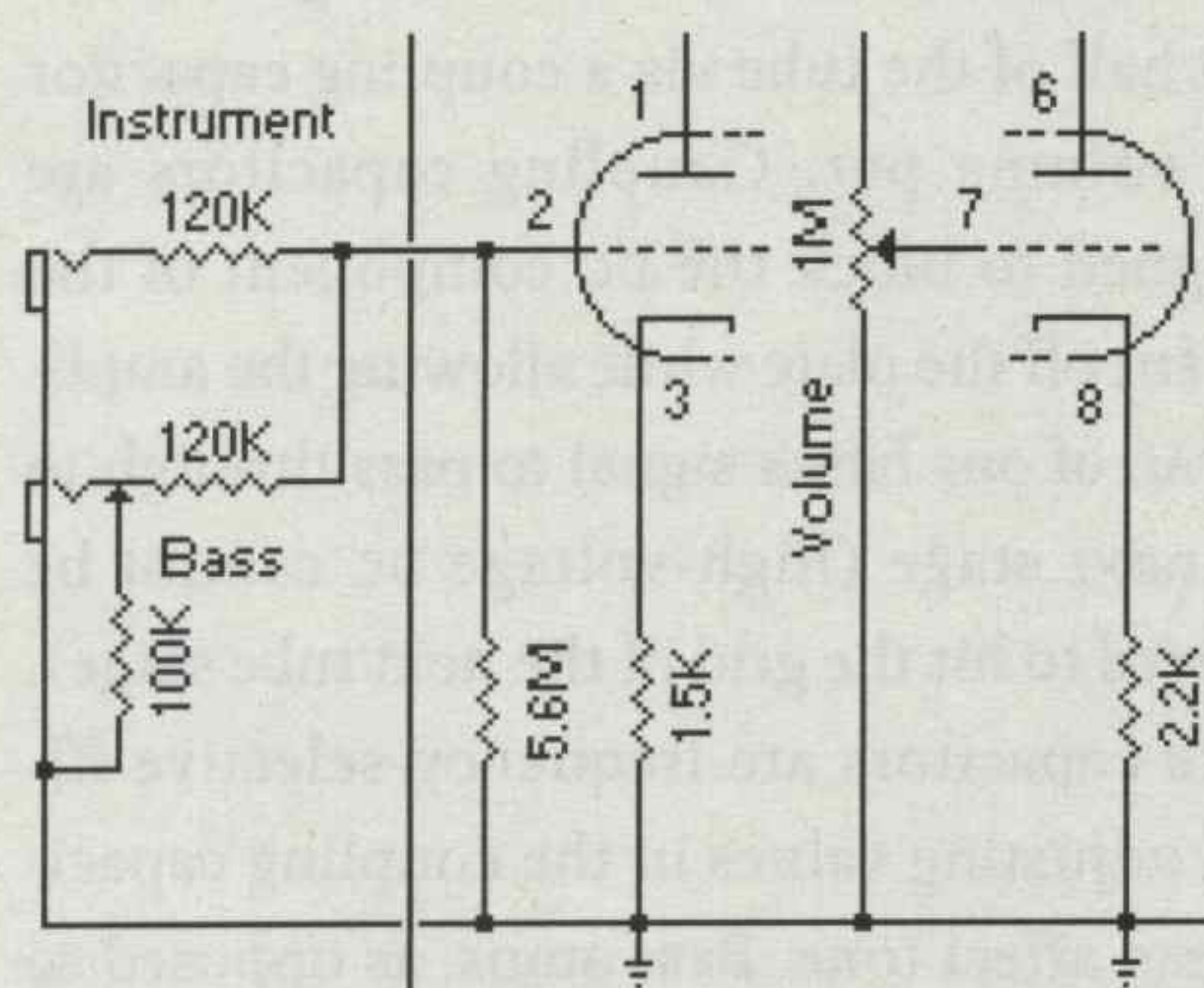
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HOW DOES IT WORK?

THE AMPEG SB-12 IS AS SIMPLE AS TUBE AMPS GET, but it shares all the fundamental principles of tube amplification with its bigger, more complicated, cousins, like the SVT. Let's reexamine the stage-by-stage description in the previous pages to understand how an all-tube bass amp operates.

INPUT JACK TO PREAMP TUBE

The signal from a bass plugged into one of the input jacks hits the grid of the first 12AX7 in the preamp. There are a few resistors in series and parallel with the signal path that help regulate the performance of the tube. Remember, the grid is the "valve" that controls the flow of electrons from the cathode to the plate. To do so, the grid must be negative with respect to the cathode, as this

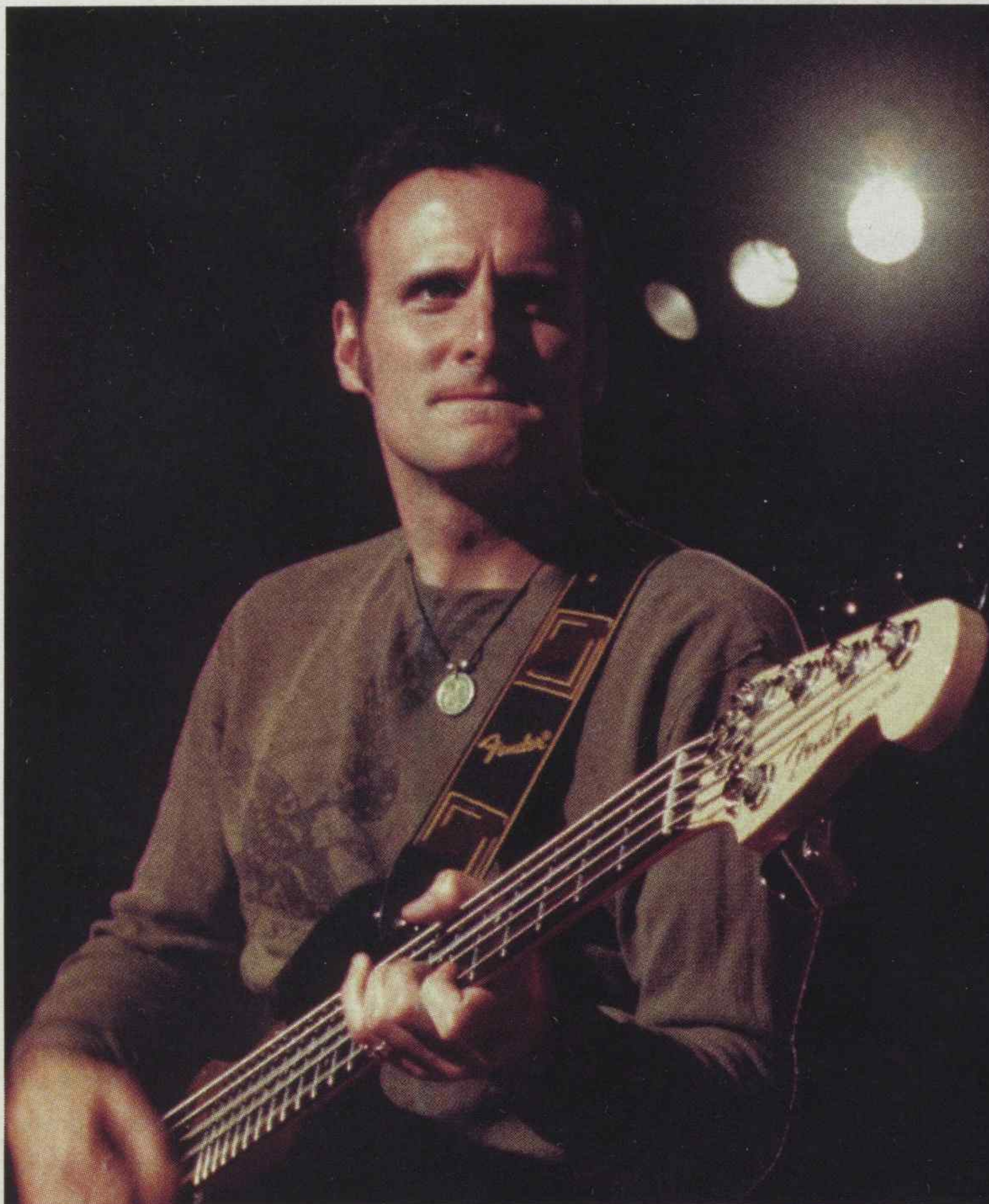


The zig-zag lines labeled "bass" and "instrument" are resistors tied to the input jacks. The semi-circular symbols are the two halves of the 12AX7 dual triode. The dashed line is the grid, the plates are at the top (labeled 1 and 6, for the corresponding pins), and the cathodes are at the bottom, labeled 3 and 8.

WHAT'S IN A NAME?

The standardized naming for tube construction (not tube type—that's a numerical code) is composed of a Greek prefix denoting the number of active electrodes in the tube and the suffix "ode," from the Greek *odos*, meaning path or way. There's some interesting etymology here: "Electrode" combines *odos* with the Greek *electron*, which means amber, because electrical phenomena were first observed by rubbing amber with a cloth. An "anode" receives current, while a "cathode" emits it. The words come, rather abstractly, from an analogy to the rising and setting of the sun; the Greek *ano*, or upward, and the Greek *kata*, or downwards.

The tube naming scheme excludes the heater since every tube has one, although in rectifier tubes, sometimes the heater doubles as the cathode. You can derive the number by counting the cathode, anode, and grids. A diode, such as a tube rectifier, has a cathode and anode, thus we use the prefix "di" for two. A triode, like the 12AX7, has a cathode, anode, and control grid—that's three components, hence the name. (Technically, a 12AX7 is a *dual* triode, since it contains two triodes in the enclosure.) A tetrode, like the 6550 power tubes used in most Ampeg SVTs, houses a cathode, control grid, screen grid, and anode—four electrodes in all.



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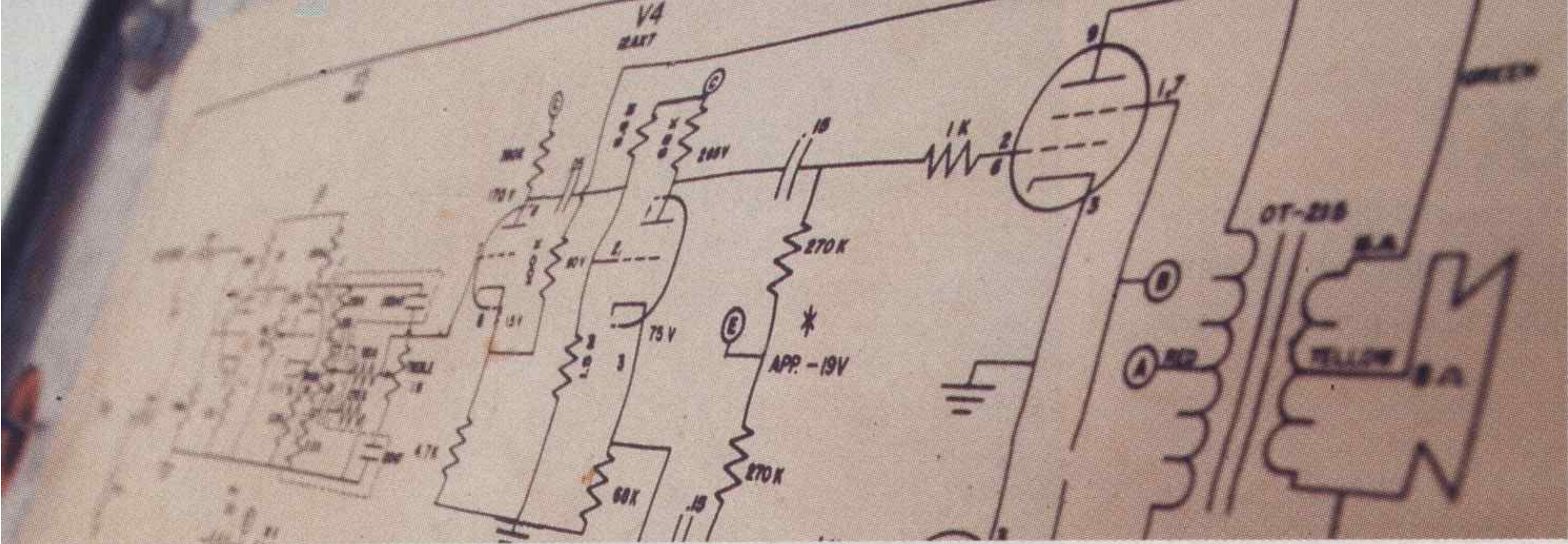
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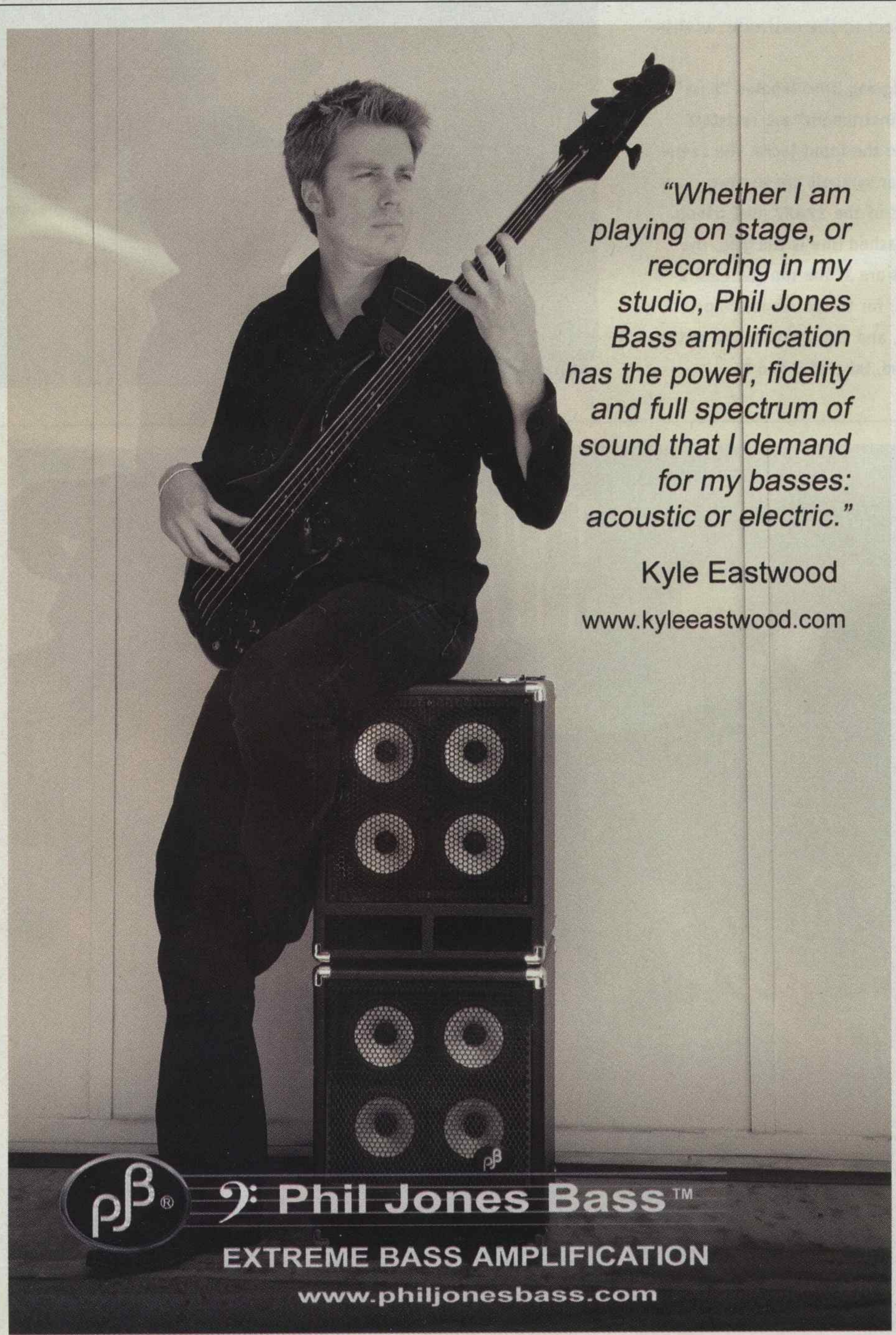


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This original schematic for Associate Editor Brian Fox's Ampeg SB-12 was scotch taped under the amp chassis. Cool!



"Whether I am playing on stage, or recording in my studio, Phil Jones Bass amplification has the power, fidelity and full spectrum of sound that I demand for my basses: acoustic or electric."

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blocks some portion of the electron flow between the cathode and plate. The AC output of our bass's signal controls the voltage of the grid, regulating the flow of electrons from the cathode to the plate. The voltage of the grid with respect to the cathode is the "bias" (see *Power Supply Basics*, page 48, for more). The 12AX7 is biased via a capacitor from the cathode to ground. This has the effect of making the cathode more positive than the grid. The power supply is injecting high-voltage DC to the plate of our 12AX7 to power the tube. The bass's signal leaves the plate of the first triode in the 12AX7 and is joined to the grid of the next half of the tube via a coupling capacitor and volume pot. Coupling capacitors are designed to block the DC component of the current off the plate while allowing the amplified AC of our bass's signal to pass through to the next stage (high-voltage DC cannot be allowed to hit the grid of the next tube stage). Since capacitors are frequency-selective filters, adjusting values in the coupling capacitor can affect tone. Bass amps, as opposed to guitar amps, have large-value coupling capacitors to extend low-frequency response.

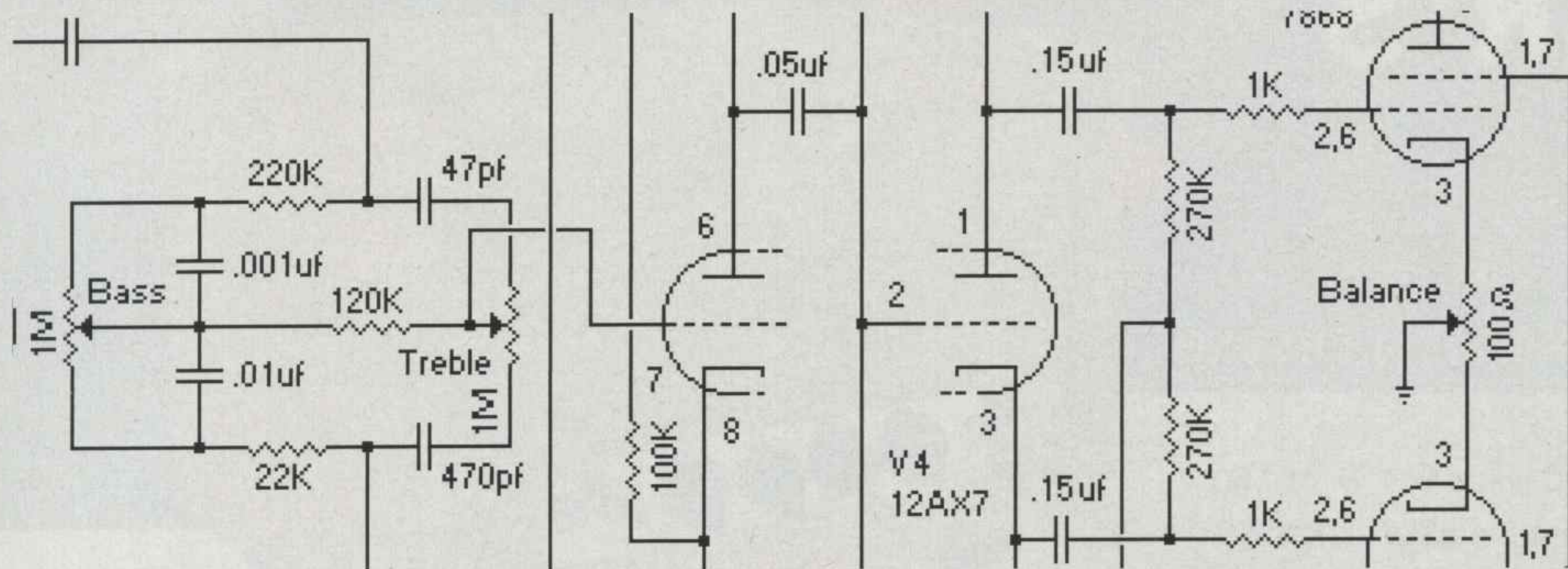
The bass's signal is amplified by the second stage of the 12AX7 and then sent, via the plate (the bass's signal will always exit tubes via the plate, except in the phase inverter) into the tone stack.

TONE STACK

The Ampeg SB-12's BASS and TREBLE knobs govern a Baxandall-style tone stack (named after its inventor, Peter Baxandall). A tone stack is a passive RC (resistor-capacitor) network that allows a player to tailor the amp's frequency response. Modern tube amps may use some solid-state components here for more precise control over EQ. The Baxandall is a fairly hi-fi circuit that works especially well for bass, due in part to its mid-emphasizing capability. When the knobs are in the center position, it gives a near-flat response, but when BASS and TREBLE are cut completely, the midrange remains. The overall signal level is reduced, but you can increase the amp's volume to compensate for the cut frequencies.

PHASE INVERTER

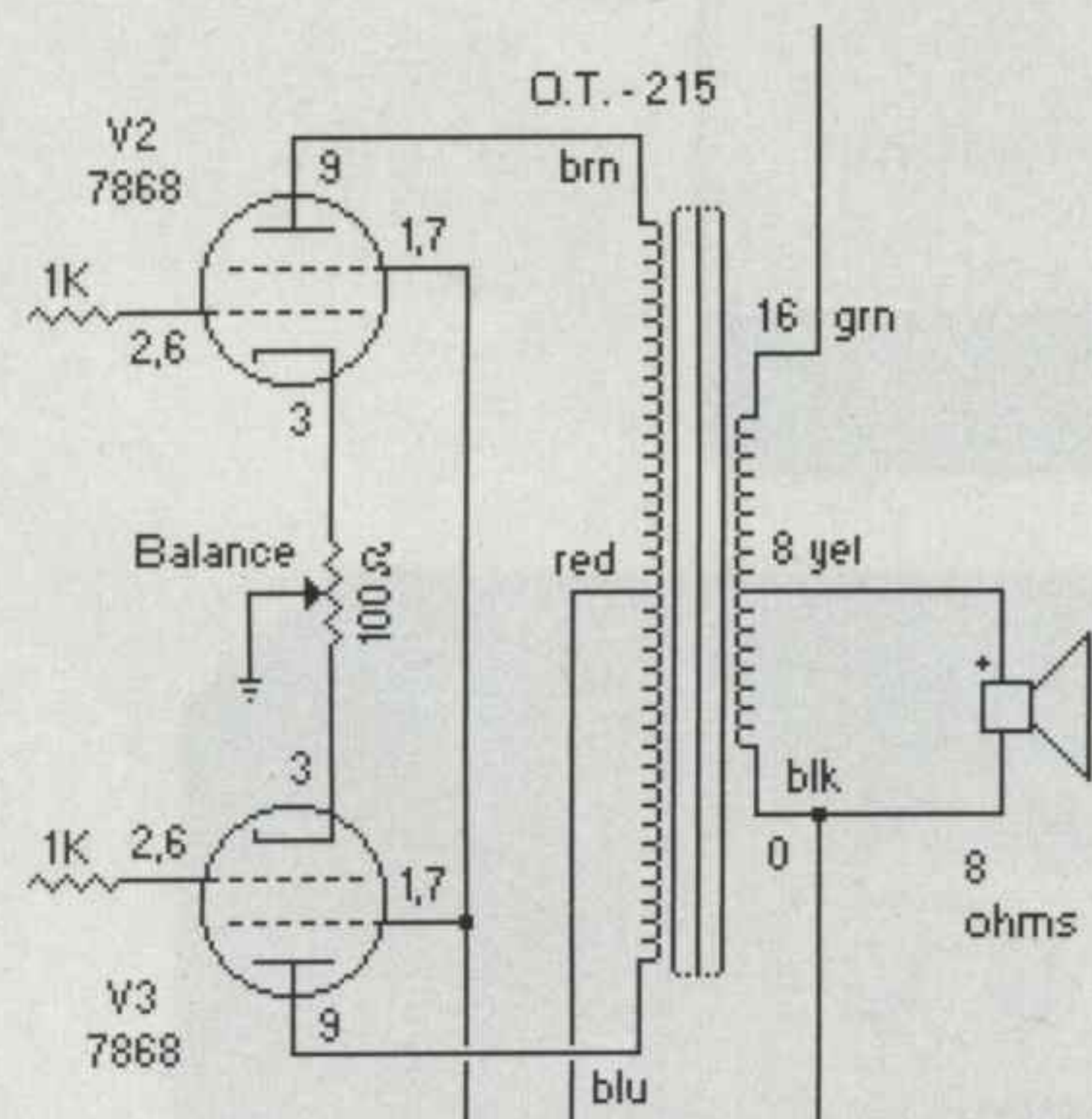
The Ampeg SB-12, and pretty much every all-tube bass amp ever made, has a Class AB power amp, which needs to be fed with two versions of a bass's signal that are identical but out-of-



The tone stack is the square-shaped circuit on the left consisting of capacitors (the parallel lines), resistors (zig-zag lines), and pots (zig-zag lines with an arrow). The PI tube is in the center, a dual triode labeled "V4 12AX7." The output of the tone stack is linked to the grid of one half of the dual triode, at pin 7.

Many thanks to Joe Piazza for his excellent Ampeg SB-12 schematic.

phase. There are several circuits for accomplishing this, but the Ampeg SB-12 uses a design known variously as the "cathodyne," "split load," or "concertina" phase inverter (PI). (It's so called because the resulting out-of-phase signals resemble the bellows of a concertina on an oscilloscope). Before the phase inversion occurs, a bass's signal gets a boost from the first triode of the 12AX7 PI in the SB-12. The second triode accomplishes the phase inversion, sending a bass's signal to the grid of one of the 7868 power tubes from the plate and an out-of-phase version of that signal to the grid of the other 7868 power tube via the cathode.



The 7868 power tubes (the circular symbol) are linked to the OT via their plates (pins 9), while the cathodes (pins 3) are tied to ground. Signal comes in via the control grid (pins 2 and 6).

POWER TUBES & OUTPUT TRANSFORMER

A bass's signal hits the grids of the two 7868 power tubes, regulating the flow of power from the cathode to the anode, and thus, an amplified version of the signal appears on the plates. The 7868's plates are tied to either end of the primary winding of the output transformer (OT) and a center tap on the primary is receiving high-voltage DC from the power supply. The bass's amplified signal is present on the primary side of the OT, and in the secondary winding it's converted to a low-voltage, high-current signal, which is connected to the speaker. **BP**

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