Vacuum Tube Guitar Amps: One Electrician's Trash is Another Guitarist's Treasure

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ABSTRACT: The transistor is the backbone of modern digital technology, but most professional guitarists insist on only using amplifiers that use vintage vacuum tubes and mid-twentieth century technology. This article transposes the technological advantages of transistors with the physical and perceived benefits of using vacuum tubes in guitar amplifiers, from their emphasis of certain sound frequencies to their simplicity of design and the subculture of musicians who build them themselves.

KEYWORDS: Vacuum Tube, Transistor, Electric Guitar Amplifiers, Amps, Vintage, Boutique

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Fig 1: Three 12AX7 Vacuum Tubes, commonly used in Guitar Amplifier Preamps (Roddy)

Introduction and History of Vacuum Tubes/Transistors

The last 60 years have been an amazing period for technological advances, as society has seen such advances as the personal computer and the Internet. Over time these devices have become smaller and faster, fueled by the invention of the transistor, a small electrical device that acts as a valve for electrical current. Yet this device, which serves as the backbone for most modern technology, is the very thing that many experienced guitarists spend thousands of dollars to avoid, instead favoring the vacuum tube, a larger and inefficient glass tube that has been emptied of oxygen and uses heated metal plates to control the flow of electrical current. The vacuum tube has many advantages over transistors in guitar amplifiers, from the perceived “tube warmth” that many guitar players describe to the different types of harmonic audio frequencies it

emphasizes and its simplicity of design, proving that the transistor, while fundamental in other fields, produces a diminished return in amplifiers.

Advances in transistors have fueled the growth of digital technology over the last 60 years, mostly replacing vacuum tubes due to the technical superiority and convenience of transistors. Vacuum tubes were a fundamental building block in most electronic devices for the greater part of the twentieth century, but have since been replaced by transistors in most arenas. Transistors gained favor due to their reliability, size, and efficiency when compared to vacuum tubes. While tubes burn out and require replacement, transistors are so reliable that they are often impossible for the end user to replace (such as inside a computer's central processing unit, or CPU). Additionally, tubes are usually between one and five inches in their longest dimension, but the latest manufacturing technologies can fit over five hundred million transistors in a single, handheld CPU. Vacuum tubes also generate a great amount of heat, which provides both a safety issue for the consumer, and wastes electricity (as a large percentage of electricity is dissipated as heat). All of these factors make the use of tubes in modern digital technology impractical, expensive, and often impossible, as portable, fast, and reliable microprocessors would be impossible without using transistors as a replacement; as a result, audio devices are one of the few remaining consumers of tubes (with microwaves being the other major user of tubes due to their "power-handling capability at high frequencies") (Barbour 24). Even most modern audio equipment has switched to transistors, but the use of vacuum tubes in guitar amplifiers has "surged over the course of the 1990s." Tubes even "hold sway over the US $100 million worldwide guitar amp business," growing as much as "10 percent-per-year" (Barbour 25).

Qualitative and Quantitative Differences Between Tube and Transistor Amplifiers

While it is immediately obvious from theses statistics that the majority of guitar players, or at least those who purchase expensive equipment, prefer tube guitar amplifiers, the more challenging question is determining the reason for the preference. One possible explanation that Eric Barbour argues in his 1998 *IEEE Spectrum* article entitled "The Cool Sound of Tubes" is that the distinct sound of tube guitar amplifiers in early rock and roll music created a cognitive bias towards that sound, and that commercially successful amplifiers must emulate "the sonic signature" of these classic amplifiers (25). While I agree with this analysis to a degree, it does not apply to areas of music that rely on vastly different guitar tones but still use tubes. For example, heavy metal music can hardly be described as similar to fifties rock tonally, but pioneering bands such as Metallica use tube amplifiers such as the Mesa Boogie Triple Rectifier to deliver their distorted sound. Surely nostalgia plays some role in the preference for tubes, but there are not many people replacing their transistor radios with tube ones for "old times' sake," which leads one to wonder what physical characteristics make tubes superior in amplifiers.

One physical and measurable characteristic that explains the vacuum tube's superiority is that it emphasizes even order harmonics, while transistor amplifiers emphasize odd order harmonics. Merriam-Webster defines a harmonic as a "vibration frequency [that] is an integral multiple of that of the fundamental" ("Harmonic"). That is, if one were to play a single note on a guitar, the resultant sound would be composed of the fundamental frequency (the note that was played) and harmonic overtones, or

frequencies vibrating at two, three, or more times the fundamental frequency, which give it a complex sound. For guitar sound, even order harmonics (second, fourth, etc…) are widely believed to add overall warmth to the tonal characteristics of the guitar, while odd order harmonics are often attributed with making a guitar sound thin (a usually undesirable trait).

In a presentation to the Journal of The Audio Engineering Society in 1972 entitled *Tubes Versus Transistors- Is There an Audible Difference,* Russell O. Hamm demonstrated a substantial difference in the magnitude of the second and third order harmonics between tube and transistor amplifiers. Figure 2, below, shows the harmonic distortion components of a typical two-stage triode tube amplifier (270), while figure 3 shows that of a multistage transistor amplifier (271).

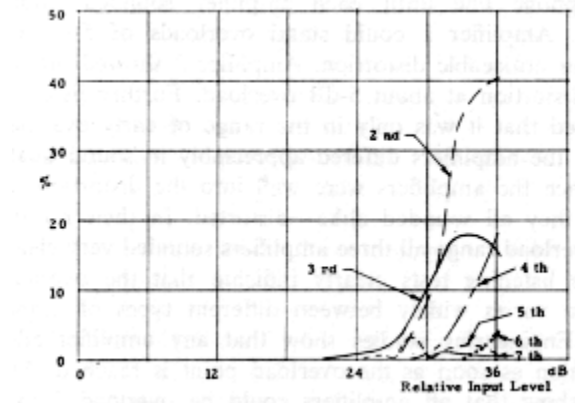

Fig 2: "Distortion components for two-stage triode amp" (Hamm 270)

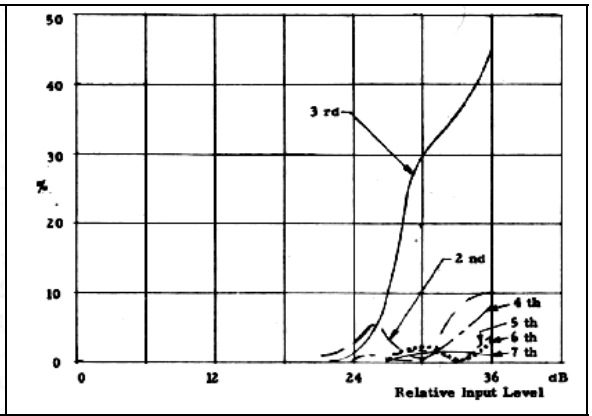

Fig 3: "Distortion components for multistage capacitor-coupled transistor amp" (Hamm 271)

A careful analysis of these graphs demonstrates that the tube amplifier emphasizes the second order harmonic while the transistor amplifier has a substantial third order harmonic. Hamm describes the even order harmonics (such as the second) as adding a

"choral" or "singing" quality to the overall sound, and odd order harmonics (such as the third) as making the tone "stopped" or "covered" (272). These differences could explain the extra "warmth" that guitar players associate with tube guitar amplifiers, and thin sterility often associated with transistor amplifiers.

Hamm's discoveries are corroborated by W. Stephen Bussey and Robert M. Haigler's 1981 publication entitled *Tubes Verses Transistors in Electric Guitar Amplifiers*. In their trials, Bussey and Haigler compared the Fender Twin Reverb tube amplifier with a similarly designed transistor amplifier (800). They analyzed the harmonic distortion spectrum of the two amplifiers and produced graphs quantifying the different levels of harmonic overtones found in each one, as shown in Figure 4 below.

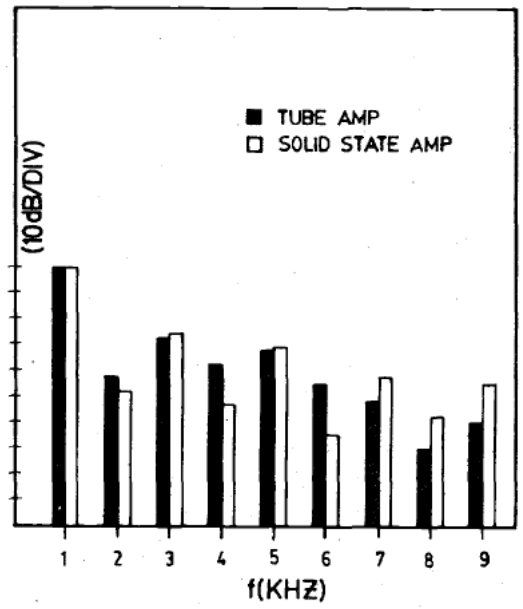

Fig 4: "Harmonic Distortion Spectrum" (Bussey 801)

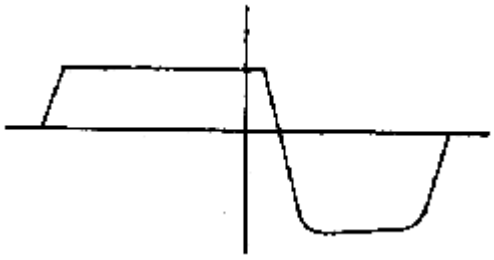

Fig 5: "Waveform of triode amp of Fig. 4 at 12-dB overload. 1000-Hz tone" (Hamm 270)

Their results are consistent with Hamm's findings, showing that tube amplifiers favor even order harmonics, while solid state (transistor) amplifiers with the same one hundred

decibel fundamental frequency amplitude favor odd order harmonics. In the case of the fourth order harmonic, the tube amplifier produced approximately 63 decibels and the solid state amplifier less than 50. This separation is even more dramatic for the sixth order harmonic. Although the different characteristics associated with emphasis of particular harmonic frequencies are hard to quantify, it is clear from these results that significant differences do exist between the two types of amplifiers.

One of the main types of guitar tone that is considered superior when produced with a tube amplifier is a saturated (often called distorted) tone when the amplifier's volume is placed at or near a maximum. Guitar players often describe tube saturation, which is when tubes are pushed beyond their limit for processing the signal cleanly, as "creamy" and "smooth," and characterize transistor saturation as "harsh" and "brittle." Barbour attributes these sonic differences to the ways in which the different amplifiers "clip," or flatten the top and/or bottom of the sound wave in saturation (see Fig. 5 above for example of clipped wave). He describes tube clipping as "smooth, which is widely considered more musical" and transistor clipping as "sharp…in a manner widely considered non-musical" (29). This explanation lends weight to the guitarist's common notion that the "holy grail" of distorted tone is a cranked tube amplifier (a tube amplifier with its volume on maximum), and that anything less is just an imitation. However, this poses another problem for the guitarist, as a tube amplifier on maximum can produce an incredible amount of volume, which disturbs neighbors and can damage one's hearing. Transistor amplifiers can reach saturation at a far lower volume, thus allowing for increased flexibility, but in doing so sacrifice overall tonal quality.

Simplicity of Design, Home/Boutique Builders, and Conclusions

Another feature of the vacuum tube which cannot be reproduced with transistors is the ability to swap out different types of tubes for a completely different sonic experience in an amplifier. Josh Workman describes this feature in his *Guitar Player* magazine article entitled “All About…Power Tubes” by saying that “unlike transistors-which are all made to very exact specs by computers and robots-vacuum tubes are still hand-assembled in different countries with different metals, and under varying conditions that can drastically affect their sound” (152). This allows so-called “tone aficionados” to customize any tube amplifier to their exact needs, just by swapping out the tubes with a different but compliant vacuum tube (whether it is exactly the same type but made by a different manufacturing process or has slightly different specifications). Workman quotes Aspen Pittman of Groove Tubes, a major modern manufacturer of vacuum tubes for guitar amplifiers, as saying “changing your tubes is the most basic modification you can have done to your amp, and, very often, you can get the sound you're looking for without further effort.” This level of fine tuning is impossible with transistor amplifiers, unless of course one were to physically unsolder a transistor from the circuit board and replace it with a different kind, which is highly impractical.

An additional draw of the tube amplifier is the simplicity of traditional tube circuits. With the help of the Internet, anyone with basic soldering skills can modify or even build from scratch a tube amplifier that fits their own personal tastes. Transistor and most modern tube amplifiers from large builders are produced on printed circuit boards that allow for cheap manufacturing, but the original tube amplifiers of the fifties and sixties were built on simple turret boards with point to point (where a wire, not a circuit

board trace, connects each component as in Figure 6) wiring. These point to point designs allow for easy circuit modification, as components can be easily substituted with a soldering iron.

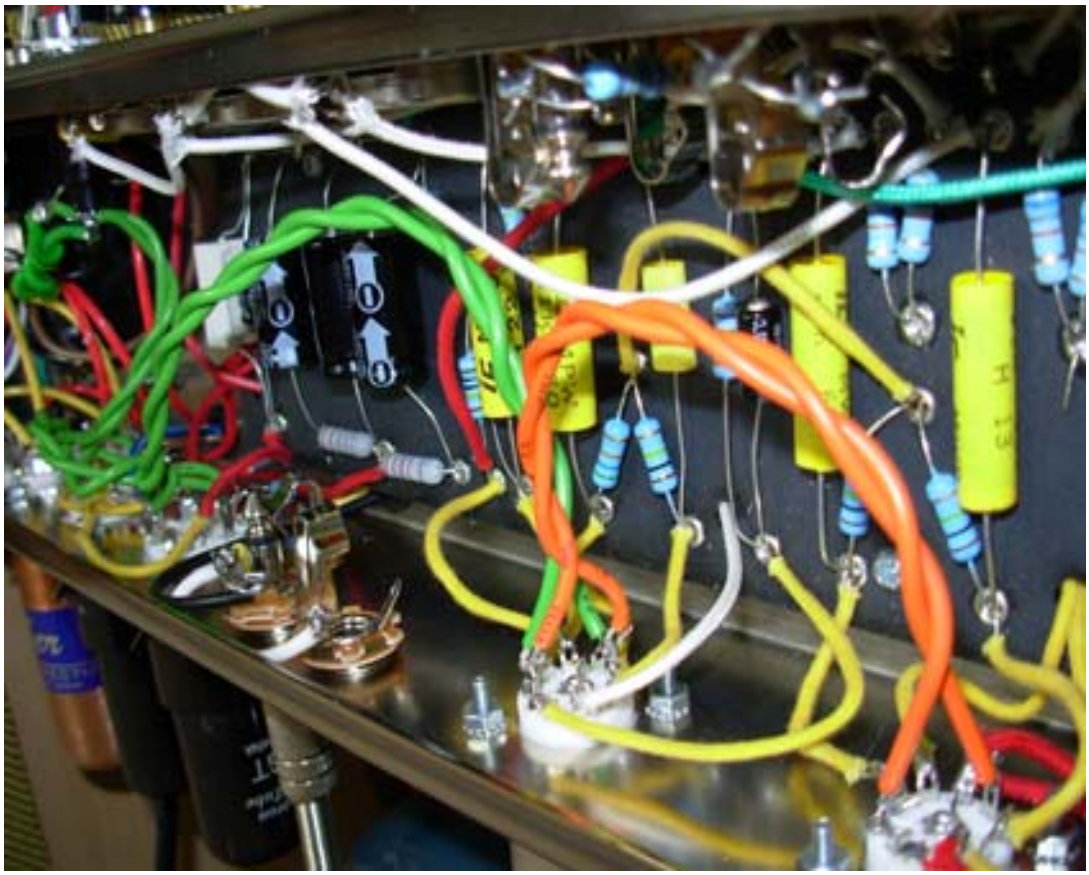

Fig 6: Home Built Reproduction of Fender 5E3 Tube Amplifier

In recent years many guitar players have begun building exact replicas of popular vintage tube amplifiers. Joe Vallina's article in *Guitar Player* magazine entitled "Homegrown Guitar Amps" describes "a new subculture of musicians-turned-amp-builders" who are "transforming tool sheds, garages, and kitchen tables around the globe into custom amp shops" (27). Below is a picture of one such home built amplifier (Figure

6), a clone of the Fender 5E3 “Tweed Deluxe,” which was manufactured in the late 1950s and early 1960s. This particular amplifier was completed in just three days by me and was my first attempt at building an amplifier. I was able to build the entire amplifier by following a schematic and circuit layout, and never encountered any problems, without any prior amplifier building experience. I have since done multiple modifications to change the tone, including replacing tubes and switching turret board components. Another extremely popular amplifier that many hobbyists have built clones of is the Marshall Amplifiers 18 Watt. The popularity of reproducing this particular amplifier eventually led to Marshall officially reissuing it for sale.

The simplicity of these circuits has also led to a resurgence of small “boutique” builders who produce quality amplifiers, which are their own interpretations of these vintage circuits. Many of these small amplifier builders are taking business away from larger manufacturers by using high quality, easily customizable components and designs. These boutique builders are growing in popularity, even being reviewed in publications like *Guitar Player* magazine. In one such article, Art Thompson wrote a 13 page assessment of five small boutique amplifiers priced between $699 and $2,500, giving each excellent reviews (147-158). These amplifiers sell simply on their simplicity, the fact that they use high quality components, and their lack of transistors.

It is no accident that most professional guitar amplifiers still use vacuum tubes. The differences between transistors and tubes in audio circuits can be measured both subjectively by perceived sound, and quantitatively by frequency analysis. Study of these differences has shown that tubes enhance the overall sound of an electric guitar when compared to transistors, especially when producing saturated or distorted tones. The

transistor may have enabled the incredible growth of digital technology, but has no place in the professional guitar amplifier. Maybe smaller, more efficient, technically “superior” technology isn’t so superior after all.

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