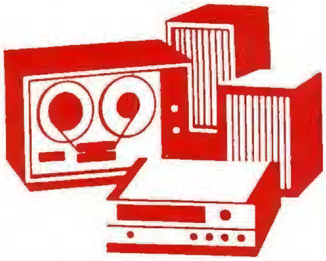


Stereo Scene

By Ralph Hodges

THE GREAT TUBE/TRANSISTOR CONTROVERSY

THE STORY, as it was told to me by a close and reliable source, goes like this. A few years ago a highly esteemed manufacturer of solid-state high-fidelity equipment was contacted by a talented group of audio amateurs who challenged him to equal the performance of their equipment — to their satisfaction — using any solid-state techniques he cared to apply. Their equipment used vacuum tubes exclusively in its signal-handling circuits and had been designed by ear as much as by instrument to satisfy the requirements of the supremely critical listener.

The manufacturer accepted the challenge and presented himself at the appointed time, with a spectrum analyzer, among other test gear, a supply of resistors and capacitors, and his stock, consumer-available electronics. He was given about a weekend to complete the test.

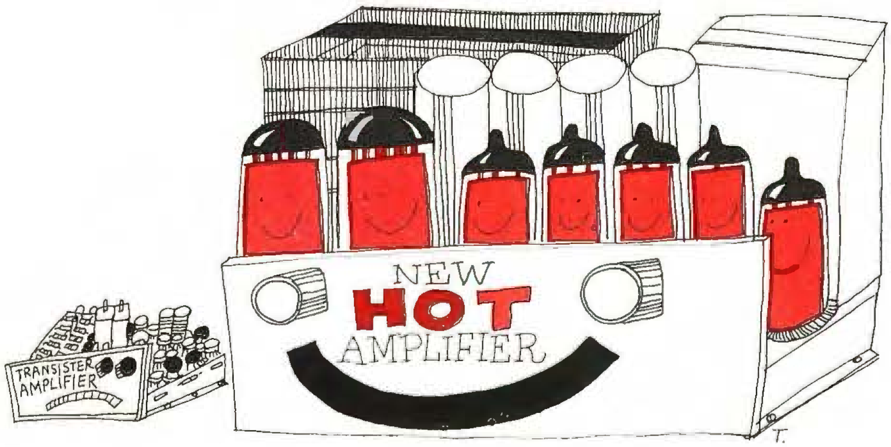
First, he analyzed the frequency response of the tube amplifier in one-third octave bands and matched the response of his own gear to that reference. Then he altered the noise spectrum of his amplifier to conform to that of the tube amplifier, adding hiss to his own designs as required. Finally, he injected just a touch of hum into his electronics — a subaudible amount at normal listening levels, but enough to provide the subliminal sense of low-frequency potency that the tube equipment's hum level suggested. Reportedly, his manipulations were so successful that not one of his challengers could consistently distinguish his solid-state amplifier from their own specially designed tube equipment, nor could they say definitely which sounded better in the long run.

A Mountain Or a Molehill? If nothing else, this anecdote demonstrates just how serious the tubes versus transistors controversy has become in the audio industry. Manufacturers of highly advanced transistorized gear are beginning to pay some attention to the experienced audiophile's views on the virtues of vacuum-tube equipment, perhaps because these preferences are steadily becoming more widespread. Vacuum-tube amplifiers and preamplifiers are briskly being sold by Audio Research, Lux (which has even developed new output and driver tubes for its designs), and Dynaco (which has had so much success with its Mark III power amplifier that it is now introducing a new tube amplifier, the 120-watt Mark VI). These three just account for the bulk of the market, but numerous smaller manufacturers are also making their contribution.

In the midst of all this activity, the manufacturers most involved are not overwhelmingly convinced that the tube itself is more desirable than the transistor. Dynaco's chief engineer, Wade Burns, says that the introduction of the Mark VI, ". . . does not contradict our feeling that in state-of-the-art audio equipment, tubes offer no distinct technical advantage over the use of modern semiconductors." And Wendell Diller, sales manager and spokesman for Audio Research, a company that deals exclusively in tube equipment, is surprisingly moderate in his views: "Tubes *per se* do not make an amplifier superior. A tube can be operated in a nonlinear fashion just as a transistor can be operated in a relatively linear fashion. We are not trying to start a tube fad. However, under the best conditions the tube is more linear than the bipolar transistor." If the major *manufacturers* of tube amplifiers are willing to concede that transistor designs can be decent or even equivalent reproducers, why is there such a polarization among amplifier users?

Defining the Difference. Analyzing the difference between tube and transistor amplifiers is not as easy as it first appears. Far from being nonlinear, a good solid-state amplifier is so linear that it can often embarrass the sine-wave signal generator used to test it. Modern tube designs can do just as well. The difference between the best of both types of amplifiers cannot amount to much more than 0.1% distortion of any sort (using standard measuring techniques). At any listening level you could stand, 0.1% distortion is lower in level than the sound of your heartbeat. You'd never hear it.

Denied any definitive help from their test gear, amplifier designers have lately fallen back on theoretical approaches and listening tests to cope with the responses from tube-oriented consumers. Bob Bird, chief engineer at ESS, neatly summarizes the listening-test criteria as centering on (1) sonic clarity, (2) bass definition, and (3) clipping characteristics. Bass definition is an area in which almost everyone, including tube proponents, feels that much vacuum-tube equipment falls short. Lawrence Niles of



Epicure has advanced some possible explanations. The output section of any amplifier is essentially an "impedance-translating stage between the last voltage-gain stage and the speaker output terminals." Practically every vacuum-tube amplifier ever designed has used an output transformer to do this impedance translation, and, "... a transformer ... exhibits considerable phase shift at both low and high frequencies. The low-frequency phase shift is a likely explanation for the loss of low-frequency definition characteristic of some tube designs."

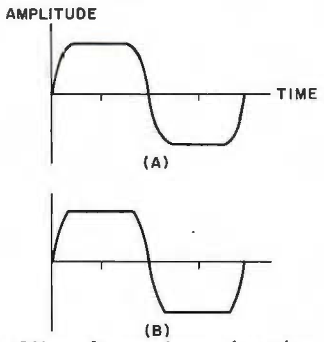


Fig. 1. Clipped waveforms in tube (A) and transistor (B) equipment.

A corollary to this is that the amplifier's output impedance tends to rise at low frequencies, which, in turn, reduces the damping factor at a point where it should be high, particularly with a vented-box (speaker system) design operating below resonance. This and problems like transformer hysteresis and core saturation, are the sources of a tube amplifier's major performance limitations in terms of bandwidth, distortion, and power handling." (Note, however, that a class-A vacuum tube amplifier can function *without* an output transformer. A suitably designed, high-power, wideband cathode follower could drive the speaker directly. This would avoid transformer-related problems. But, to my knowledge, no commercial amplifier has such an output circuit.)

"Sonic clarity" is a subjective concept that no one knows how to handle without performing listening tests. But clipping characteristics, although not so easy to generalize on as you might expect, are readily measurable, and some investigators of the tube-versus-transistor controversy have been having a field day with them.

How Does It Clip? As is well known an amplifier clips on signal peaks when the output signal voltage reaches the upper and/or lower limits of the power supply voltage. However, just before this occurs, the active output devices (tubes or transistors) are being operated in the nonlinear regions of their input/output characteristic curves. It is in such nonlinear operations that the difference between tubes and transistors becomes apparent. As illustrated in Fig. 1, the rounded corners of tube clipping are quite different from the squared-off plateaus of a transistorized amplifier. This means that a heavy dose of spurious high-order harmonics is generated by a transistor amplifier when it clips, the almost universal consensus being that these harmonics just don't sound good.

In May 1973, Russell Hamm published a paper in the *Journal of the Audio Engineering Society* that is probably the most complete guide to the observable consequences of clipping available. Hamm, a recording engineer, investigated the differences between tube and solid-state recording equipment as heard by technicians and musicians. He got such re-

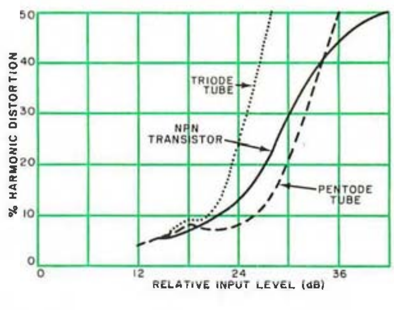


Fig. 2. Single-stage amplifier comparison of total harmonic distortion (THD).

sponses as, "With tubes there is a space between the instruments, even when they play loud ... Transistors make a lot of buzzing" and "Transistors give a 'shattered glass' sound that restricts the dynamics." He stated further that whenever he or his associates heard "an unusually loud and clear popular-music studio recording," they investigated and found in almost every case that the recording console involved used vacuum tubes in its critical circuits.

Hamm delved pretty deeply into the physics and psychoacoustics of the situation and discovered, among other things, that the vacuum tube's clipping characteristics are not so "gentle" in terms of total harmonic distortion as is generally believed (Fig.

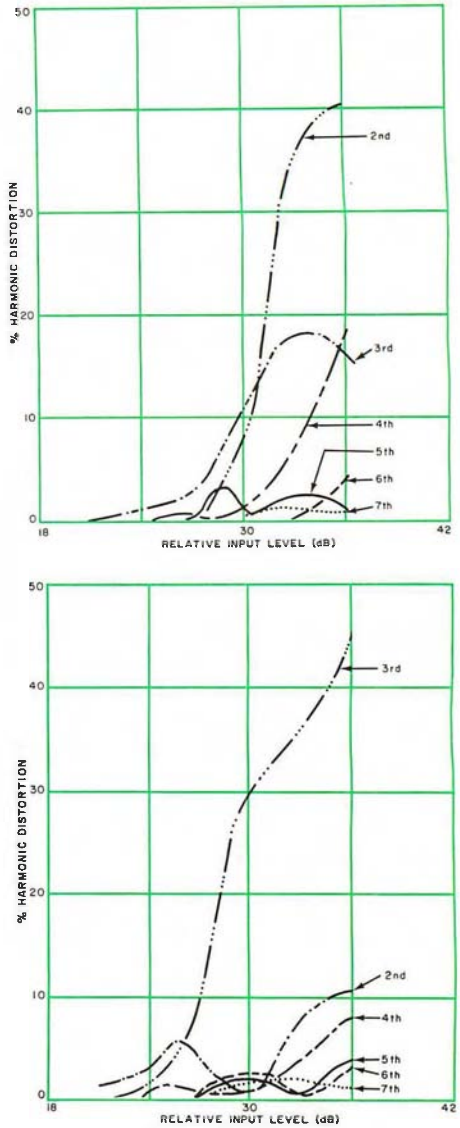


Fig. 3. Distortion components for two-stage triode amplifier (top) and for a multistage capacitor-coupled transistor amplifier (bottom).

2). But at the same time, he found reason to attribute the preference for tube sound to the spectral distribution of distortion products (Fig. 3). In a fascinating discussion based on the techniques for musical instrument design, Hamm suggested that the triode's generation of second-order harmonic distortion during overload made the sound fuller, which would account for the more satisfying dynamic range that listeners heard when tube electronics was used. He also identified harmonics above the seventh as the cause for the sharply defined "edge" we hear on tones from instruments like violins and trumpets. This "edge" is purportedly a loudness cue to the human ear. When we hear it unsupported by a strong second harmonic (presumably the result of transistor clipping), the sound is overly loud, annoying, and "glassy." When the distortion products include a prominent second harmonic (as in the output of a clipping triode amplifier), the sound is naturally loud, rich, and full-bodied.

Hamm's descriptions of transistor behavior read like a tube enthusiast's critique of transistor amplifiers. But who, besides recording studios, operates his equipment in a state of almost constant overload? Also, most audio enthusiasts don't object to amplifier overload when they recognize it as such. They *do* object to poor sound on relatively quiet musical passages when the amplifier can't be close to exceeding its specified power output. And, apparently, they are hearing effects from transistor amplifiers that sound remarkably like Hamm's clipping symptoms — but without any obvious possibility of clipping in the amplifier.

TIM Again. Although the concept of transient intermodulation distortion (TIM) is being taken very seriously in Europe and elsewhere, it gets almost no attention here in the U.S. Perhaps that's because it's not widely understood that TIM (like any type of distortion) can arise from numerous causes, and therefore it's tricky to isolate. Also, the mechanism of TIM is so obvious that you'd not expect an amplifier designer to overlook it. Also, it's possible that TIM has been misnamed; maybe it should be called "feedback inertia," because it invariably arises when there are high-speed events within the amplifier that are too short in duration for the feedback to affect properly.

Most transistor amplifiers use large amounts of negative feedback. They use it for various reasons, such as to extend frequency bandwidth and maintain stability and to convert 0.5% distortion figure to 0.005%, which looks very good in the test labs. But the test labs employ a steady-state sinusoid signal to evaluate amplifiers, and they allow the amplifiers to cope with the signal for a finite period of time before measurements are made. It's just possible that the amplifier under test could go crazy at the first moment the test signal is applied to it, and then settle down to a comfortable accommodation a few milliseconds later. But music almost never stands still, and TIM devotees claim that an amplifier that can't keep up with the music signal is not suitable for audio reproduction of the highest quality.

If the amplifier under test goes crazy in these critical first few milliseconds, it has TIM. What does this mean? First of all, it means that a small fraction of the input signal gets through without being "corrected" by negative feedback. Maybe that will result in 0.5% distortion rather than 0.05%, for that instant. This is trivial. What is not trivial is that the feedback-receiving stage of the amplifier is designed to work with a lot of negative feedback, and for a moment it's not getting it! Overload is a likely result — not overload of the output stage, which might coast effortlessly through the whole process, but overload of a preliminary driver stage. If you consider the possibilities of such a situation — poor overload recovery in the stage affected or in other parts of the amplifier, current limiting in subsequent stages, etc. — you'll begin to realize why some people describe all amplifiers as having special characteristics of their own. They may not always do so for the right reasons, but they do have justifiable cause. The audible symptoms seem to point to overload, just as Russell Hamm describes it. The measurable symptoms point to driver or pre-driver stages as being responsible.

Why are tube designs comparatively free of this effect? I suggest it's because tube amplifiers don't employ a lot of negative feedback. And if you use a minimal amount of feedback, you'll get a minimum of TIM.

The Overall Outlook. Lots of people have theories why tubes sound different from transistors. Many others have theories why they don't. I believe that amplifiers, tube or transistor, can sound different from one another, for reasons essentially unrelated to the inherent characteristics of the active devices they employ. In support of my argument, I'll quote Tom Jelsing of Bang & Olufsen:

"When complete knowledge of the waveform at all stages in an amplifier is essential, it is not adequate to analyze the total transfer function from input to output in an amplifier with feedback. The transfer function must be analyzed at all points in the circuit, or at least at all possibly critical points. Some of these (analyses) are more straightforward than others, but the analysis must be made if the designer is to be certain that the signal amplitudes do not exceed the dynamic range available at every point."

I'll also quote Tomlinson Holman of Advent:

"In 1976, tube technology must be considered to be very mature; transistor technology should be considered to be approaching adolescence. A comparison of the average tube unit with the average transistor unit would certainly demonstrate a lopsided balance in favor of the tube unit, simply because only a few high-quality tube units remain on the market at this time.

"I see no *inherent* advantage with any of the possible technologies: bipolar transistors, field-effect transistors, tubes, or integrated circuits. Tubes have frailties and can definitely age. Transistors can be nonlinear if tube-based designs are translated to solid state. Yet very fine transistor designs have evolved by treating transistors as what they are." Amen! ◈