Reprinted from Electronic Engineering Times, October 3, 1994

Electronic Engineering TIMES

Monday
October 3, 1994
Issue 817

A CMP Publication

**TECHNOLOGY**
Tuning in to the analog-vs. digital-sound debate, an audio engineer/physicist calls on Fourier analysis to aid in simulating the tube amp with solid-state components.

### CAN SOLID-STATE SOUND REALLY MATCH THAT OF TUBES?

# Volume cranked up in amp debate

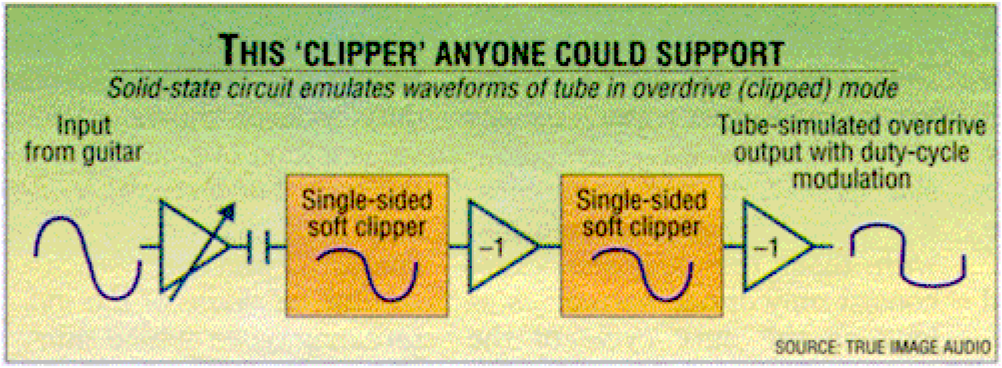
By Brian Santo

*Escondido, Calif.* - The analog world is being translated into bits faster than you can say compact disk. Whether that's progress or an unfortunate progression is open to debate-and nowhere is the argument more heated than in the music industry, where many audiophiles still value vinyl and musicians treasure tube-based amplifiers.
Both groups seek a quality of sound presumably unattainable by the solid-state and digital counterparts of their analog artifacts. But those holdouts may be left behind by the latest in technology.

Recently, Deja Vu Audio (Berkeley Springs, Va.) reported the creation of a solidstate tube emulator that provides the sounds of several classic electric guitars (see July 11, page 39). Other tube emulators have preceded the Deja Vu design. The catch is that whenever attempts are made to bridge the gap between tube and solid-state sound reproduction, subjective criteria such as "warmth" often overwhelm scientific engineering principles.

But one audio engineer and physicist contends that the physics involved with the recreation of sound are no mystery and, furthermore, pretending that audio reproduction is a black art only confuses the market. That engineer, John Murphy of True Image Audio (Escondido), has designed a number of tube and solid-state preamps and power amps for the musical-instrument and professional-audio markets.

"Any product containing vacuum tubes is especially likely to be surrounded by exaggerated claims of supernatural performance," Murphy asserted. "From an engineering point of view, there is nothing new or mysterious about vacuum tubes. They have been in use since Lee de Forest first inserted a control grid into a Fleming valve in 1906 to create the first triode. Today, tube audio products are surrounded by such excessive disinformation that the small, but real, sonic advantage that tubes offer is almost lost in the hype."




When operated in a linear (or unclipped) mode, Murphy explained, tube amps sound the same as their solid-state counterparts, provided that their frequency response and group delay characteristics are well matched and their distortion levels are sufficiently low. The audible difference between tube and solid-state amps emerges only when they are clipped.

Murphy cited published results of several carefully conducted double-blind listening tests confirming that even highly trained listeners cannot hear the difference between tube and solid-state amplifiers when the amps are operated m their linear range. "Only a handful of fanatics-but mostly those with blatant financial interests-persist in making claims to the contrary," he said.

Everything changes when you clip (overdrive) the amps, however. "Then it becomes easy to hear the difference between typical tube and solid-state amps. It is also easy to see the difference on an oscilloscope trace," he said.

A typical tube amp (such as a pair of triodes in series) can be seen to clip with a softly rounded waveform, while typical solid-state amps (such as op amps) clip with razor-sharp edges.

"Every engineering student who has studied Fourier analysis knows why these two waveforms sound different: the harmonic structure," Murphy said. The hardclipping waveform of the solid-state amp has a different harmonic content from the soft-clipped tube amp, simply because the waveforms are different. While the harmonics from the solid-state amp have strong amplitudes out to frequencies beyond the limits of audibility, the harmonics from the soft-clipping tube amp fall rapidly in level with increasing frequency.

# Amplifier debate rocks on

Those harmonic differences account for the "raspy and obnoxious" sound of the solid-state amp in clipping, compared with the much-more-mellow sound of the tube-amp clipping. A second, more-subtle difference is that solid-state amps tend to have a fixed 50-percent duty cycle as they clip, whereas most class A tube amps clip with a duty cycle that varies as a function of the drive level.

Push-pull, class AB tube power amps tend to clip much like solid-state amps, but they sound different because of their high output impedance. In particular, tube power amps exhibit a peak in their frequency response by as much as 10 dB or more at the resonance frequency of the speaker they are driving.

"No wonder they are reported to sound 'warmer' than solid-state power amps," Murphy said . "This aspect of tube power amps is not seen in test reports, where reviewers use nice 8 dummy loads for their tests. But measure the frequency response at the input terminals of your speaker, and you will see this effect clearly."

As for class A tube preamps, Fourier analysis helps reveal the harmonic structure of the clipped waveforms, Murphy said, noting that the unclipped waves have no harmonics, except for residual distortion. For instance, any square wave, regardless of its source, is composed of only the fundamental and odd harmonics (first, third, fifth, etc.).

**Square wave**

To a first approximation, the clipped output of either type of amp looks much like a square wave, and spectrum analysis shows that the waveforms consist largely of odd harmonics. Even the tube-amp waveforms, with their rounded shoulders, consist only of odd harmonics as long as the duty cycle of the wave is 50 percent and the left half is an inverted image of the right half (in other words, as long as half-wave symmetry is maintained). The even harmonics are introduced only as the waveform deviates from a perfect 50-50 duty cycle.

"This is what I call duty-cycle modulation," Murphy said, adding that many class A tube amps exhibit that characteristic. But most solid-state and push-pull tube amps have perfect 50-50 duty cycles, he explained, and therefore have no significant even-harmonic content in their clipped waveforms.

When the tube amp clips, its duty cycle starts at 50 percent and typically shifts to 55 percent (or even as much as 65 percent) as it is driven further into clipping. That has the effect of adding even harmonics as the amp is pressed further into clipping. Plotting the duty cycle vs. the input level provides a kind of sonic signature of the amp. For a typical solid-state amp, that signature is just a flat fine at 50 percent.

"But for some of the more interesting types of tube amps, that signature starts at 50 percent, goes to maybe 55 percent and then back to 50 percent or even 45 cent," Murphy said.

# Solid state v. tubes: cranking the volume

"In response to a strong transient, these amps exhibit what looks like 'dancing harmonics' the spectrum analyzer. First the odds rise, and then the evens rise and fall between the odds. When a guitar is used as the signal source, the audible effect is a subtle, but musically interesting, sort of 'reedy' sound mixed with an otherwise 'brassy' sound," he explained.

"Besides the obvious soft clipping, I believe this to be an important reason why guitar players like tube amps. But so much for the truism that says: 'tubes have even harmonics, and solid state has odd harmonics.' Bull dung. The waveforms of both consist primarily of odd harmonics. Tube amps with duty modulation just throw in a sprinkling of evens.

Further, Murphy contended, "the occurrence of those even harmonics is not critically important , when you consider that most of the guitar-overdrive devices in use by players today employ solid state diode circuits, which exhibit soft clipping but with a fixed 50-percent duty cycle."

In 1983, Murphy designed a tube-emulator circuit that, to his knowledge, is the only solid-state overdrive device to exhibit duty cycle modulation.

"I have worked with at least one well known guitar player who sets up an array of tube-amp stacks on stage, only to use a small solid-state pedal-effects unit 'stomp box,' as players say-for his actual overdrive sound," he said.

'From the [perspective of the] audience, you would think he was using the amps, but those are just for show. The advantage of the stomp box is that it is reliable-no tubes to change, it's consistent and it usually provides more gain or overdrive than a typical tube guitar amp. The stomp box drives another guitar amp - tube or solid state - which then drives a limited number of the speakers. Most of the amps on stage are just props without any electronics or speakers."

The point, Murphy said, is that some professional artists would just as soon use their solid-state pedals as their tube amps. They can get a satisfactory overdrive sound from either. The pedal is simply more convenient.

"But ask a kid in the a audience," Murphy said, "and he will insist that his favorite guitar player uses a tube amp, because he saw it. Ha! A lot of really expensive tube amps are sold this way.

"As far as other characteristics of tube guitar amps are concerned, I have found that the pre-clipping frequency equalization and post-clipping EQ are absolutely critical adjustments. Once you have a well-behaved clipper-even if it's just simple diodes, as in the stomp boxes-it is the precise combination of pre- and post-clipping EQ that mostly determines how an amp sounds. The 'secret' of the best sounding guitar amps lies in the pre-clipping EQ response curve."

## Subtle harmonic effects

If one could devise a solid-state amp that had soft clipping along with waveform duty-cycle modulation, Murphy contends, the amp would look substantially like a tube amp in the lab and would sound much like a tube amp in the listening room-down to the subtle effects of the time-varying even harmonics.

"From our knowledge of Fourier analysis, we can be confident that the waveform tells the whole truth and nothing but the truth. 'The waveform contains no 'secret' information as to whether it was produced by a tube amp, a solid-state amp, a digital waveform generator or hundreds of sinewave generators operating in parallel, for that matter," he said. "The mathematics of Fourier assures us of this. If we can make a solid-state amp produce the same waveform as a tube amp when it clips - including duty-cycle modulation - then we have successfully simulated the tube amp with solid-state components."

## Reproducing the tube amp

Murphy created his solid state tube emulator circuit in 1983, when he was chief engineer for Carvin Corp. He claims his invention reproduces the significant characteristics of a tube amp.

"This circuit was first used in a line of solid-state guitar amplifiers by Carvin and introduced in their 1987 catalog of musical-instrument products. That circuit continues in production today in Carvin's SX series solid-state guitar amps," he said. Carvin could not be convinced to pursue a patent, and as a result, the tube simulator is now in the public domain.

"Common diodes are employed to clip first the one half of the waveform and then the other half of the waveform, but not at the same stage," Murphy explained. That follows the way in which a pair of tube triode stages, operating in series, clips only one half of the waveform at a time. It is the independent clipping of the two halves of the waveform that allows the duty cycle of the clipped wave to modulate away from 50 percent and introduce the even harmonics.

"My invention employs op amps to buffer each diode-clipper stage," Murphy said. "To more closely match the waveform of a 12AX7 triode clipper, my circuit also employs diodes in the feedback loop of the inverting op-amp buffers to make the clipping a bit less soft."

Besides applications in guitar amps, the circuit could be employed in the front end of any solid-state preamp or power amp to provide controlled clipping characteristics that measure - and sound - very much like a class A tube amplifier.

The next step in audio technology Murphy envisions, will be vacuum microelectronics-thermionic emission with cold arrays of microtips based on quantum tunneling as the electron source, and promising to provide triodes, pentodes, and the like.

"Though this new technology is targeted at microwave amplifiers and flat-panel displays, it is entirely possible that it will end up in guitar amps and hi-fi gear," Murphy said. "Imagine that."