Although solid-state technology overwhelmingly dominates today's world of electronics, vacuum tubes are holding out in two small but vibrant areas. They do so for entirely different reasons. Microwave technology relies on tubes for their power-handling capability at high frequencies ("Tubes still vital after all these years," Robert S. Symons, IEEE Spectrum, April, 1998, pp. 52-63). The other area—the creation and reproduction of music—is a more complicated and controversial story.

The complications and controversy stem from the fact that music is played to be heard by human beings, whose nonlinear ear-brain hearing systems are far from fully understood. Since no one knows exactly how to model the human auditory system, no one knows exactly what engineering measurements are appropriate to evaluating the performance of audio equipment. A smidgen of some kinds of distortion may sound worse to the car than larger amounts of other kinds. So ultimately, the only way to judge audio equipment is by listening to it. Hence the controversy, subjective human perception—especially when flanked by questions of artistic merit—made to order for arguments and disputes.

Briefly stated, a commercially viable number of people find that they prefer the sound produced by tube equipment in three areas: musical-instrument (MI) amplifiers (mainly guitar amps), some processing devices used in recording studios, and a small but growing percentage of high-fidelity equipment at the high end of the audiophile market. These areas employ vacuum tubes of the type once known as receiving tubes, but now called simply tubes. Not only has the use of vacuum tubes in these fields definited the semiconductor tide elsewhere, but now usage and demand has even surged in the course of the 1990s.

Today's vacuum-thermionic devices hold sway over the US $10 billion worldwide guitar amp business. One rough estimate shows a 10-per-cent-per-year growth in demand for tubes used in MI amplifiers and high-end audio since the late 1980s, with no apparent slackening—never during the U.S. recession of 1991-93.

Interestingly, much of the demand for audio tubes derives not from the United States, but from Asia. In Japan, Taiwan, and mainland China, tube-based high-end equipment enjoys a powerful cult status, and vintage U.S. and European electric guitars and guitar amps are valued collectors' items.

Why tubes—subjective reasons

The three areas of tube audio tend to be mutually exclusive and appear not to influence each other, even though all three directly involve the production and reproduction of music. It is common to see the same tube types, such as the popular EL34 power pentode, in electric-guitar amplifiers and in high-end stereo amplifiers. Often, these disparate product lines employ similar circuit topologies.

Electric-guitar amplifiers, it is estimated, consume as many as three out of four of the world's production of audio tubes. This is hardly surprising, since the tube guitar amp seems undauntedly entrenched at the top of the rock n' roll world. In this case, the use of tube amplifiers in the early rock of the 1950s and 60s caused their distinctive distortions to become the standard tonal effect for the electric guitarist. A cultural bias formed during those years among U.S. and British musicians in favor of the particular nonlinearities of those amps, which typically were quite simple and had little or no negative feedback to improve their linearity.

As documented in many books on electric-guitar technique, in magazines such as Guitar Player, Guitar World, Vintage Guitar, and others, and on Usenet newsgroups such as alt.guitar.amps, the clipping distortion and other sonic artifacts of 50s-designed tube amplifiers supply the sonic signature required for a successful guitar amp.

Discussion of an amp's merit frequently hinges on the clipping effect, which is often described as yielding a

ONE OF THE LAST REMAINING TUBE DOMAINS IS IN MUSIC APPLICATIONS, BUT THERE THE DEVICES FLOURISH AND EVEN INNOVATE
Defining tubes

5A4: rectifier tube, used to convert alternating current to direct current, and to provide plate power for amplifiers. One of the most common tubes used in audio amplifiers, it is commonly used in hi-fi amplifiers, stereo equipment, and power supplies.

6H1: used in audio amplifiers, it is commonly used in hi-fi and hi-fi amplifiers. It is also commonly used in hi-fi and hi-fi amplifiers.

6C5: used in hi-fi amplifiers and hi-fi amplifiers. It is also commonly used in hi-fi amplifiers.

12AX7: preamp tube used in any audio equipment. It is commonly used in hi-fi amplifiers and hi-fi amplifiers. It is also commonly used in hi-fi amplifiers.

2A3: used in hi-fi amplifiers and hi-fi amplifiers. It is also commonly used in hi-fi amplifiers.

46: used in hi-fi amplifiers and hi-fi amplifiers. It is also commonly used in hi-fi amplifiers.

6L6: first successful beam power tube introduced by RCA in 1938 and made in several versions and various types. It was widely used in radios and hi-fi amplifiers.

12AX7: dual triode with a gain of 70, originally designed for audio-frequency amplifiers. It was used by many manufacturers in their own designs. It was also used in hi-fi amplifiers and hi-fi amplifiers.

12AT7: dual triode with gain of 70, originally designed for audio-frequency amplifiers. It was used by many manufacturers in their own designs. It was also used in hi-fi amplifiers and hi-fi amplifiers.

12AU7: used in hi-fi amplifiers and hi-fi amplifiers. It was also used in hi-fi amplifiers and hi-fi amplifiers.

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12AX7: dual triode with gain of 70, originally designed for audio-frequency amplifiers. It was used by many manufacturers in their own designs. It was also used in hi-fi amplifiers and hi-fi amplifiers.
Defining terms

Black-plate: usually refers to the 6L6GC (6L6 GB) having a heavy black coating on its plate and former manufactured by RCA Electron Tube division of General Electric Co. It was the first large plate transistor, and was once quite common in cathode and other materials. A few other RCA-made tubes, such as the 5881, had small-signal triodes, but were also black-plate types.

DI (direct input) box: an interface device that allows direct signal input to the audio signal to the balanced input of a professional mixing console. Some even allow ground lift and provide zero signal gain, while others incorporate tubed or solid-state preamplifiers.

Head: a separate guitar amplifier chassis in its own cabinet, used with a speaker which is known as a combo amp. The separate head and speaker give maximum flexibility and keep tubes away from vibrations produced by the cabinet itself.

Microphones: changes in electrical characteristics of a device translateable to mechanical vibrations. A common use is to translate sound waves into electrical signals.

New old stock (NOS): a term borrowed from antique collectors to describe new equipment that is no longer being manufactured and found unused in its original factory packaging.

Smooth plate: colloquial name for Telefunken’s original version of the 12AX7 ECC83 dual triode, which has large plates with no embedded features, and no anode grid in the form of the amplifier using them with their solid-body guitars, such as the famous and widely-copied Stratocaster and Telecaster.

The most primitive design for a Fender amp is the Champ model. Being intended as a clean, low-cost amplifier for students, it was the first to use a basic circuit with a cathode follower and a parallel bias at the output of the tube. The Champ’s name is a result of its typical use of a low-cost, standard tube.

The most popular Fender models among serious players are the Bandmaster. Twin, Showman, and Bassman, and with pull-push 6L6GC or 5881 output tubes. The Champ had a variety of tube options, and the Touch sensitivity, a term used by electric guitarists to describe some kind of gain or distortion that is usually caused by loose power-supply regulation or clipping distortion in a guitar amplifier, which can change the signal volume change greatly with the “touch” or force applied to the instrument.

Tweed: refers to guitar amplifiers made by Fender Musical Instruments. It is a term derived from the Tweed-like, yellowish fabric covering their wooden cabinets.

Vacuum tubes and transistors compared

Vacuum tubes: advantages
- Easily linear with relatively few feedback, especially small-signal types.
- Clipfree operation, which is not common to tube amplifiers.
- Large dynamic range of 100,000:1 or greater, which is typical of vacuum tubes.
- Sound quality is very subjective and varies widely.
- Presence of warmth and musicality.
- Low cost per watt.
- Can be paralleled for improved gain and output.
- More complex circuitry.
- Can be damaged by overload, which can cause irreversible damage.
- Tube replacement costs can be substantial.

Transistors: advantages
- Higher efficiency than vacuum tubes.
- Dependable and require less maintenance.
- Less expensive to manufacture.
- Less noise than vacuum tubes.
- Can be paralleled for improved gain and output.
- More complex circuitry.
- Can be damaged by overload, which can cause irreversible damage.
- Tube replacement costs can be substantial.
New Filtz, N.Y. and Marley Labo-
retors, in their new series 2200-2297, lin-
earizes signals to push-pull circuits, frequently
using 1287 or 1297 dual tubes along with
12AX7s to drive the audio output. With the
putting coupling transformers, to match
impedances of 600-ohm lines to the tube
circuit, a matched pair of transformers. The
spite of the difficulties of making high quality
audio transformers.
A new phase of recording is the recording
chain is in signal compressor, also called
limiters or leveling amplifiers. In general,
terms, a limiter is a device whose output is
consists of a preamp, a so-called sidetone
with audio signal rectifier and peak detect-
er, and a volume-controlling device, is driven
by the peak-detected voltage. The control is
arranged so that signal gain in the preampli-
ifier region is inversely proportional to the
level on the input, giving a narrow
ranged dynamic range. Compressors of this
class are considered mandatory in
recording and production studios, for
variety of sonority effects. Rock music is
often heavily compressed to give the illu-
sion of greater loudness.
Tube compressors tend to follow the example of the landscape of>
the most influential was the Teletronix
LA-2A, in which a controlled attenuator
continuously varied the output level of
drivers directly by the tube peak detec-
to a light-sensitive, cadmium-
seled resistor. Such devices have a
response range of at least 10:1—not large
compared with the exponential response
ratios available with modern solid-
state designs.
The limitations of the tube compres-
sors have apparently not affected their
value. LA-2As known to sell for $400 on
the street today, were perhaps worth $100
in 1980. Whereas all the masters of
vintage compressors are currently out of
business or no longer producing such
equipment, most of the modern firms pro-
duce compressors, ranging from stand-
alone devices (TubeBassence) to vin-
tage-style designs.
A tube compressor of modern design is the
Summit Audio EQ-100, built by Eric
Cowdrie (EAC), who are known for their
designs and passive RF filters combined
input-output drivers based on op-
a small number of transistors.
Other specialized areas in which tubes
find application include mixers and rotat-
ing heads; the multitracks were pioneered
in the ’50s by Leslie, have re-
mained in favor for their distinctive phas-
er. The Leslie speaker design is considered
essential for use with the Hammond B-3
electric organ, a standard instrument for
rock and jazz music at least 40 years. In
test of fact, Leslie speakers with tube ampl-
ifiers are still being manufactured by
Hammond Sound Systems, while Motion
Sound Inc., Salt Lake City, Utah, has introduced rotating speaker de-
signs that incorporate tube-based elec-
tronic circuitry.
High-end equipment
Perhaps the oldest subgenre of tube audio
is the high-end audio component market.
High-end equipment is aimed at the most
obsessive audiophiles, famed for worrying
about details which most of us would
never notice. The equipment is expected even
in spite of its obesity and its notoriously
marketing-oriented focus, high end is the
上限 of high-end audio.
Until recently, the high-end market
be considered to be the solid-state
world for the sake of being a semi-acoustic
sub-
ject. The first version of a tube audio
system of the hi-fi tube audio from before 1990.
Unlike audio in the music performance
environment, most hi-fi enthusiasts have often preferred
tubes for their clean, smooth-sounding
in some cases, far more detailed and life-like
than most solid-state equipment.
Manufacturers of new tube equipment
Audio Research Corp., Minnetonka,
Minn., and Conrad-Johnson Design Inc.
Fairfax, Va., appeared during the ’70s.
The field was small and sedate until the
late ’80s, and the number of new manufacturers
began to skyrocket.
Whereas the hi-fi market originated
after World War II in the United States and
Europe, the latest aggressive rise in
high-end sales has been concentrated in
the last decade, primarily by Japan. Although
the high-end equipment in the
West is exported and sold in the Far
East, Japanese companies also sell
“Made in US” and “Made in Eng-
land” as badges of status and quality.
This flood of high-end sales was influ-
enced by the statements of subjective
audio reviewers, whose nonmechanical and
psychological exploration of the music
covered HiFi uses the word HiFi
Perhaps more to the point, the growth
of sales of tube equipment was also facili-
tated by the increased number of tubes
drivers that is generated by my OTL.
I wish I could, because I could sell 100 times as many units.
Choosing a tube
It may not come as a surprise to tube audio-designers, like to
use tubes from the same small
group of types. In guitar amps, preamp and speaker stage circuits
can try some of the better
old Fender/Marshall/Vox designs. Preamp stages are made of 12AX7s, phase

Svetnik’s EQ81’s low-noise pentode was once
common in European hi-fi and guitar amplifiers.

EIIROR – THE COLD SOUND OF TUBES
Distortion under test

Since much of the rationale for the continued use of tubes in audio equipment is based on distortion and noise, we decided to compare how several representative tubes and transistors performed in this regard. Using basic circuit designs in which these devices are typically used, we tested two tubes against four types of transistor—respectively, a medium-mu triode and a pentode against a low-voltage bipolar transistor, a low-voltage junction FET (JFET), a high-voltage bipolar transistor, and a high-voltage MOSFET. The figures show the distortion and noise spectra of each device.

All the measurements were made with an Audio Precision System 2 with its analog oscillator set to 1 kHz. The output level was adjusted to give an rms voltage of 2.00 V at the output of the test device. The output impedance of the oscillator was either 20 Ω or 600 Ω, depending on the device under test.

The test device was monitored by the System 2's fast Fourier transform (FFT) function using its 20-bit analog-to-digital converter running at 48-kilohertz per second. The FFT was synchronous (no windowing), and was averaged over 16 samples. The residual harmonics were at least 120 dB down. The input impedance of the System 2 was set to 100 kΩ. Both input and output were floating, with the test fixture separately grounded to the System 2.

In the vacuum-tube test fixture, the filament voltage was dc-regulated to 6.3 V. The output of the tube was monitored through a 10:1 compensated divider so as to reduce ac and dc loading.

The summary of second-harmonic distortion levels follows:

- 65N7GTB triode: -52 dB
- 6AU6A pentode: -88 dB
- 2N2222 low-voltage bipolar: -30 dB
- 2N5457 low-voltage JFET: -30 dB
- MJE2961 high-voltage bipolar: -46 dB
- BF242 high-voltage MOSFET: -41 dB
- HS-11 transformer: -90 dB

Although this is not intended to be an exhaustive examination of all available semiconductors or tubes, the resulting frequency spectra lead us to some conclusions that experienced audio designers have often remarked upon in the past.

- Transistors operating on low-voltage supplies tend to have higher spectral distortion components than tubes.
- If we go to high-voltage transistors, operating on supplies comparable to those of the tubes, the distortion settings are large and complex and often equipped with computer-controlled automated mix-down capability. Although expensive, large mixing desks are frequently based on low-cost Op-amp ICs such as the 5534, and use electrolytic capacitors for coupling the audio signal from stage to stage.

Some recording engineers have found this scheme wanting, hence recent introductions of tubed mixers. Companies producing such mixers are Summit Audio, the UK's Manley Laboratories and TL Audio Ltd., the latter being the sole producer of full-size mixing consoles with tubes at this time. The market may expand in the future, as interest in audio-telephony grows.

The most interesting new development is in the introduction since 1996 of new tube types specifically designed for audio applications. Russian, Slovakian, Serbían, and Chinese factories currently opt to imitate the popular audio tubes of past types, such as 6L6GC and 12AX7. Yet the market has been open to some new tube types not directly based on any U.S. or European tube or modification thereof. These types have aroused some interest from original equipment makers, even though they seldom fit existing equipment.

In the guitar and pro-audio markets,
products are less objectionable. Unfortunately, the noise floor of such devices is much higher. The IFR82 was a tripod-like device in distortion yet suffered from noise floor some 30 dB higher than that of the triode.
• No other active device possesses both the low distortion products and the low noise floor of the medium-mu triode—subject at the expense of voltage gain.
• The distortion products of transformers are much lower than those of active devices, yet quite different in character. Note that the odd-order harmonic products tend to be higher in level than the even-order products— actually, the reverse of the tubes and transformers.

It should also be obvious that the same techniques can be applied to triodes or to tubes; and if this were done, the triode would continue to enjoy some advantages over the semiconductors—and the pentode, for that matter.

—E.M. with John Atwood

John Atwood is a consultant on audio design and owns One Electronic Co., Santa Clara, Calif.

To probe further


A taste of the fascinating and obscure world of "boutique" guitar amplifiers is afforded by Art Thompson’s "20 out of 1964, we threaten a herd o new boutique amps," in Guitar Player, February 1997, Vol. 31, No. 2, p. 118. Plenty of publications intensively cover vacuum-tube audio electronic design. Their emphasis is usually on hi-fi audio, although material about guitar amps and professional studio electronics appears regularly. English-language publications include Glass Audio (Box 174, Peterborough, NH 03458) and Vacuum Tube Valley (1095 E. Duane Ave., Suite 106, Sunnyvale CA 94086).

Magazines that concentrate on high end audio design include Sound Practice (Box 180782, Austin, TX 78731), Ultra-High Fidelity (Box 138, Chestnut, Herst., KN7 6UR, UK), and VaVe (Box 2788, Pauola, WA 98370).

Non-English audio-preservation publications include:
• The Italian Audion (Piazza Madonna Aldobrandi 7, 50123 Firenze) and Cudzore Mu- (Via Tei 9, 20100 Barneggi, Italy).
• The French Musique Et Technique (Bureau de Depot 1958, Brouage, S. Belgium).
• The German Hi-Fi Scene (Durburenstrasse 165, CH-8008 Zurich, Switzerland).

About the author

Eric Barron has been an applications engineer with Svetlana Electronic Devices Inc., Fort Lauderdale, Calif., since July 1994. His work involves testing and characterizing new vacuum-tube types and constructing and testing amplifying circuitry for Svetlana audio and RF tubes. Earlier, he was a senior techni- cal and then an engineer with the U.S. Department of Energy, Intelligent Electronics Co., and Dionex Corp.

A staff editor of Vacuum Tube Valley magazine (Sunnyvale, Calif.), since its founding in 1995, he also contributes to Glass Audio magazine, Peterborough, N.H.

Spectral editor: Michael J. Riezmann

MJE2361 high-voltage bipolar transistor

In this test, the transistor was substituted for the 6S7GT/B tube, and the bias voltage was given the same operating point as the tube. The MJE2361 exhibited excellent distortion characteristics, which were compromised by its noise floor of about -110 dB—about 30 dB above the tube’s. Second harmonic distortion is 41 dB down, which is only 39 dB above the noise.

IRFR22 high-voltage enhancement MOSFET

When substituted for the 6SN7GT, with bias adjusted to give the same operating point as the tube, the MOSFET exhibited excellent distortion characteristics, which were compromised by its noise floor of -110 dB—about 30 dB above the tube’s. Second-harmonic distortion is 41 dB down, which is only 39 dB above the noise.

Triad HS-11 input transformer

Source impedance was set to 600 Ω. The transformer was loaded by the 100-kΩ input impedance of an Audio Precision analyzer. This test was included because some professional audio experts commented on the unusual behavior of audio coupling transformers in tube circuits—specifically, that the odd harmonics tend to be stronger than the even ones. The HS-11 is typical of small input transformers used to couple a 600-Ω balanced line to a tube grid.

Residual noise plus distortion of the analyzer, with only a 600-Ω resistor in series, is at least 118 dB down.

NEW VARIETIES OF CLASSIC POWER TETRODES AND PENTODES INCLUDE, FROM THE Teslacoil Co., Cadca, Slovenia, the KT885 and E4154, which are modified and uprated in power dissipation rating from their KT88 and EL34 prototypes. New high-power triodes, such as the SV11/572 series and 3X300A1, have been introduced by Svetlana. Even more than other fields, the high-end market has seen an explosion of power triodes: the VV308 and VV6K from KR Enterprise Co., Prague, Czech Republic; Svetlana’s SV11/8572 series, the AV10L8 SL and AV10L8 SL from AVT Technologies, Prague, Czech Republic; and many versions of the 300B from two different factories in China, two in Russia, and one in Slovakia—not to mention the revival of Western Electric and its renamed manufacture of the original 300B.

The KT60 beam tetrode, made by EI Electronic, Nis, Serbia, has proved so popular for audiophile amps that a Chinese factory has even introduced its own version. Also winning a following in high-end audio are some Russian tubes unknown in the West until recently such as the 6C3C8 CB from Elektroprobi Ulyanov, Ulyanovsk, Russia. More new types are expected to be introduced, and some out-of-production types will be reintroduced, over the next several years. Vacuum tubes enjoy an unsinkable position in the design of guitar amplification. Their use in the recording studio and in home audio often seems like a fact, but it has very old roots and is therefore unlikely to disappear overnight, as some do. Technical reasons for the use of tube electronics in some applications last solid and are well-defended both by professional designers and by the users, who define and drive the marketplace. So long as musical tastes demand them, tube audio equipment and replacement tubes will be produced well into the next century, and probably thereafter.

BAXFORD — THE COOL SOUND OF TUBES

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