

Borg Directive

Resistance is futile.

(This is the bumper slide that everybody puts in a presentation to get folks interested in the talk that is about to begin. Did it work?)

Something completely different...

Jerry Whitaker, ATSC, and old radio guy


The Tube Sound: Fact or Fiction?



Scope of This Presentation


The latest trend in audio is actually a very old trend

Tubes > transistors > integrated circuits > digital > tubes?



We will revisit the attributes of vacuum tubes for audio applications

Attempt to answer the question—**are vacuum tube amplifiers better or just different?**



What about source material, in particular vinyl records?

Tubes and vinyl—the ultimate audio pairing for high-fidelity listening?



Observation #1

Vacuum tubes have been around for a very long time. Appreciated for their distinctive sound, amplifiers built around tubes have found a permanent home with audio enthusiasts and experimenters alike.

You don't need to be an "audiophile" to appreciate them.

Tube-based systems can coexist nicely in today's digital-based environment.



Preferences

The differences make it interesting

Preferences

Audio is all about preferences and real-life experiences

- Certain fundamental reference points exist
 - Loudness, frequency response, noise, distortion, etc.

Audio has another dimension as well—perception

- The artist has a wide and varied pallet with which to paint
- There are few absolutes when it comes to audio perception
- With video, absolutes abound
 - Viewers know that the grass should be green and the sky should be blue and people should look like...people

Appointment Listening: Gone for Good?

Consumer listening habits have changed dramatically in the last decade

- Portable playback devices abound
- Convenience is the key product motivator
- Listening typically done while doing something else

The heyday of appointment listening now well in the past

- Circa 1965—console stereo in the family room, LPs on the turntable
- Circa 1945—radio in the living room, family gathered around



Observation #2

Appointment listening is making a comeback and doing it with tubes and vinyl.

Variously described as the “tube sound,” amplifiers build around vacuum tubes remain in demand for demanding consumers.

Intrigued by new technology, few realized what we were giving up by discarding vacuum tube equipment in favor of new solid state hardware. Ditto for vinyl records.

Technology Waves

The more things change, the more they change

Technology Waves

1950s	High-end audio equipment offered to an emerging discriminating market
1960s	Top-quality audio systems using turntables as the input source move into mainstream use <ul style="list-style-type: none">• Exceptional tube-based audio products made during this time• The console stereo was the focus of countless living rooms
1970s	All about component audio, and increasingly solid-state <ul style="list-style-type: none">• Enhanced performance, customized systems
1980s	Solid-state takes over; the CD dominates music playback
1990s	The first personal entertainment devices emerge
2000s	iPod changes the world (or at least how we listen to music)
2010s	Vinyl records and tube amps return—curious...

Conventional Wisdom

▶ Consumers want

- ▶ Everything on demand
- ▶ Convenience
- ▶ Wide selection
- ▶ Low price
- ▶ Convenience
- ▶ Small size
- ▶ Good quality
- ▶ Convenience

▶ What I want, when I want it



Retroville

Broadcasters have a history of embracing new technologies, but...

- Broadcasters also need to differentiate themselves in marketing and technology
- Perhaps “retro” has a place, particularly in radio
- Rather than run from retro, try embracing it
- Some trials have been run...with good results

With the benefit of history, it is clear that for consumer audio

- Solid-state devices do some things very well
- Vacuum tubes do other things very well
- Today, there is room for both in a high-fidelity entertainment center



Observation #3

The market for vacuum tube-based amplifiers is small but increasing. Moreover, the market for vinyl records is significant and growing.

Radio broadcasters may find that a music block focused entirely on vinyl records has commercial appeal.

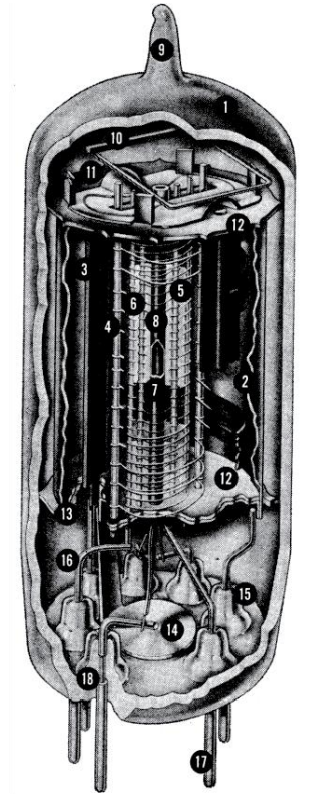
The fact is, tubes never went away; neither did vinyl records. They are here now and there is a market for them. Old is new...once again.

A Closer Look at Vacuum Tubes

Sophisticated simplicity

Applications

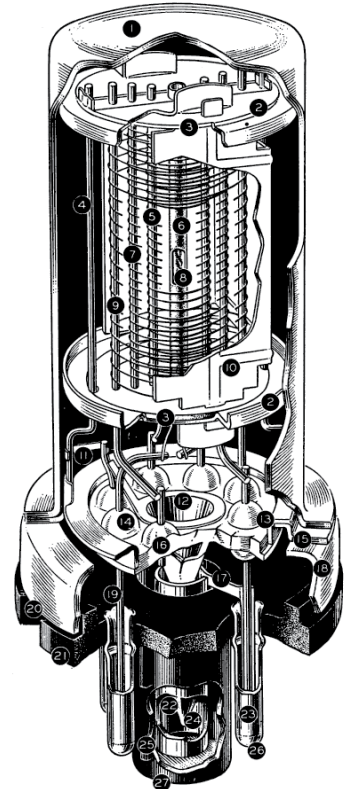
- ▶ Current use of tubes for consumer applications is focused on audio
 - ▶ Audio power amplifiers
 - ▶ Audio preamplifiers
 - ▶ Microphone/phonograph preamps
 - ▶ Hybrid systems also exist
 - ▶ Tube preamp and solid-state power amp
 - ▶ Solid-state preamp and tube power amp
- ▶ Power ratings from tens of watts to hundreds of watts



(From: RCA Receiving Tube Manual, 1974.)

Tube vs. Solid-State

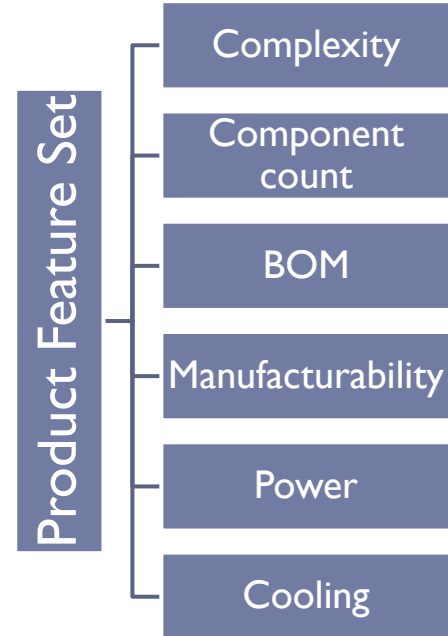
- ▶ The corner piece of the component audio system is—inevitably—the power amplifier
- ▶ The benefits of solid-state technologies in low-level audio circuits are well known
 - ▶ Similar attributes apply to RF circuits
 - ▶ For the power amplifier, however, the choice is not always so clear cut
- ▶ Modern solid-state designs can mimic the characteristics of tube amplifiers, if desired
 - ▶ Digital effects provide a variety of available “sounds”



(Source: RCA Receiving Tube Manual, 1974.)

Engineering Tradeoffs

- ▶ Design of a consumer product is usually an exercise in compromise
 - ▶ Variables include
 - ▶ Technical complexity
 - ▶ Overall component count
 - ▶ Bill of materials
 - ▶ Manufacturability
 - ▶ Power requirements
 - ▶ Cooling requirements
 - ▶ Time-to-market
 - ▶ A “perfect” consumer product is hard to find



Observation #4

Vacuum tube-based circuits can perform reliably for many years. They are capable of exceptional performance.

Generally speaking, tubes are forgiving of short-term overloading and other transient events.

Many audio amplifiers built in the 1950s and 60s are still providing service in countless living rooms around the world today.

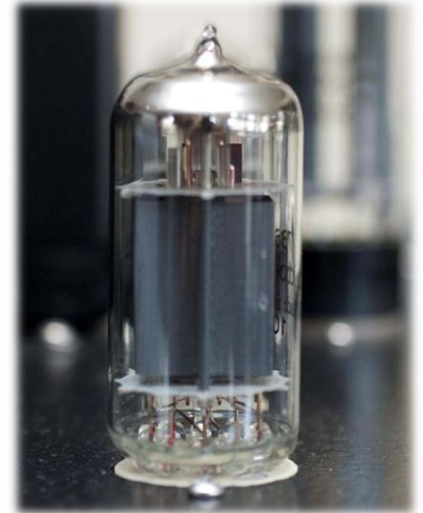


The Tube Sound

Easy to describe, hard to measure

The Tube Sound: What Is It?

- ▶ Comparison is made more difficult by the differing architectures used
 - ▶ Innovative solid-state designs have been developed to improve efficiency and/or measured performance
- ▶ Identifying the characteristics that define the differences may not be all that important
 - ▶ Audio is all about how humans react to it
 - ▶ How a selection of music is heard (perceived) is—in the end—all that really counts
 - ▶ Personal preferences play a major role



Viewed Objectively...

- ▶ Audiophiles often disagree on the relative merits of tube vs. solid-state amplification
- ▶ Some prefer the sound produced with tube-based circuits on the grounds that it is more “natural” and “satisfying” than the sound from typical solid-state amplifiers¹
 - ▶ Often a long discussion
 - ▶ Often more about perceptions than measurements
 - ▶ Often strongly held opinions on both sides
 - ▶ Arguments rarely sway either side



¹ Wikipedia

Attributes of the Tube Sound

Tubes may be subjectively described as having a “warmth” and “richness” that may be lacking in solid-state designs¹

The source(s) of these attributes are by no means agreed on

Higher levels of harmonic distortion may tend to make the sound seem “rich” or “fat”¹

THD and IMD are usually higher in tube-based amps
TIM not usually an issue for tube systems

Circuit topology used with tubes vs. transistors and MOSFETs

For tubes, push-pull accounts for most designs
Numerous approaches are used for solid-state designs

Response roll-off at the low and high end, relative to solid-state (in many cases)

Frequency response may be restricted due to output transformer limitations

¹ Wikipedia

Sound Reproduction

Typically, in high-fidelity sound systems, accurate reproduction of the sound of the original recording is the goal

Distortion and uneven spectral response within the audible frequency band is something designers deliberately seek to avoid

The “sound” of an amplifier is a complex relationship

A number of variables are involved

Type of architecture employed

For tubes, single-ended or push-pull

Quality of the components used in the system

Notably the output devices

Operating points of the active devices

In particular the output devices

Type of power supply used

Tube vs. silicon rectifier, filter type

Sound Creation—Guitar Amps

In guitar amplifier systems, modification of the original sound is the goal

Characteristic distortion and harmonics define the sound we've become used to for blues and rock music

The “sound” of an amplifier is a complex relationship among various factors

A number of variables are involved including the topology and the speakers

Type of architecture employed

For tubes, single-ended or push-pull

How far past the edge is the system operating?

Musicians like to turn to “11” or beyond

How we got here

Distortions due to inexpensive components in the Fender Bassman amplifier led to our musical tastes.





Courtesy Rich Chernock

Observation #5

Musicians, especially guitar players are traditionalists. Basic instrument and {especially} amplifier designs currently in use date back 50 or more years.

Variations on these basic designs abound, but the acceptance of newer technologies has been poor—primarily since they simply often don't sound as good.

About Architectures

Form follows function

Circuit Architectures—Topology

Triode vs. pentode (beam power tube)	Fundamental differences between device types
Operating class	Class A = 360° conduction angle <ul style="list-style-type: none">• Low waveform distortion, low efficiency• Well suited to single-ended operation
	Class AB = 180° to 360° conduction angle <ul style="list-style-type: none">• Higher waveform distortion, improved efficiency• Well suited to P-P operation
	$_1$ = no grid current flows, $_2$ = grid current flow
Single-ended vs. push-pull	With P-P, even-order harmonic products cancel, leaving odd order products to dominate
Soft clipping	Not usually a factor in high-fidelity amplifiers

Circuit Architectures—Feedback

- ▶ Negative (inverse) feedback is commonly used in power amplifiers to improve overall performance
 - ▶ Moderate levels of feedback are typical for tube systems
 - ▶ Higher levels of negative feedback are common in solid-state designs
 - ▶ Reduced overall THD, notably second-order harmonics
 - May be perceived as having a “drier” mid-range¹
 - ▶ May also be observed as having “tighter” bass performance due to lower effective output impedance¹
 - ▶ Transient intermodulation distortion not usually a major concern in tube amps due to relatively low levels of negative feedback

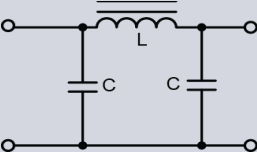
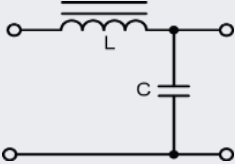
¹ Wikipedia

Circuit Architectures—Transformers

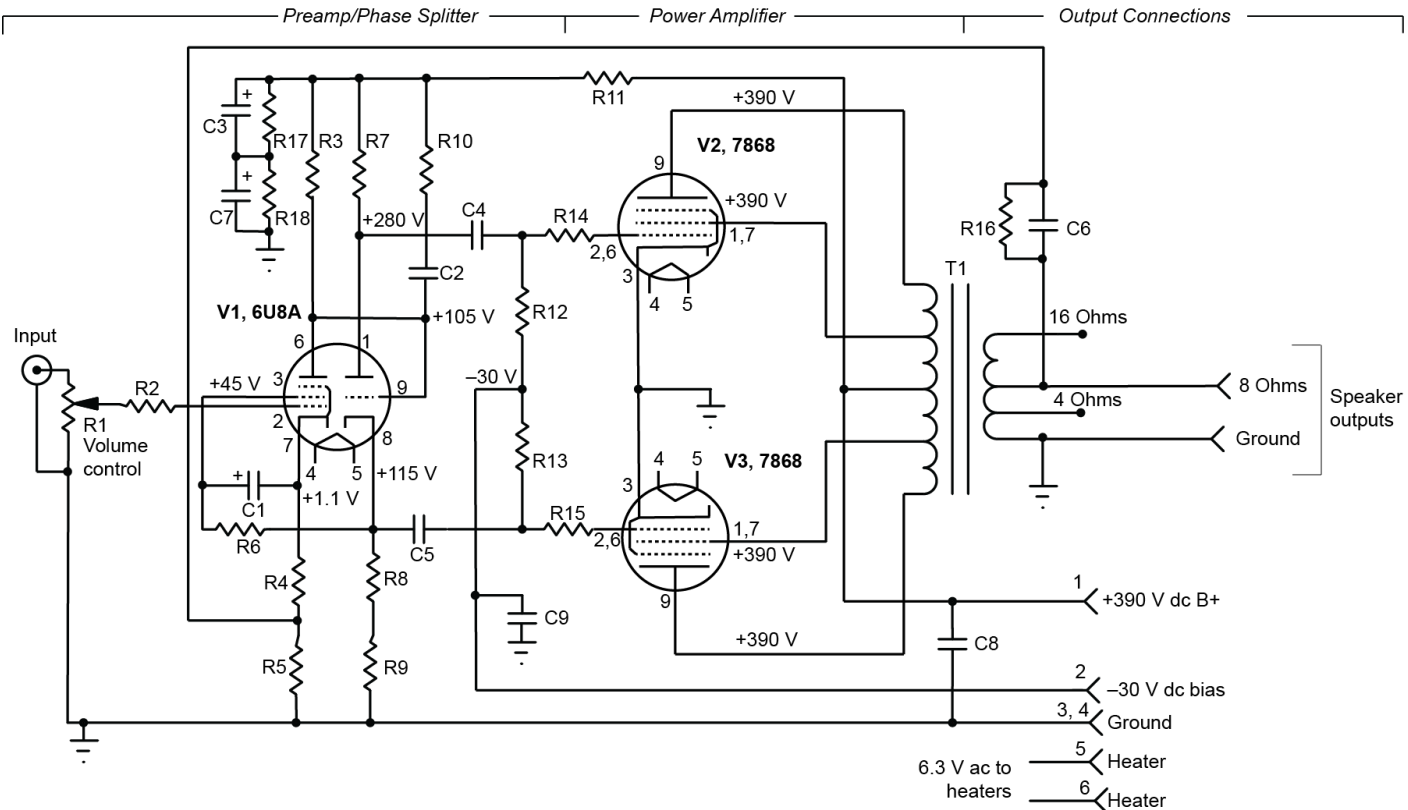
- ▶ Solid-state amplifiers have the benefit that they can typically be operated without output transformers
- ▶ Tubes invariably use transformers to match the high impedance plate to the low impedance load
 - ▶ The performance of output transformers can vary widely
 - ▶ Some are very good; others not so much
 - ▶ Common high-quality audio output transformers are typically specified at 30 Hz to 30 kHz, although some do better
 - Practical 3 dB points of below 10 Hz and above 50 kHz quite achievable at rated output



Circuit Architectures—Power Supply

Power supply considerations	Rectifier tube vs. silicon diodes <ul style="list-style-type: none">• Possible noise issues with silicon diodes (disputed by many)	
Voltage regulation	Uncommon in tube amplifiers	
Type of filter used	Capacitor-input filter <ul style="list-style-type: none">• Example: 5U4 rectifier, 900 V plate-plate• $C = 40 \mu\text{F}$, $L = 5 \text{ H}$• Voltage regulation = $60 \text{ V} = \sim 13\%$	
	Choke-input filter <ul style="list-style-type: none">• Example: 5U4 rectifier, 900 V plate-plate• $C = 40 \mu\text{F}$, $L = 5 \text{ H}$• Voltage regulation = $15 \text{ V} = \sim 3\%$	

Circuit Architectures—Example





Observation #6

Often described in very nonscientific terms, the “warmth” of the tube sound nonetheless exists and has attracted a loyal following.

Vacuum tube-based audio equipment remains in demand and is likely to remain so for a very long time.

Tube-based audio systems have been out of the public eye long enough to be “new” again.



Vinyl Records

Prairie tube companion

Vinyl

- ▶ A funny thing is happening in the music business....
 - ▶ Consumers are collecting (well, recollecting) vinyl records
 - ▶ Choices include used, new-old-stock, and new reissues
 - ▶ 180 gram pressings are top end
 - ▶ Some 200 gram versions are available
 - ▶ On amazon.com today, a search for “vinyl records” brings more than 350,000 results
 - ▶ New releases; e.g., FUN.
- ▶ Listen out loud for a change



In the Beginning...

- ▶ The LP (Long Play) *microgroove* record was introduced in 1948 by Columbia Records
 - ▶ Quickly adopted as a standard by the recording industry
 - ▶ Stereophonic sound capability later added
- ▶ The LP was a major step forward for the industry
 - ▶ Playing time of a 78 rpm 12-inch record less than 5 minutes/side
 - ▶ Utilized an abrasive (and noisy) shellac compound
 - ▶ Employed a much larger groove structure



Attributes of the LP

- ▶ LP uses a 12-inch fine-grooved disc made of vinyl and played with a smaller-tipped “microgroove” stylus
 - ▶ Operating speed is $33\frac{1}{3}$ rpm
 - ▶ Each side of a 12-inch LP can play for over 20 minutes
 - ▶ Well suited to classical music because of its extended playing time
- ▶ The LP was not the first record format to use the $33\frac{1}{3}$ rpm operating speed
 - ▶ But it was clearly the most successful
 - ▶ Still in use after more than 60 years
 - ▶ And you can read the liner notes



LP Fun Facts¹

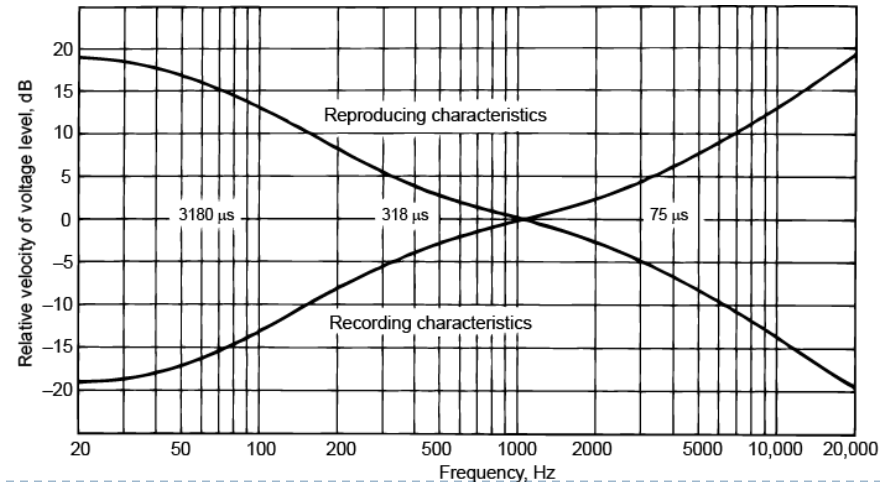
- ▶ The average LP has about 1,500 feet of groove on each side
 - ▶ The tangential needle speed relative to the disc surface is approximately one mile per hour, on average
 - ▶ It travels fastest on the outside edge
- ▶ The term “album” dates back to the 78 rpm record
 - ▶ Due to the short play time of the 78, classical music was broken into parts and sold as sets bound together in a book of sorts
 - ▶ While commonly black, vinyl records can be produced in various colors



¹ Wikipedia

Equalization

- ▶ The RIAA equalization curve was introduced in 1954
 - ▶ It de-emphasizes the bass notes during recording, allowing closer spacing of record grooves and hence more playing time
 - ▶ Boosts high frequency signals during recording to improve overall noise performance
 - ▶ On playback, the pre-amplifier reverses the RIAA curve to flatten the frequency response
 - ▶ Response of ± 1 dB typical for preamp



About the Vinyl

- ▶ The composition of vinyl used to press records has varied considerably over the years
 - ▶ Virgin vinyl is preferred
 - ▶ During the 1970s energy crisis, it became commonplace to use recycled vinyl!
 - Sound quality suffered, with increased ticks, pops, and other surface noise
- ▶ Today, high fidelity pressings use 180 or 200 gram virgin vinyl
- ▶ The difference in vinyl weights is readily apparent



¹ Wikipedia



Observation #7

There is something timeless about a vinyl record. It is not just nostalgia, there is a difference in the sound of an album on vinyl as opposed to a CD (or other type of digital copy).

Depending on the pressing, the difference can be significant and obvious. The audible effect (at least to me) is a different perception of the music that encourages focused listening, rather than casual multitask-based listening.

In Summary...

Main points repeated in case you missed them the first time

How to Quantify the Difference?

- ▶ Undefined terms used so far in this presentation
 - ▶ Warmth, natural, satisfying, richness, fat, drier, tight, harsh
 - ▶ No known instrument can measure these parameters
 - ▶ Still, differences can be heard by observers
- ▶ Measurable parameters may not tell the entire story
 - ▶ The inability to clearly articulate a difference doesn't mean there is not a difference
 - ▶ In the end, it may not really matter why
 - ▶ Personal preference is a valid reason



Final Thoughts...



Tubes and vinyl go together to form an elegant system

Not just a fringe pastime for the sake of nostalgia

Put some effort into listening...and get more out of it

Starting Point

This is probably the first presentation on tubes or vinyl records that you've heard in at least 30 years

In 45 minutes, we can only scratch the surface, and hopefully give folks some ideas



Two years ago, I was a nonbeliever—but not anymore

There is something here



I urge you to

Reconnect with classic technologies as they can still be relevant today



Observation #8

Vacuum tube amplifiers and vinyl records are cool not just to baby-boomer engineers (like most folks here). Even high school and college students know (or have heard about) tube amplifiers and are intrigued by them. Many (maybe most) have never held a vinyl record but find them fascinating just the same.

Speaking from personal experience, these technologies have an appeal that is universal.

The Tube Sound...we know it when we hear it

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<http://www.vacuumtubeaudio.info>





Added benefits

Besides improvements in audio, the use of vacuum tubes provides other benefits, such as a reduction in heating costs during the winter months.

Although disputed by some, the heat produced by vacuum tubes has been observed to be more satisfying than that produced by common resistance heaters or natural gas-based systems.

(OK. I made that up.)