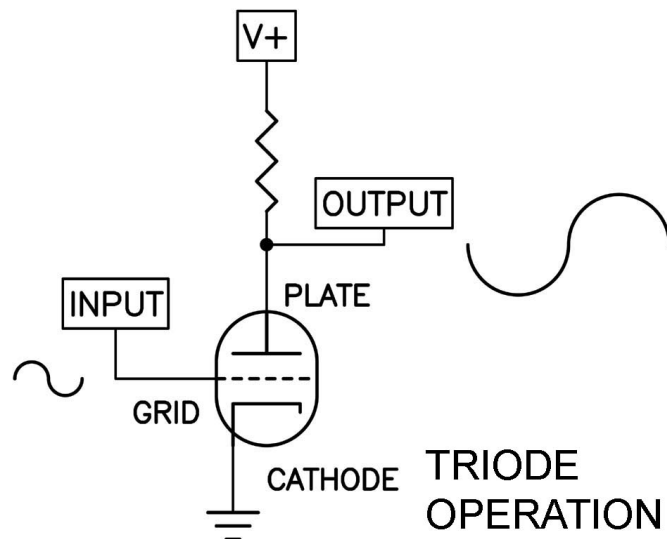


TALK AT THE CALIFORNIA AUDIO SHOW 2015

Thank you all for coming out. I'm out of practice speaking to non-technical audiences, or any audience for that matter, but I get by through having a bunch of pictures strung together to have some sort of arc or lead to some point, which prompt me as to what I'm supposed to be talking about and also distract the audience from my performance.



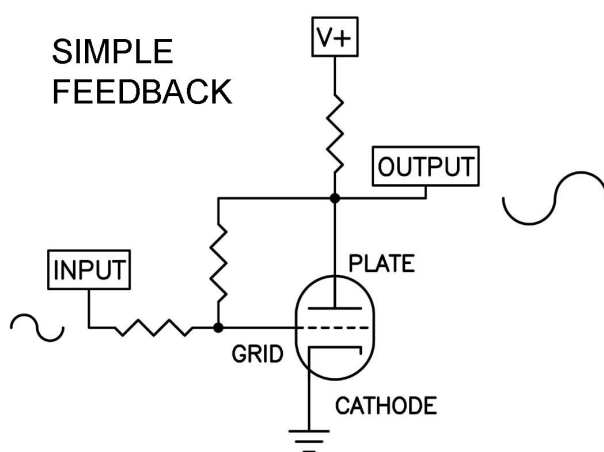
Our first picture is of the very first Triode tube, at least that's what Google came up with for me. This is the first active gain device, invented at the beginning of the 20th century, and is slightly more complicated than the incandescent light bulb it is based on.



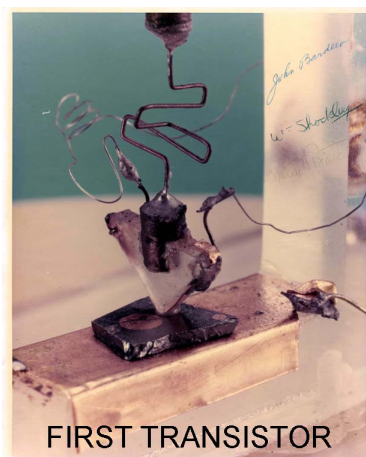
In this diagram we see that the triode has three connections in addition to the filament heater (the light bulb part), although in many early tubes the Cathode connection was also the heater. The tube works by getting the Cathode temperature hot enough so that the electrons on its surface start dancing. Hot enough that quite a few of them jump off the Cathode surface altogether and become free to travel through the vacuum of the interior of the tube.

At the other end of the tube is the Plate, and for the tube to work it will have been hooked up to a voltage source, maybe a battery, so that it has a positive charge, and this charge attracts those loose electrons, which tend to travel to the Plate forming an electrical current through the tube. If that's all there was, we would have a rectifier, which is a valve which allows current to flow freely in one direction but not the other – this because the plate is not allowed to be very hot.

Anyway, if we stick a wire grid in between these two electrodes, it can act like a gatekeeper of the current as it tends to hide the Plate charge from the loose electrons at the Cathode. By varying the voltage on the Grid, we can adjust the quantity of electrons that flow, and that is how we create an electronically controlled valve for electricity. We use this valve so that a small amount of energy can control a much larger amount of energy. It's more than a century later, and we have tons of different types of tubes, but they all bear a resemblance to this diagram, and they all have electrons boiling off heated plates.



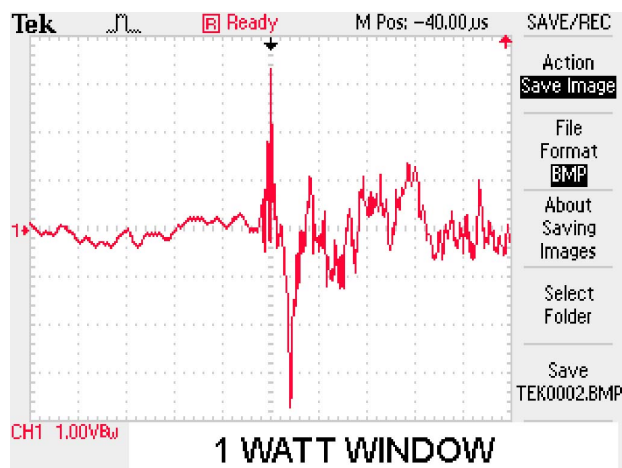
In the 1920's a clever guy named Harold Black thought of a way to get more performance out of tubes, and we call this feedback. This diagram shows the previous circuit but with a couple of resistors added. Here we also show a wavy input signal representing audio and a larger version of that at the output. The output is also out of phase, that is to say it is the inverted version of the input. Because it is inverted, we can send a little bit of it back to the input which reduces the size of the input, also lowering the size of the output, but in doing so it stabilizes the operation of the tube and lowers its distortion and output impedance.



In 1947, armed with Quantum Mechanics and a paperclip, Bardeen, Brattain, and Shockley created the first transistor, the solid state equivalent of the tube. The photo above shows the device, although it is smaller than it looks, and you can see the paper clip toward the top. This is a scan of a photo, one of several that was taken just after testing at Bell Labs and autographed by the inventors. I am happy to say I own a signed original. Within a few years people were building audio amplifiers with this, and now here we are today.

Since this audience is theoretically composed of people who might actually buy something, I should probably offer some guidance on buying amplifiers. **I only do amplifiers, folks - don't look for anything else!**

Perhaps you want to know something about how much power you want to buy? Here's something that I call the One Watt Window.



It's a picture of some music on an oscilloscope screen, and you can see that there's a line that wiggles up and down, that's the voltage representing the music over a small period of time. I have set the voltage scale so that this is the output voltage that an amplifier with a 1 watt rating can fill from top to bottom. Any waveform that stays in this window can be done by a 1 watt amplifier, and you see that this music is safely inside that range.

I made this image yesterday while I was listening to music on my Tannoy loudspeakers. The sound was at a normal listening level, and the group was Massive Attack. The spike you see is percussion. The Tannoys have about 95 dB/watt sensitivity, and this room is a relatively small listening room. So using this as a guideline, we see the following sort of calculation:

POWER CALCULATION

1 W = 95 DB SPEAKER / NORMAL LEVEL / SMALL ROOM

X10 FOR 85 DB SPEAKER

X10 FOR LOUD LEVEL

X4 FOR BIG ROOM

400W = 85 DB SPEAKER / LOUD LEVEL / BIG ROOM

If you had this setup and wanted to listen to Massive Attack at a moderate level, loud enough to hear but not loud enough to make a reasonable neighbor bang on the wall, then a 1 watt amplifier would pretty much do it. However, if your speaker is 85 dB efficient, then maybe you need 10 watts, and if it's party time, maybe you want 100 watts, and if your party is a good one, then it's in a bigger room, and maybe you need 400 watts.

I'm not advocating that you buy a 400 watt amplifier. I'm saying that you might never have imagined that you could be happy with a 1 watt amplifier.



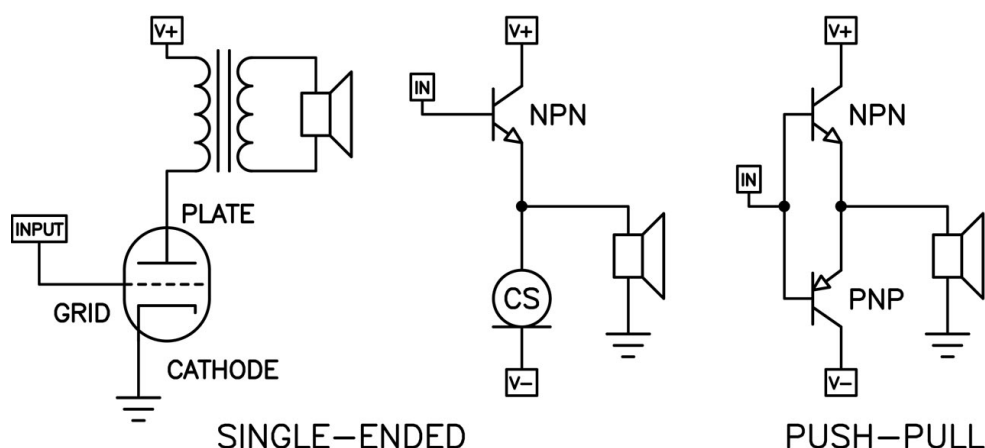
"If either of these amplifiers is RIGHT...
the other must be WRONG."

Here's a cover from Stereophile in '94, that says a lot. There's a bit of polarization among audiophiles between the “objectivists” who trust test measurements and the “subjectivists” who don't. Stereophile magazine tries to reconcile both viewpoints by printing subjective reviews accompanied by some measurements. There are plenty of times when a piece of equipment sounds and measures good, but what do you do when something measures awful and the listening reviewer likes it, or conversely when it measures great and but not so much with ears?

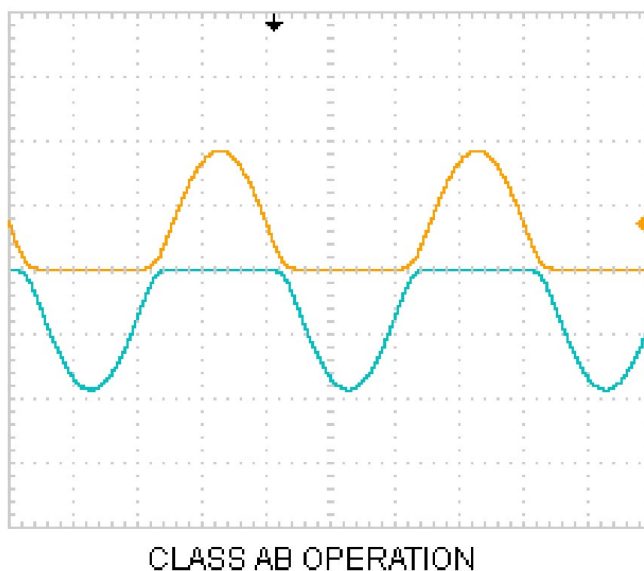
There are some patterns that have emerged, and looking at them might help a potential buyer think about what is going to make him happy. Here's a helpful little comparison chart between two genres of amplifier that tend to represent the opposite viewpoints while still being fairly popular choices: Single-Ended Class A and Push-Pull.

SINGLE-ENDED	PUSH-PULL
HIGH 2ND HARMONIC	2ND HARMONIC CANCELLED
LOW POWER	HIGH POWER
LOW DAMPING	HIGH DAMPING
CLASS A	CLASS B, AB, A
LITTLE / NO FEEDBACK	LOTS, LITTLE, OR NO FDBK
INEFFICIENT	EFFICIENT
EXPENSIVE	LESS EXPENSIVE

Schematically, the differences between them look like the following:



The two on the left are Single-Ended, and as a concept they have one amplifying device. The tube one looks a lot like our earlier tube circuit, except that it talks to the loudspeaker through a transformer which converts the high voltage / low current tube into lower voltage / higher current that the loudspeaker prefers. This is a pretty popular design, and is a simplified version of the one on the magazine cover. The middle one is also single-ended, but uses a transistor, which means that it doesn't need the transformer. On the right we see a transistor push-pull design, where two transistors alternate doing the work of sending plus and minus voltages to the loudspeaker, like this:



The top yellow trace is the current that flows through the NPN type transistor, and the bottom blue trace is the current that flows through the PNP type transistor. Works real well, and is efficient, but has a little difficulty with the hand-off between the devices, that zone being called the crossover region. The Single-Ended circuit just has one device sitting in the middle, doing the whole job by itself. It's much less efficient, has more 2nd harmonic distortion, but no problem with crossover distortion.

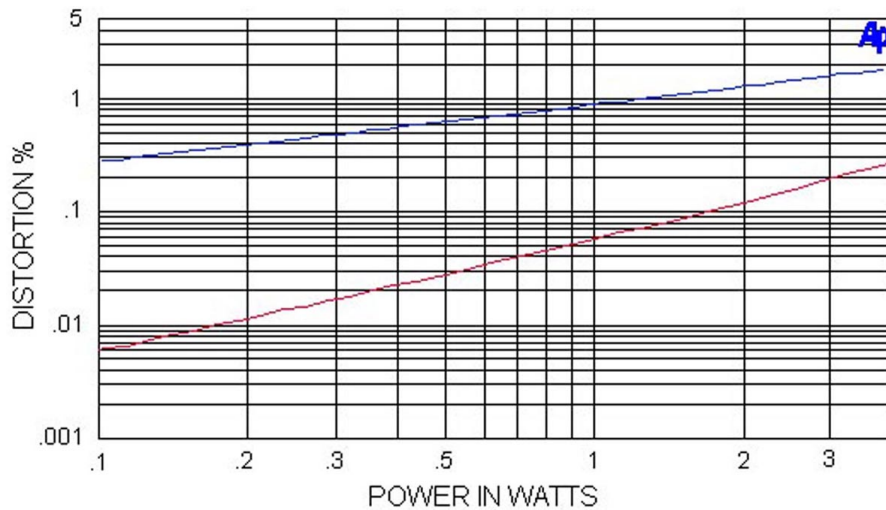


FIG 4 DISTORTION IN SINGLE-ENDED VS PUSH-PULL

We see this difference in above curves, which show the relative distortion between the two types. On the top is Single-Ended Class A, where the distortion is 2nd harmonic. It has more distortion than Push-Pull, where the 2nd harmonic distortion is largely canceled. Push-Pull has lower distortion, but it rises at a faster rate with power. This particular example is Class A.

Here is an exaggerated graphic of what a distorted Single-Ended amplifier waveform might look like:

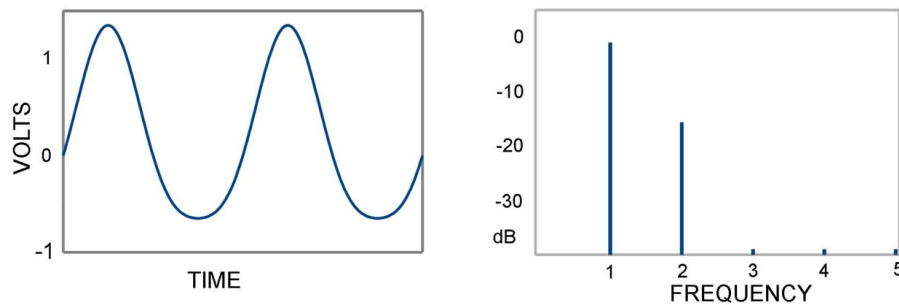


FIG 2 SINE WAVE WITH 2ND HARMONIC DISTORTION

And here's an exaggerated view of a Push-Pull third harmonic:

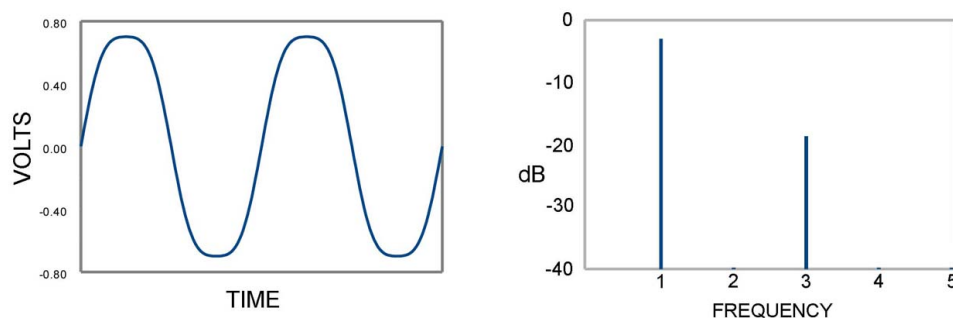


FIG 3 SINE WAVE WITH 3RD HARMONIC DISTORTION

In Push-Pull in Class A mode a lot of idle current is run through the output stage in order to eliminate crossover distortion. Here's an example of how it would look if we don't run that "bias" current:

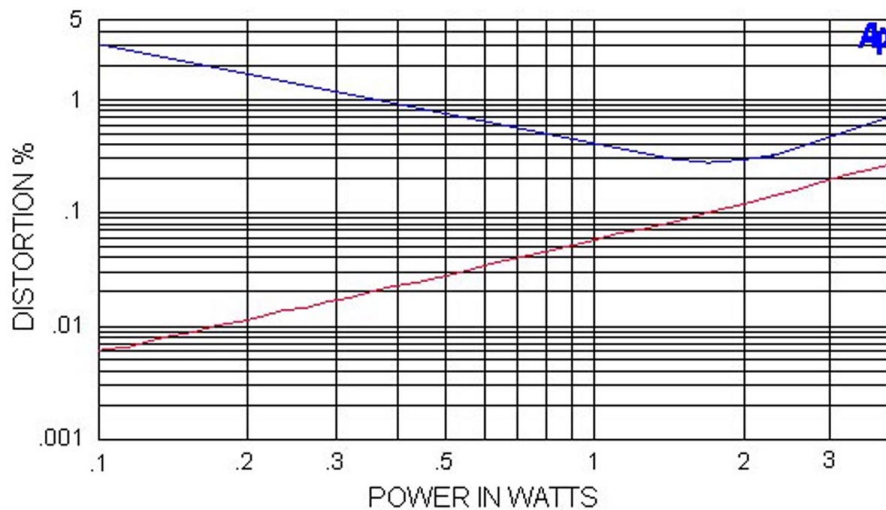


FIG 6 PUSH-PULL CLASS A vs CLASS B

For Class B where there is no bias current, we see the distortion climbing as the power goes down due to the failure of the push and pull halves to mate up smoothly. There is a condition where the bias current is smaller than Class A, called Class AB, and it generates a curve in between these two.

Crossover distortion results in unwanted harmonic components as seen here in a spectral analysis, showing the harmonic components of the distortion:

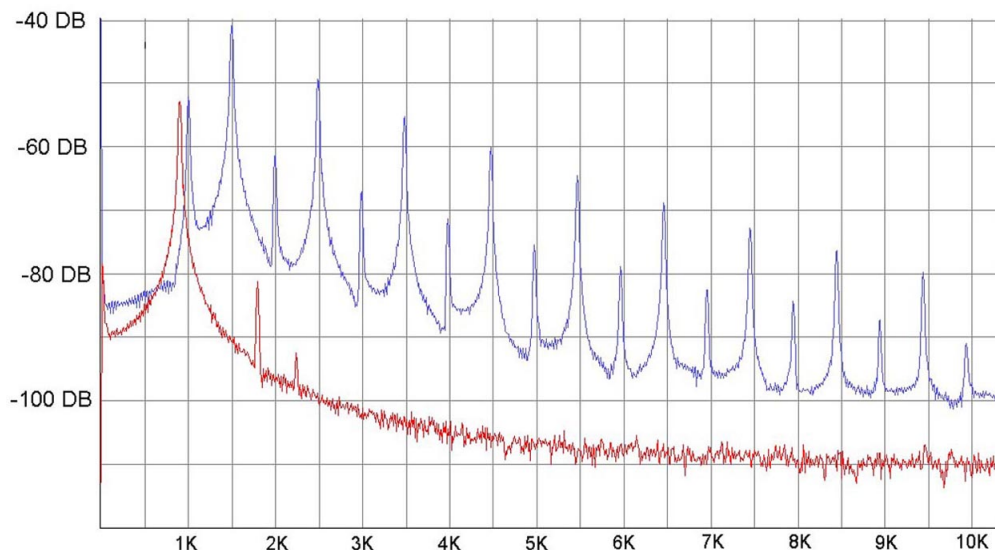
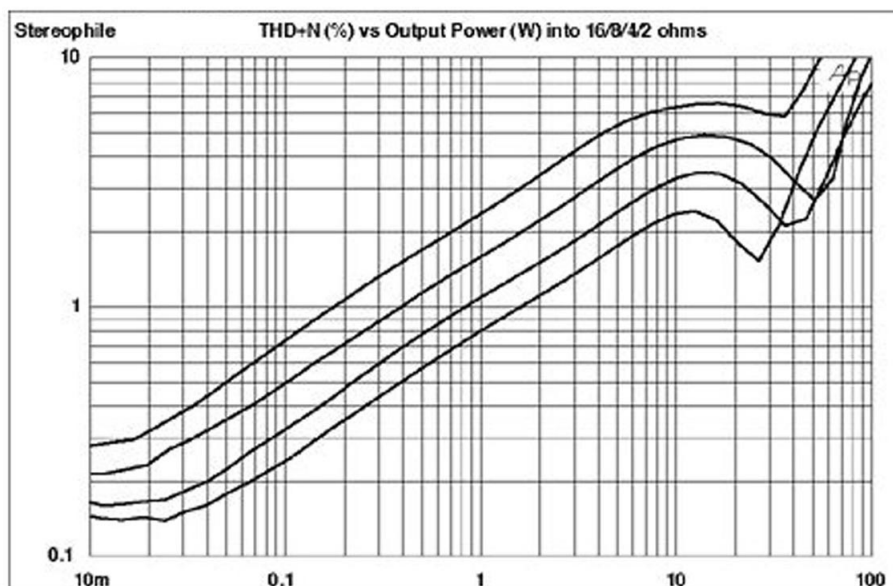


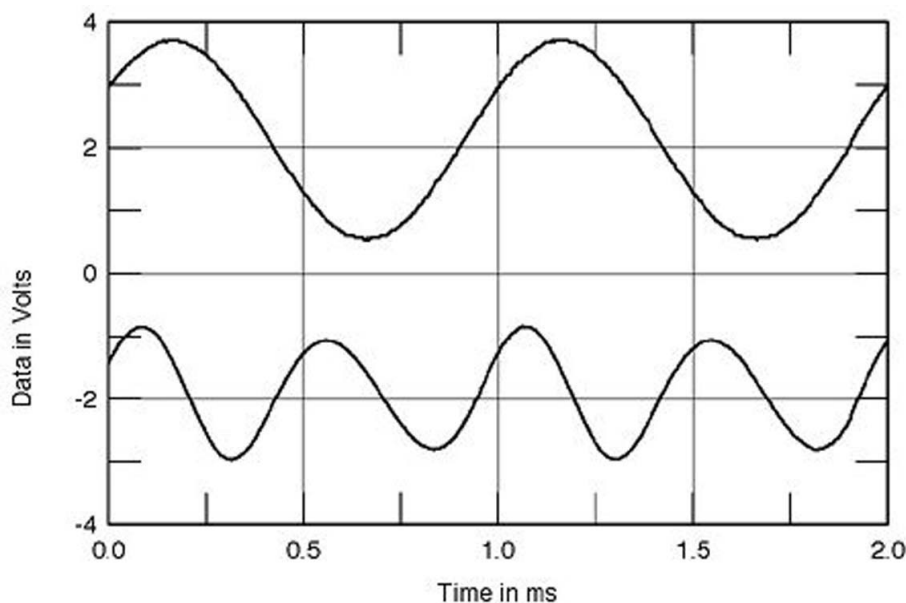
FIG 5 DISTORTION SPECTRUM - CLASS A VS CLASS B

This is not regarded as desirable, and if the output stage has this, you generally see the use of negative feedback to tone it down.

So, understanding some of the above, let's look at a few of John Atkinson's (Stereophile's editor) curves.

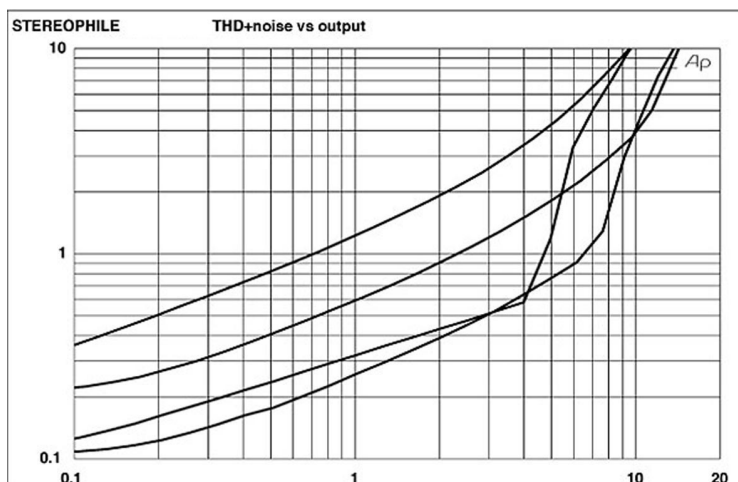


Here is a Single-Ended tube amplifier without negative feedback that costs around \$40,000 or so for a pair of channels. It got a good review from the subjective reviewer, but the distortion measured was considered so egregious that it created some excitement. If we look at the distortion waveform, (signal is top trace, distortion is bottom) we see that it has a 2nd harmonic characteristic. If you count the ups and downs you will see that the lower trace has exactly twice as many:

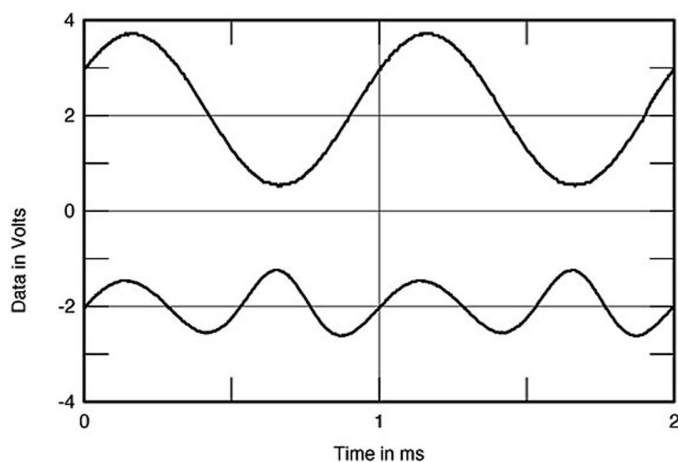


The timing of this second harmonic reflects that the top half of the signal is being amplified slightly more than the bottom half, and I refer to this as “in phase” second harmonic.

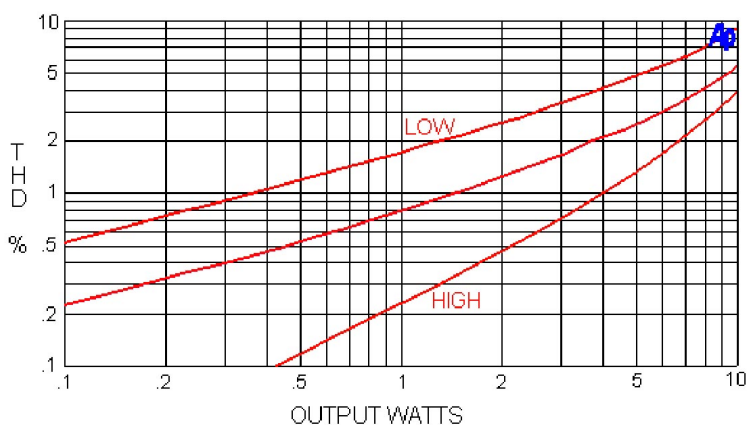
Here is another highly regarded amplifier, similar in approach and price:



And we see that it also has a 2nd harmonic distortion:

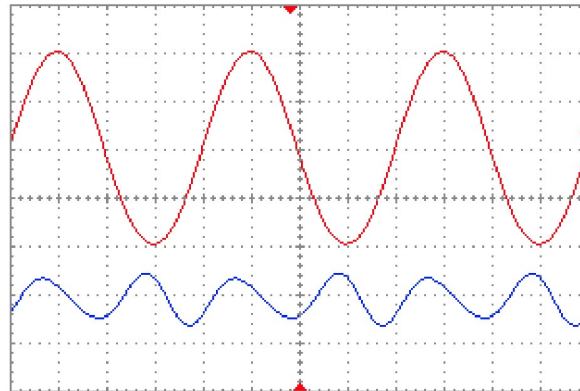


Not one of John's curves, but my own, a solid state Single-Ended FET circuit along the same lines, using a Static Induction Transistor (SIT) and offering an adjustment of the 2nd harmonic:



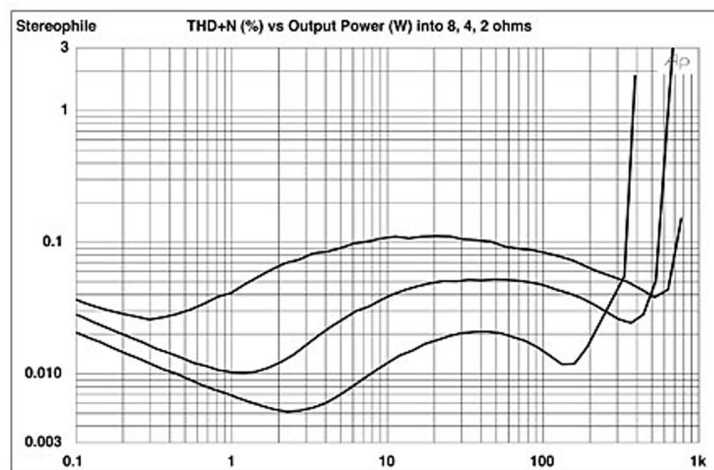
SIT-1 THD @ 8 OHMS VS OPERATING POINT

You can null this out for lower distortion, leaving mostly 3rd harmonic, but people generally set it for some arbitrary amount of 2nd harmonic.

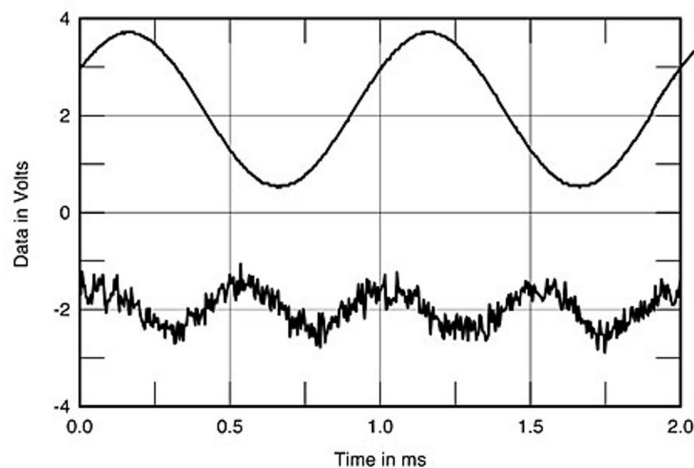


SIT-1 DISTORTION WAVEFORM

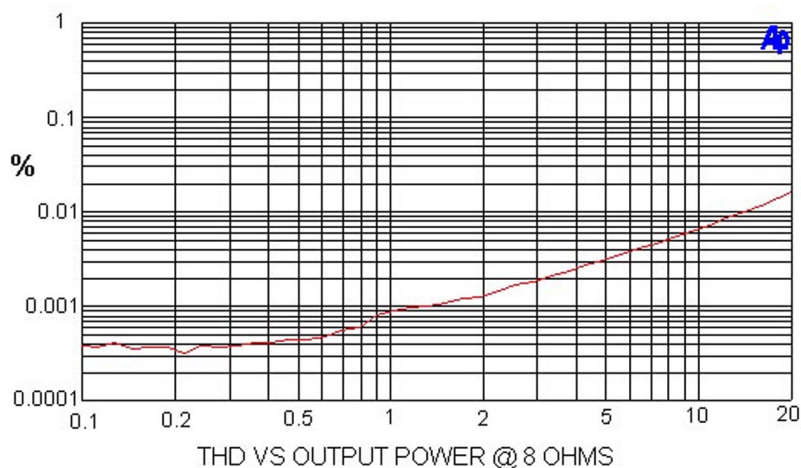
Back to John's curves, here is a push-pull Class AB amplifier that uses no feedback loop:



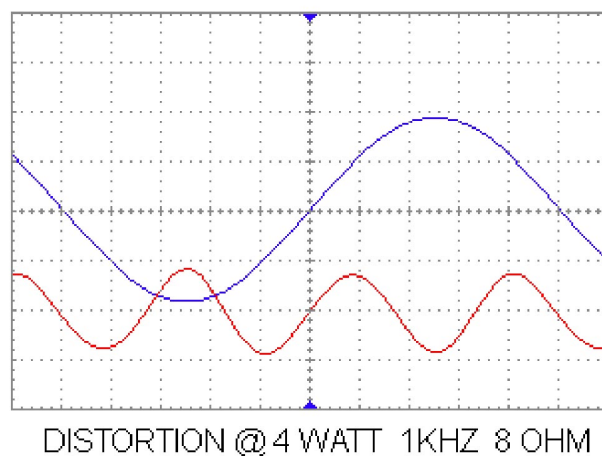
It also got good reviews, and we note that the distortion is quite low, and as seen below, the character of that distortion a low power is also 2nd harmonic:



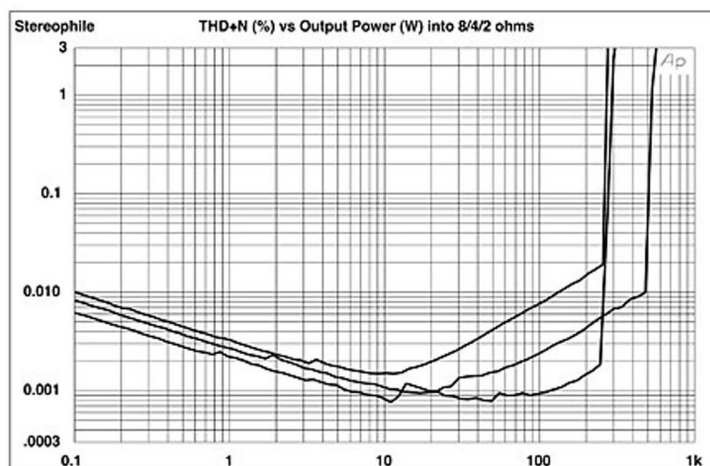
You want to see how low distortion can get without negative feedback? Here's a special case, my own "Beast with a Thousand Jfets" (no kidding, really.)



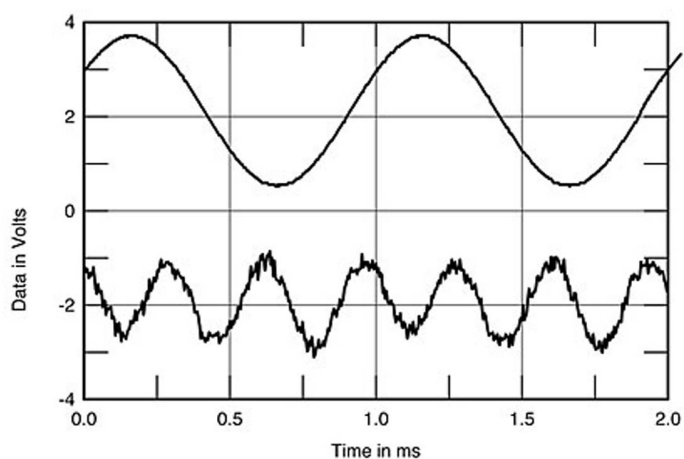
And it's distortion waveform, which is 3rd harmonic:



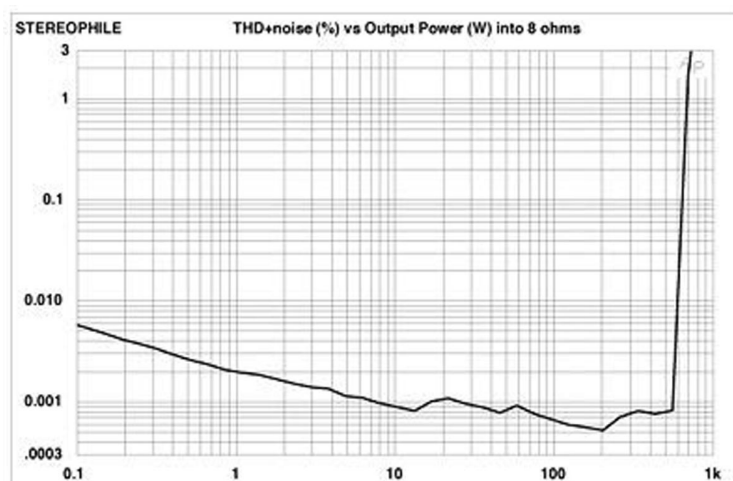
OK, enough of my toys, here's three for the books. Until more recently the record holder for low power amp distortion, a push-pull Class AB:



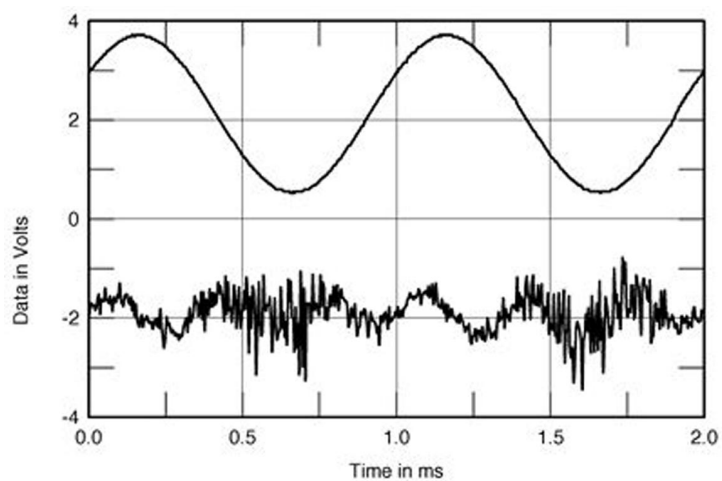
And it's attendant waveform:



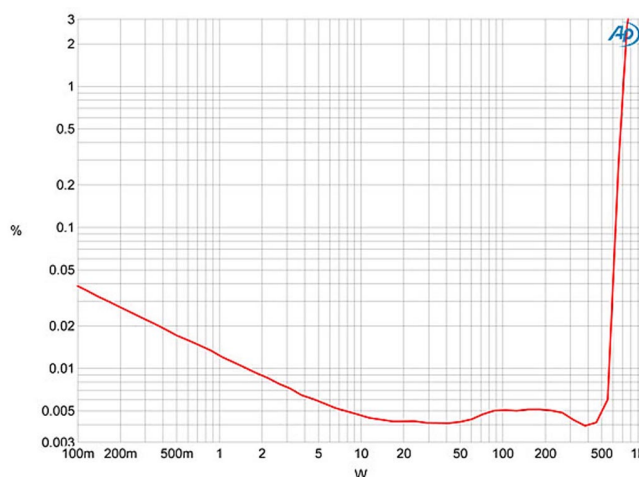
And along comes the current champ:



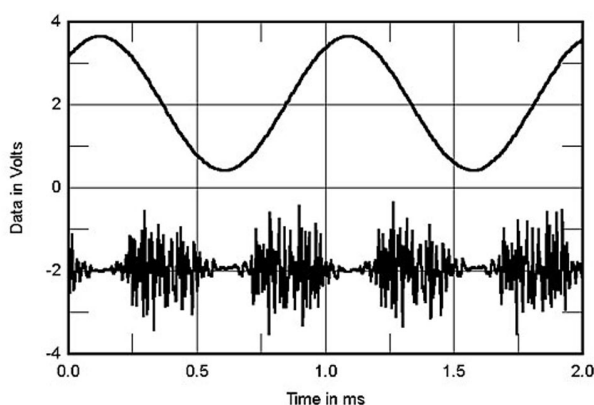
And its distortion wave:



Not far behind it is a Class D entry:



And of course it's distortion wave:



Except for the SIT and the Beast, these amplifiers come in around \$40,000. They all represent the two polarities, and they all have gotten a good subjective review somewhere.

So what's the deal? How can there be such a discrepancy between measurement and subjective hearing. Are these guys deaf? Are the accusation really true that “audiophools” listen with their eyes and their wallets?

It is not my experience that subjective reviewers are deaf (or corrupt). Although it is true that a beautiful faceplate, an interesting story and a high price tag are enticing, by themselves they are not enough to swing a review. Of the amplifiers shown above, not all of them have enjoyed particularly good reviews at Stereophile, and I would not consider all of them economically successful.

Do these curves tell us something useful?

I think so.

The human cognitive system is complex and subtle, and we don't understand it very well, however in some of these cases the distortion components were adequately high to exceed the standard stated in the 70's by Julian Hirsch – greater than 0.1%

If we rationally decide that there is a lower limit to audible harmonic distortion, then it looks like some of these amplifiers lie above that limit. Most of those “sweeten” the sound with some second or even third harmonic.

Having built a large variety of amplifiers at First Watt, floating them out to listeners for blind evaluation, and paying close attention to what they say, it appears that there are people who prefer second harmonic and some who prefer third.

Some listeners perceive a little more dynamic quality to music played through an amplifier with a 3rd harmonic character. Of those hearing second harmonic, there are comments about greater warmth, or a different sense of location and space. I trust these listeners perceptions insofar as they did not know what they were listening to and were not prompted as to what to listen for and the responses had some consistency.

Assuming a lower limit to these sorts of things, what might it be? A lot of the more knowledgeable I have talked to seem to think that it's down around 0.01%, and I think that's pretty reasonable.

Do amplifiers with less than .01% have inaudible distortion? Possibly so, although harmonic distortion is only one metric, and there are other qualities that could be considered (including faceplate and price tag).

We have a lot of sayings around Pass Labs, and one of them is “It's entertainment, not Dialysis.” It's perfectly legitimate to want an amplifier with a few parts per billion distortion. It's also perfectly OK to have an amplifier with few parts per thousand, or even more. As long as the paying customer experiences what he's looking for, we're both happy.

Often we find that audiophiles who prefer the low power Single-Ended Class A amplifiers listen to simpler sorts of musical material at modest volume levels. If this describes you, then you might want to look at some of these sonically colorful amplifiers.

In the other hand, if you play Symphony Fantastique at the level experienced by the conductor, you will probably want to explore amplifiers with more power and more modest distortion figures.

The most important thing is to try the equipment out for yourself. Yes, you can pay attention to the reviewer's taste in music and associated equipment, and you can read what people say on the internet, but the best way to find out is to put the new amplifier in a system that you know well (yours) and spend some time with it.

At Pass Labs what we look for is that quality that invites you to listen, and then listen more.

We want the sound that makes you stay up late into the night going through your entire record collection. If a component makes you do that, it's probably a keeper.

By way of analogy, when I go to the store, I am confronted by an entire aisle devoted to bottled water. Up on the top shelves is melted glacier water, fizzy water from Italy and other expensive offerings. Below those are the less expensive and exotic products, and below those are the colorful sugared waters. Finally down near the bottom I see the only fluid less expensive than gasoline - purified tap water. Off in the corner somewhere there is distilled water. Offhand, it seems that distilled water, the most pure, is the least popular.

Anyway, here's what I drink:



And That's Entertainment.

Closing, here's a shot of the Beast With a Thousand JFETs, a homage to Roger Corman.

