Updating the Rules on Amplifier Metrics

By
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Are your engineers using "hammers on screws" audio design methods to support outdated marketing claims? If so, it may be time to rethink your Class D audio design and measurement practices.

When I grew up, I was fascinated by fast cars. The faster, the better. In kindergarten, when I was playing Supercar Trump Cards with my friends and talking about which cars we'd drive when we grew up, like most boys that age, we focused heavily on metrics like "top speed" and "break horsepowers."

Peering into the window of a parked car that looked fast and fancy, the focus of my attention was on the speedometer dial. The higher the numbers on it, the greater my excitement would be. Not until later, I discovered that looking at the speedometer dial might not be the best way to gauge the qualities of a car.

As I grew older, I started to appreciate other metrics such as acceleration, torque, and gas mileage. Later in life, when I eventually had a driver's license and started buying my own cars, I even realized some of the aspects that were actually most important to me like how well the car handles when you drive it, are fairly poorly judged by these metrics. Analogous to this, my view of audio metrics and performance claims has also changed over the years.

The FTC "Amplifier Rule"

Following some pretty outrageous power claims made by Hi-Fi amplifier manufacturers back in the early 1970s, in an attempt to level the playing field prevent misleading consumers, the Federal Trade Commission (FTC) instated its "Amplifier Rule" in 1974. The Amplifier Rule says: for advertising and specifications of amplifiers sold in the US, continuous power measurements should be performed "using sine wave signals and at the impedance for which the amplifier is primarily designed, measured with all associated channels fully driven to 1/3 of rated per channel power."

Rated power is usually determined by measuring the output voltage (RMS), with a sine wave signal, at the onset of clipping with a predetermined percentage of total harmonic distortion (THD), typically at 1% or even at 10% (at which point the output actually looks more like a square wave than a sinus curve) into a specified load resistance of 8 Ω or 4 Ω, depending upon amplifier ratings.

As such, although the test specification was perhaps not ideal, the "amplifier rule" served a purpose by somewhat leveling the playing field and enabled consumers to make better comparative product comparisons and purchasing decisions. In 1998, the amplifier rule was amended to also cover self-powered speakers (e.g., those now commonly used in home audio and portable applications).

However, as new audio technologies have emerged, and as consumers have since become more discerning, today they are more concerned with the actual listening and user experience of the audio product than how many watts of output power is claimed on the retail box.

Consumers still want audio products that sound great and play loud—but as I aim to illustrate with this article, the "Amplifier Rule" and other commonly used amplifier metrics, do not always pay justice to the best interests of consumers and/or manufacturers.

At the turn of the century, the advent of Class D audio amplifiers, which are a lot more power efficient than previous amplifier classes—especially at high power output levels, meant that audio manufacturers could now boast huge output power numbers. For that reason, the equivalent of the proverbial "top speed" cliché started to get a lot of marketing attention.

However, as shown in **Figure 1**, although their efficiency is a lot higher than with previous amplifier classes, conventional Class D amplifiers are still not particularly efficient at lower output power levels. The issue with this, is that for real-life input signals such as speech or music, where the input signal will be at or near idle most of the time (i.e., where the average output power is much lower than the peaks), it is the efficiency near idle that becomes dominant and determines the overall power efficiency of the amplifier.

Instead of converting all of the available energy into currents that can move speaker coils and produce sound, this means that most of the energy in this important output range is dissipated as heat in the amplifier and its surroundings. To make a meaningful assessment of an amplifier's power efficiency, it needs to be benchmarked in a typical music and speech volume scenario—just like the gas mileage of a car should be measured under normal driving conditions and not at near maximum speed on an uncontrolled roll-stand.

With recent technological improvements such as multilevel Class D amplifiers, which are designed specifically for superior audio quality and power efficient amplification of music signals, failing to consider this means that the audio designers could miss out on opportunities to create better products for their customers.

If power efficiency is only measured at rated output power with a 1 kHz sinusoidal input source (which is actually more suitable for stress testing than as a design target) and if we pretend that speaker

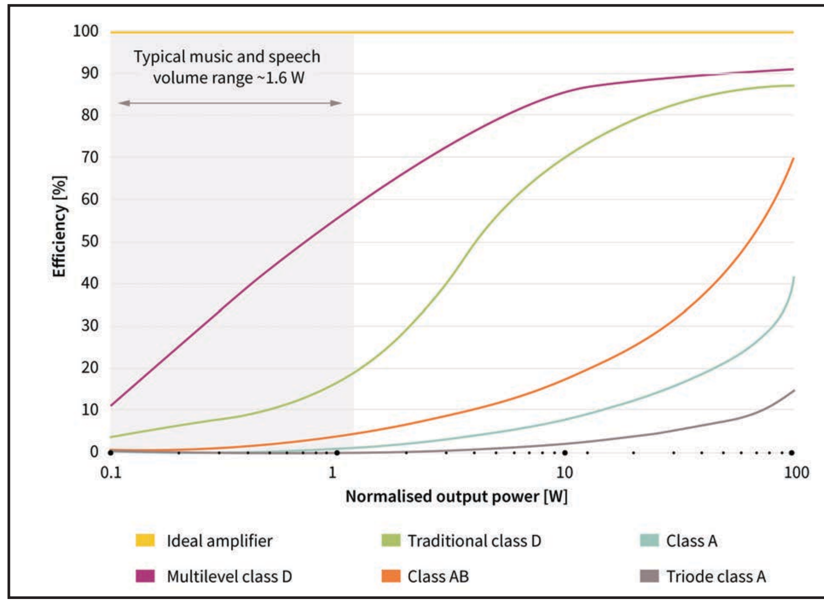


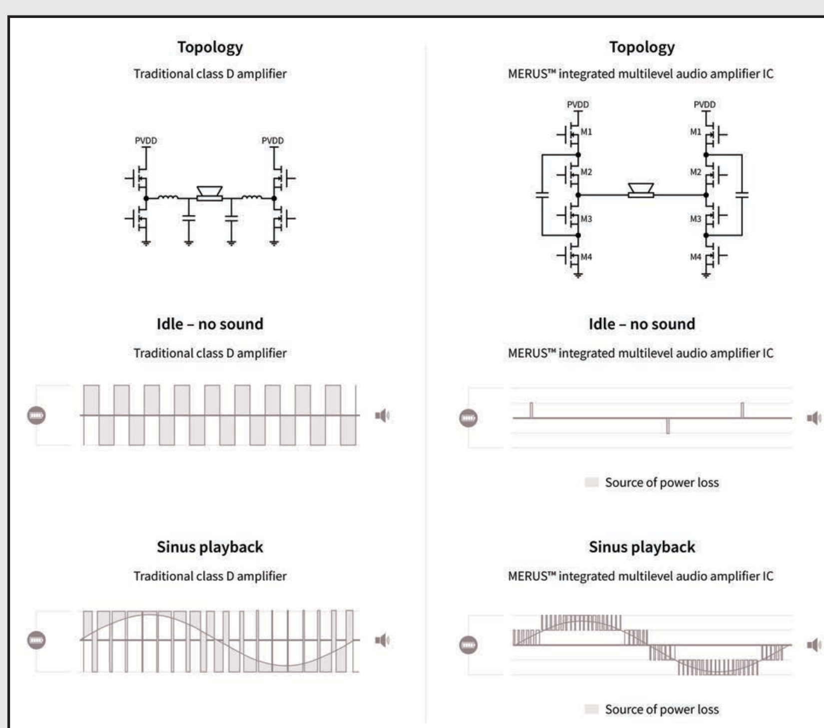
Figure 1: Conventional Class D amplifiers are still not particularly efficient at lower output power levels.

What is a Multilevel Class D Amplifier?

In a conventional Class D amplifier, there is a lot of switching activity even in idle and near idle mode. Each half-bridge in the output stage changes the duty cycle to create the desired output level—but even if no output and no sound is coming out of the speakers, there is a lot of internal switching activity going on, which entails switching loss. You can see this in **Figure 1** as the shaded area in the curve.

In contrast, due to the proprietary and patented circuit architecture (shown in Figure 1), the multilevel amplifier 8 smaller MOSFETS can scale the output to a much higher granularity in terms of resulting switch frequency and output levels.

Essentially, this dramatically reduces power losses, provides much higher output signal granularity and yields many other additional benefits.



loads are purely resistive (which they are not), then important characteristics of these new amplifier types could be overlooked and this can result in sub-optimal designs—both in terms of audio performance and overall solution cost. Let me explain why.

The Dynamics of Music

Consider a typical music input signal as shown **Figure 2**, as an example of a real-life audio signal. The peak value of the input signal is 1 V and the root mean square (RMS) value of the input signal is 0.125 V meaning that the Peak/RMS ratio is 8, corresponding to a crest factor of 18 dB. In contrast, a sinus input signal has a Peak to RMS ratio of √2 corresponding to a 3 dB crest factor.

If we wish to amplify the music input signal with a Class D amplifier that has a rail voltage of 20 V in a 4 Ω nominal load (i.e., with a 5 A maximum peak current—meaning that it can deliver 100 W of instantaneous power) the resulting average value of the instantaneous output power waveform PAVG this amplifier will produce is only around 1.6 W.

To get to this number, we need to calculate the multiplication of the instantaneous voltage and current (which may not necessarily be in phase, if the speaker load is not purely resistive) averaged over time:

$$P_{AVG} = \frac{1}{T}\int_0^T v(t)\times i(t)\,dt$$

Also, it should be noted that the ~ 1.6 W average output power is at the absolute highest volume setting (aka "delinquent teenager level"). For normal listening situations regardless of the music source which may have a slightly lower crest factor at decent harmonic distortion levels (i.e., unclipped signals) the resulting average output power is much lower.

Actual measurements of typical music listening levels with a reasonably efficient speaker, producing say 70 dB SPL (which is quite loud), the average output power—even with a 100 W instantaneous power amplifier—is only around 0.25 W (i.e., 400 times smaller than the instantaneous power number).

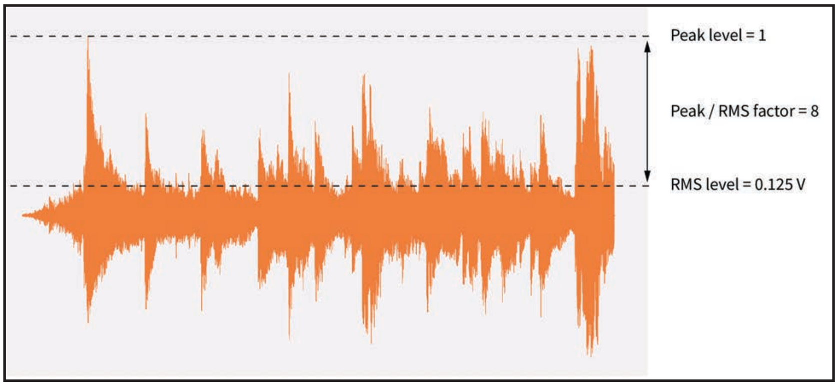


Figure 2: We used Norah Jones' song "Come Away with Me" as an example of a real-life audio signal.

If this is not considered and if power efficiency is measured with a sinusoidal input source and using purely restive loads then the integral equation above can be reduced to:

$$P_{AVG} = \frac{V^2_{peak}}{2\times R}$$

where R is the resistive load impedance.

However, by using the sinusoidal input as substitute for music signals or other higher crest factor input sources and by applying a purely resistive load instead of a speaker (assuming that currents and voltages are always in phase), we may falsely conclude that the average output power of the amplifier would be 50 W or half of the instantaneous power number—derived from the RMS of the 20 V peak sine wave voltage in a 4 Ω load:

$$P_{AVG} = \frac{V^2_{peak}}{2\times R} = \frac{20^2}{2\times 4} = 50W$$

This number is often referred to as "continuous RMS power" or "watts RMS," which are also references in regulations presented by the Consumer Electronics Association (CEA—currently the Consumer Technology Association) in examples of how to mark electronic products. However, the term "RMS power" is in itself slightly misleading, as this is not actually the RMS value of the power output curve we are calculating (this would be a larger, but a somewhat meaningless number).

Continuous as opposed to "instantaneous" implies that the device can function continuously at this power level for long periods. Hence, it might be inferred that the amplifier in our example will have to produce a continuous output of 50 W in a resistive load from a sinusoidal input source at 1 kHz for extended time spans.

In contrast, the typical use-case average of playing real music is below 1.6 W so with the simplification the average output power is overestimated by a factor of 31.25 times!

Moreover, at the 1.6 W average output power level, the efficiency of a conventional integrated Class D amplifier IC is only around 20% meaning that 80% of the energy will go to waste as heat in the amplifier rather than used to move the speaker coil and produce sound. In contrast, the efficiency of a multilevel amplifier (e.g., the Infineon MERUS MA12070) at this output level is well above 50%.

Since an increasing number of audio applications are portable and battery operated, the difference in efficiency during operation is becoming increasingly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About the Author

After the Infineon acquisition of Class D Amplifier IC startup Merus Audio, where Jens Tybo Jensen was serving as VP Sales and Marketing, Jens became head of Marketing & Application Engineering for all Class D Audio Products within Infineon Technologies. Prior to his tenure with Merus Audio, Jens held a European Sales Director position with Knowles Electronics—a global supplier of high-performance micro-acoustic components and intelligent audio IC solutions.

His global business development experience stems from a variety of start-ups and international hi-tech companies. Jens was co-founder and VP Sales at Nangate, Inc., which was subsequently acquired by Silvaco, Inc. a leading provider of EDA software tools and IP used for process and device development in analog/mixed-signal and power ICs. He also served as VP Sales & Marketing for Danish Hi-tech start-up, Exbit Technology A/S and is now a part of Microsemi Corp. Jens holds a B.Sc.EE degree from the Technical University of Denmark and an Executive MBA from Copenhagen Business School.

significant. As an example of what is at stake, multilevel amplifiers can often double the effective battery playback time (or use half the battery capacity). However, if power efficiency is never measured with a realistic measurement setup (i.e., with music input or other high crest factor signals and real speaker loads or at least inductive loads to mimic a speaker impedance), this may not be apparent.

In addition, even if the targeted amplifier is reasonably power efficient at higher output power levels, the resulting heat from exaggerated continuous RMS power ratings must be removed at the same rate it is generated, without temperature building up to the point of amplifier shutdown. Consequently, this may lead to over design of the thermal relief in terms of more PCB layers than necessary or even the addition of bulky, expensive and unnecessary heatsinks.

Alternatively, if this is considered too expensive, it may be tempting to lower the amplifier rail voltage below what is ideal to lower the power rating and thereby solve the thermal issues. For instance, a rail voltage of 12 V (yielding a 36 W instantaneous peak capability in 4 Ohms) might be used instead of the original design intent of 20 V (which would yield a 100 W peak capability).

However, lowering the instantaneous output power capability of an amplifier can have detrimental effects on the subjective listening experience of the audio system. Ensuring lots of headroom and good dynamic range by enabling a high enough rail voltage is perhaps the single most important sound quality aspect associated with the use of Class D amplifiers. The additional energy reserve can be "heard" and subjectively experienced as deeper and fuller sound even by non-audiophiles, much the same way that a car feels and drives differently, depending on its engine also below maximum speed.

Multilevel amplifiers are essentially efficient high performance "audio engines," which are specifically designed for music playback. They produce high undistorted SPL output and excellent sound quality with heatsink-free operation. As input-levels shift up and down their power efficiency stays high and at the same time they have enough energy in store for those high output peaks that constitute real audio.

As such, the difference they make becomes apparent if the amplifiers are tested with real music signals and real speaker loads. On the other hand, if they are tested exclusively with a sinusoidal input source in a resistive load, as suggested by the FTC, then the advantages of the new technology may not be utilized and the analogy of using "hammers on screws" come to mind.

Sinusoidal signal sources are great for worst-case continuous output stress testing and other types of benchmarking—but to avoid overdesign the recommendation is to separate the design specification from the stress test requirement.

As a general rule of thumb, one-eighth of the maximum sine wave peak output power is sufficient for stress test purposes. In the example case, with a PVDD of 20 V, a nominal load impedance of 4 Ω and instantaneous peak output power of 100 W this would correspond to 6.25 W continuous power—which is quite feasible for a power efficient amplifier to handle—also without a heatsink. Infineon provides additional detailed recommendations on how to benchmark, measure, and stress test multilevel Class D amplifiers for real use cases.

Finally, in line with the car analogy: nothing beats a real test drive.

Test It Yourself

If you want to find out what multilevel Class D amplification can do for your products, I would strongly recommend that you make a comparative trial under realistic usage situations using your ears as well as your Audio Precision measurement setup.

Ideally, the test should use the same music sources you expect your end customers to play. If the music is played to the same SPL level, I am convinced you will hear, see, and feel the difference.

Check the Power vs. Consumption Ratio

A good measure of how efficient a Class D amplifier performs in real-use cases is to look at the ratio between instantaneous peak power and idle power consumption. Generally speaking, the higher that number is, the better it is for the application. To learn more about the multilevel technology and its working principles, please read this article.

To check out Infineon's audio offering and technical specifications, please visit www.infineon.com/merus.