Exploding the efficiency myth of Class D amplifiers

Exploding the efficiency myth of Class D amplifiers

Much has been written about the efficiency of Class D amplifiers, with figures of 90% or greater routinely quoted. Such numbers might seem to suggest that the efficiency problem of audio amplifiers has been well-solved by conventional Class D. However, a closer look shows that this is far from the truth, with these amplifiers frequently seeing only single-digit percentage efficiencies, or less, in real product usage conditions. To address this problem, a new generation of audio amplifier solutions has just emerged, heralding a massive reduction in average power consumption.

The problem

Figure 1 shows a plot of efficiency versus power output for a typical Class D amplifier, but plotted with a logarithmic power axis, rather than the linear scale invariably seen in data-sheets. Sure enough, the top right of the graph, corresponding to maximum power output, shows the efficiency reaching almost 90%. However, in typical consumer usage, an audio amplifier hits its rated maximum power comparatively rarely – only when the volume is turned right up to the onset of clipping. Even then, maximum power is reached only on the loudest audio peaks, which make up a relatively small proportion of typical content. Across the operating life of an amplifier, it is seen that average power output typically sits at around 20 to 50dB below full scale, a massive 100 to 100,000 times in linear power terms, as we now explore. At this comparatively tiny output level, corresponding to the lower left region of Figure 1, the efficiency of the conventional Class D solution is seen to be disappointingly low. Clearly, a different approach is needed to bring true energy efficiency to consumer audio.

Extreme statistics

Amplified audio signals have some extreme characteristics, and it is the exploitation of these that underlies the success of the new ultra-efficient methods. For example, music content typically has a peak-to-average-power-ratio (PAPR) in the range of 10 to 20dB, or 10 to 100 in linear power terms. TV or movie audio is even more extreme, typically having a PAPR exceeding 20dB. This is termed the *content* PAPR (CPAPR) – see Table 1 for a few examples. However, an audio amplifier has to cope with a significantly greater dynamic range than just the CPAPR, since the user volume control adds another significant element of power variation. This is characterized as the *gain* PAPR (GPAPR), which is defined as the ratio between the volume gain when the amplifier is playing at its lifetime average power output, and the volume gain corresponding to the onset of clipping of the amplifier, i.e. “full blast”. It is seen that GPAPR typically varies between about 10 and 30dB in consumer systems. To illustrate this, consider two examples.

Example 1. Consider an audio system that can deliver up to 10W (i.e. 10dBW) peak into a speaker system with an efficiency of 90dB@1W@1m. Assume that across the operating lifetime of the system that the CPAPR is 15dB, and that the average sound pressure level (SPL) is 73dB at 1m (a level commonly used by consumer audio manufacturers for battery lifetime testing). Therefore, we can calculate the GPAPR of this system as follows. At maximum volume (onset of clipping), the system delivers 90+10 = 100dB peak SPL at 1m, and accounting for the CPAPR, this equates to 100-15 = 85dB average SPL at 1m. Therefore, in this case GPAPR = 85-73 = 12dB.

Example 2. Consider a 100W (i.e. 20dBW) peak system, with the same speaker efficiency, but with a CPAPR of 10dB, and delivering 65dB average SPL at 1m. At maximum volume this system delivers 90+20-10 = 100dB average SPL at 1m, yielding GPAPR = 100-65 = 35dB.

Finally, CPAPR and GPAPR are brought together in a measure of the amplifier termed the *lifetime* PAPR (LPAPR), which is simply the multiple of CPAPR and GPAPR – or, equivalently, their sum in dBs. We can see from the figures discussed that since CPAPR lies in the range of about 10 to 20dB, and GPAPR lies in the range of around 10 to 30dB, then LPAPR lies in the range of approximately 20 to

50dB. Maximizing amplifier efficiency over this wide range of power is the challenge that must be solved by any truly energy efficient solution.

New approaches

Some technology developments have recently emerged to address these issues, yielding solutions that claim high efficiency across the complete power output range of consumer audio amplifiers.

Low-rate modulations

In any switching amplifier, energy is lost each time the amplifier switches its output from one state to another. This is true not only for the main output transistors, but also throughout the preceding driver circuitry and logic. Most Class D amplifiers employ pulse width modulation (PWM), typically operating at a switching rate of hundreds of kilohertz to achieve the required system performance. However, new *low-rate modulation* (LRM) schemes are now emerging that deliver substantially lower average switching rates, with a commensurate reduction in switching power losses.

Low-supply architectures

Conventionally, amplifiers tend to take a relatively high voltage as the basic supply voltage. The output stage, whether switching or linear, then effectively “scales down” this supply voltage to the required output signal level. These amplifiers are classed as “high-supply architectures” (HSAs). The problem with HSAs is that they are highly inefficient at handling the large LPAPR of amplified audio. Nearly all power loss mechanisms in amplifiers scale with the square of the rail voltage, and since HSAs use a high voltage just to support very occasional maximum voltage requirements at the output, large losses occur. However, amplifiers employing *low-supply architectures* (LSAs) are now becoming available. These amplifiers “start low”, by taking a low supply voltage, and “stay low”, by using this low voltage throughout most of the amplifier’s circuitry, including the power stage, for most of the operating time. When the amplifier does need to output a higher voltage, this is provided by a boost converter. Note that since the converter is only used for a small proportion of the time, any power conversion losses have little effect on the amplifier’s average efficiency.

Rail tracking and switching

Rail tracking is another method that can be used to counter the voltage-dependent losses of amplifiers, by varying the output-stage rail voltage either with the audio envelope, or simply tracking the user volume level. One issue for rail tracking can be the speed with which the rail voltage can be varied, especially since it is usual to have relatively large decoupling capacitances on the output rails, implying that considerable currents need to flow to change the rail voltage rapidly. Rail switching provides one answer to this, by employing two rails: a lower voltage rail is used most of the time, and a higher voltage rail is employed only when the output signal exceeds the voltage available on the lower rail. Both rail tracking and switching have been known for some time in linear amplifier design, as Class G and Class H, but transferring these approaches to a switching amplifier presents new challenges. For example, the switching algorithm must be designed to avoid any objectionable clicks, or other artefacts, as the amplifier transitions from one rail to another.

The results

The most efficient solutions combine all of these techniques, and consequently they enjoy a large “multiplicative” reduction in power wastage. For example, Audium Semiconductor’s latest family of audio amplifier ICs employs all of the methods discussed here, and they deliver an average power consumption that is a small fraction of traditional Class D for a wide range of consumer applications. Figure 2 highlights this, comparing measurements made on an Audium amplifier IC and a conventional Class D amplifier IC. In both cases peak power output capability is 100W. Equivalent SPL is shown below the x-axis, assuming a single speaker with an efficiency of 90dB@1W@1m. The relative power consumption of the two amplifiers, N, is highlighted at two points on the graph: at 73dB SPL, the Audium amplifier consumes 20 times less power than the conventional Class D; and at 65dB SPL, the Audium amplifier consumes 50 times less power.

Conclusions

By understanding the characteristics of an audio signal, together with normal consumer listening levels, new amplifier solutions have been developed that deliver a step-reduction in average amplifier power consumption, by as much as tens of times. The new amplifier ICs, now available from Audium Semiconductor, bring significant benefits to a wide range of consumer audio systems, for example: battery-powered audio products can enjoy greatly increased battery lifetimes; input-power constrained systems (such as USB-powered devices) can now deliver substantially higher audio power outputs; and mains-powered audio systems can be realized in smaller, cooler, and lower-cost product form-factors.

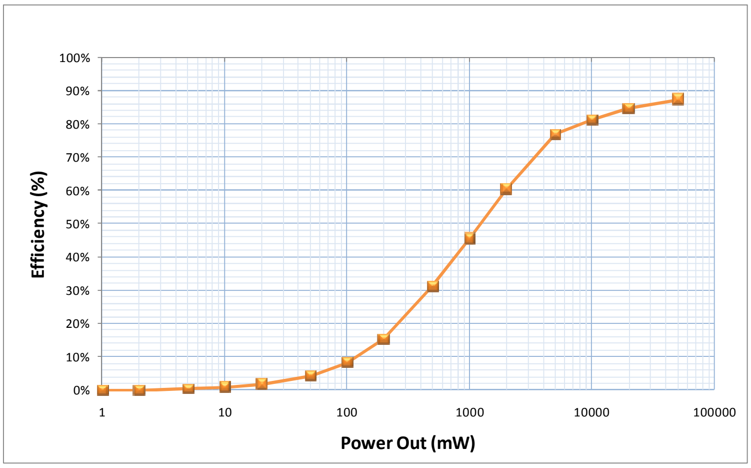

Figure 1: Efficiency of conventional Class D, logarithmic power scale (max power output 100W peak)

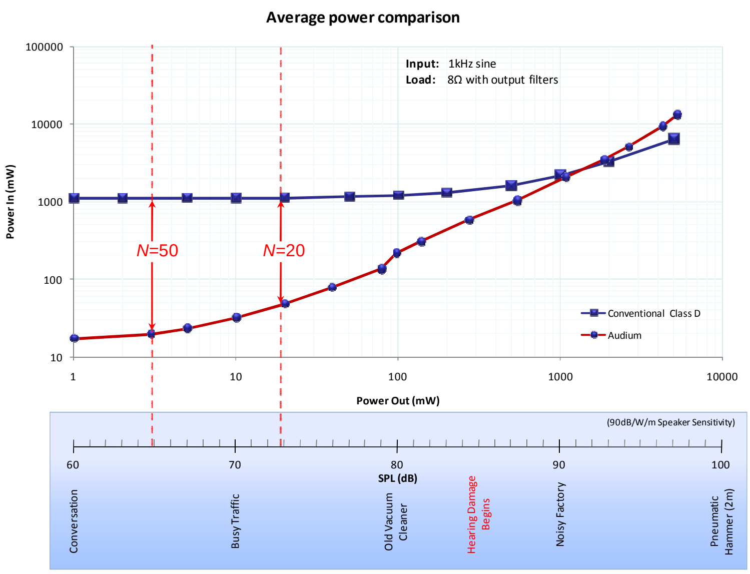

Figure 2: Average power consumption of conventional Class D IC and an Audium amplifier IC

	CPAPR	
Sample	**dB**	**linear**
Music		
Eminem, Stan	9.7	9.4
All Saints, I Know Where It's At	13.6	22.7
JS Bach, Toccata and Fugue in Dm	17.9	61.9
TV/Movie		
TV advert break	21.7	147.1
Baywatch	23.8	242.1
The Godfather	26.1	408.4

Table 1: The content peak-to-average-power ratio (CPAPR) of various audio samples