IS CLASS D THE MOST EFFICIENT AMPLIFIER FOR REAL AUDIO SIGNALS?

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1 INTRODUCTION

Recent European Union regulations have sought to reduce the power ratings of items as diverse as light bulbs and vacuum cleaners, and other power limiting regulations have been proposed. How does this affect the power amplifier? As multichannel amplifier use continues to grow is it possible that amplifier designs too might be constrained by the need to reduce perceived energy demand?

Currently, “Class-D” switching amplifiers are considered to be the most efficient amplifiers available on the market, with some designs being funded by governments that seek more efficient consumer devices.

However, not everyone wishes to used switching based technologies in their amplifiers and the possibility of such regulation could be a cause for consternation for them. Could power consumption regulations spell the end of conventional linear amplifier designs in the marketplace?

In many cases the peak efficiency and power rating of the amplifier is used as the metric for deciding how much energy an amplifier will use. However, in most domestic environments the amplifier is rarely used at full power levels for any sustained period of time. Thus such a measure can give a false energy rating for the typical power consumption of amplifiers. Likewise, any measure based purely on quiescent consumption is also likely to be inaccurate.

This paper seeks to quantify the true power consumption of the different amplifier classes; “Class-A”, “Class-AB”, “Class-B”, “Class-D”, “Class-G”, and “Class-H”, when fed with real audio signals at a variety of volume levels. In particular it will focus on the interaction between the statistical distributions of typical music signals and the amplifier power consumptions of the various amplifier classes when played at the same equivalent power levels.

In order to do this, the paper will first look at the typical distributions of a variety of audio signals, both stereo and multichannel material. In addition the effect of filtering the signal, such as might be required for a sub-woofer plus main system or an active crossover will also be considered.

The paper will show that the situation is not as clear-cut as it seems when the probability distribution functions of real audio signals are taken into account.

Furthermore, it will show that it may be possible to further optimize some of the amplifier classes by considering the audio signals amplitude distribution such that further reductions in average power consumption may be achieved thus resulting in a high quality yet “Green” amplifier.

2 AMPLIFIER EFFICIENCY

2.1 Average Sine Wave Efficiency

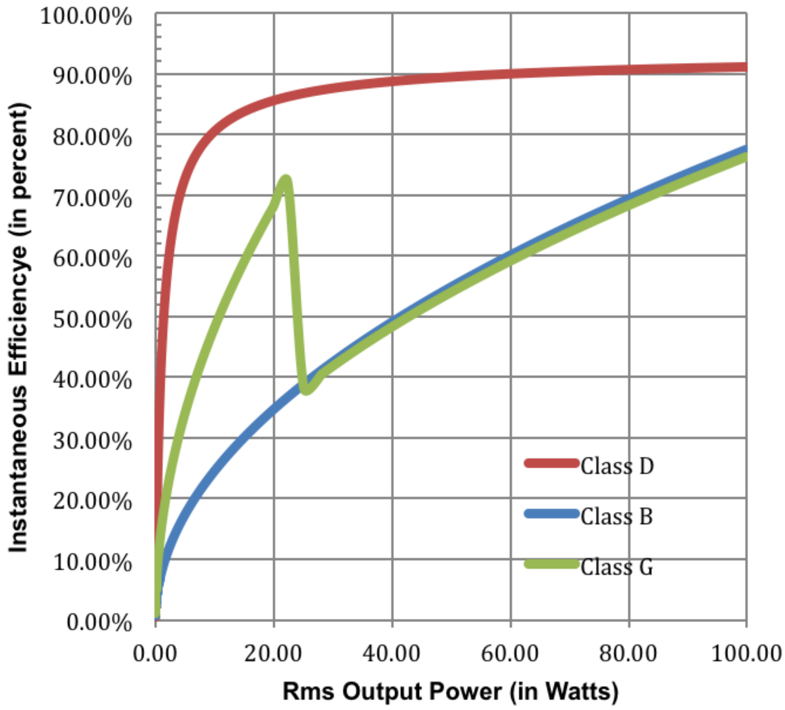

Figure 1, Rms efficiency vs. output power for different classes

The classic way of presenting an amplifier's efficiency is to present its average efficiency when driven by a sine wave for different power levels. This approach is the subject of lectures at university, and the paper by Bortoni, Rosalfonso et al.[1], as it provides a tractable theoretical means of analyzing and comparing different amplifiers, as well as providing a repeatable means of measuring objective amplifier performance. The results of these analyses give us the typical efficiency curves for class B, G, and D shown in figure 1. This clearly shows the traditional class B peak efficiency of 78.6% and the superior efficiencies of class G and Class D amplifiers.

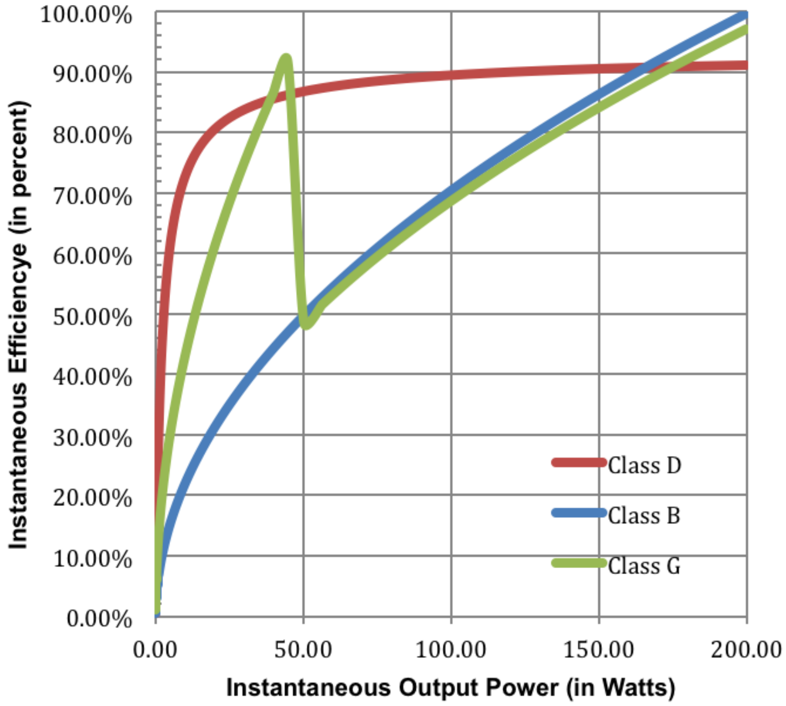

Figure 2, Instantaneous efficiency vs. output power for different classes

2.2 Instantaneous Signal Efficiency

However, real audio signals are not generally sine waves, and an average sine wave definition of efficiency fails to give the whole picture and misestimates the true average efficiency for audio signals at a given level.

Ideally, we need to incorporate the statistics of real audio signals into our measure of amplifier efficiency, and to do that we need to consider the instantaneous amplifier efficiency. This is the ratio of the output power to the input power at a specific voltage, and hence current, output into a given load, and is given by:

$$\eta_{inst} = \frac{P_{load}(V_{out}, I_{out})}{P_{diss}(V_{out}, I_{out}) + P_{load}(V_{out}, I_{out})} \qquad (1)$$

Where:

η_{inst} is the instantaneous efficiency,

$P_{load}(V_{out}, I_{out})$ is the output power,

$P_{diss}(V_{out}, I_{out})$ the power dissipated,

and V_{out} and I_{out} are the instantaneous output voltage and current respectively.

The instantaneous efficiencies of class B, G, and D amplifiers are shown in figure 2. Now figure 2 yields some surprising results. As expected, the efficiency of class D amplifiers increases slightly. However, the efficiencies of both class G and class B amplifiers markedly increase and are similar to that of a class D amplifier at high output levels. This is easily explained by the fact that, at peak output voltages relative to the supplies, the voltages across the output transistors in class G and class B amplifiers are similar to those in class D amplifiers. To see how these results affect the efficiencies of amplifiers when fed with real audio signals we need to look at the typical statistics of audio signals versus sine waves.

3 AUDIO SIGNAL STATISTICS

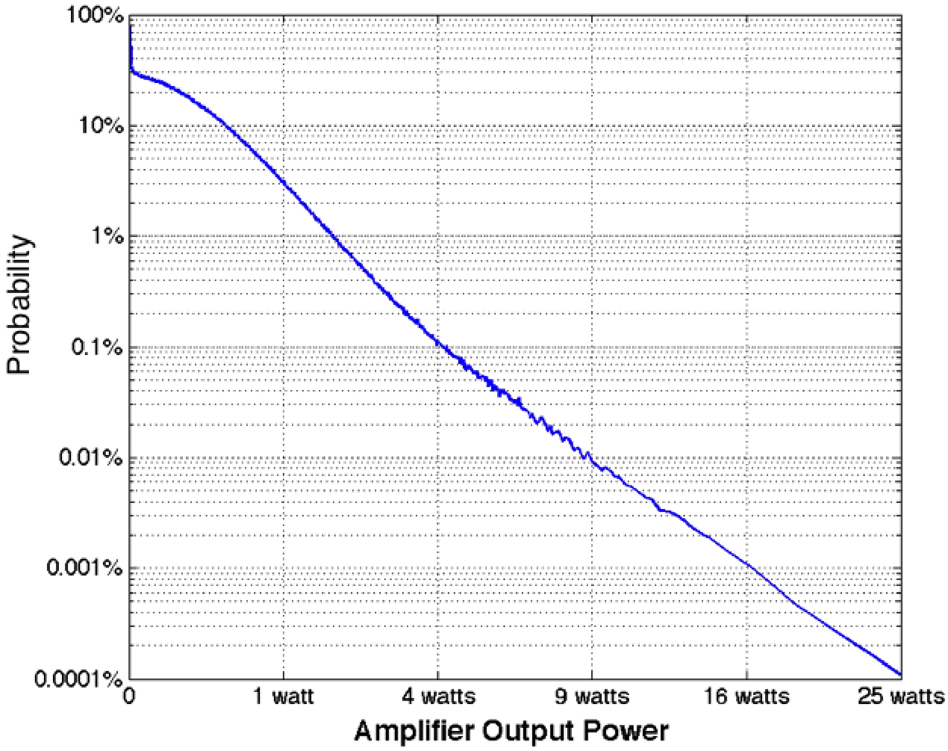

Figure 4, The probability density function of a typical audio signal

Sine waves and audio signals have radically different probability density functions. A comparison is shown in figure 3. Figure 3 shows the measured probability density function (pdf) of a given voltage level for a typical popular music track compared to that of a sine wave with the same mean power. Of particular note is that the pdf of the music has an exponential roll-off with respect to amplitude, whereas the sine wave has a higher probability of being at high amplitudes in comparison. The music has an approximately Laplace distribution given by:

$$P(x) = \frac{1}{2b}\exp\left(-\frac{|x|}{b}\right) \quad (2)$$

Where *b* can be simply estimated by finding the mean absolute value as shown in equation 3.

$$b = \frac{1}{N}\sum_{i=1}^{N}|x| \quad (3)$$

In practice a linear fit will modify this parameter slightly, however, the probability of high output levels still decreases exponentially with level.

This means that the top 10dB of the amplifier's power is only being used for 1% of the time, assuming no clipping. Furthermore, at this level, the average output level is 1.2 watts. This would correspond to an average sound level of 85.8dB at one meter for, typical loudspeaker sensitivities of 85dB per watt at one meter. This would probably be louder than what a typical user would want.

It also suggests that plotting the efficiency on a linear power output scale will hide detail because most of the time the output power is in the bottom one-hundredth of the scale. If one plots the instantaneous efficiency on a logarithmic power scale, as shown in figure 4, then the efficiency of all the classes is much lower at the levels that the music normally uses although class G shows some promise at the lower amplitudes.

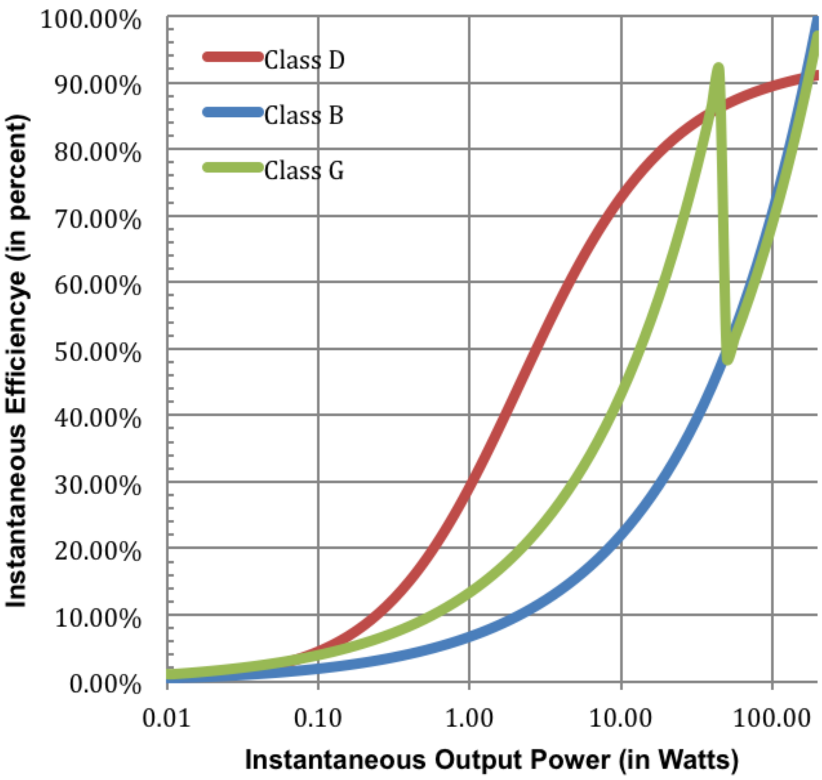

Figure 4, Instantaneous efficiency vs. log output power for different classes

Given the highly non uniform distribution of audio signal levels need to calculate a better measure of efficiency based on the actual amplitude distribution of audio signals.

4 EFFECT ON THE OVERALL EFFICIENCY

The average power output of an amplifier for a signal with an arbitrary probability density function (pdf) is given by:

$$\overline{P_{out}} = \int_{-\infty}^{\infty} P(P_{out}) P_{out} dP_{out} \tag{4}$$

Where:

$\overline{P}$ is the mean output power,

$P(P_{out})$ is the pdf of the output power,

and P_{out} is the instantaneous output power.

For a resistive load the dissipation in the amplifier will also be proportional to the power out so we can say that the overall efficiency will be given by:

$$\bar{\eta} = \int_{-\infty}^{\infty} P(P_{out})\eta_{inst}(P_{out})dP_{out} \qquad (5)$$

Where:

$\bar{\eta}$ is the mean efficiency,

$P(P_{out})$ is the pdf of the output power,

and P_{out} is the instantaneous output power.

Equation (5) can be further simplified by assuming that the pdf of the signal is symmetrical and that the power output is limited to some finite value P_{max}. When this is done equation 5 becomes:

$$\bar{\eta} = \int_{0}^{P_{max}} P(|P_{out}|)\eta_{inst}(|P_{out}|)dP_{out} \qquad (6)$$

If the pdf of a sine wave is used in equation (6) the average efficiency corresponds to the sine wave efficiencies shown in figure 1 for different sine wave output powers.

However, the pdf of the signal shown in figure 4 is used then the mean efficiency drops dramatically, for all classes of amplifier, because the signal spends so much of its time at low power levels.

5 IMPLICATIONS

Because audio signals naturally spend a lot of more time at low levels, even when compressed, the effective efficiency of any power amplifier, irrespective of class, is dominated by their low signal level performance.

Thus even class D amplifiers are not as efficient with audio signals as they could be given their excellent high-level efficiencies. In many cases the crest factor of audio signals is also high indicating the need to be able to supply high output powers for short peaks and transients. This makes the problem worse as it means that we must have amplifiers capable of high peak powers, in order to maintain the fidelity of these transients. Yet most of the time they will be operating at much lower power levels and thus inefficiently.

Clearly any solution must allow efficient operation at both high and low power operations. One obvious outcome of these results is that class G switching points could be a lot lower than is currently used thus allowing the amplifier to be far more efficient for most signals.

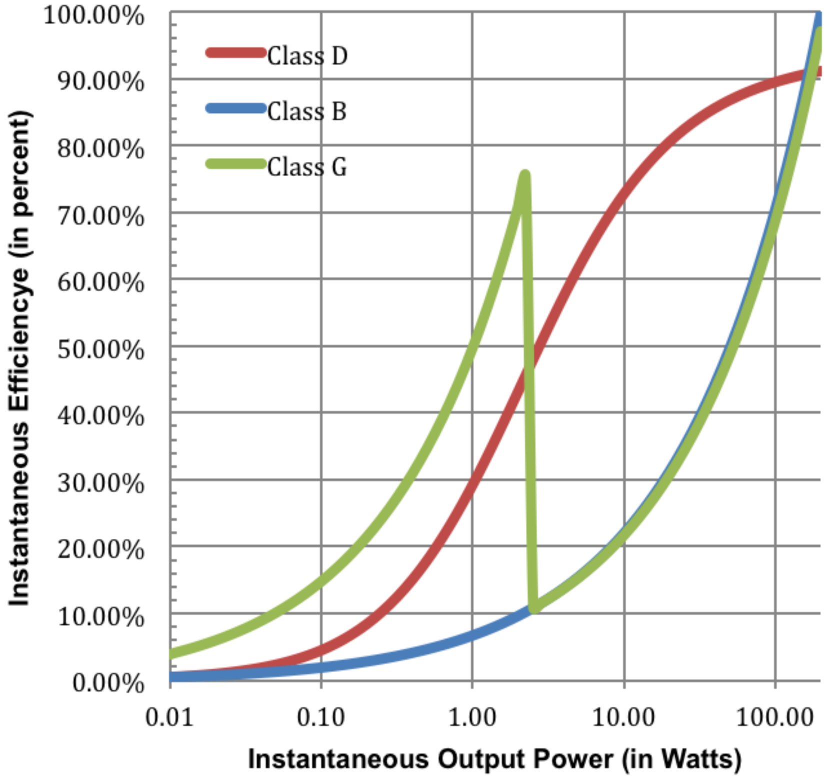

Figure 5, Instantaneous efficiency vs. output power class G with a lower switch point.

Figure 5 shows the effect of reducing the switching point to ±5v in the instantaneous efficiency for a 100w amplifier. In this case for signals below 3 watts the class G amplifier is more efficient that the class D amplifier.

But other more radical solutions are also possible that would improve the efficiency of all classes of amplifiers, except for pure class A.

6 POSSIBLE SOLUTIONS

The same problem has also been faced by the designers of mobile phone and wireless local area network radio frequency (RF) power amplifiers. Modern digital radio transmission requires very linear RF power amplifiers to avoid in-band, and out of band, distortion on the quadrature amplitude modulated (QAM) digital signals. Their dominant solution has been to use some form of envelope modulation of the linear RF power amplifiers power supply to enable it to be operating at a high efficiency. To that end very agile signal controlled tracking power supplies have been developed[2,3] to enable this to occur. By modulating the power supply it is possible to keep the dissipation low at low signal levels using rail switching, or switched mode power supply control to efficiently give the power amplifier a close to optimum power rail for efficiency while still allowing the use of linear, or switching, amplifiers for the amplifier [4,5].

As the original modulating signal is generated in the digital domain the delays necessary to permit the power supply to track the signal accurately can easily be built in.

The most extreme examples of these amplifiers use the digital domain inputs to separate the input signal into purely amplitude (signal envelope) and “carrier” (signal phase) components, as shown in figure 6. This “Constant Envelope” technique allows the use of switching amplifiers on the constant amplitude “carrier” ant comparatively low switching frequencies thus further improving the overall system efficiency. This method is not without problems, such as sharp wideband transitions in the "carrier" and a variety of methods have been proposed[6,7] to alleviate them. Unfortunately many of them are not directly applicable to audio signals, but the concept of creating signals in the digital domain that permit a more efficient amplifier topology is one that might bear fruit as we continue to move away from analog to digital domain interconnections.

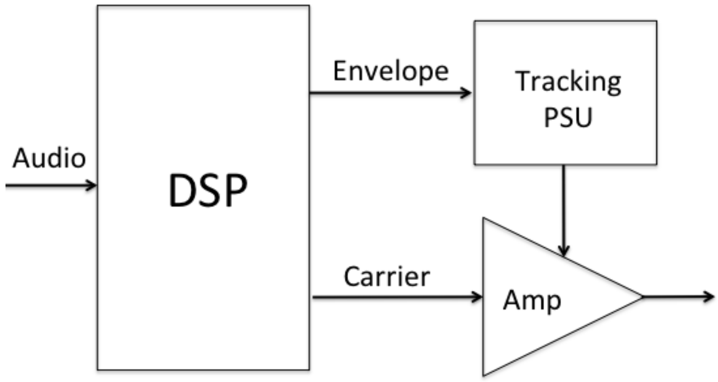

Figure 6, An envelope modulation amplifier

7 CONCLUSION

Various amplifier classes have been compared and although class D is always more efficient when sine wave signals are used. When the probability density functions of typical audio signals are used the efficiency gains are dominated by the low power output performance of the amplifier class and in this case the performance advantage of class D amplifiers is less clear-cut.

By moving the switching point of a class G amplifier to a much lower voltage its performance could rival that of a class D amplifier.

However all classes would benefit from a more radical approach such as envelope modulation.

8 REFERENCES

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