White Paper
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MERUS™ multilevel class D audio amplifier supports ultra-compact and low-power applications

Technology and design benefits

Abstract

Traditional class D amplifiers present significant design challenges in compact applications such as portable consumer sound systems and smart speakers. These challenges include relatively low efficiency, high heat generation even at low to medium listening levels, and a need for bulky and costly filters to reduce out of band noise.

A relatively new range of class D amplifiers address these limitations using so-called multilevel amplification. This approach improves power consumption while inherently reducing interference and out of band noise. In addition, manufacturing costs are reduced by eliminating or minimizing the use of filters, which also helps save design space.

By:
Rien Oortgiesen, Application Engineering Manager for Class D Audio, Infineon Technologies Denmark
Jens Tybo Jensen, Head of Application Engineering for Class D Audio, Infineon Technologies Denmark

Table of contents

1 Introduction

In recent decades, switch-mode audio amplification has been the preferred method to bring an input audio signal to life. The various switch-mode amplifier topologies, known collectively as class D amplifiers, are popular due to their low power consumption, small size, and low heat generation – especially when compared to earlier class AB amplifiers.
Traditional class D amplifiers can achieve an efficiency of 90 percent or better at the highest output power. However, efficiency at typical music volume listening levels is only around 50 or less. This and other limitations have inspired Infineon's MERUS™ audio product designers to develop a new generation of amplifiers with high efficiency at all listening levels; The multilevel class D amplifier. This new class of amplifiers excel in applications that require small size, low heat dissipation, and/or low power consumption which is the case for an increasing number of compact and demanding audio applications.

1.1 Evolution of amplifier technology

Silicon semiconductor devices have been the subject for intensive research and development and for good reasons, class D amplifiers are now preferred for most portable and power-sensitive applications, replacing earlier linear amplifier classes such as class AB amplifiers. Although just as powerful in terms of output power capability, class AB amplifiers are significantly less efficient which means that they require large heatsinks and hence require too much space for the vast majority of audio applications.

The technological advancement from class AB amplifiers to class D amplifiers has been significant. Now, audio product designers are taking the next big leap in performance improvement, from traditional class D amplifiers to multilevel class D amplifiers.

2 Traditional class D amplifiers

2.1 Traditional class D working principle

The working principle of the output stage of a traditional class D amplifier is shown in Figure 1. It consists of two power metal-oxide semiconductor field-effect transistors (MOSFETs, shown as M1 and M2 in Figure 1), each driven by a pulse-width-modulated (PWM) signal. The duty cycle of this PWM signal is modulated by the audio signal that is fed into the amplifier. This typically takes place inside a control loop.

The switch-node (V_{PWM}) in Figure 1 transfers the amplified PWM signal. Note that an LC filter is used to smoothen the audio signal from the PWM signal before the amplified audio signal reaches the speaker. While this filter is not required for smaller applications such as mobile phones due to the low power output of the audio amplifier, applications would typically need an LC filter for output levels higher than around 20 W.

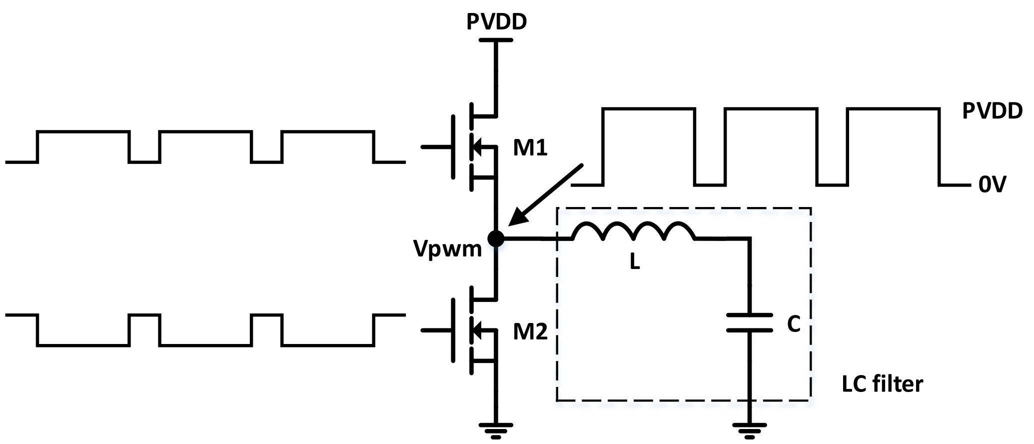

Figure 1 Traditional class D output stage

2.2 Traditional class D limitations

The limitations of traditional class D amplifiers include:

- Size due to the need for an LC filter and heatsink
- Cost due to the need for filters
- Inefficiency at typical listening levels
- Heat and thermally challenging operating conditions

2.2.1 Efficiency of about 50 percent at typical listening levels

Traditional class D amplifiers have a 2-level power stage (half-bridge): Meaning that each half-bridge can have the voltage potential of either 0V or PVDD. Consequently, they have relatively high power

consumption even in or near idle mode. In part, this is due to the inherent and constant rail-to-rail switching of each half-bridge which is required to maximize dynamic performance.
Figure 2 graphs the efficiency of a traditional class D amplifier. The horizontal axis is plotted on a logarithmic scale to emphasize the lower end of the output power scale. For typical listening levels of 0.1 to 1 W of output power per channel, efficiency barely reaches 50 percent. The headroom above 1 W is typically used to deliver the peak power which is required every now and then to accurately reproduce the music signal. Figure 2 shows that a traditional class D amplifier can reach 90 percent efficiency, but only for levels above 10 W (in this case, up to 40 W)—levels that are rarely reached by real-life audio signals for extended time-intervals.

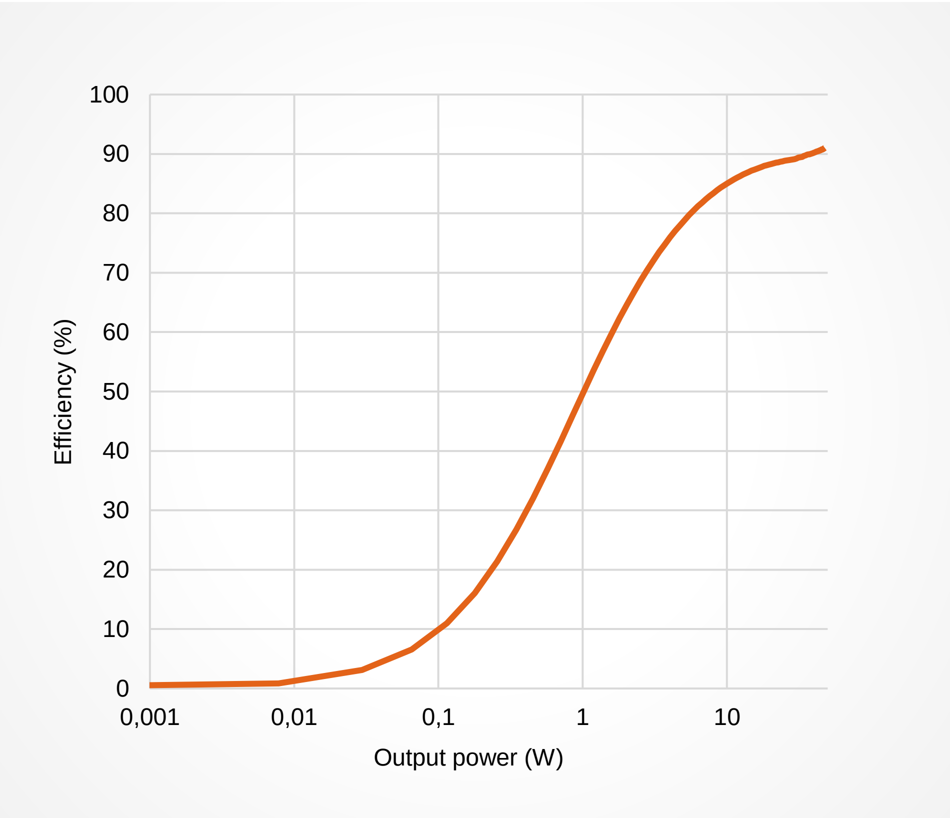

Figure 2 Efficiency of a traditional class D amplifier

At the lower end of the power output scale, the overall efficiency is dominated by the power consumption (input power) of the amplifier in the idle condition— i.e. the power consumption of the amplifier when it is not producing any output.

Figure 3 shows idle power consumption at close to 1 W for a conventional class D amplifier, which is running on an 18V power rail. Due to the less than ideal curve shape, the audio amplifier easily dominates power consumption of the complete audio system – not just at high output volumes but even between idle and medium output volumes.

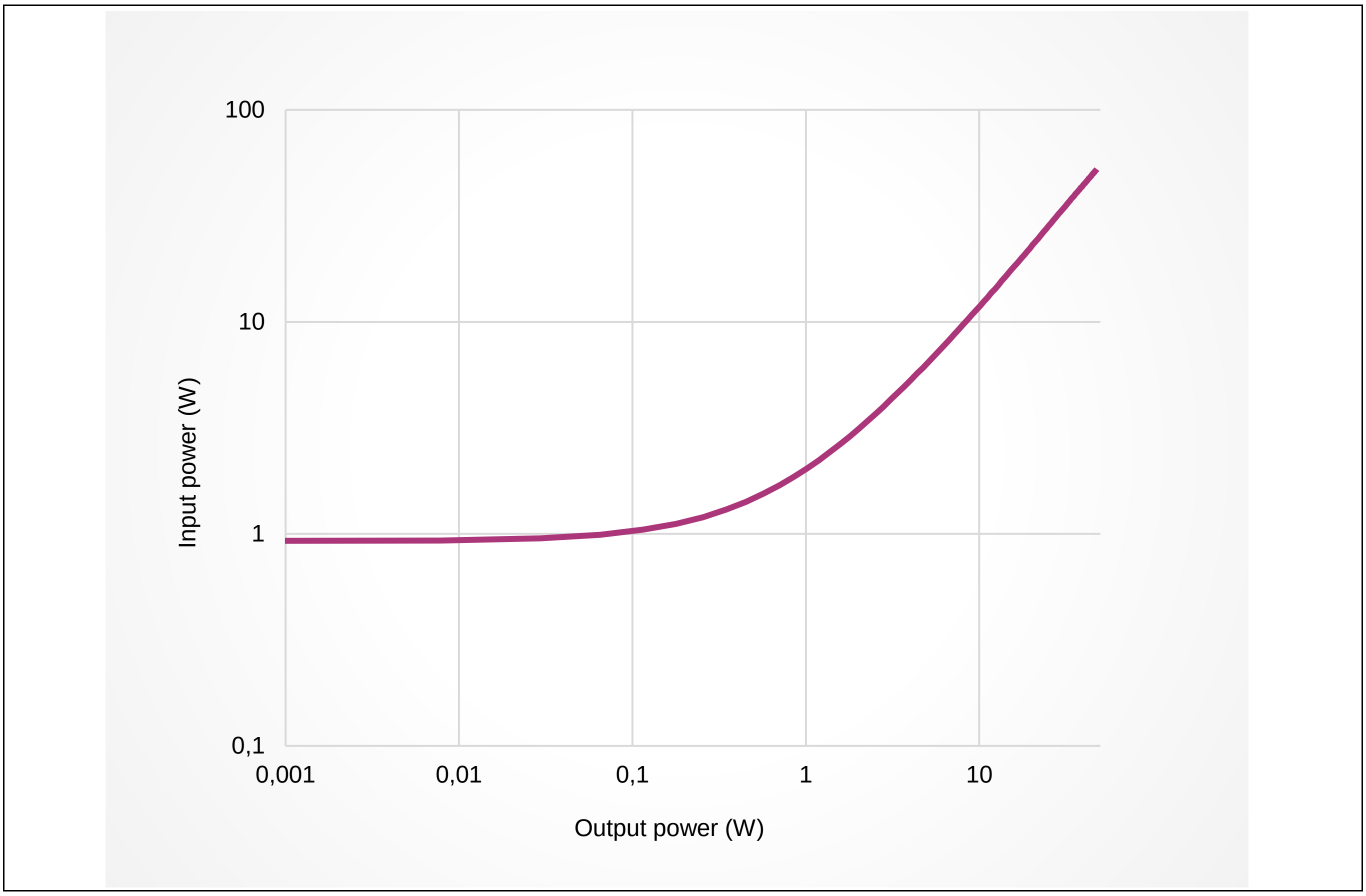

Figure 3 Input power for a traditional class D amplifier

2.2.2 Bulk and cost issues

For traditional class D amplifiers, it is normal practice to apply a common-mode LC filter to reduce electromagnetic interference (EMI) and improve electromagnetic compatibility (EMC).
In addition, traditional class D designs may incorporate two extra resistor–capacitor (RC) networks which also increase the overall solution size:

- A Zobel network is an RC series filter used to dampen the LC filter.
- A series RC filter is commonly added on the switching side of the filter to dampen the switching edges and further improve EMI and EMC.

The use of filters limits the application because filters:

- Add costs
- Are bulky and takes up printed circuit board (PCB) space
- Increase power consumption

3 True multilevel class D amplifiers

3.1 Multilevel class D working principle

Multilevel class D amplifiers use a multilevel power stage (half-bridge) to achieve low power consumption (normalized to maximum output power) also at idle or near-idle operating points.

MERUS™ amplifier products create amplified output with a unique power stage topology that has four transistors or MOSFETs for each half-bridge power stage instead of the two seen in traditional amplifiers, as shown in Figure 4. The multilevel output stage offers great flexibility and allows for the configuration of the amplifier for optimal power performance in any application.

The half-bridge establishes multiple PWM output levels from a single supply. Each half-bridge uses four MOSFETs (shown as M1 through M4 in Figure 4), and each MOSFET is driven by an individual PWM signal. The capacitor (C_{fly}), which is “flying” between the top and bottom MOSFETs, is constantly charged by separate circuitry, thereby maintaining a fixed voltage potential. The “flying capacitor” therefore functions essentially as an extra supply rail. In this way, each half-bridge power stage establishes a 3-level output signal at the output-switching node: 0 V, ½ PVDD and PVDD.

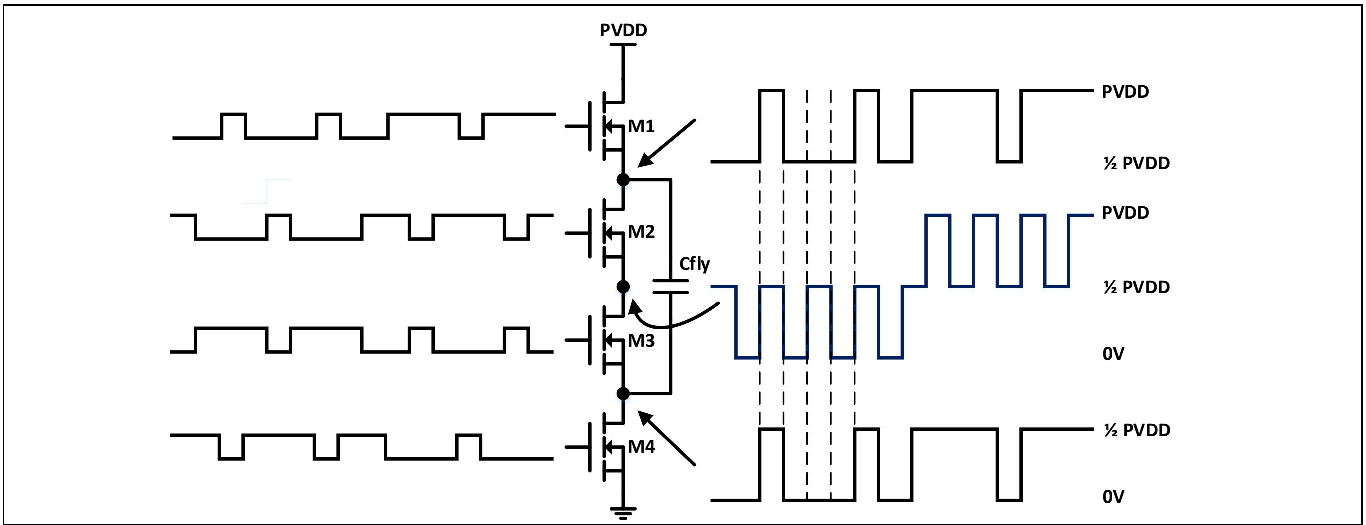

Figure 4 Multilevel output stage

In a full bridge-tied load (BTL) configuration (see Figure 5), which is achieved by combining two 3-level half-bridges with a switching pattern in which each half-bridge switching pattern is modulated with a 90° phase shift relative to the other, the resulting power stage can provide up to five levels of multilevel modulation patterns to a differentially connected speaker load.

Since the resulting output frequency is higher and the individual voltage steps are smaller this approximates the output audio signal much closer to the input waveform than a conventional class D amplifiers.

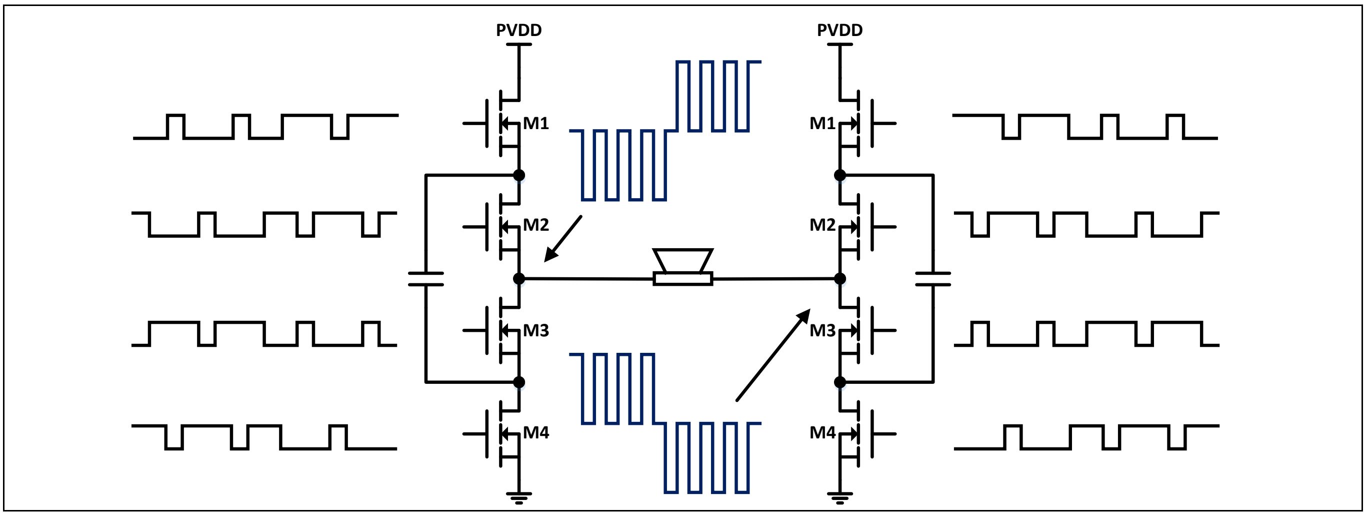

Figure 5 Multilevel full-bridge (BTL) output stage

A five-level system inherently quadruples the switching frequency at the output nodes the differentially connected speaker load also has much less out-of-band switching residuals. With high efficiency and better EMI and EMC management, the amplifier can thereby effectively be configured for filter-less operation.

Figure 6 shows the resulting five-level differential output in a BTL configuration for one sinusoid cycle.

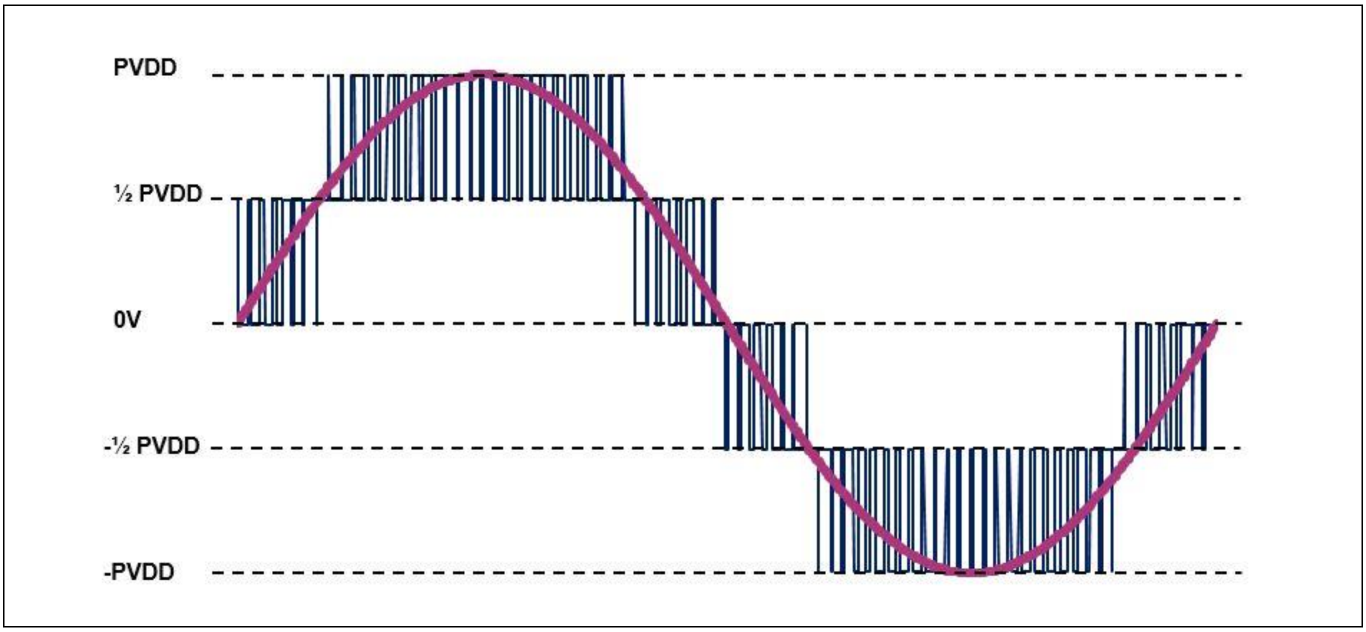

Figure 6 Full bridge-tied load five-level output signal

In this case, the speaker load switching frequency is 4 times the switching frequency of the MOSFETs at the half-bridge output nodes. Also note that the switching pattern gives rise to three states (as opposed to just one in a conventional Class D amplifier) where complete cancellation of the out-of-band switching residue takes place , namely at - ½ PVDD, 0 V and +½ PVDD. In these states the output of the two half-bridge outputs are either both 0V or they both produce a perfectly 'mirrored' 50 percent duty-cycle output.

For the application, this translates directly to a reduction of the ripple current in the audio system output section. With no need to suppress out-of-band switching noise or artefacts, many applications do not require a common-mode applied LC filter.

The effect of the reduced ripple current is shown in Figure 7. When normalized to the ripple current of a traditional class D amplifier (red line), three-level or half bridge (blue line) and five-level or BTL (black line) modulated output signals exhibit strongly reduced ripple currents. Also note the zero states for three-level and five-level signals, points at which there is no ripple current. In addition to the inherently more efficient switching principle, overall dissipation and power loss are also significantly reduced due to the reduced ripple current in the external components.

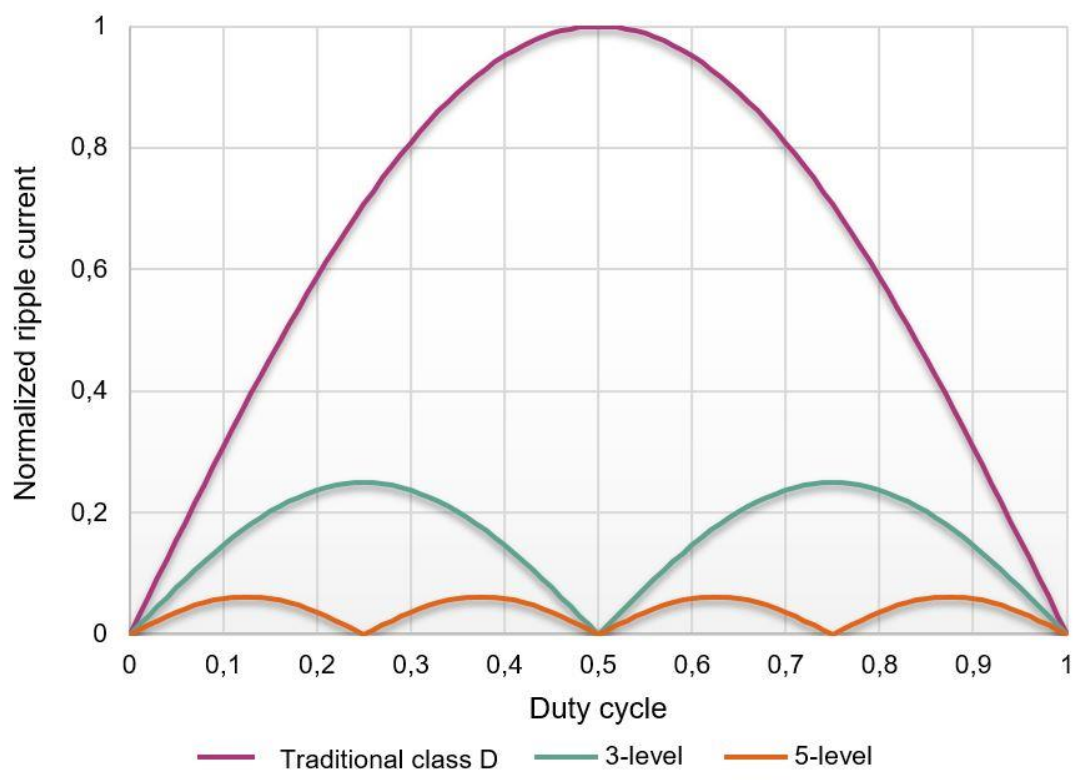

Figure 7 Multilevel amplifier zero states

3.2 Benefits of multilevel class D

The benefits of innovative multilevel class D amplifiers include:

- Smaller solution size and lower cost with less reliance on filters
- Improved efficiency at typical listening levels
- Lower heat generation through greatly reduced power loss
- Enhanced audio quality through more accurate signal reproduction

3.2.1 High efficiency at typical listening levels

Multilevel class D amplifiers are very effective at reducing overall power consumption which is dominated by near idle power-loss, making them a great alternative to traditional class D amplifiers.

When a multilevel amplifier is running in idle operation, each MOSFET in each half-bridge output stage is driven by a 50 percent duty cycle PWM signal.
As Figure 8 demonstrates, the actual output node contains only a direct current (DC) signal (1/2 PVDD). In a combined BTL configuration, the differential speaker load will only “see” a resulting zero signal in idle.

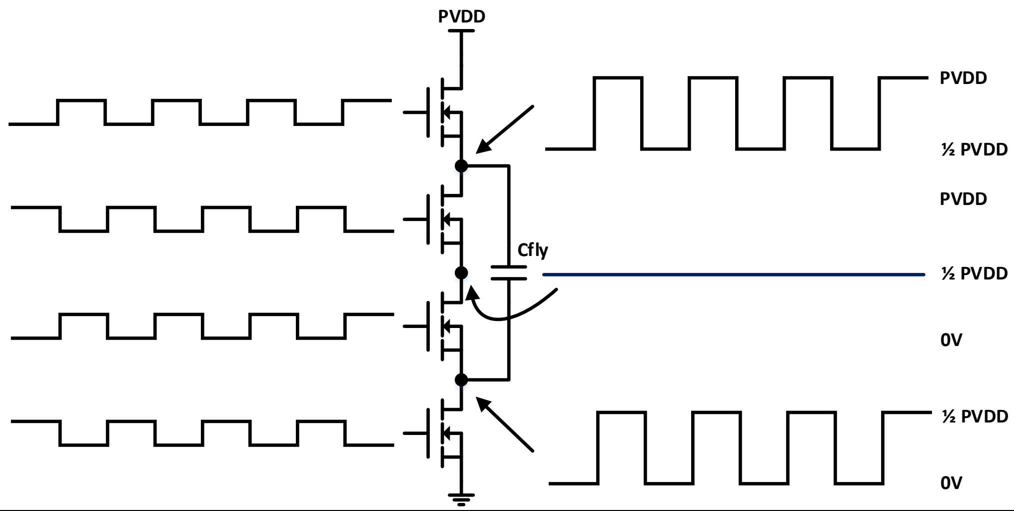

Figure 8 Multilevel output stage in idle operation

For the multilevel audio amplifier system, since no switching activity occurs at the output node when idle, two main mechanisms significantly help reduce the power loss:

1. Elimination of idle conduction losses in the power stage, filter and speaker (which are notoriously inefficient load). This applies both for conductive as well as magnetic losses.
2. Effective reduction of capacitive switching losses due to the inherent frequency multiplication which is used to scale down the MOSFET switching frequency.

The MERUS™ MA12040 multilevel amplifier as example, consumes only 250 mW in idle, as seen in Figure 9, which is a power consumption plot. Notice that the near idle power consumption is relatively flat and significantly lower than a conventional Class D amplifier all the way up to 2 W output power per channel. Since the overall power consumption is determined by the average power loss and as this is greatly dominated by idle loss when reproducing common audio signals, compared to most conventional class D amplifiers, the multilevel amplifiers demonstrate an overall power efficiency improvement factor of 4 or higher.

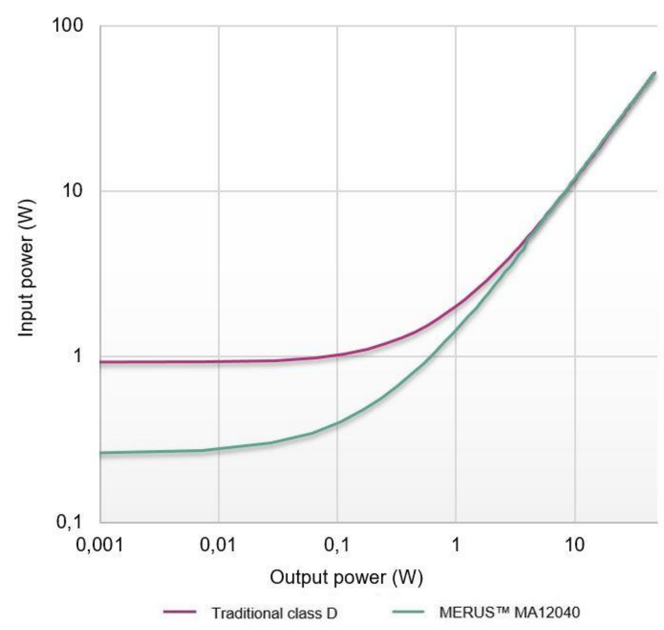

Figure 9 Power consumption of the MERUS™ MA12040 amplifier

The importance of improved power consumption is further emphasized when efficiency is considered in Figure 10. For both Figure 9 and Figure 10, the MERUS™ MA12040 amplifier has a maximum output power of 40 W into a 4 Ohm load; in both cases, the amplifier runs on an 18V power rail.

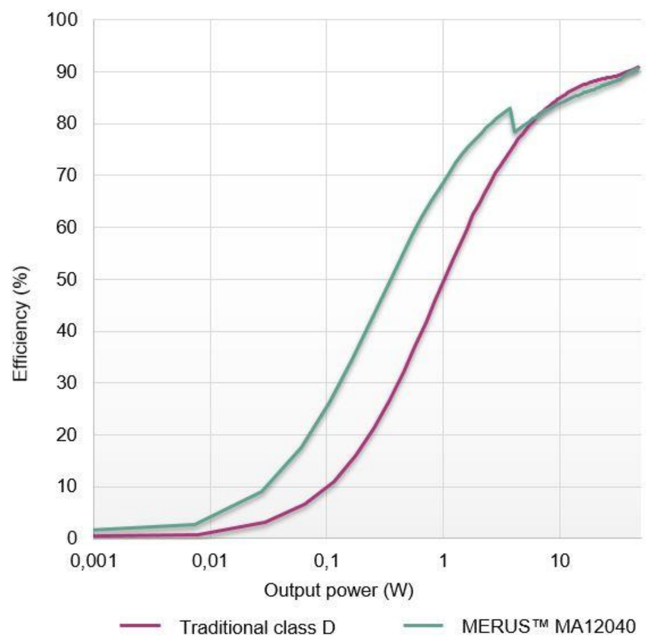

Figure 10 Efficiency of the MERUS™ MA12040 amplifier

Using a digital control interface, various power modes can be accessed by selecting the modulation method and the switching frequency. During amplifier operation, the integrated power management

algorithm automatically selects the optimal power mode for a given power level. The seamless transition between power modes ensures that power losses are minimized across the entire output power range while ensuring high audio performance and low EMI.
With low power consumption both for idle operation and for average audio volume levels, portable audio systems can be designed for significantly extended battery life or smaller batteries.

MERUS™ amplifier products allow product designers to develop some of the world's most efficient portable audio devices, appealing to a vast market of environmentally-conscious consumers who want innovative products.

3.2.2 Size and cost improved

Multilevel modulation schemes have lower EMI signal content than traditional class D amplifiers. EMC is also much improved. Figure 11 shows radiated EMI as measured on the Infineon reference design, pictured in Figure 11.
It can be observed in Figure 11, that EN55022-B limits (red line) are easily met with sufficient headroom. EN55022 class B (radio disturbance characteristics limits and methods of measurement) is one of the most stringent standards for consumer products.

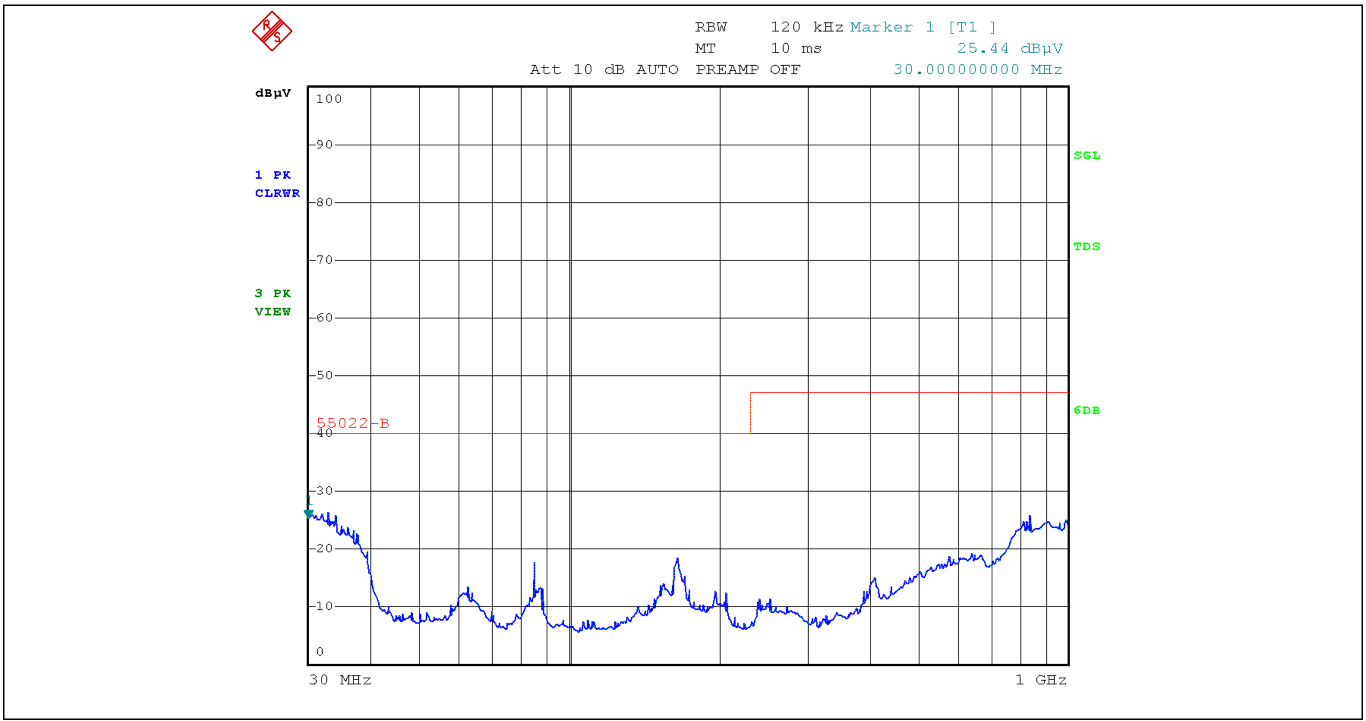

Figure 11 Radiated EMI measured on a Snowflake reference design

Infineon developed a reference design (Figure 12) as a small-sized circuit board used to demonstrate MERUS™ multilevel amplifier devices for ultra-compact and low-power consumer applications. The solution measures 40 mm x 45mm and yet still achieves output power up to 80 W per channel. Only a small EMI filter is used with an SMD-sized (1210) ferrite bead and an SMD-sized (0402) 1.0 nF capacitor placed at each half-bridge output of the amplifier.

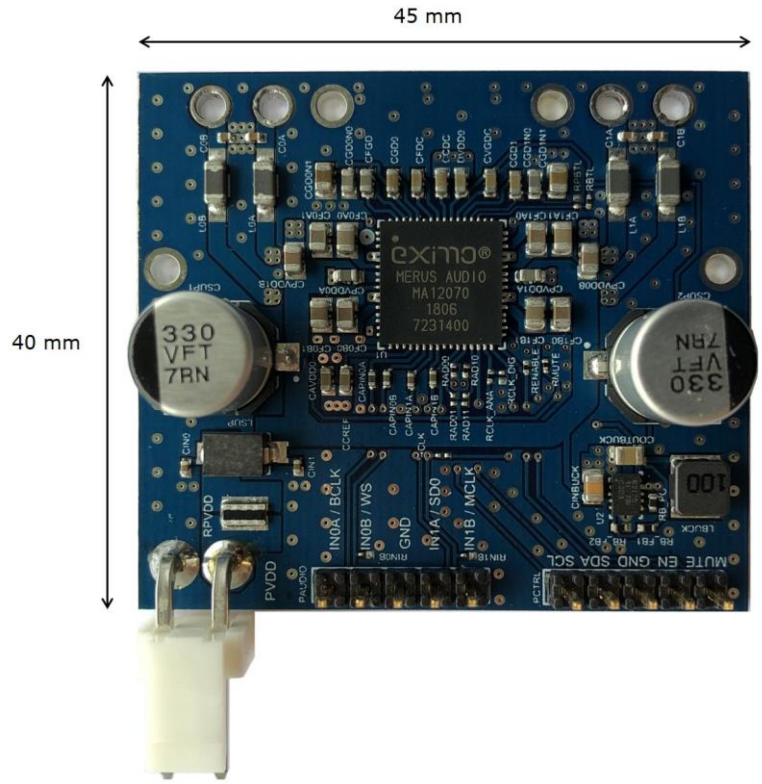

Figure 12 The Infineon reference design with the MERUS™ MA12040 multilevel amplifier

With no need for significant filtering to combat unwanted interference, multilevel amplifiers can drive speakers directly, often without the use of LC and RC filters, even in higher-powered applications, which reduces application costs. If the audio product designer still wishes to use LC filters, filters can be smaller than those used for traditional class D amplifiers.

As illustrated, multilevel amplifiers are ideally suited for ultra-compact solutions and they are easier to integrate into the target application than traditional amplifiers.

3.2.3 Cooler operations

Lower power loss directly translates to less heat generation and cooler operating conditions. In most cases, the amplifier circuit board itself will offer sufficient heatsinking capability, even in relatively high-powered applications that would traditionally require a dedicated heatsink.
With generally cooler operation inside the audio application, there is much larger headroom for periods of higher output power, for example during music playback at high volume levels.
Several integrated protection features including on-chip temperature sensors ensure that both the amplifier and speakers are protected from potential damage during various fault events. Cooler operation reduces thermally accelerated aging, which also improves audio application reliability.

3.2.4 Exceptional audio quality

MERUS™ multilevel audio amplifiers incorporate a fourth-order feedback loop to more effectively suppress error sources that might cause audio quality degradation. A multilevel amplifier uses the audio signal to modulate the duty cycle of the PWM signal inside the fourth-order feedback control loop. A fourth-order loop gives much better gain and thus suppression of error sources compared to the more traditional second-order loop. This guarantees very low signal distortion, excellent audio performance and robustness against real-world system imperfections such as a non-ideal power supply rail voltage which produces noise/ripple.

MERUS™ amplifier products, in both analog and digital input versions, fully integrate the feedback loop on-chip. This allows the designer to achieve loop stability and satisfactory performance while minimizing the design-in effort, avoiding a time-consuming selection and optimization procedure for the external loop filter component.

4 Conclusion

This paper explores the benefits of true multilevel class D amplifiers, exemplified by MERUS™ products as the world's first multilevel audio technology.

Through ultra-high energy efficiency and very compact solutions, true multilevel amplifier technology, which is available both is analog and digital input versions, gives designers of consumer audio applications additional design freedom.

Operating from a fixed power supply voltage, a multilevel amplifier drastically reduces power losses at normal listening levels and in most applications it eliminates the need for LC and RC filters.

Multilevel class D amplifiers excel in applications that require small size, low heat, or low power consumption, including:

- Battery-powered speakers
- Soundbars
- Wireless speakers
- Multi-room audio systems
- Home theatre systems

Multilevel amplifiers enable more powerful sound combined with the lowest power consumption and the smallest footprint for battery and mains powered audio devices alike.

The combination of a multilevel switching topology and a dynamic power management scheme pushes the boundaries of efficiency and the compactness of audio amplifier solutions with exceptional audio quality.

In a world where green technology is becoming more and more important, MERUS™ products fit right in with our mission at Infineon:

Part of your life. Part of tomorrow.
We make life easier, safer and greener – with technology that achieves more, consumes less and is accessible to everyone. Microelectronics from Infineon is the key to a better future.

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