Filterless Class D Amplifiers

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Introduction

As portable electronic devices continue to shrink in size, manufacturers look for ways to push the envelope and develop the smallest, yet most functional product available. The promise of longer battery life, smaller size and an enhanced sensory experience appeals to customers. Like the voltage regulator market, where system designers moved away from the simple but power hungry linear regulator to the more complicated, more efficient switching regulators, audio designers are adopting the switching, or Class D amplifier for the same reasons; less heat build up and longer battery life.

One area where manufacturers look to decrease power consumption is the audio portion of the system. In the past, system designers were offered only one option, the tried and true, but inefficient linear audio amplifier. Steps were taken to improve the linear amplifier efficiency while preserving audio fidelity resulting in the topology that provides the best balance between performance and efficiency, Class AB. Class AB exhibits a theoretical peak efficiency of 78%, and is only 30% - 40% efficient at normal operating levels. Efficiency is where the switching, or Class D, audio amplifier has large advantages over linear classes. Although Class D amplifiers offer increased battery life and lower operating temperatures, early generations were met with guarded interest; cost, size and performance were sub-par compared to linear amplifiers and limited their adoption. However, recent advances in Class D technology have made these amplifiers more appealing. Improved audio performance and the introduction of filterless devices have contributed to the increasing acceptance of Class D.

The major advantage of using Class D is efficiency. The more efficient a device is, the less power it wastes; a 90% efficient amplifier at 1W output dissipates 100mW, while a 60% efficient amplifier with the same 1W output consumes 400mW. Lower power dissipation, or power consumed by the device, leads to longer battery life and less heat generation.

Figure 1 compares the efficiency of the LM4673, a mono 2.65W Class D amplifier to a similar Class AB amplifier. At peak output power (1.5W) the class D amplifier has 88% efficiency while the Class AB amplifier only achieves 75%. At a mere 13%, the difference does not appear siginificant. However, a comparison at nominal output levels reveals a dramatic difference between the two architectures. At 500mW into an 8Ω load, a typical class D amplifier exhibits 85% efficiency while the Class AB amplifier is only 44% efficient. The difference in power dissipation is a very significant 550mW. At a 500mW output level the increased power consumption shortens the life of an 800mAh single cell lithium-ion battery by 197 minutes, well over three hours. *Figure 2*shows the theoretical operating time of an 800mAh lithium-ion battery powering a LM4673 and a comparable Class AB amplifier.

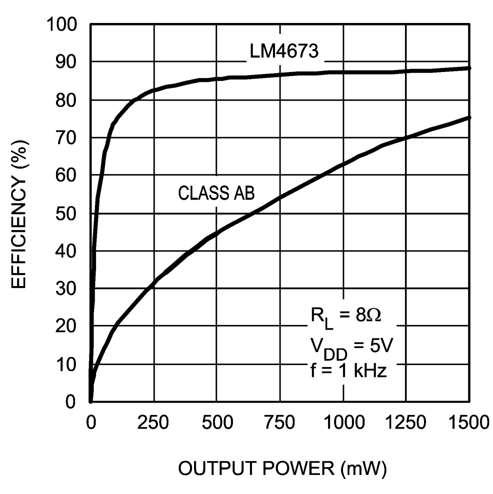

FIGURE 1. LM4673 vs. Class AB Efficiency

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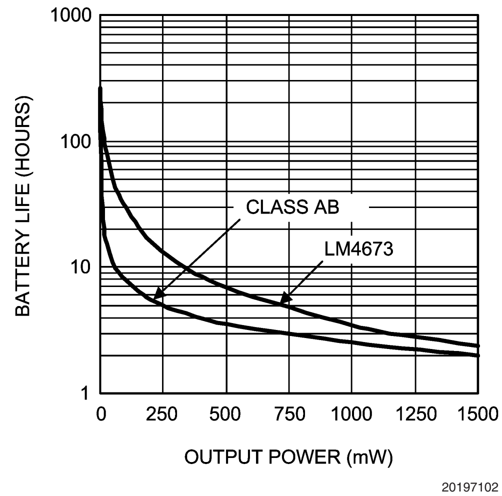

FIGURE 2. Battery Life Time

Despite the efficiency advantage, early generations of Class D amplifiers were viewed as large, expensive, noisy, cumbersome to design, and featured sub-par audio performance. Not only were the ICs more expensive than their linear counterparts, but since the amplifiers utilized a switching architecture, layout became critical to minimize noise coupling. Magnetic components were required for filtering also increasing the complexity, size and cost of the overall solution. The requirement for output filters limited the use of class D amplifiers in space sensitive applications such as cell phones.

The output filter requirement came about from the need to extract the audio component of the PWM output. The output filter, typically a second order low-pass LRC filter (*Figure 3*), attenuates the high frequency content of the amplifier's output allowing the audio portion to pass to the load. Because the filter components sit in the audio signal path between the amplifier and speaker, the filter components, especially the inductors, must be sized to handle the maximum output current. This leads to physically large, expensive inductors for high power applications. In addition to the increased component count and cost, the output filter degrades the overall performance of the amplifier. Filter non-linearities in the pass band contributes to THD and noise. Finite inductor DCR, as well as any filter attenuation in the audio band, further reduces the efficiency of the system.

Although the class D outputs a high frequency PWM signal, an external LC filter is, in fact, not required to extract the audio content. Speakers have a limited frequency response. Speakers are characterized by their DC resistance, typically 4Ω or 8Ω for loudspeakers and 16Ω or 32Ω for headphones. However, a speaker is not a simple resistive element with a flat frequency response over a very wide bandwidth. A speaker consists of a coiled wire (voice coil) suspended in a magnetic field. The inductive nature of the coiled wire combined with its resistance gives the speaker a finite frequency response. *Figure 4* shows a simplified electrical model for a speaker, basically a low-pass filter. Therefore, a speaker cannot respond to the high frequency component of a PWM signal, instead reproducing only the audio component without extra filtering required.

The other "filter" inherent in the audio reproduction system is one that is often overlooked. The 20Hz to 20kHz audio bandwidth is based upon the accepted response of the human ear. Even if a speaker were capable of reproducing the switching component of a class D amplifier, it would never be heard by the human ear.

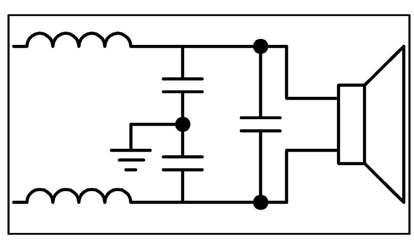

FIGURE 3. LRC Output Filter

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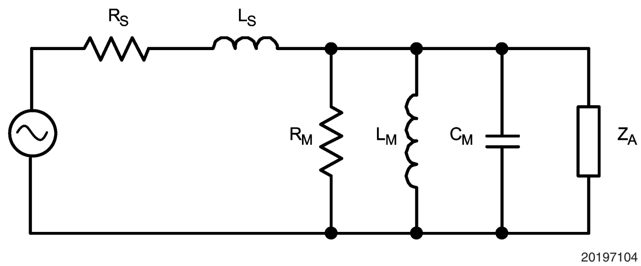

FIGURE 4. Electrical Speaker Model

Conventional Class D amplifiers use two PWM outputs, 180o out of phase, to drive a BTL load. This architecture results in a 50% output duty cycle when there is no input signal such that the load sees the entire supply voltage in alternating polarity. Idle mode switching (*Figure 5*) causes continuous current to flow through the speaker, increasing quiescent current and leading to possible speaker damage. Not only does the offset voltage increase power consumption, but also limits the dynamic range of the speaker (DC current offsets the voice coil, limiting the range of motion and distorting the audio), and may lead to speaker damage. DC current through the voice coil can cause permanent offset, or worse, burn out the voice coil, destroying the speaker.

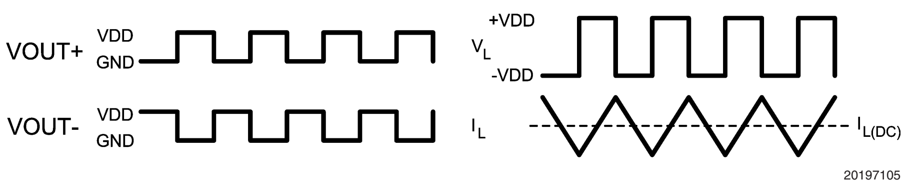

FIGURE 5. Conventional Class D Switching

The issue of idle mode switching is more difficult to resolve than audio reproduction. In order to eliminate the no-input associated output offset, the modulation scheme had to be changed. Instead of the outputs switching with a 50% duty cycle 180o out of phase with each other, the outputs now switch in phase with a a 50% duty cycle. With the two outputs in phase the result is no net voltage across the speaker and no load current during the idle state. *Figure 6* shows the outputs of the LM4673. Traces 1 and 2 are the device outputs; trace 3 is the total output (VO1 – VO2) across the load. Because of the cancelling architecture, the total output at idle is ideally 0.

When signal is applied, the outputs behave as shown in *Figure 7*. For positive input voltage, the duty cycle of VO1 increases, while the duty cycle of VO2 decreases. For negative input voltage, the converse occurs, the duty cycle of VO2 increases while the duty cycle of VO1 decreases. The difference between the two pulse widths yields the differential output voltage across the speaker.

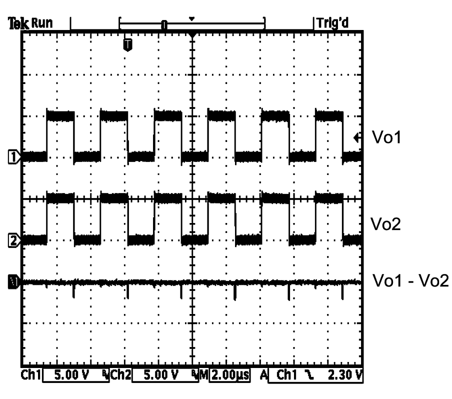

FIGURE 6. In Phase Switching

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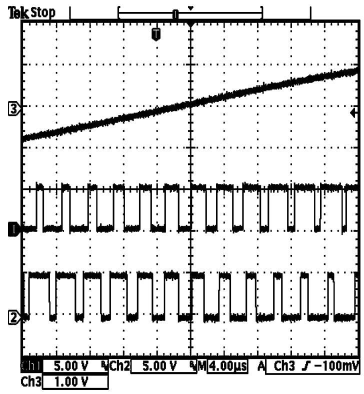

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FIGURE 7. Switching Waveform with Input Signal

Beyond eliminating the output filter, current class D amplifiers offer vastly improved audio performance over their predecessors. Early class D amplifiers typically operated open-loop (no feedback path), a situation not conducive to high fidelity audio reproduction. Open-loop operation meant that the effect of any error introduced by comparator offset, device mismatch, oscillator jitter, or finite rise time of the class D output, along with noise contributed by the power supply could not be cancelled. Thus, these amplifiers exhibited poor THD+N (>0.5%), and almost non-existent (0 dB) AC PSRR.

As a result of' the switching nature of class D, the feedback path consisted of more than just a couple passive components. Operation amplifiers with extensive RC networks were required for filtering and differential to single-ended conversion. Unlike a linear amplifier, a class D signal path includes a delay associated with the conversion from a linear input to a PWM output. This conversion delay further complicated the design of the feedback loop. The burden of applying feedback was placed upon the system designer. Amplifier manufacturers suggested external feedback architectures and provide guidance, but the success of the final amplifier rested upon the expertise of the system engineer, not the amplifier designer. Such external feedback topologies, though effective, increased component count, board space, and cost, as well as system complexity.

New class D amplifiers, such as the LM4673, feature integrated feedback. The LM4673, in particular, features global feedback; the input signal to the error amplifier is taken after the H-bridge. Now the effect of any mismatch, jitter, finite rise/fall time, or supply noise present at any point in the amplifier signal path is reduced resulting in class D amplifiers with class AB quality audio. The LM4673 exhibits excellent THD+N (< 0.02%, well than an order of magnitude below an open loop amplifier) and PSRR (78dB @ 217Hz) (*Figure 8*, *Figure 9*, and *Figure 10*). Now instead of a costly, complex, under-performing multi-device solution, system designers have at their disposal simple, robust, efficient class D amplifiers that rival their linear counterparts.

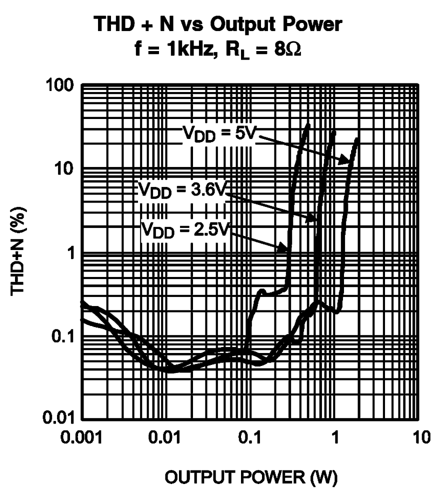

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FIGURE 8. LM4673 THD+N vs. Output Power

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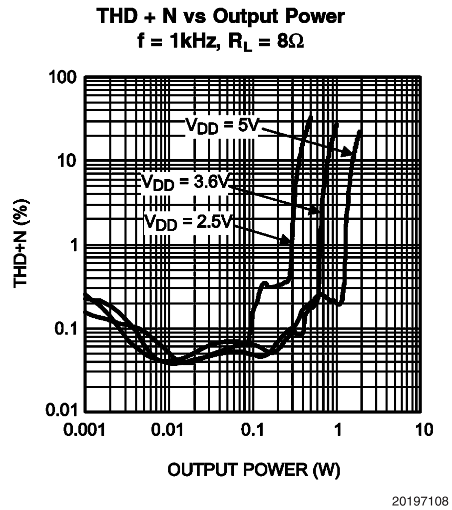

FIGURE 9. LM4673 THD+N vs Frequency

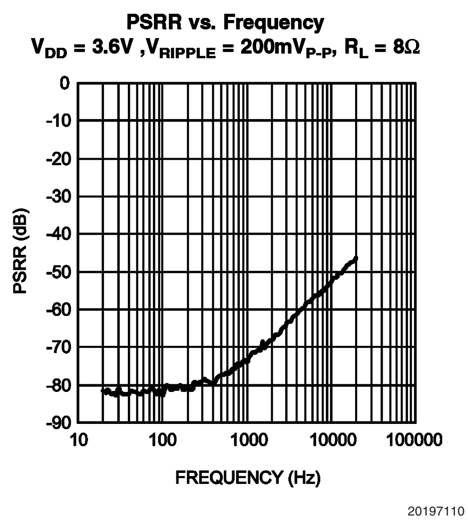

FIGURE 10. LM4673 PSRR

The advances in switching amplifier technology have improved performance, eased amplifier design and lowered the cost of a class D audio solution. System designers can achieve quality audio reproduction with the added benefit of increased efficiency; longer batter life and reduced heat. Filterless amplifiers, along with improvements in performance, enable manufacturers of such products as cell phones, PDAs, and laptops to produce feature rich, portable multimedia devices with a smaller form factor and longer battery life.

Revision History

Rev	Date	Description
1.0	05/24/06	Initial WEB release.

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