Performance and Reliability Improvements in High-Power Class D Audio Amplifier Design

Class D Amplifiers

Green energy standards, the continuing need to reduce costs and the demand for higher audio fidelity are driving the adoption of Class D amplifiers in high-power audio applications. Traditional analog implementations, such as Class AB topology, are more complex and less efficient, yet they have dominated the high-end audio market due to their high-fidelity performance. Class D systems are quickly narrowing this gap with simpler, more efficient designs offering fidelity that can surpass that of analog amplifiers.

A typical Class D audio system converts audio signals at its input to a digital pulse-width modulated (PWM) signal, adds power amplification in the digital domain, then converts the digital signal back to analog at its output. As shown in Figure 1, the incoming audio signal is applied to a PWM modulator consisting of an operational amplifier and comparator. This modulator digitizes the audio input by varying the modulator duty cycle in direct proportion to the instantaneous value of the audio input signal.

This PWM signal is then appropriately level-shifted and applied to a gate driver that switches a two-state power circuit consisting of MOSFETs (M1 and M2). The resulting amplified signal is then passed through an output filter, which removes the PWM carrier frequency, leaving only the amplified analog audio signal that ultimately drives the speakers. Audio output fidelity is further enhanced by the outer feedback loop from the filter input to the error amplifier input, thereby reducing distortion and noise.

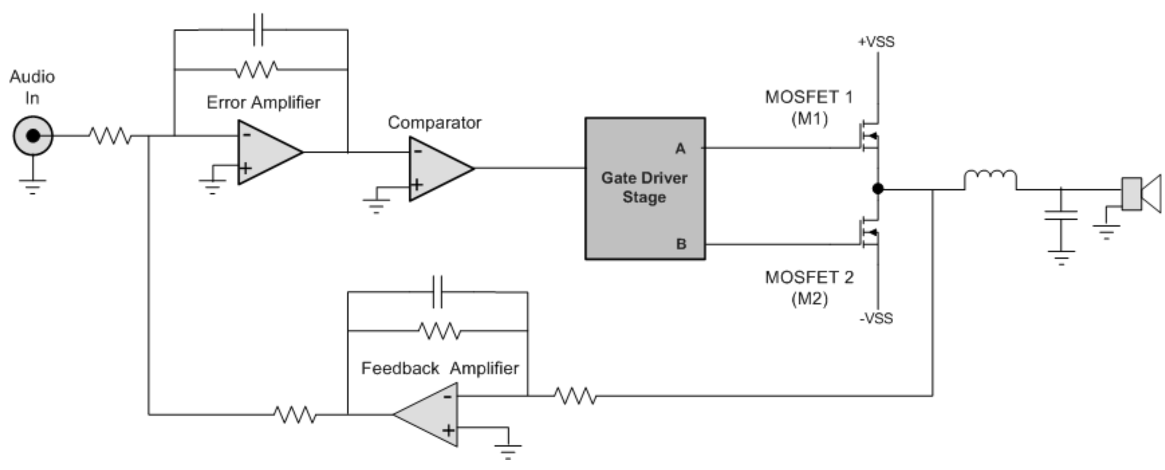

Figure 1: Class D Amplifier Basic Block Diagram

Class D Amplifier Design

Power Efficiency

Historically, analog power amplifiers have relied on linear amplification circuits that are prone to high power losses. By comparison, Class D amplifier power efficiencies can be 90% or higher, depending on the design. This high efficiency benefit is intrinsic in Class D technology where binary switches (usually power MOSFETs) are the amplification mechanism. These switches are either fully on or fully off, and very little time is spent transitioning between those two states. This discrete switching action and low MOSFET on-resistance minimize I^2R losses and increase efficiency. In practice, however, the switch transition time (dead time) must be long enough to avoid efficiency-killing shoot-through currents that result from both switches being on simultaneously.

High Fidelity

Audio fidelity can be defined as the accuracy with which sound is reproduced. For audio systems, fidelity is a proxy for the all-encompassing term “sound quality”. Various specifications are used to quantify fidelity, and while several measures are commonly used, we will focus on those that pose the greatest challenge for designers, namely Total Harmonic Distortion (THD) and Noise (N), collectively referred to as THD + N.

THD is a measure of the accuracy of an audio system and is very much akin to high fidelity itself. Inaccuracies in signal reproduction create additional signal components at harmonic multiples of the input frequencies, which obviously distract from the purity of the output signal. THD is the ratio of unwanted energy from all harmonic frequencies to the energy of the fundamental frequencies of the input, typically measured at half of full power for a given system. While THD performance less than 0.1% is adequate for most non-audiophile audio applications, discerning listeners usually prefer THD levels of 0.05% or less.

Output noise level is a measure of the noise floor level of the amplifier outputs with no signal input. For most speakers, a noise floor of 100-500 µV is inaudible from most normal listening distances, while a noise floor as high as 1 mV will prove to be quite annoying. Combined, THD+N is a very good measure of audio fidelity in a given amplifier.

Class D Driver IC - Features and Benefits

Programmable Dead-Time

Class D amplifier dead- time (i.e. the period when both switches are off) directly impacts efficiency as well as THD. An overly short dead-time causes shoot-through currents that decrease efficiency; an overly long dead-time results in increased THD, which negatively affects audio fidelity.

Therefore, the dead time period must be precisely set to hit the “sweet-spot” that optimizes both power efficiency and THD. The typical high-voltage audio drivers (HVICs) available today have coarse and overlapping dead time settings (i.e. 1 of *n* delay values); so, most designers choose to implement the dead-time period discretely, which can be expensive and time-consuming. A more elegant and cost-effective solution would be to integrate a gate driver with a highly-precise dead-time generator.

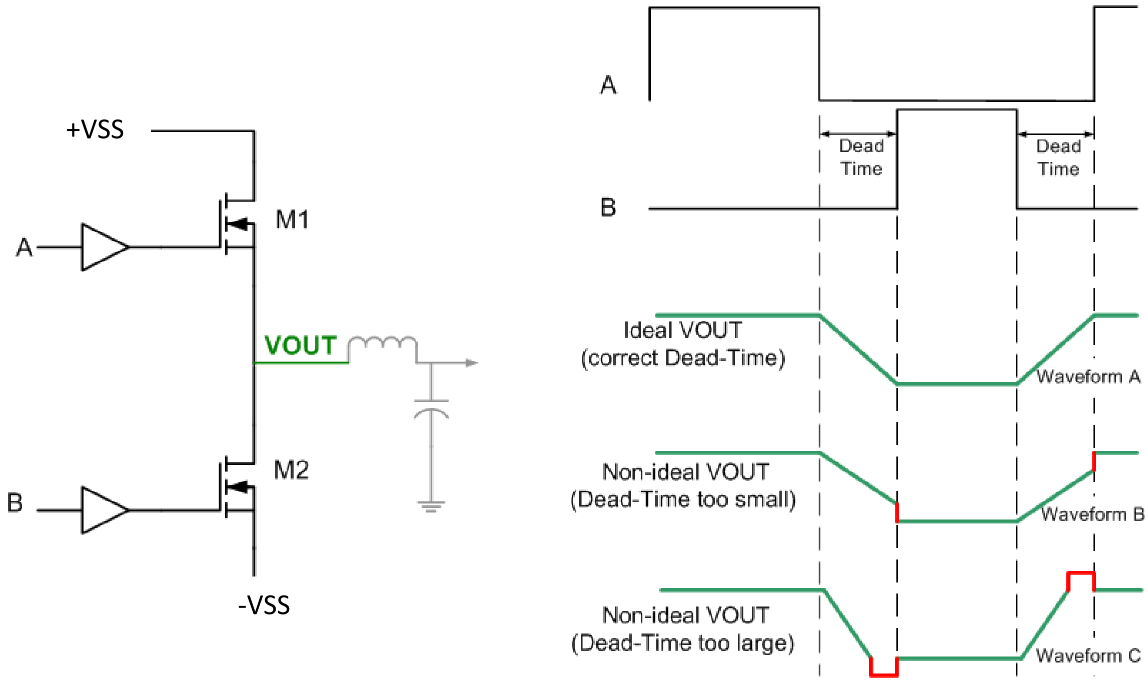

Figure 2: Dead-Time and its Effects on THD and Power Consumption Performance

Level Shifting

Implementing a two-state, Class D amplifier can be difficult due to input level shifting requirements. In high-power Class D amplifiers, it is desireable to have high-voltage supply rails (± VSS) for the power MOSFET stage. For practical Class D amplifier designs, a voltage of ±100 Vdc can deliver an impressive 600 watts of audio power into 8 Ω.

Most available HVIC Class D drivers lack the capability to provide level shifting from the low-voltage modulation section to the high-voltage power section. Drivers that provide level shifting have other deficiencies making them less than ideal for Class D operation. For example, the driver output ground terminal is referenced to a negative voltage rail, requiring the input drive signal to be level-shifted to the negative supply. This functionality is added through discrete components, which can be costly and difficult to design and which take up an inordinate amount of space. Level shifting solutions for interfacing to high-voltage bipolar supply rails would be a significant advantage in Class D designs.

Most driver solutions do not offer input-to-output isolation or isolation between the drivers, and it becomes necessary to provide a level-shifting mechanism with extra components.

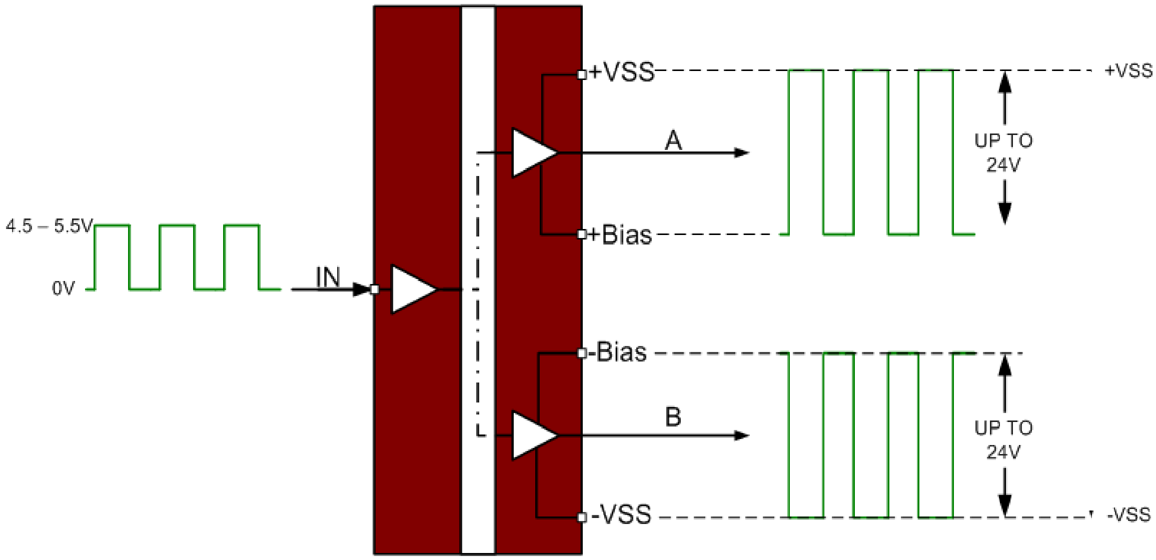

Figure 3: Level Shifting Required to Interface Low Voltage Digital Modulator to High Voltage Bipolar Output Supply

Reliability and Noise Immunity

Typical gate driver ICs available today have a tendency to latch-up at high voltage transients of 20 V/ns or greater and typically do not have any immunity to high slew rate noise transients coupling back from the power stage to the precision digital input side. This is a major disadvantage when trying to keep the noise floor as low as possible for the best audio fidelity.

High Frequency Operation

One of the best attributes a Class D gate driver can have is the ability to operate at high switching frequencies with minimal propagation delay. These attributes allow the total loop delay in the feedback path to be exceptionally low for the best possible noise performance. Higher frequency operation also improves the “loop gain,” which typically improves the distortion performance of the amplifier. Most HVIC drivers available today only support modulation frequencies of up to 1 MHz.

Integration

With today’s highly-competitive global markets, a solution that integrates all of these features provides a much needed advantage to Class D amplifier designers, allowing them to get their products to market earlier by minimizing costly design time, insertion costs and the implied reduction in reliability that comes with higher part counts.

Summary

Class D amplification offers attributes far beyond traditional analog amplifiers, including lower total harmonic distortion (THD), reduced board space, higher power efficiency and lower BOM cost. A highly-integrated gate driver IC can have a significant positive impact on both system architecture and audio performance. Silicon Labs' Si8241/8244 audio drivers are the first devices that effectively integrate all the desireable features of a high-power Class D solution in a single IC package. The benefits include high precision dead-time settings for the lowest possible THD and best efficiency; elimination of level shift circuits, which reduces design complexity and component count; isolated output drivers for easy two-state switcher implementation and a high immunity to power supply transients. To learn more about the Si824x Class D audio drivers and how they provide a new paradigm for the audio market, visit www.silabs.com/audio-driver.