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Go Green With 100-W And Higher Audio Power Amplifiers

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Class D outshines Class AB with three times greater efficiency and an order of magnitude power loss reduction per channel.

We know Class D audio amplification offers advantages in efficiency and size for battery-powered devices. What you may not know, however, is that these advantages can now extend to amplifiers up to 500 W thanks to solid-state driver ICs designed specifically for Class D. Systems based on these new ICs outperform Class AB when it comes to THD+N measurements and simplify the designer's job by accepting ground-based analog audio inputs. Other attractive features include overcurrent protection for both rails and programmable dead time. This article addresses the performance, size, and cost benefits of Class D versus Class AB topologies for medium power levels.

As a bit of historical background, audio amplification needs a speaker (also called a driver) to be driven back and forth in opposite directions, moving air to produce a sound wave that's deciphered by the human ear. To accomplish this, a voltage of alternating polarity is impressed upon the speaker by means of either a half-bridge or full-bridge topology for Class D topologies (Fig. 1).

The half-bridge amplifier requires a split-rail power supply, having positive and negative voltages of equal magnitude, and two power switches between them. When the load is tied between the common switch point and system ground it's referred to as a single-ended load (SEL). The full-bridge amplifier, referred to as a bridge-tied load (BTL), consists of two half-bridges with the load tied between their center points. The switches are turned on and off in such a way that the speaker moves to recreate the audio output, which must average to zero.

BTL configurations produce higher power for a given switch rating, and a single power supply and output capacitor allows the circuit to be ground-referenced. This simplifies input controls at the expense of two more power switches and gate drivers. An SEL or BTL topology can be used for either Class AB or Class D.

Class A was the earliest audio amplifier design, whereby both switches were ON simultaneously, although not fully, to produce the required voltage at the load (Fig. 2). This produces excellent audio performance, but very poor efficiencies of approximately 15%, resulting in large and expensive systems.

Class B followed, where only one switch at a time was turned on. While efficiency improved to approximately 75%, it was hampered by significant problems at the zero crossing of the output waveform. Instead of crossing smoothly through zero, Class B had a flat section, or zero voltage between the positive and negative halves of the waveform, producing high distortion.

Class AB compromised the two by turning on both switches simultaneously. However, the switch not carrying load current was only minimally on so that the nonlinearity due to the loss of gain at the zero crossing was greatly reduced. This improved zero-crossing distortion to acceptable levels and improved efficiency over Class A, but still an overall Class AB efficiency of 30% was typical.

These three topologies vary the bridge output voltage with the audio frequency and are, therefore, relatively low frequency designs. Class AB dominates the field of linear amplifiers, and bipolar transistors are typically used as the control devices.

Class D Amplification
Today's switching power supplies are far smaller and lighter than the linear, line-frequency supplies of the past due to the advent of high-frequency power conversion, made possible by improvements in power silicon, control ICs, magnetics, and capacitors. Likewise, thanks to the continuous improvements of key electrical components, Class D amplifiers decrease the size, weight, and system cost of audio amplifiers by switching at 200 to 800 kHz instead of being linearly driven by 20 Hz to 20 kHz audio frequency signals. MOSFETs are commonly used as the switches due to their fast switching speeds. Each power switch of opposite polarity is fully turned on or off one at a time with dead-time between the on states, and the I2 Â´ RDS-ON conduction andÂ VSIStSfS switching losses are far less than the (VRAIL - VOUT) Â´ I loss of the linear Class AB. Even though switching losses increase with frequency, Class D efficiencies of 90 to 96% for medium power are now achievable.

A Class D amplifier half-bridge output produces a rail-to-rail switched digital power signal. The waveform in Figure 2 shows the switching losses (green) and conduction losses (blue). The analog output is reconstructed at the load by the LC stages of an output filter. The duty cycle D of the powered signal determines the filtered output voltage, as shown in the half bridge (Fig. 1, again).

As D approaches unity, the output voltage approaches the positive rail or positive peak of the waveform. When D is 50% the output voltage is zero, and when D approaches zero the output voltage approaches the negative rail, or negative peak of the waveform. At switching frequencies of 400 kHz and above, a single-stage output filter can be used, comprised of one inductor and one capacitor.
To achieve the THD curves of Figure 3, we plugged a Class D motherboard containing the output filter and a two-channel, power-stage daughtercard into a commercial Class AB stereo receiver (Fig. 4). With an identical power supply and input controls, the power specs and noise floor are identical, permitting fair measured performance comparisons. The Class D metal mounting plate covers the large heatsink of the original Class AB amplifier. It should be noted that for the case shown feedback is only from the switch node.

The Class D two-channel, half-bridge daughtercard outlined in orange is rated at 125 W per channel in still air without a heatsink, made possible by dedicated Class D MOSFETs (in this case, the IRF6645). Such state-of-the-art packaging features extremely low inductance, resulting in cleaner switching waveforms and improved performance.

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Class D GATE Driver Features
Many medium power applications use the lower-cost half-bridge power stage versus the full bridge, since it requires fewer active elements. However, inputs and feedback are easier to manipulate when ground-based rather than referenced to the negative rail. Grounded input capability in Class D drivers greatly simplifies design by providing level shifters to drive both upper and lower switches from signals referenced to system ground. If necessary, the input to these drivers can also be referenced to the negative rail in SEL mode, or to ground in BTL configuration.

Dedicated Class D drivers for medium power are now available with either pulse-width modulation (PWM) or analog audio inputs. An integrated error amplifier provides pulse-width modulation, further simplifying design, reducing cost, increasing density, and improving performance by eliminating EMI around an external PWM.

The switching frequency of Class D gate drivers can be configured for self-oscillation, removing switching noise from the audio frequency band (noise shaping). Self-oscillation provides more effective loop gain than Class D fixed-frequency PWM switching, delivering improved performance over both fixed-frequency Class D and Class AB. This becomes more pronounced at higher power levels, as shown in Figure 3. Switching frequency decreases as power increases, aiding efficiency. There is no Class AB counterpart for this feature.

Some Class D drivers offer programmable dead time, or the time when both switches are off. The time between the ON-state of the switches is adjusted so that they can Â to safely turn ON. This is important because switches used for various power levels have a wide range of total gate charge, and need varying amounts of time to turn on and off. Programmable dead-time optimization reduces THD and increases efficiency.

One of the most frustrating parts of audio amplifier design is removing the ON/OFF click noise, or speaker "pops." A relay is often used to eliminate these pops, but cost, size, and reliability suffer. Class D drivers now integrate click noise reduction, significantly reducing this annoyance.

Protection

When driving a switching audio amplifier, great care must be taken to ensure that each switch of a half-bridge doesn't exceed its current rating due to a low load impedance or shorted output. Rugged amplifier design, therefore, includes overcurrent protection (OCP) for both rails. OCP in a dedicated Class D driver is simply accomplished by sensing the I Â´ RDS-ON voltage drop across the FETs, providing an indirect measurement of power dissipation. The trip point is set for the minimum load impedance, taking into account the FET maximum RDS-ON and temperature coefficient. Internal IC level shifting alerts the controlling circuitry of a fault.

OCP circuits in Class AB systems require monitoring both the current and voltage of the control device and multiplying these values together, requiring many parts or use of an impedance bridge. In contrast, providing OCP in a dedicated Class D driver IC is significantly simpler, shortens design time, increases reliability, and reduces cost.

A Class D driver can also provide undervoltage lockout protection (UVLO) for the control power supplies of both switches to ensure that adequate energy is available to drive the gates fully on. If either gate voltage is too low, catastrophic system failure may result in FET overheating and potential failure. UVLO protection improves reliability by identifying a dangerous condition before it occurs.

Cost

Class D's main advantage over Class AB is its operating efficiency. However, consider a 100 W example in terms of power loss. Class AB dissipates 70 W of heat versus 5 W for Class D - a 14-fold difference. Multiply this by two or more channels and heat management becomes an even greater design issue.

For the same output power as Class AB, Class D needs a much smaller heatsink, or, depending on power level, no heatsink at all and no labor costs for mounting power switches (Fig. 4, again). With the cost of the heatsink come the expenses of machining, labor for installation, and a larger enclosure to accommodate it. Integrating level shifting and protection circuits reduces board space, and dedicated Class D drivers that accept analog inputs and provide PWM contribute to further system cost reduction.

Summary
Dedicated Class D IC drivers for medium power audio amplifiers enable efficiencies three or more times greater than Class AB and reduce power loss by an order of magnitude or more per channel. Class D amplifiers have equal or better performance, higher density, and lower cost than Class AB. With ground-referenced analog or digital inputs, programmable dead time, OCP, UVLO, and click noise reduction, these ICs enable fully protected products that are easy to design, fast to market, highly reliable, and environmentally friendly. Just as the components of today's high-frequency, high-efficiency switching supplies have replaced the bulky, heavy, and expensive components of yesterday's inefficient linear supplies, Class D is now poised to supplant medium power Class AB audio amplifiers in the near future.