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Integrated Driver Shrinks Class D Audio Amplifiers

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From automotive entertainment to home theater systems, consumers are demanding more channels and speakers with higher amplitude of high-quality audio per channel. However, driving each channel individually translates into higher power consumption, more components, and bigger board space. The end result is a complex design with thermal issues, lower sound quality and reduced reliability at higher cost.

Consequently, to minimize power dissipation and simplify thermal management of multi-channel high performance audio systems, designers have been taking advantage of high-efficiency class D audio amplifiers with efficiencies over 90% across a wide range of output power levels. By comparison, the traditional class AB amplifiers serving this market offer about 50% efficiency and that efficiency drops off quickly as the output power level falls. In turning to Class D amplifiers, engineers are also seeking to cut component count and minimize board space through use of integrated solutions.

Taking such factors into consideration, International Rectifier has developed the IRS2093M, an integrated audio driver chip that packs four channels of high-voltage power MOSFET drivers on the same die. This article discusses the operation of the IRS2093M and presents an audio amplifier design example based on this IC.

Audio Driver Features

Housed in a compact 48-pin MLPQ package, the IRS2093M is a 200-V device that integrates on-chip error amplifier, PWM modulator, programmable preset dead-time and robust protection functions specifically designed for class D audio amplifier applications in a half-bridge topology (**Figure 1**). Aside from preventing shoot-through, the programmable preset deadtime also enables scalable power design both in terms of power and number of channels. The protection features include overcurrent protection (OCP) with self-reset control and undervoltage lockout (UVLO) protection. Another feature offered by the integrated driver is start-up click noise reduction, which suppresses unwanted audible noise during PWM start-up and shutdown.

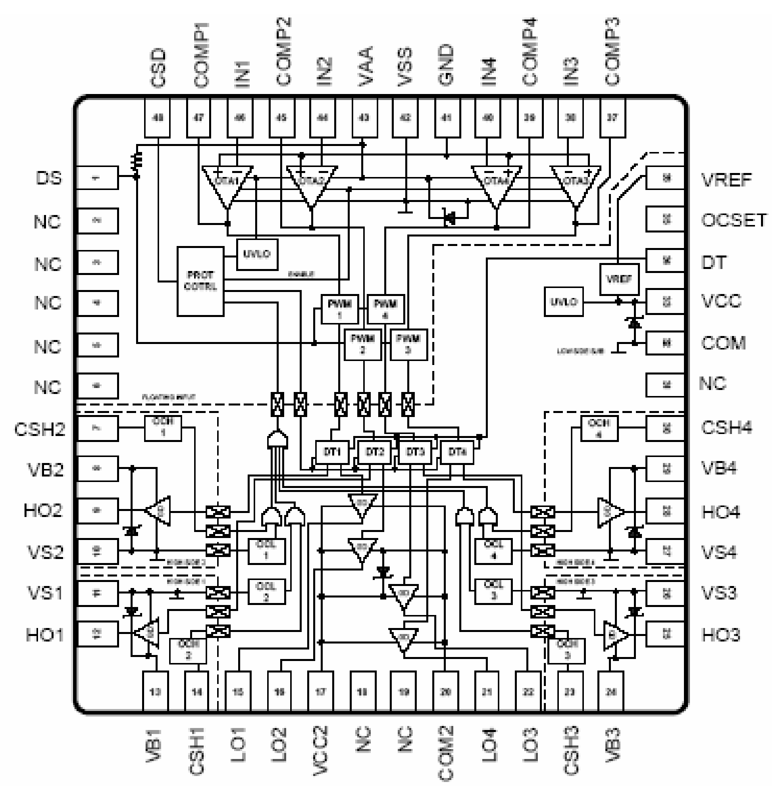


Fig. 1. Besides packing four channels of high-voltage power MOSFET drivers on the same die, this 200-V device also integrates on-chip error amplifier, PWM comparator, gate driver, and robust protection circuitry.

For isolation between the channels, the audio driver implements proven high-voltage junction isolation techniques and floating-gate drivers using the company's Gen 5 HVIC process. As a result, there is a high degree of internal signal isolation on the die, enabling the circuit to process signals on multiple channels simultaneously. This isolation ensures that the noise floor in each channel is low, while minimizing crosstalk between the channels. Internal tests indicate that the noise floor in each channel remains below -80 dBV over the entire audio range. While crosstalk between the channels is better than -70 dB over the audio range.

For realizing a smaller design solution with high performance and robust design, this four-channel class D audio amplifier driver offers self-oscillating PWM modulation. Since this topology corresponds to an analog version of a second-order sigma-delta modulation with a class D switching stage inside the loop, all the errors in the audible frequency range are shifted to the inaudible upper frequency range. The result is lower noise. In addition, sigma-delta modulation permits a designer to apply a sufficient amount of error correction to lower noise and distortion further.

Design Example

Although, it can switch at much higher frequencies, the design described here operates at 400 kHz. This switching frequency is considered optimum for several reasons. First, at lower frequencies, the efficiency of the MOSFET stage increases, but so does inductor ripple current. And leakage of the PWM switching carrier to the output also rises. Secondly, at higher frequencies, switching losses degrade efficiency, but wider bandwidth is possible. While inductor ripple decreases, iron losses go up.

To protect both high-side and low-side MOSFETs against overcurrent in either direction, the on-chip programmable OCP offers bidirectional protection. For that, it uses the $R_{DS(on)}$ of the output MOSFETs as current-sensing resistors.

To prevent shoot-through or the rush of current through both MOSFETs, a blanking period known as deadtime is inserted between either high-side turn-off and low-side turn-on or low-side turn-off and high-side turn-on. For optimized performance, the integrated driver permits the designer to select deadtime from a range of preset values, depending on the size of the MOSFETs selected. In fact, only two external resistors are required to set the deadtime via the DT pin of the driver.

Similarly, for UVLO protection, the driver monitors the status of voltage supplies V_{AA} and V_{CC} to ensure that both the voltages are above their respective thresholds before starting normal operation.

When combined with IR's eight optimized digital audio power MOSFETs and a few other external passives, a four-channel half-bridge class D audio amplifier with output power up to 120 W per channel can be realized as shown in **Figure 2**. Digital audio power MOSFETs, such as the IRF6665, have been optimized around parameters critical to audio performance like efficiency, total harmonic distortion (THD) and electromagnetic interference (EMI).

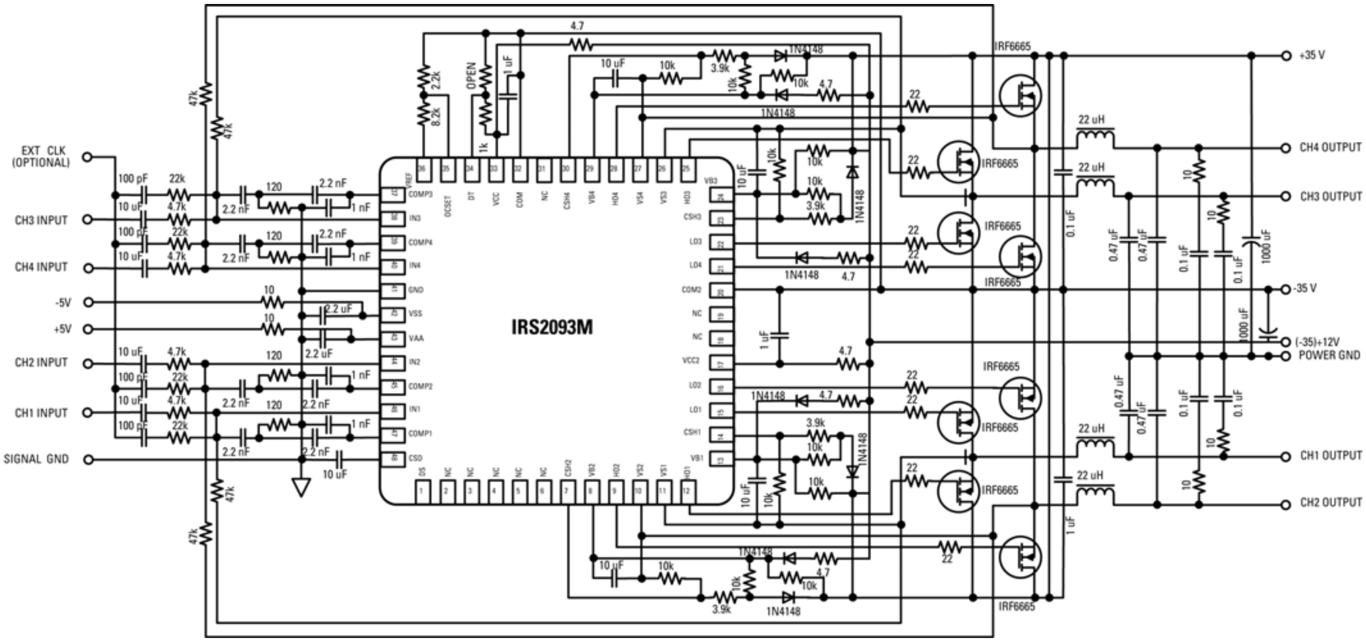


Fig. 2. System level schematic of a four-channel class D audio amplifier using the IRS2093M integrated driver. This design can deliver 120 W per channel.

Besides offering low on-resistance, these digital audio power MOSFETs are also tailored for achieving minimal gate charge, body reverse recovery and internal gate resistance[1]. In addition, their DirectFET packaging offers lower parasitic inductance and resistance as compared to conventional wire-bonded packages.

In reality, the output of the power stage comprising the high- and low-side digital audio MOSFETs is an amplified PWM waveform. The audio signal is recovered from this PWM waveform by the LC low-pass filter at the output. The LC filter removes the class D switching carrier frequency and leaves audio signal at the speaker load. However, to damp any LC resonances and prevent peaking frequency response with light loading impedance, an RC filter called a Zobel network follows the low-pass filter.

To ensure optimal performance of the four-channel audio amplifier, the PCB layout incorporates separate grounding for the low voltage input audio and high power output signals[2]. Furthermore, the current loops are localized so that the area covered is as small as possible. Meanwhile voltage spikes are prevented from spreading to the rest of the system by using appropriate high-frequency decoupling capacitors. An RC snubber in the final stage further reduces the remaining artifacts of switching. To minimize the noise floor, the sensitive analog PWM section is separated from the high-power switching stage. And the components are routed to achieve minimum stray inductance.

Performance Results

Measurements conducted using a sinusoidal signal of 1 kHz at 1 Vrms and a 4-Ω load impedance show that efficiency per channel is about 90% over a broad output-power range. Major factors contributing to high channel efficiency are low conduction and switching losses. Plus, there is no cross conduction because of the secure dead-time provided by the integrated driver. The DirectFET IRF6665's low on-resistance ensures low conduction loss, while its low input capacitance and gate charge Q_G keeps switching loss to a minimum.

As illustrated in **Figure 3**, the THD plus noise (THD+N) is less than 0.01% below 50 W per channel. This performance remains consistent even as the output power is enhanced from 10 W per channel to 50 W per channel with a 4-Ω load.

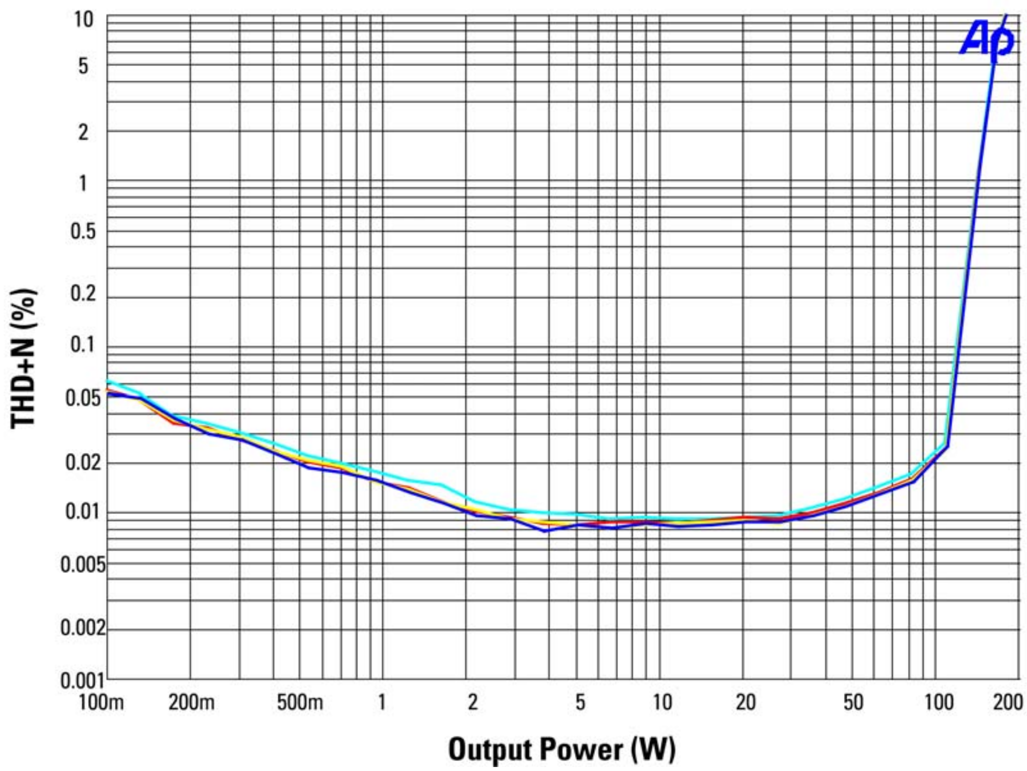
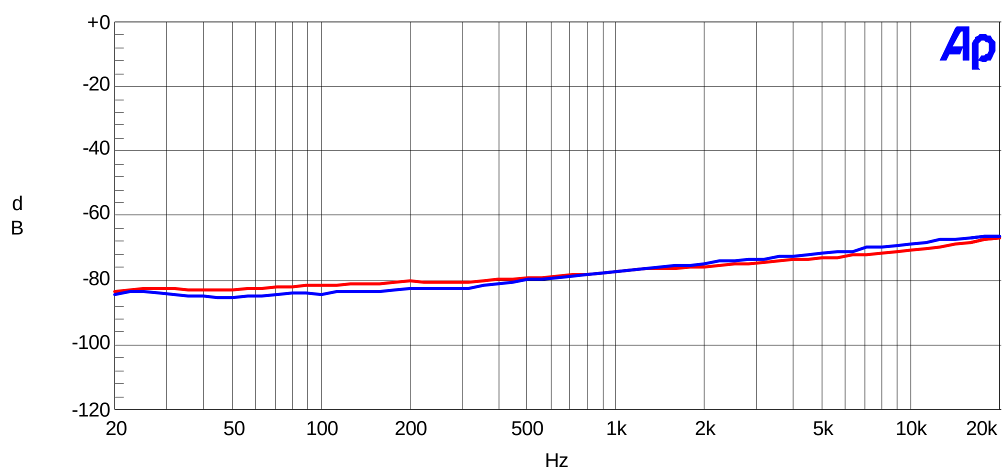


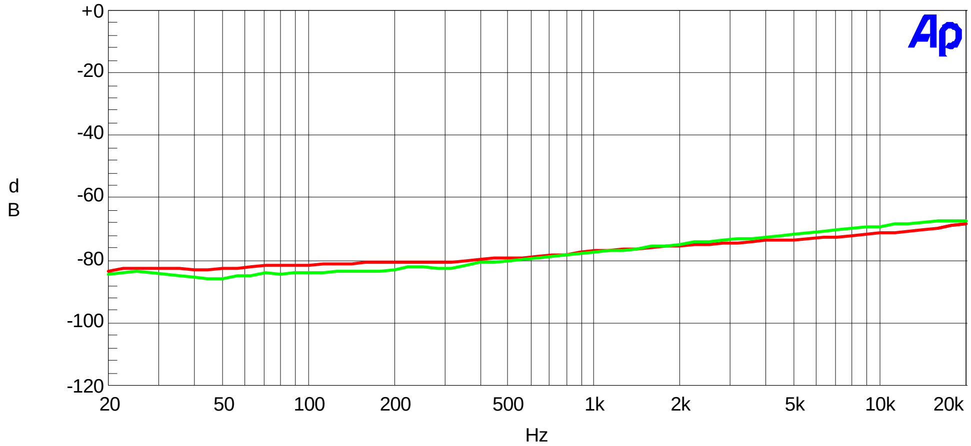
Fig. 3. THD+N performance is below 0.01% per channel.

This four-channel class D audio amplifier design was also tested for channel separation. Conducted tests show that the crosstalk between channels 1 and 3 and 1 and 4 is better than -70 dB over the entire audio range at 60-W output per channel. These results are demonstrated in **Figures 4 and 5**.



Sweep	Trace	Color	Line Style	Thick	Data	Axis	Comment
1	1	Red	Solid	2	Anlr.Crosstalk	Left	
1	2	Blue	Solid	2	Anlr.Crosstalk	Left	

Fig. 4. At 60-W output power per channel, the crosstalk between channels 1 and 3 is below -70 dB over the entire audio range.



Sweep	Trace	Color	Line Style	Thick	Data	Axis	Comment
1	1	Red	Solid	2	Anlr.Crosstalk	Left	
1	2	Green	Solid	2	Anlr.Crosstalk	Left	

Fig.5. When tested at 60-W per channel output, this design exhibits better than -70 dB crosstalk performance between channels 1 and 4 over the entire audio range.

This design offers a power supply rejection ratio (PSRR) of -68 dB at 1 kHz. The high PSRR is the result of the self-oscillating frequency of the driver. As a result, the four-channel class D amplifier delivers high performance even with unregulated power supplies.

Combining the attributes of a high-voltage integrated controller and driver such as the IRS2093M with optimized digital audio power MOSFETs, it is possible to build a four-channel class D audio amplifier whose efficiency, THD+N and EMI performance is comparable to the performance of a single-channel design. Additionally, the noise floor remains below -80 dBV over the entire audio range. And there is high degree of isolation between the channels to keep intermodulation distortion (IMD) to a bare minimum for satisfactory audio performance. While high efficiency eliminates heatsinks, the integrated audio driver realizes a four-channel class D audio amplifier solution in a 50% smaller footprint than competing solutions.

References

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2. *"PCB layout with IR class D audio gate drivers"* by Jun Honda and Connie Haung, IR Application Note AN-1135
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About the Author

Jun Honda is a senior staff engineer in International Rectifier's Energy Savings Product Business Unit in El Segundo, Calif. Jun has more than 15 years of experience in designing consumer, as well as professional audio circuits, including class D audio amplifiers.