

# Differentiating Cost-Competitive Class D Amplifier Designs

*No heatsink for normal class-D operation*

*Class D amplifiers are critical to achieving low physical profile and high audio output for modern consumer TV and audio markets. Building a working class-D solution, however, is not straightforward. The design of the power switching stage, in particular, represents a significant risk to audio designers not familiar with power electronic design.*

*By Jun Honda, International Rectifier*

Off the shelf class-D amplifier chips can take away these power design headaches, but at the same time restrict opportunities to optimise other aspects of the amplifier. This prevents designers from implementing performance enhancements to differentiate products in the marketplace.

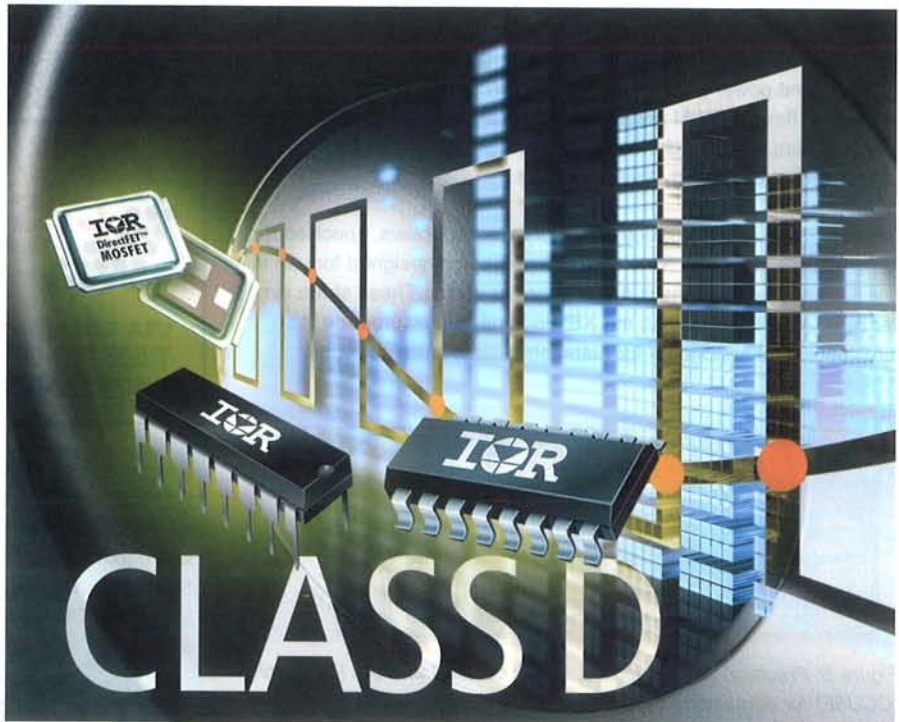
Ideally, audio designers need a turnkey solution to the power electronic functions that also leaves them free to apply specialist knowledge in areas such as the feedback path and output filter.

## Class-D Design for Flexibility

To help understand how a class-D chip solution may offer this combination of out-of-the-box functionality and design flexibility, figure 1 illustrates the functional blocks of a generic class-D amplifier. The input audio signal is compared with a high frequency sawtooth waveform to produce a pulse-width-modulated square wave representation of the input. The sawtooth frequency is set much higher than the maximum audio signal frequency, in the region of 400kHz, to reduce distortion and simplify output filter design.

The pulse-width-modulated equivalent of the audio signal is then used to drive the amplifier output stage, which may be either a full-bridge or half-bridge MOSFET array. The choice of output topology depends on system requirements including cost, power output, power supply design and signal characteristics. A half-bridge output stage, for example, requires positive and negative power supply rails. A full-bridge, on the other hand, is able to operate from a single power supply and also produces a higher output for a given switch rating.

In either case, the output MOSFET characteristics are optimised for class-D audio amplifier operation, to maximise efficiency and ensure low Total Harmonic Distortion plus Noise (THD+N), and EMI. This calls for a combination of low on-resistance for high power density in the end product, as well as optimised gate charge and body-diode reverse recovery for fast, efficient switching.



The amplified audio signal is contained within the square wave present at the output of the MOSFET bridge. Low pass filtering is applied to remove the out-of-audio frequencies and restore the pure audio signal to drive the speaker.

## Switching-Design Challenges

The design of the class-D power switching stage, which generates the gate drive signals for the MOSFET bridge, is a major challenge for designers who are not necessarily familiar with switching power electronic design principles. Precise gate control is necessary for good audio performance, requiring designers to achieve low pulse-width distortion as well as good matching between high- and low-side driving signals to preserve linearity.

One particularly difficult challenge involves the insertion of deadtime, which is required to prevent shoot-through currents from damaging the output MOSFETs. Inserting deadtime introduces non linearity to the amplifier characteristic, so that designers often are unable to



achieve a satisfactory balance between audio fidelity and safety margin. The requirement to implement other protection functions for the gate driver and MOSFETs, including over-temperature protection and over-voltage protection, imposes additional complicated challenges that require significant switching power electronic design skills.

To compound these challenges, perfecting a design can be difficult as any flaws tend to produce catastrophic failures that effectively prevent analysis and correction of the fault.

To help designers overcome these barriers and deliver successful class-D amplifier products quickly, International Rectifier has implemented the IRS2092 turnkey MOSFET gate driver with built-in protection features. The device also integrates the error amplifier and PWM comparator to allow designers to quickly get a class-D solution up and running.

Other important amplifier features that are closely linked with the design of the power switching stage include circuitry to implement click/pop noise reduction during start-up and shut-down. By also implementing these features internally, the IRS2092 further reduces design overheads and component count. This approach solves the power electronic design challenges associated with class-D amplifiers and provides a foundation from which engineers can apply specialist audio skills to further improve performance.

The IRS2092 is also designed to provide flexibility for designers to determine output filter characteristics and to take feedback from one of a number of places to optimise audio performance and amplifier stability within targets for cost and component count.

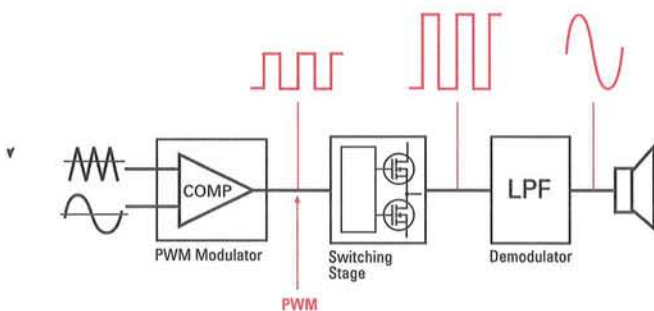


Figure 1: PWM operation

#### Customising the Feedback Loop

Feedback design is a crucial differentiating feature for class-D amplifiers. In some cases an open loop configuration may deliver satisfactory performance. However, timing errors inherent in the amplifier can increase distortion and noise. This is best reduced by applying negative feedback. A straightforward solution is to feed back a proportion of the switching signal to the input of the error amplifier, applying preconditioning with a passive RC low pass filter. Many off-the-shelf class-D amplifier chips implement feedback in this way. However, designers may wish to further optimise the amplifier's distortion performance and reduce load dependency by taking feedback from nearer to the output. For example, feedback may be taken from the furthest point of the audio filter output, just before the speaker. Some designers may achieve further improvements by including the speaker electrical components as well, as their effect can be considered as part of the amplifier's output filter. Other designs may combine two feedback signals, taken at the switch node and the filter output.

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The IRS2092 gate-driver IC gives designers the freedom to take feedback from whichever point is considered to be optimal. With judicious implementation of feedback, plus compensation to maintain stability, designers can achieve audiophile levels of harmonic distortion and noise (THD + N) performance.

#### Optimising Output Filter Performance

The output filter has a major influence on overall efficiency, reliability and audio performance. A simple LC filter is the norm, having a cut-off frequency just above the audio band and 40dB-per-decade carrier rejection. A simple filter can be designed to deliver adequate performance in many applications, subject to careful control of the speaker impedance. On the other hand, skilled designers may wish to apply more sophisticated filters exhibiting higher order response, a tuned notch characteristic, or special carrier suppression techniques, to further improve distortion and noise performance.

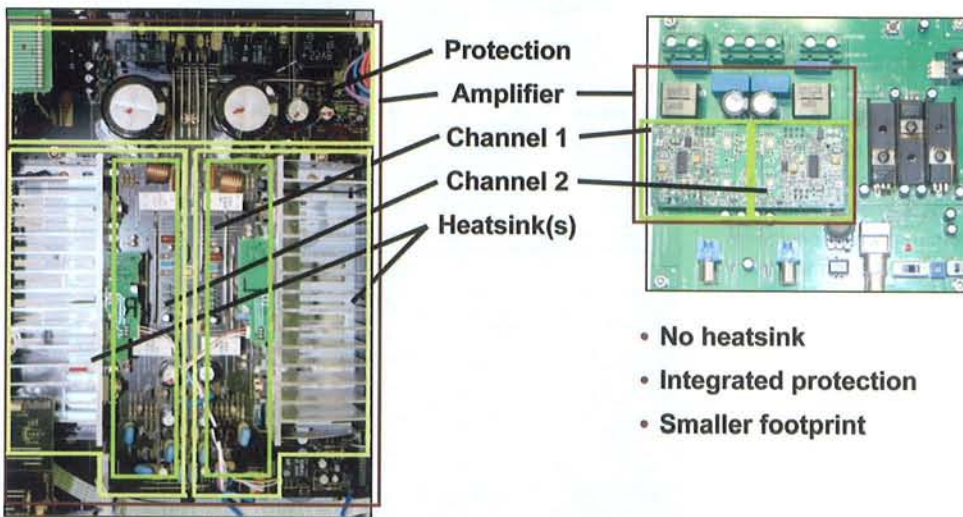


Figure 2: Reference design with the IRS2092 gate-driver IC and two IRF6645 DirectFET MOSFETs

By providing the freedom to adjust parameters such as switching frequency, the IRS2092 allows engineers to optimise the output filter design and to select components offering desirable characteristics such as high linearity and low DC resistance in the inductor. A significant benefit of the programmable switching frequency lies in the ability to manage the trade-off between bandwidth and switching frequency. In the case of a sub woofer amp with a 200Hz bandwidth, for instance, the ability to set a lower switching frequency will be beneficial.

#### Maximising Damping Factor

Since the design of the feedback and filter circuits influences the amplifier output impedance, designers also need control over these aspects to achieve a sufficiently high damping factor. This is an important figure of merit, particularly for automotive audio systems where load impedances are lower and where designers for example, must ensure tight control over speaker movement for acceptable performance within the confines of a vehicle cabin. Careful control of the amplifier's output and feedback design can achieve damping factor better than 100. This is generally considered more than adequate for most audio amplifiers.

#### Scalability

Another benefit to using an integrated IC solution such as the IRS2092, which incorporates the four essential Class-D

amplifier building blocks, is its scalability to meet higher output power levels or additional channels. Scaling the amplifier can be achieved quickly and easily by specifying external MOSFETs of appropriate rating and re-optimising the deadtime and the overload protection threshold. By retaining the same base design and, possibly, the same PCB design, this rapid scalability saves time to market and also reduces design costs as end products evolve. Furthermore, multi-channel systems can also be realised quickly through multiple iterations of the driver-MOSFET combination. Cost-effective and compact 6.1- or 7.1-channel surround-sound equipment, for example can be configured quickly and easily.

#### Ensuring Class-D Success

Class-D audio amplifier chips not only solve design challenges and accelerate project completion, but also enable valuable savings in part count. To further help designers deliver these benefits, Interna-

tional Rectifier has built a reference design around the IRS2092 gate-driver IC and two IRF6645 Direct-FET MOSFETs configured as a half-bridge. This design is illustrated in figure 2.

Using this reference, designers can build a 120W-per-channel switching amplifier within a total PCB area of 61cm<sup>2</sup>, or less than 16% of the area of the 120W class-A/B amplifier also illustrated. As no heatsink is required for normal class-D operation, the savings in total volume are even more dramatic. The complete class-D solution occupies only 109cm<sup>3</sup>, or less than 6% of the class-A/B amplifier's volume.

At the same time, this reference design achieves low THD+N of 0.005% while delivering 60W into a 4 $\Omega$  load, has residual noise of 170 $\mu$ V, and achieves a damping factor of 170 at 1kHz. From this functional base platform, designers are free to customise feedback and output filtering as described, to achieve an optimal combination of audio performance and overall cost for a given application.

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