

The car audio challenge: More power, more heat, less room to design

As premium sound systems grow in size and power requirements, Class-D audio amplifiers are being redesigned to answer the unique automotive challenge

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As the entertainment and infotainment systems of cars add more features and subsystems, the audio power budgets of the head and trunk units are being pushed to the limit. Automotive audio designers are looking for a high-performance, cost-effective solution. For many, the judicious use of ultra efficient Class-D amplifiers is emerging as the best possible choice.

In high-end cars in particular, multi-channel and multi-speaker systems are becoming commonplace. The design challenge for automotive engineers is to maintain -- or even to improve upon -- the high audio amplification levels and low distortion that customers have come to expect.

A specific instance of the need for higher power is the trend toward high-power two or even three-way speaker systems and subwoofers.

Unlike audio amplifiers in home entertainment systems, design engineers can't simply crank up the power and simultaneously find clever ways to control the audio quality to achieve these goals. Heat dissipation and space constraints in the head unit under the dashboard are quite stringent. The power supply voltage is also restricted and is frequently disrupted by events such as voltage spikes and interference from other electronic and mechanical systems in the car.

Every new model year brings a new subsystem, such as video or even navigation and Global Positioning System (GPS), into the audio design space: More speakers, more channels, higher power requirements and, typically, less space to house the audio drive system.

Audio power requirements are certain to increase. There are two primary ways to meet those needs. The conventional approach is to add more channels driven by standard audio amplifiers. This solution is already being used in active systems in which each amplifier drives a single speaker. But it is becoming complex and increasingly untenable as a complete solution because of the sheer number of channels.

Another approach is to raise power outputs by either lowering the speaker impedance or raising the supply voltage using DC/DC converters. With this solution, a single amplifier can drive two or three speakers and still produce high performance audio.

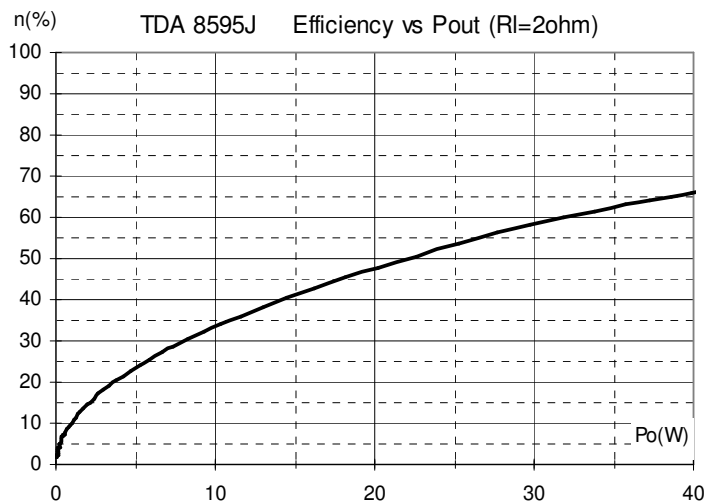
Although the second solution is less complex, both methods have something in common: they both increase dissipated power. Therefore, to meet power dissipation goals, utilizing more efficient amplifiers become a critical part of the solution.

This need for more efficient amplifiers has made the discussion of Class-D audio amplifiers a hot topic among audio engineers.

With efficiencies as high as 95% -- compared to around 50% for Class-AB amplifiers -- Class-Ds can get the power budget under control and still produce superior sound. Their superior power efficiency means they need a smaller heat sink, which in turn means more space available for electronics in the tight space of a head unit. Class-Ds are, however, more expensive than Class-AB amplifiers and they have special design considerations.

Figure 1 shows the relative efficiencies of Class AB (Fig. 1a) and Class D (Fig. 1b) amplifiers over a range of output powers.

Class-AB



Class-D

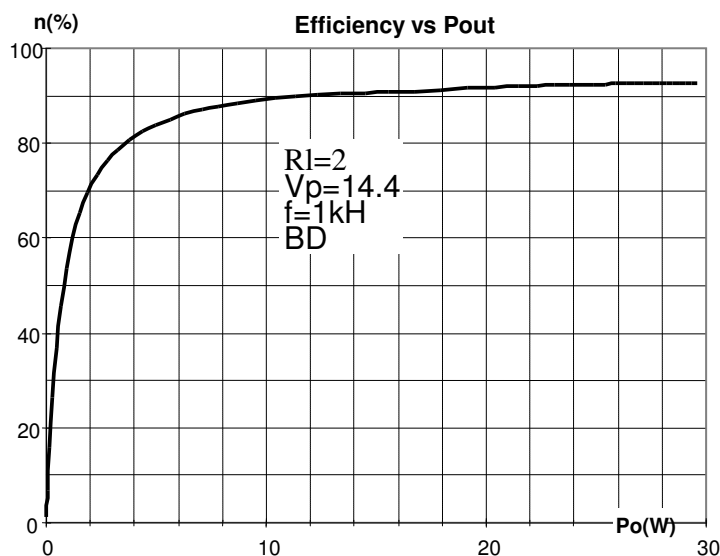


Figure 1. Class D amplifiers provide better efficiency over a wider range

It should be kept in mind that the two approaches are not mutually exclusive. In fact, innovative engineering often uses hybrid solutions. Automobile audio power is no exception. Design engineers will make their decisions based on several key considerations:

- The size, power requirements and power dissipation capability of the head unit
- Cost of the audio system
- Audio performance
- Mitigating interference from other electronic and electromechanical equipment.

Amplifier basics

In order to more fully understand the benefits and drawbacks of Class-D amplifiers, a short review of amplifier types is helpful.

- The output devices used in Class-A amplifiers conduct continuously during the entire cycle. In other words, a bias current is always flowing in the output devices. Class-A amplifiers deliver the most linear output and therefore create the least distortion. The downside is that they are inefficient, typically about 20% efficient.
- Output devices of Class-B amplifiers conduct for half the sinusoidal cycle (one in the positive region, the other in the negative). If there is no input signal, there is no current flow in the output devices. Class-B amplifiers have maximum efficiencies of 78.5% at maximum output power. But the interval between the time one device turns off and the other turns on creates linearity problems at the crossover point.
- Class-AB amplifiers combine the two types. Both devices conduct at the same time (although minimally) near the crossover point. Each device conducts for more than half but less than the whole cycle and this overcomes the non-linearity of Class-B designs. Class-AB amplifiers have efficiencies of about 50%. They are presently one of the most common types of power amplifier.
- Class-D amplifiers are switching or Pulse Width Modulation (PWM) amplifiers. Because the switches are either fully on or fully off, losses in the output devices is drastically reduced. Efficiencies of 90-95% have been reported. The audio signal is used to modulate a PWM carrier signal which drives the output devices. Since Class-D amplifiers are switchers, however, they create switching noise. The last stage is a low pass filter that removes the high frequency PWM carrier frequency.

Comparing Class-D to Class-AB

Class-AB amplifiers are today's standard in automotive audio applications for good reason. The technology is mature and well understood so applications are relatively easy to develop and do not require tweaks or re-spins. High volume production and keen competition between several IC manufacturers make prices reasonable. Bill-of-materials cost is further reduced because AB amplifiers require very few external components. And when comparing them to the initial product offerings of Class-D amplifiers, AB amplifiers have the inherent advantage of not creating electromagnetic interference (EMI).

The shortcomings of AB amplifiers -- comparatively high power consumption and heat dissipation caused by 50% operating efficiency -- are only becoming important as audio

systems become more sophisticated. A new shortcoming in the head unit will be that AB amplifiers are not useful with supply voltages above 18V for higher output power due to their increased power dissipation.

In addition to the benefits derived from its 90% operating efficiency, Class-D amplifiers can be designed with a digital interconnect to the Digital Signal Processor (DSP) that processes the audio and this saves the DSP the cost of an integrating A-to-D converter. (Class-AB amplifiers have primarily an analog link -- but it is a misnomer to call Class-D "digital" amplification.) Finally, Class-Ds can be integrated into 60-V power distribution mains.

The case for six channels

Most high volume cars manufactured today have four audio channels that feed eight speakers. In addition, the amplifier must support the full audio frequency range and the bass and mid-tone speakers typically share the same channel and power amplifier. This last accommodation to the four-channel configuration can create resonances in the door (see Figure 2).

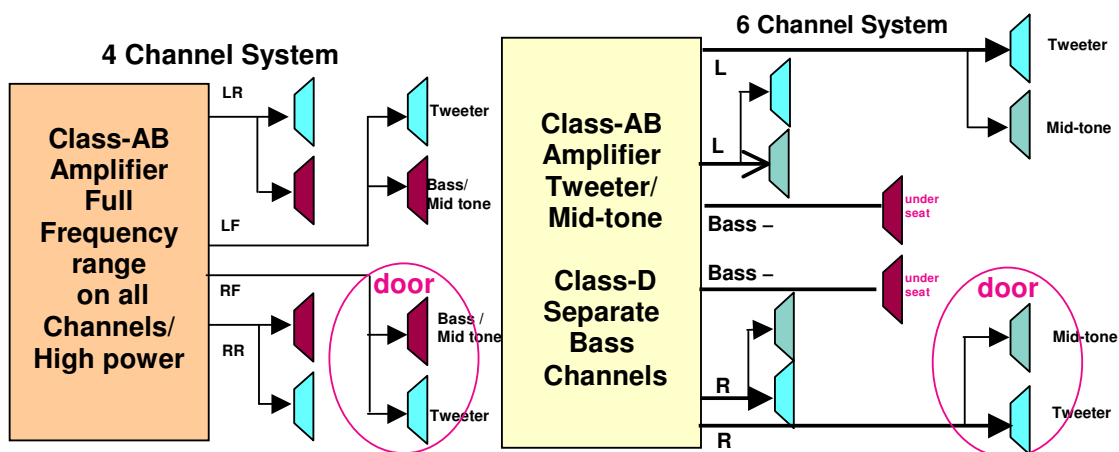


Figure 2. Four-channel versus six-channel audio architectures

Adding two channels solves several problems. First, it allows the power-hungry bass speakers to be driven independently over the two new channels to speakers under the front seats of the car. Door resonance is eliminated. Higher sound fidelity is also possible because all of the speakers are not obligated to operate over the entire frequency range.

But as any automotive audio designer will tell you, space and heat dissipation restrictions limit the power dissipation of the head unit to 20 W. The conventional way around this problem is to route some of the speakers to an external amplifier box in the trunk unit. While feasible, this solution increases overall system complexity and cost.

The judicious use of Class-D amplifiers provides a cost-effective answer. Starting with conventional amplifier values, a 55% efficient AB amplifier would dissipate 4.5 W. A 94% efficient Class- D amplifier would dissipate 0.6 W.

Using six Class-AB amplifier channels would result in a total of 27W power dissipation - 7W more than the value typically considered the maximum for a head unit. (See Figure 3, Case A.) But mixing the two types of amplifiers would meet the power budget even if only two Class-Ds were used, which would most likely be for the bass speakers. The bottom row of Figure 3 shows the difference between 20W and the total power dissipation of the particular configuration.

Output power	Case A: 1W / Ch	Case B: 1W / Ch	Case C: 1W / Ch	Case D: 1W / Ch
Channel configuration	6 x Class AB	4 x Class AB + 2 Class D	2 x Class AB + 4 x Class D	6 x Class D
Class AB dissipation	6 x 4.5W	4 x 4.5W	2 x 4.5W	
Class D dissipation		2 x 0.6W	4 x 0.6W	6 x 0.6W
Total power dissipation	27.0 Watt	19.2 Watt	11.4 Watt	3.6 Watt
Head Unit Power Limitation: 20 Watt	+ 7 Watt	-0.8 Watt	-8.6 Watt	- 16.4 Watt

Figure 3. Using as few as two Class-D amplifiers can make a six-channel system an optimal cost performance feasible for a head unit.

The cost of Class-D amplifiers probably makes Case B the most likely choice for a mid-range vehicle. But looking into the future -- particularly the future of the "premium audio sound system" market (and higher voltage power rails) -- Class-D amplifiers are likely to expand their market penetration.

The audio systems of a premium vehicle may support at least eight and as many as 22 channels -- and many of these would be in the trunk unit. Without incorporating Class- D amplifiers into the system, supporting large numbers of channels would be a nearly impossible task.

In their never-ending balancing act between cost and quality goals, design engineers will find many combinations of Class-AB and Class-D amplifiers. Class-Ds will find their initial niches where low power dissipation is critical and also (somewhat surprisingly) in applications where very high power output is required. These applications include greater than 90W systems where stereo Class-Ds are a good fit. The options, however, are likely to fall into four categories:

- Premium: 8 to 22 channels driven by a combination of Class-AB and Class-D with over 28W/channel goal.
- Mid-range sound **optimized for low power dissipation**: 4 to 6 channels all driven by Class- D with a goal of greater than 25W/channel.
- Mid-range sound **optimized for cost**: 4 to 6 channels all driven by a combination of Class-AB and Class- D amplifiers

- Basic sound: 2 to 4 channels with all AB driven with a goal of less than 28W/channel

Taming the Class-D for automotive

The automotive environment is challenging for Class-D applications. All the knowledge and skill of a semiconductor vendor with plenty of experience in Class-D amplifiers and automotive applications needs to be applied to design an outstanding product.

For starters, I²C control has to be included because automotive designs require it. Beyond that, the challenges become more difficult. The output voltage of a Class-D is influenced by the supply voltage, for example, and the supply voltage in a car is not constant. Measures have to be taken for supply ripple voltage rejection. The best way to accomplish this is to use a negative feedback loop. Using a second-order feedback loop provides superior ripple rejection.

As previously mentioned, EMI caused by switching is one of the most important Class-D problems and a very difficult one to solve. At the design level, EMI can be mitigated by phase staggering, frequency hopping, and AD/BD modulation.

But NXP has gone a step further by devising and patenting a solution that designs EMI suppression into the amplifier itself.

Current spikes that contribute to EMI are created as a result of the dead time between the transistors in the amplifier switching. During the dead time, a charge builds up in the body diode and this charge is released as a current spike as shown in Figure 4 where the red line indicates the spike.

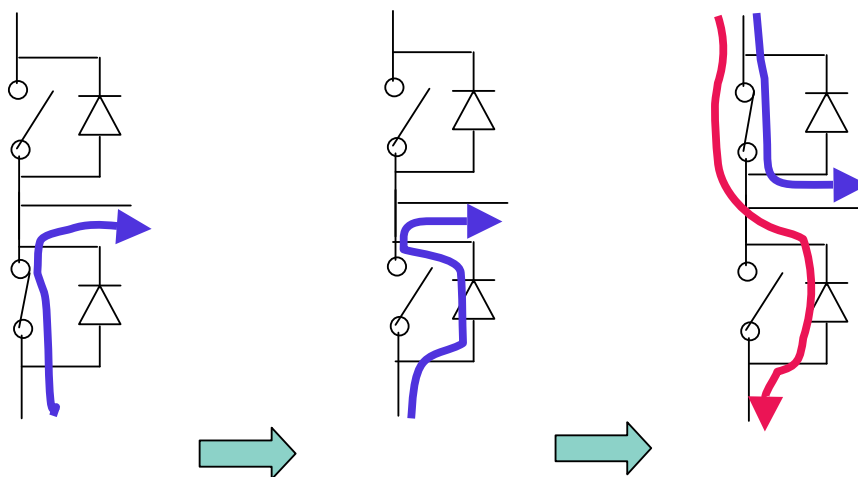


Figure 4. Dead-time induced current spikes cause EMI

The obvious solution is to eliminate dead time. To accomplish this, NXP turned to its semiconductor fabrication expertise. Silicon-on-Insulator (SOI) technology is ideal because all components are isolated by oxide. When an output falls below ground no

charge is built up in the substrate of the device, which reduces the reverse recovery time and there is no cross talk to other channels.

NXP uses an **SOI Advanced Bipolar- CMOS-DMOS (ABCD)** technology to fabricate its Class-D amplifiers. In addition to taming EMI, this process has another advantage over bulk Bipolar -CMOS-DMOS (BCD) processes. It is not subject to latch-up, which can potentially destroy the device.

Conclusion

Class-D amplifiers are increasingly finding their way into automotive audio applications and will continue to win market share. By 2015 they may have 30% of the audio amplifier automotive market.

NXP's long experience in consumer electronics has provided it with an enormous amount of knowledge about Class-D amplifiers. This consumer experience is complemented by a similarly long history in automotive electronics, particularly car radios.

As Class-D amplifiers make their way into cars, NXP will not just be along for the ride. It will lead the way.