Keywords: class D, thermal, performance, heatsink, exposed, pad, TQFN

APPLICATION NOTE 3879

Thermal Considerations for a Class D Amplifier

Aug 16, 2006

Abstract: A Class D amplifier provides much better efficiency and thermal performance than a comparable Class AB amplifier. Despite these improvements, a Class D amplifier's thermal performance must be considered. This application note examines the thermal performance of Class D amplifiers and employs general examples to illustrate good design practices.

Continuous Sine Wave vs. Music

When a Class D amplifier is evaluated in the lab, a continuous sine wave is often used as the signal source. Although this is convenient for measurement purposes, it represents a worst-case scenario for thermal loading on the amplifier. It is not uncommon for a Class D amplifier to enter thermal shutdown if driven near maximum output power with a continuous sine wave.

Audio content, both music and voice, has a much lower RMS value relative to its peak output power. The ratio of peak to RMS value, known as crest factor, is typically about 12dB for voice and 18dB to 20dB for musical instruments. **Figure 1** shows an audio signal in the time domain along with a sine wave. Both are measured for their RMS values by the oscilloscope. Although the audio signal has a slightly higher peak value than the sine wave, its RMS value is almost half that of the sine wave. Also, the audio signal displayed corresponds to a burst of music; average values will be even less than that shown. Therefore, although an audio signal may reach peaks similar to that of a continuous sine wave, its thermal impact on the Class D amplifier is highly reduced. If the thermal performance of a system is being evaluated, it is important to use actual audio signals rather than sine waves for testing. If sine waves must be used, the thermal performance will be less than the system's actual capacity during normal use.

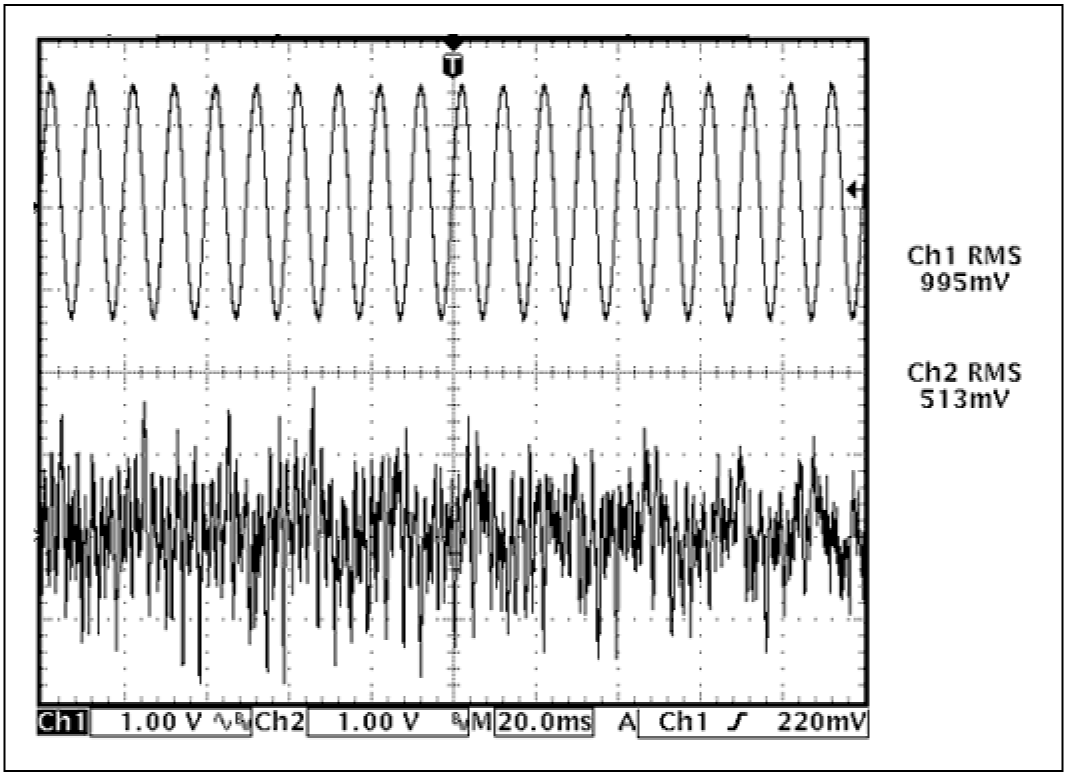

Figure 1. The higher RMS level of a sine wave vs. an audio signal predicts the additional thermal burden placed on a Class D amplifier when tested with a sine wave.

PC Board Thermal Considerations

In an industry-standard TQFN package, the exposed pad is the primary path for heat to move away from the IC. For a package that has a bottom-side exposed pad, the PC board and its copper are the Class D amplifier's primary heatsink. When working with a Class D amplifier mounted on a typical PC board, as shown in **Figure 2**, the following directions should be helpful: Solder the exposed pad to a large copper polygon. Add as much copper as possible from this polygon to any adjacent pin on the Class D amplifier as well as to any adjacent components, provided these connections are at the same potential. In this particular case, the copper connects the upper right side and the lower right side of the thermal pad (Figure 2). These copper paths must be as wide as possible, as they contribute to the overall thermal capability of the system.

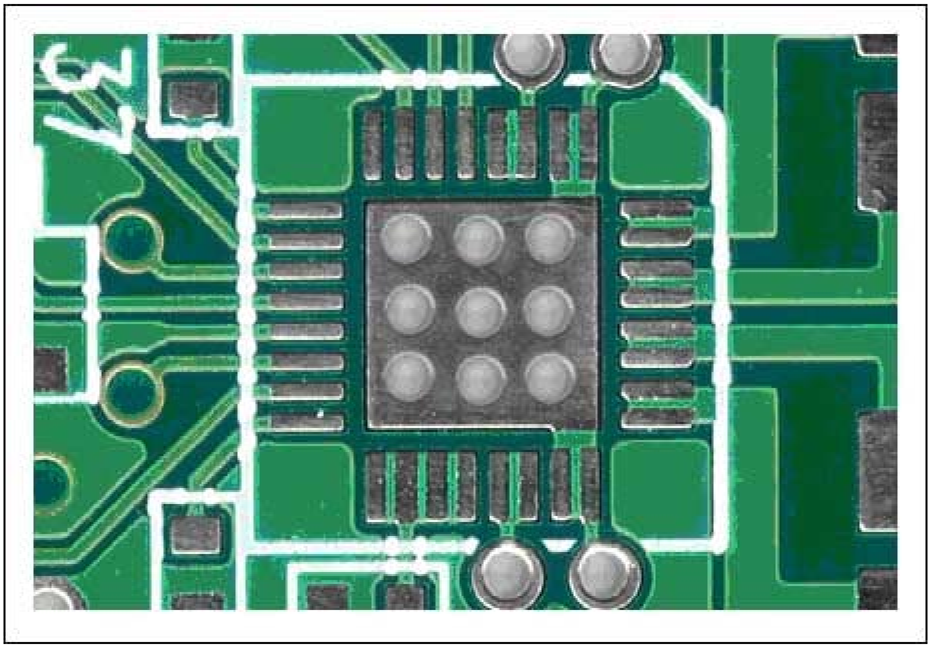

Figure 2. The exposed pad is the primary thermal path away from a Class D amplifier when it is housed in a TQFN or TQFP package.

The copper polygon to which the exposed pad is attached should have multiple vias to the opposite side of the PC board, where they would connect to another copper polygon. This polygon should be as large as possible within the system's constraints for signal routing.

Additional improvements are possible if all traces from the device are made as wide as possible. Although the IC pins are not the primary thermal path out of the package, they do dissipate a small amount of the heat. **Figure 3** shows a PC board in which a wide trace connects the Class D amplifier outputs to two inductors on the figure's right side. In this case, the copper windings of the inductors provide an additional thermal path away from the Class D amplifier. The total improvement is no more than about 10%, but it could make the difference between acceptable thermal performance and thermal problems.

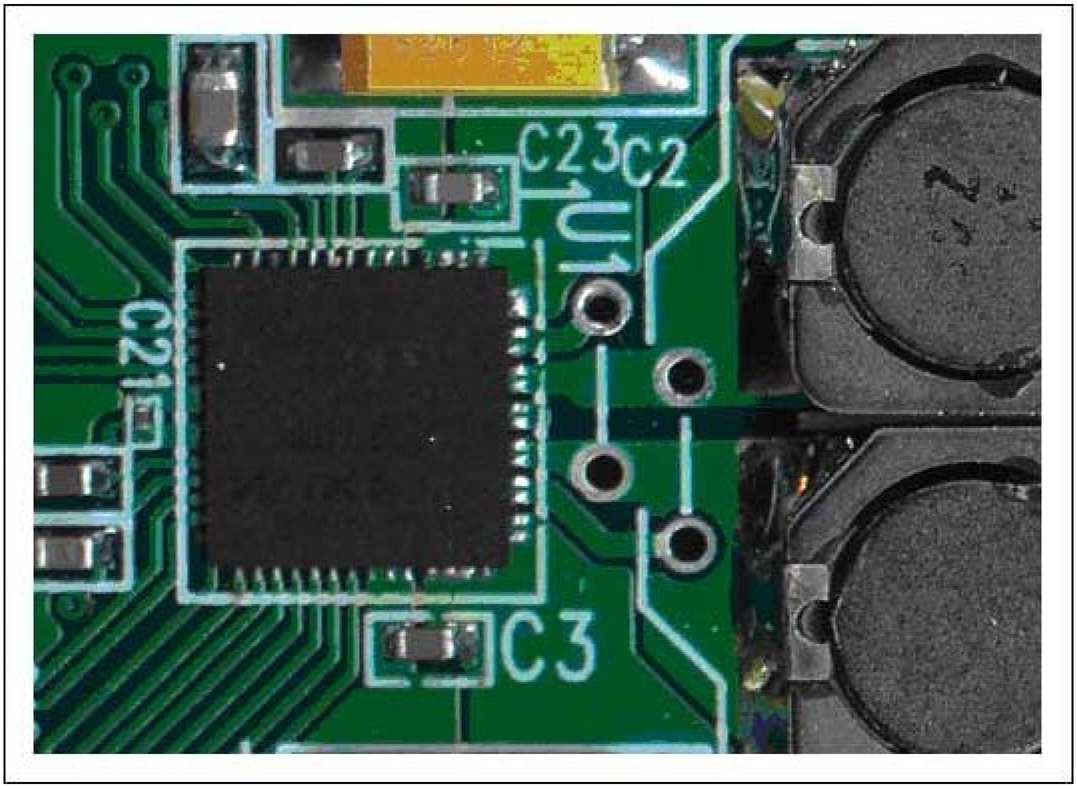

Figure 3. The wide traces to the right of the Class D amplifier help conduct heat.

Auxiliary Heatsinking

When Class D amplifiers are operating at higher ambient temperatures, it is possible to improve the thermal performance of a PC board with the addition of an external heatsink. The thermal resistance of such a heatsink must be kept as low as possible to maximize its performance. With a bottom-side exposed pad, the lowest resistance thermal path is on the bottom of the PC board. The top side of the IC is not a significant thermal path for the device, and therefore is not a cost-effective location for a heatsink. **Figure 4** shows an example of a PC-board-mounted heatsink (218 series, available from Wakefield Engineering). This heatsink, soldered to the PC board, is a good compromise between size, cost, ease of assembly, and thermal performance.

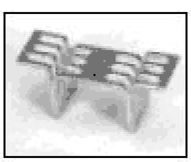

Figure 4. An SMT heatsink, such as the one pictured here, may be needed when a Class D amplifier is operated at higher ambient temperatures. (Photo courtesy of Wakefield Engineering.)

Thermal Calculations

The die temperature of a Class D amplifier can be estimated with some basic calculations. The temperature in this example is calculated for the following conditions:

- T_{AM} = +40°C
- P_{OUT} = 16W

- Efficiency (η) = 87%
- Θ_{JA} = 21°C/W

First the Class D amplifier's power dissipation must be calculated:

$$P_{DISS} = \frac{P_{OUT}}{\eta} - P_{OUT} = \frac{16W}{87\%} - 16W = 2.4W$$

This power dissipation is then used to calculate the die temperature, T_C, as follows:

$$T_C = T_A + P_{DISS} \times \Theta_{JA} = 40°C + 2.4W \times 21°C/W = 90.4°C$$

From these numbers, we can conclude that the device will operate with reasonable performance. It is important to start these calculations based on a realistic estimate of the ambient temperature inside the system. Very seldom do these systems have the luxury of +25°C as the actual ambient temperature.

Load Impedance

The on-resistance of the MOSFET output stage in Class D amplifiers affects both the efficiency and the peak-current capability. Reducing the peak current into the load reduces the I^2R losses in the MOSFETs, thus increasing efficiency. To keep the peak currents low, choose the highest impedance speaker that can still deliver the desired output power within the voltage swing limits of a Class D amplifier and its supply voltage, as in **Figure 5**. In this case, assume that the Class D amplifier has an output-current capability of 2A and a supply-voltage range of 5V to 24V. A 4Ω load will exceed this 2A current limit at supply voltages of 8V and above, with a corresponding maximum continuous value of 8W. If 8W is an acceptable output power level, consider using a 12Ω speaker and a supply voltage of 15V. Then, the peak current is limited to 1.25A, with a corresponding maximum continuous output power of 9.4W. Furthermore, the 12Ω load will operate with 10% to 15% higher efficiency than the 4Ω load, resulting in lower power dissipation. Actual efficiency improvements will vary with different Class D amplifiers. Although most loudspeakers are either 4Ω or 8Ω, other impedances are available that can provide a more thermally efficient solution.

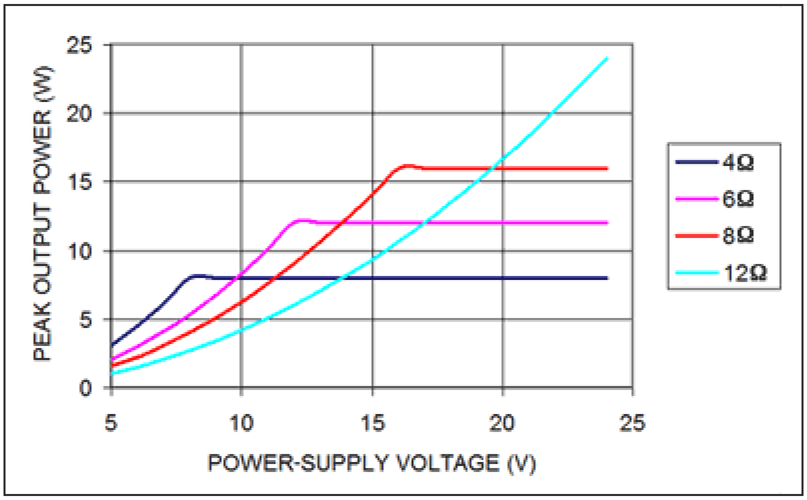

Figure 5. Selecting an optimal impedance and supply voltage maximizes output power.

Another consideration is load impedance across the audio frequency band. A loudspeaker is a complex electromechanical system with a variety of resonances. In other words, an 8Ω speaker usually exhibits an 8Ω impedance within only a very narrow range. For much of the audio bandwidth, the impedance is higher than the nominal specified, as shown in **Figure 6**. Over much of the audio bandwidth, this loudspeaker has an actual impedance that is much higher than its nominal value of 8Ω. Unfortunately, this impedance is usually reduced by the addition of a tweeter and a crossover network. The total system impedance must be considered to ensure adequate current and thermal capability.

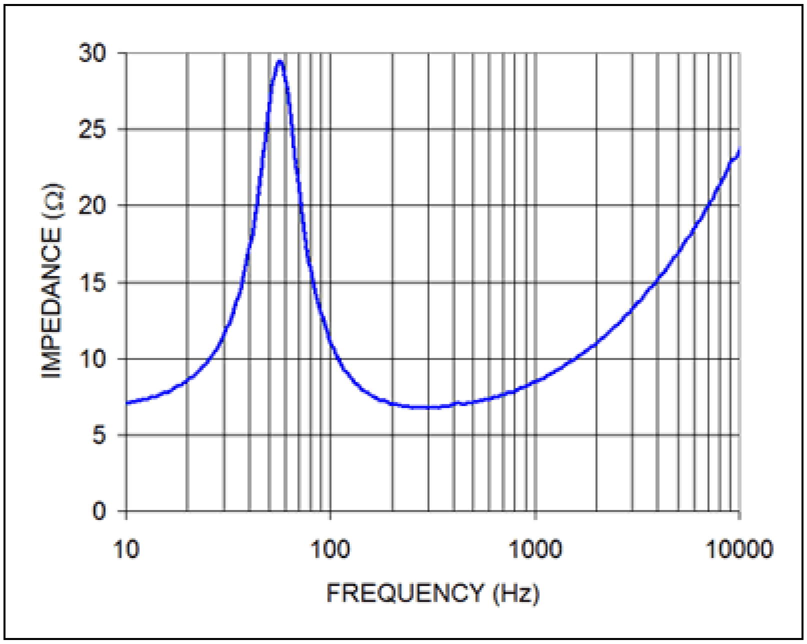

Figure 6. The impedance of this 8Ω, 13cm wide-range loudspeaker varies significantly with frequency.

Conclusion

Class D amplifiers provide significant improvement in efficiency over Class AB amplifiers. Although this efficiency reduces the thermal considerations during system design, it does not eliminate them. However, by using good design practice and establishing realistic expectations, Class D amplifiers make audio system design simpler.

Related Parts		
MAX9704	10W Stereo/15W Mono, Filterless, Spread-Spectrum, Class D Amplifiers	Free Samples
MAX9741	12W+12W, Low-EMI, Spread-Spectrum, Stereo, Class D Amplifier	Free Samples
MAX9742	Single-/Dual-Supply, Stereo 16W, Class D Amplifier with Differential Inputs	Free Samples
MAX9744	20W Stereo Class D Speaker Amplifier with Volume Control	Free Samples
MAX9768	10W Mono Class D Speaker Amplifier with Volume Control	Free Samples

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