Consider Thermal Dissipation In Class D Audio Power Amplifiers

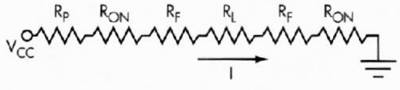
JIHAD HAMMOUD | Ford Motor Co., Dearborn, Mich.
jhammou3@ford.com

Designers of multimedia products must provide high-quality audio functions, including high-output speaker modes. This places greater demand on the system's audio amplifiers. Linear amplifier efficiency is about 50%, so a small increase in output power comes at the cost of a large increase in current consumption—and excessive heat dissipation—which typically requires bulky heatsinks. These thermal considerations are onerously expensive in automotive audio systems, where space and cost are at a premium.

Class D amplifiers, however, have maximum power dissipation at peak output power. When playing music, the amplifier spends very little time at peak output power, resulting in lower rms output power. This feature allows for a much smaller heatsink than linear amplifiers and thus becomes a tremendous advantage to automotive OEMs. Head units can offer extra output channels without the need for an expensive external amplifier. In addition, the sound quality is high, packaging and heat-generation costs are minimized, and it saves on the power supply.

Class D heatsinks can be safely sized for half the peak output power. However, the designer must still determine the correct heatsink size, cost, and application. The amplifier's pc-board design can also help minimize heat dissipation. Using large IC copper pads and maximizing the widths of all pc traces that connect to the IC can minimize power dissipation.

The Class D output transistors operate in a switch mode from full "On" to full



1. A simple series arrangement of the appropriate resistances serves as a dc equivalent circuit for a typical Class D amplifier.

"Off," spending very little switch-time in the linear regions, so little power is lost to heat. If the transistors have a low on resistance, little voltage drop occurs across them, which further reduces power losses.

The dc equivalent circuit for a typical Class D amplifier with two transistors "On" is simply a string of series resistances: R_{ON}, the output conduction loss for each transistor; R_P, the parasitic resistances of the metal interconnects, lead frame, and pc-board traces; R_F, the filter resistances; and R_L, the load resistance *(Fig. 1)*. Another contributor to power losses is the switching delay in the output resistors *(Fig. 2)*. The overall system efficiency can then be estimated:

$$\eta = \frac{P_{LOAD}}{P_{SUPPLY} + P_{SWITCH}} = \frac{I_{OUT}^2 R_L}{I_{OUT}^2[2(R_{ON} + R_F) + R_P + R_L] + P_{SWITCH}}$$

As an example, consider a two-channel Class D amplifier that drives two 4-Ω subwoofers, operates in a 60°C ambient, with full-power efficiency of 90%, off a 14-V dc supply, and has an IC junction resistance (ΘJA) of 5°C/W. For a sine-wave signal, the output peak current limit is:

$$I_{PEAK} = (V_{PEAK}/R_L) = 3.5\ A$$

This corresponds to output peak power of $P_{LOAD\ PEAK} = I^2_{PEAK}R_L = 49$ W/channel and rms output power of $P_{LOAD\ RMS} = P_{LOAD\ PEAK}/2 = 24.5$ W/channel. Using the efficiency formula:

$$\eta = P_{LOAD\ RMS}/(P_{LOAD\ RMS} + P_{DISS})$$

the total heat dissipation is about 6 W.

The maximum junction temperature isn't directly related to amplifier performance. However, junction temperature is significant in defining heatsink size because a higher T_J can handle higher power losses. The die temperature is $T_J = T_A + P_{DISS} \times \Theta_{JA} = 90°C$, which is within the device maximum junction temperature of 150°C.

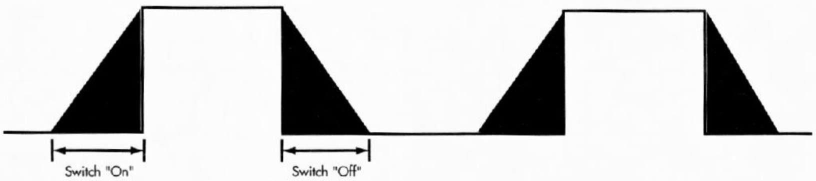
In a practical example using a music signal, the designer must consider the peak amplitude to average ratio of the signal (crest factor). A typical music signal has a crest factor of 3 to 10. In decibels, that's 10 to 20 dB [$P_{dB} = 20\log_{10}(V_{PEAK}/V_{REF})$]. So to pass a music signal's loudest portions without distortion, the amplifier needs 10 to 20 dB of dynamic headroom compared to the average power output.

With the Class D amplifier operating from a 14-V supply, a 98-W peak is available. Converting that to dB:

$$P_{db} = 10\log(P_{PEAK}/P_{REF}) = 10\log(98/24) = 6\ dB$$

Subtracting the crest factor restriction to obtain the average listening level without distortion yields:

6 dB − 20 dB = −14 dB
(less than zero means softer)
6 dB − 10 dB = −4dB



2. The switching delays in the output resistors also contribute to the overall power losses in the amplifier.

Converting back into rms output power:

$$P = 10^{P_{dB}/10}$$
$$P_{REF} = 955\text{ mW (for } -14\text{ dB)}$$
$$= 10\text{ W (for} -4\text{ dB)}$$

For P_{PEAK} = 98 W and an rms output power of 955 mW, total power dissipation is 0.2 W and maximum junction temperature is 61°C. For the 10-W rms output, total power dissipation is 2.2 W and maximum junction temperature is 71°C. Therefore, the maximum power dissipation for an audio CD signal without distortion happens at an average listening level of −4 dB.

These examples show that a sine-wave signal leads to considerably higher power dissipation than a real audio signal. Thus, a sine wave can serve as an extreme thermal test load that can drive the amplifier to thermal shutdown.

Presently, the Class D IC design meets Ford's EMC requirements, which allowed Ford to exploit the Class D ICs in the standalone amplifiers for model year 2009.

JIHAD HAMMOUD, *senior thermal engineer, holds a PhD in mechanical engineering from the University of Akron, Ohio, and a PE license from the state of California.*

ED ONLINE 17661