Practical Thermal Design With DC/DC Power Modules

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ABSTRACT

All DC/DC converters dissipate power in the form of heat. This heat has to be managed properly so that the converter maintains operation within the recommended temperature limits. Usually, the copper on the printed circuit board (PCB) is utilized to help dissipate the heat. This application note outlines a design procedure to quickly estimate the minimum required copper area on the PCB for a successful thermal design with DC/DC power modules.

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1   Introduction

A user just designed their DC/DC converter, and it turns out it is not 100% efficient. This is not surprising and means that some heat is always generated in the power conversion process. This heat has to be dissipated properly into the ambient because high temperatures can affect the lifetime, as well as the operation of the converter and the nearby circuits. The PCB design and copper area is very important for a good thermal design of any DC/DC power converter but is often difficult to predict how much PCB copper area is really enough. Given the application requirements (for example, input voltage, output voltage, output current, and maximum ambient temperature), how would a user estimate the minimum required board area to keep the DC/DC converter solution cool enough? This application note provides a quick design procedure to get users started.

2   Power Modules and Thermal Design

Using power modules for DC/DC switching regulator design can greatly simplify the power solution and achieve excellent efficiency, solution size, and EMI compliance. For solutions using power modules, all of the relevant power dissipation components are part of the module package. Because of this, the thermal design for the particular application can also be greatly simplified if the package is well-characterized by the module manufacturer. Many of TI's power module packages are already thermally characterized on several different board areas. This characterization can then be used to plot the relationship between the package thermal resistance-to-ambient and the available board copper area, as illustrated in Figure 1. Having this resistance model plot allows the power designer to easily estimate a starting point for the thermal dissipation area based on the expected power dissipation and maximum ambient temperature.
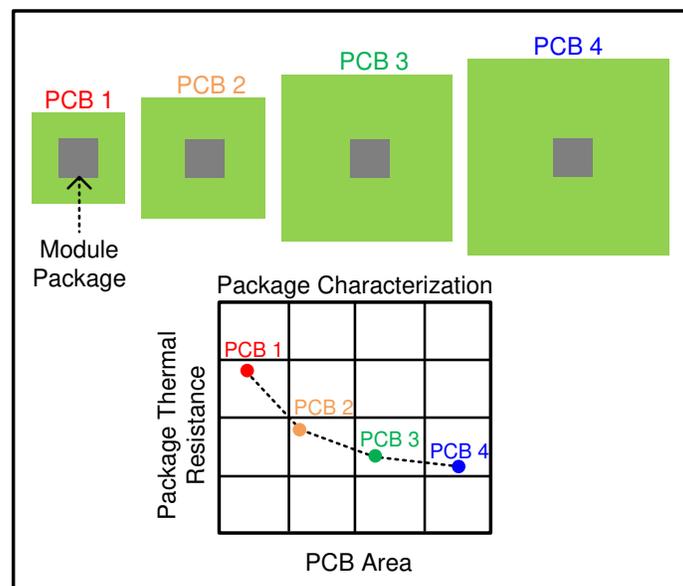

Figure 1. Package Characterization and Thermal Resistance Plot Versus Board Area

3   Thermal Design Steps

1. Find the power dissipation in the module package.
2. Calculate the required thermal resistance for the application.
3. Estimate the minimum copper area to achieve the required thermal resistance to the ambient.

3.1   Look up or Calculate the Power Dissipation

Step 1 in the thermal design process is to look up or calculate the module power dissipation, P_D, for the design specifications. The data sheet for each power module usually has power dissipation curves for many input and output voltage conditions. If the curves are available, the power dissipation can be looked up directly. Alternatively, the efficiency curves in the device datasheet can be used to calculate the total power dissipation. Since all of the significant power dissipation is part of the module package, the calculation is fairly simple.

$$P_D = P_O \times \frac{1-\eta}{\eta}$$

where

- P_O is the output power (I_{OUT} x V_{OUT})
- η is the conversion efficiency   (1)

3.1.1   Using Engineering Judgement

The power dissipation P_D:
The power dissipation of the converter normally increases at higher ambient temperature. For example, the power dissipation at 85°C ambient may be 10% to more than 30% higher than the dissipation at room temperature. The power dissipation at elevated ambient temperature may be available in the device data sheet already. It can also be obtained from testing the device on its evaluation board. Having the typical efficiency or power dissipation curves at room temperature is a good starting point, but using the power dissipation at elevated temperature results in a more accurate estimation of the required board area. Use conservative engineering judgement with the power dissipation parameter.

3.2   Calculate the Required Thermal Resistance

Step 2 is to calculate the maximum allowed thermal resistance to the ambient environment. This thermal resistance has to be low enough so that the device does not exceed its maximum operating junction temperature. The calculation for the maximum thermal resistance R_θ for the application is based on the power dissipation in step 1 and the maximum ambient temperature for the application.

$$R_\theta \leq \frac{T_{J\_MAX} - T_{A\_MAX}}{P_D}$$

where

- T_{J_MAX} is the maximum junction temperature allowed for the module. This can be 125°C. See the module data sheet.
- T_{A_MAX} is the maximum ambient temperature for the application.
- P_D is the power dissipation found in step 1.   (2)

3.2.1   Using Engineering Judgement

The ambient temperature T_{A_MAX}:
It must be noted that the power converter is usually not the only component on the board and there may be co-heating effects from other hot components nearby. This may affect the local T_{A_MAX} around the power converter. This parameter directly affects the required thermal resistance and may have to be adjusted higher to compensate for other hot components around the power solution. Use conservative engineering judgement with the ambient temperature parameter.

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3.3 *Estimate the Required Copper Area*

The thermal resistance to the ambient environment depends on the PCB copper area. Step 3 is to estimate the required copper area to achieve the necessary thermal resistance from step 2. This is done directly from the provided plots of package thermal resistance versus board area, such as Figure 2.
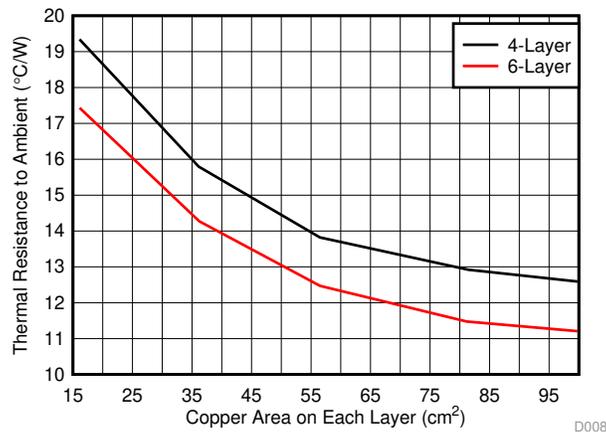

Figure 2. Thermal Resistance Versus PCB Copper Area for LMZM33606

For example, if R_θ for the application must be less than 15°C/W, then the PCB copper area for the LMZM33606 design using a 4-layer PCB must be at least 45 cm². This copper area on each layer is a good starting point for this design specification. More copper area achieves even lower thermal resistance and results in more conservative design with better margin.

4 Design Example with LMZM33606

The LMZM33606 is a 3.5-V to 36-V input, 1-V to 20-V output, 6-A power module in a QFN package. For this design example, consider an application with a typical 24-V input rail requiring 5-V output at 5-A peak current, as well as 80°C for the maximum ambient temperature T_{AMB_MAX}.
How large should the board be in this case to keep the module in the safe operating area?

Follow the thermal design steps:

1. Look up the power dissipation in the module package or calculate it based on the efficiency. In this case, the power dissipation information is readily available in the device data sheet. For 24-V input, 5-V output at 5-A load the power dissipation P_D = 3.2 W.

2. Consider the power dissipation P_D from step 1. The maximum junction temperature T_{J_MAX} for this module is 125°C. Consider an application with T_{AMB_MAX} = 80°C. Using P_D = 3.2 W, T_{J_MAX}= 125°C, T_{AMB_MAX} = 80°C, equation (2) above suggests that the maximum allowed package thermal resistance R_θ to the ambient for this application is 14°C/W.

3. Looking at Figure 2, to achieve 14°C/W of thermal resistance the estimated board copper area must be at least 55 cm² if using a 4-layer board.
   This copper area must be on every layer and must be connected to the PGND thermal pads of the package using thermal vias. Also, the copper thickness in this case is 70 μm (2-oz).

Many modules also include safe operating area (SOA) curves in their data sheets. The SOA curves specify the maximum ambient temperature for a particular input voltage, output voltage, and output current. The safe operating area curves are always applicable for a particular PCB copper area. The larger the board is, the better the SOA curve is. The data for the SOA curves is usually collected on the standard evaluation board for the product. The plot can be used as a sanity check for the above thermal resistance estimation. Here is the LMZM33606 safe operating area plot for the design example condition. This plot can be found in the product data sheet.
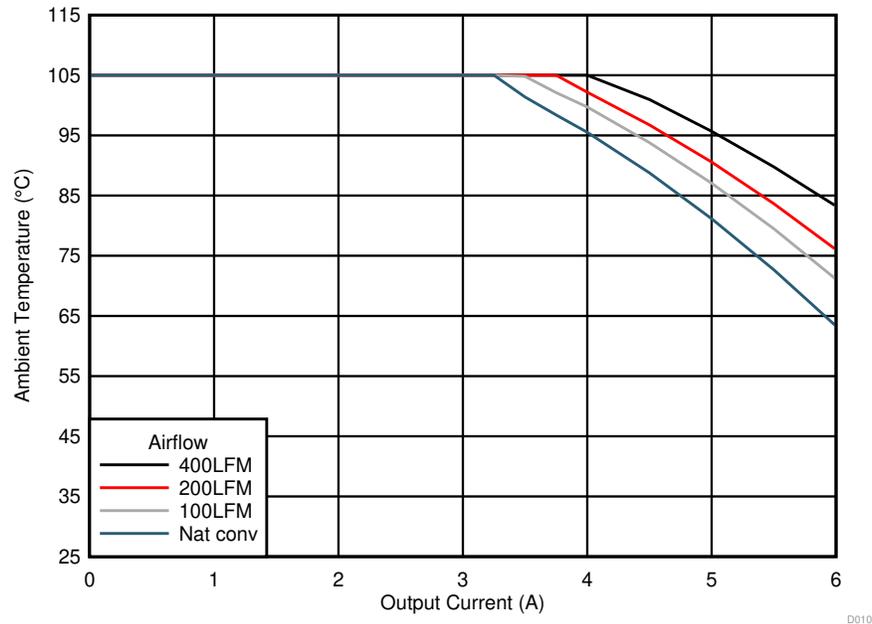
Figure 3. LMZM33606 SOA Curve for 24-V Input and 5-V Output

The standard 4-layer evaluation board for this device is 7.5 cm x 7.5 cm, which is 56 cm². Assuming natural convection, the plot in Figure 3 suggests that the maximum ambient temperature for 24-V input, 5-V output, and 5-A load is around 81°C. The estimated minimum area of 55 cm² in step 3 of the design example above for 80°C ambient temperature aligns well with the SOA curve.

5 Thermal Characteristics of Various DC/DC Module Packages

The following section contains several curves for typical thermal resistance versus PCB copper area for various DC/DC power module package types.

5.1 QFN Packages
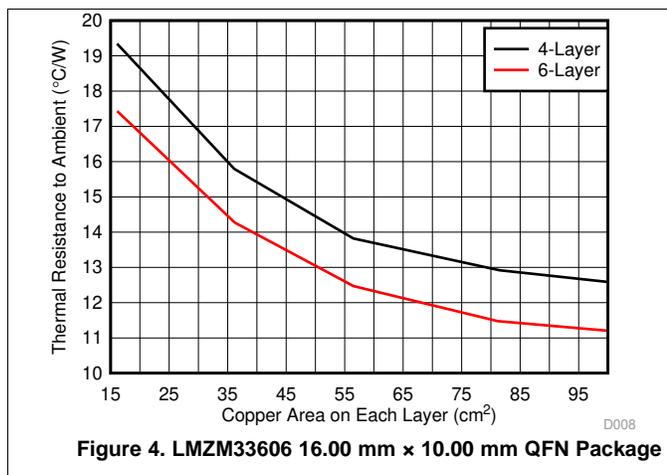
Figure 4. LMZM33606 16.00 mm × 10.00 mm QFN Package
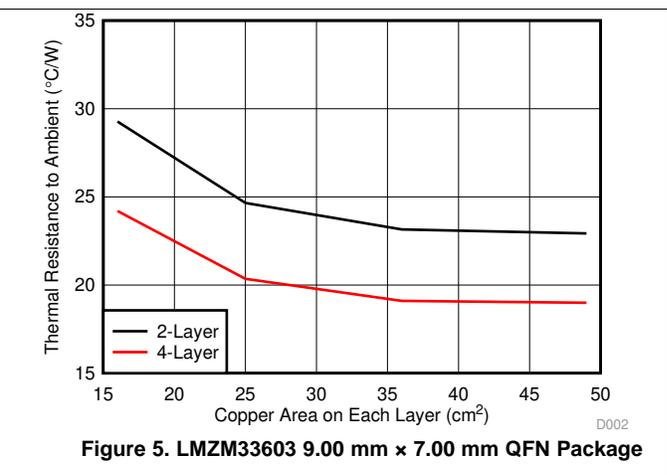
Figure 5. LMZM33603 9.00 mm × 7.00 mm QFN Package

Figure 6. TPSM53604 5.00 mm × 5.50mm QFN Package

Figure 7. TPSM846C23 15.00 mm x 16.00 mm QFN Package

Figure 8. LMZ31710 10 mm × 10 mm QFN Package

5.2 MicroSiP Packages

Figure 9. LMZM23601 3.80 mm × 3.00 mm MicroSiP Package

Figure 10. LMZ21701 3.50 mm × 3.50 mm MicroSiP Package

Figure 11. TPSM236R1 2.80 mm × 3.70 mm MicroSiP Package

5.3 Leaded Packages

Figure 12. LMZ14203(H) 10.16 mm × 9.85 mm TO-PMOD Package

Figure 13. LMZ23610 15 mm × 15 mm TO-PMOD Package
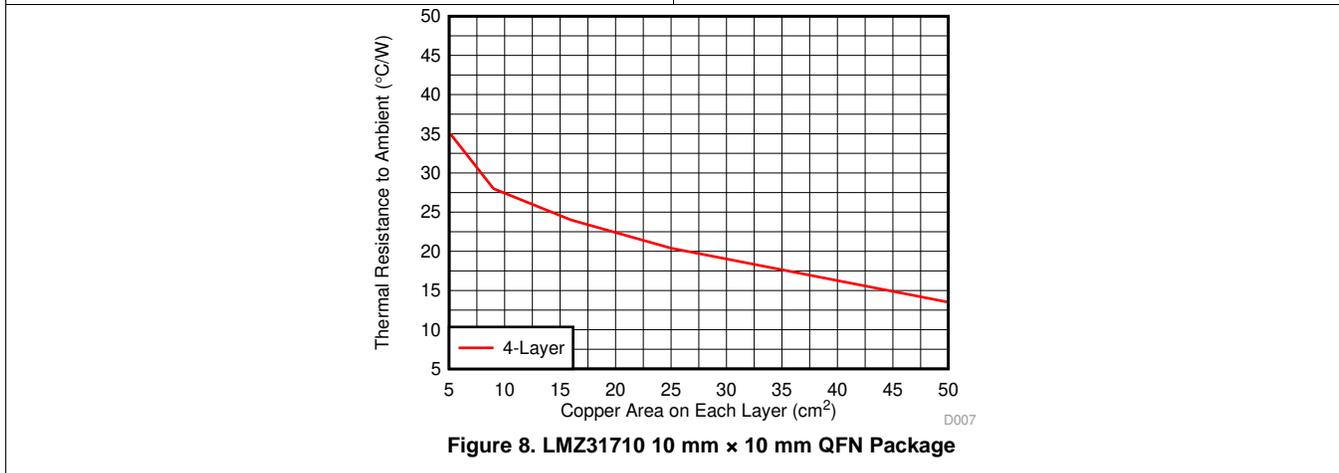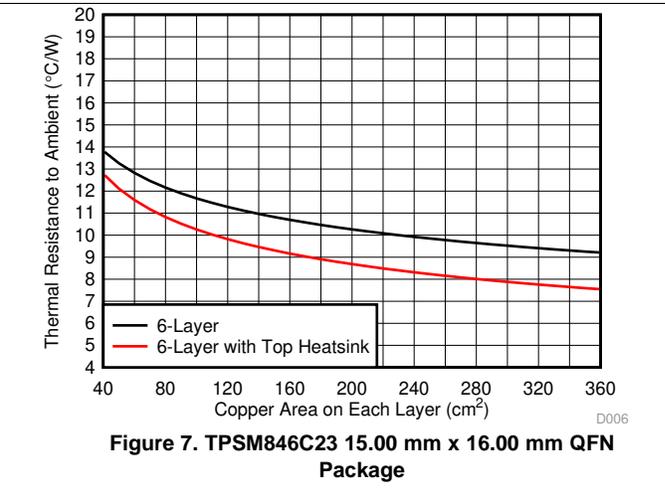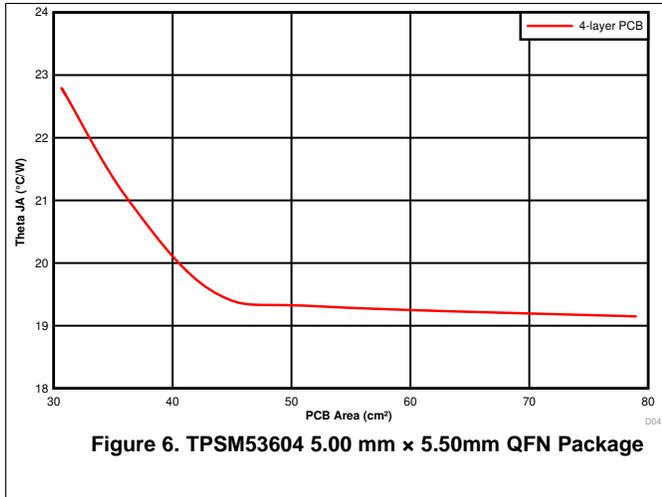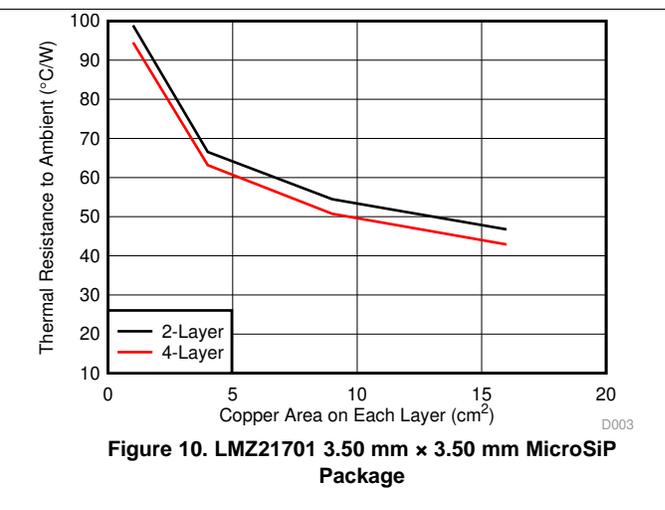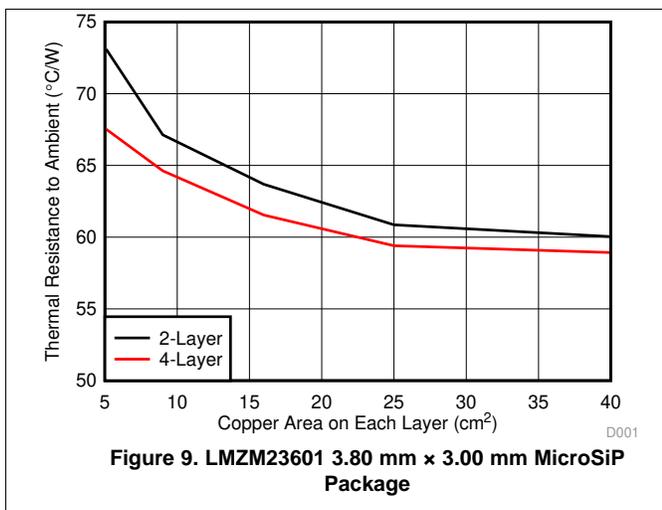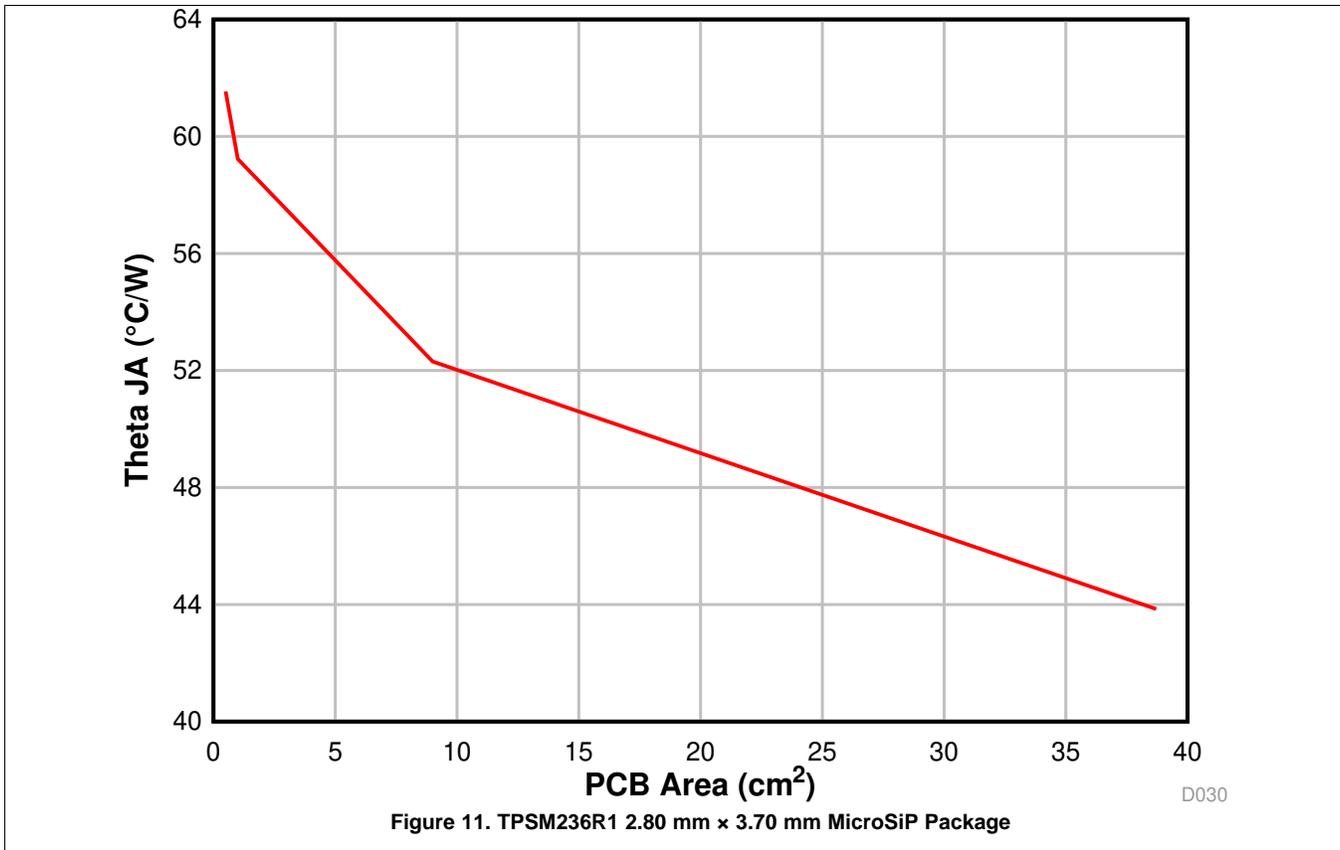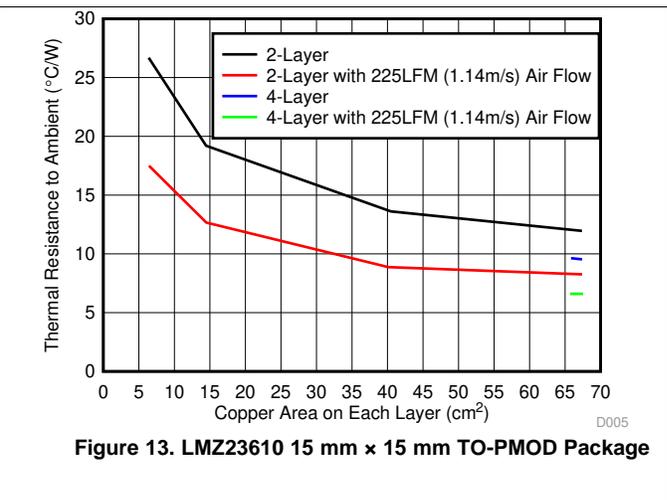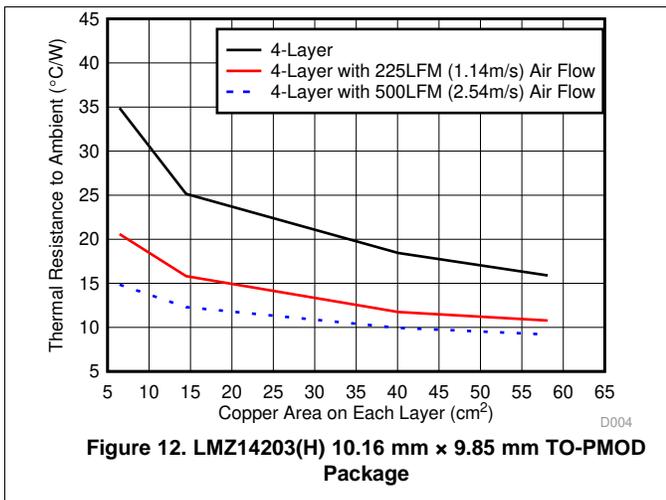
6 Conclusion

Every DC/DC converter dissipates some amount of power during the conversion process. The PCB copper area can be utilized to dissipate this power into the ambient and prevent overheating the converter above its operating temperature range. Using DC/DC power modules along with the provided practical thermal resistance vs board copper area plots can simplify the thermal design process. The provided design procedure considers the particular application conditions and offers a quick estimation for the minimum required copper area on the PCB.

7 References

- Texas Instruments, *AN-2020 Thermal Design By Insight, Not Hindsight* Application Report
- Texas Instruments, *AN-2026 The Effect of PCB Design on the Thermal Performance of SIMPLE SWITCHER® Power Modules* Application Report
- Texas Instruments, *LMZM33606 4-V to 36-V Input, 1-V to 18-V Output, 6-A Power Module* Data Sheet
- *Hot Air Rises and Heat Sinks: Everything You Know about Cooling Electronics Is Wrong*, ASME Press (Kordyban 1998).

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (October 2018) to A Revision   **Page**

- Added TPSM53604 5.00 mm × 5.50mm QFN Package 5
- Added TPSM236R1 2.80 mm × 3.70 mm MicroSiP Package 6