Application Report

Extended Temperature DC/DC Switching Regulator Solutions

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ABSTRACT

Many applications need electronics that operate up to the typical industrial ambient temperature range of -40°C to 85°C. Texas Instruments developed DC/DC switching regulators to satisfy quality needs and reliability beyond such temperatures. Devices developed by TI that can operate in *extended temperatures* (ET), have a junction temperature (T_J) range of -55°C to 150°C. This application report provides an overview of applications that require the use of switching regulators that can handle temperatures outside the common industrial range, the challenges encountered under these applications, and the solutions TI developed to overcome such challenges.

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1 Applications for Switching Regulators that require ET ratings

Most common applications requiring ET capabilities include:

- Aerospace and Defense
- Industrial
- Medical
- Military

Texas Instruments devices capable to operate in extended temperatures strive in space constrained applications and wide thermal requirements. Having -55°C on the low operating temperature allows capability for more applications, for example, powering components that might be placed externally to an aircraft and across many military applications.

2 Challenges for Switching Regulators in ET environments

When working with switching regulators, power is dissipated in the form of heat. This heat has to be managed properly so that the converter maintains operation within the recommended temperature limits. Otherwise, the lifetime and performance of the device will not meet expectations. Thermal management is one of the most important aspects of designing power supplies. The goal of thermal management is to keep the maximum junction temperature of the device at or below a safe value.

2.1 Solution Size vs. Thermals

Thermal management becomes a main point of concern especially in high density systems. Keep in mind that not only is the heat dissipated by the converter affecting itself and nearby circuits, but it is also experiencing heat from nearby components. It turns out that placing heat producing components too close together can have a larger effect on thermal performance than one would think. This is where an extended temperature device can be very beneficial. Figure 2-1 illustrates an example of a heat generating component in a defined *thermal footprint*. A thermal footprint is the area of the PCB that is part of the radiation and convection of the package. Usually, the copper on the printed circuit board (PCB) is used to help dissipate the heat. But, not all applications are flexible when it comes to board space. That is why in such circumstances, devices with extended temperature capabilities will strive.

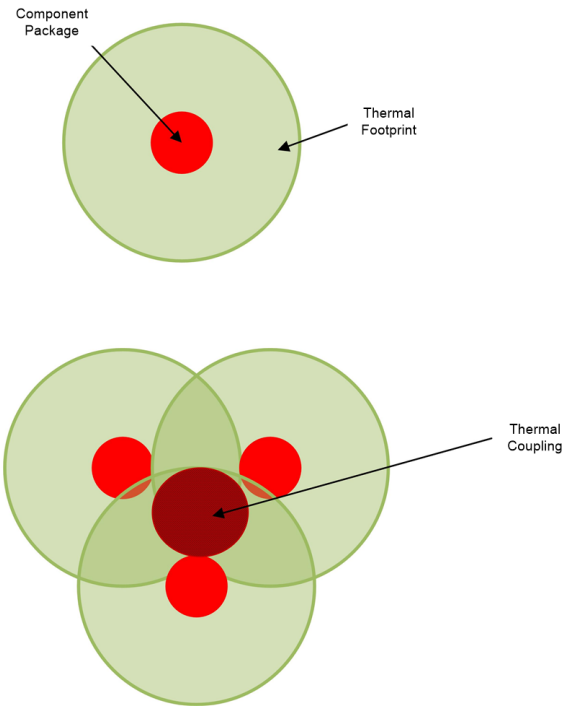


Figure 2-1. Example of Thermal Footprint Concept

2.2 Junction Temperature (T_J)

It is important to understand that the critical factor affecting device reliability and functionality is the junction temperature, not the ambient temperature even though they are interrelated. The lower the maximum ambient temperature, the easier it is to satisfy junction temperature for a given regulator. Meanwhile, a higher ambient temperature (hot) requires the use of a regulator with better thermal resistance.

Due to the nature of components changing performance with temperature, operating at cold temperatures can also influence the lifetime and performance of the device. The device can experience faulty conditions under cold temperatures such as poor start-up, stability and in some circumstance it might not start up at all.

3 Extended Temperature Solutions

Using TI's devices that are able to operate in ET environments can greatly simplify the power solution for your design. For example, LMR36015S, is designed to simplify implementation for a wide range of end equipment, including space critical applications and wide thermal requirements. The LMR36015S is in a HotRod package which enables low noise, higher efficiency, and smallest package to die ratio. The device requires few external components and has a pinout designed for simple PCB layout. See Figure 3-1 for a simplified schematic of the device.

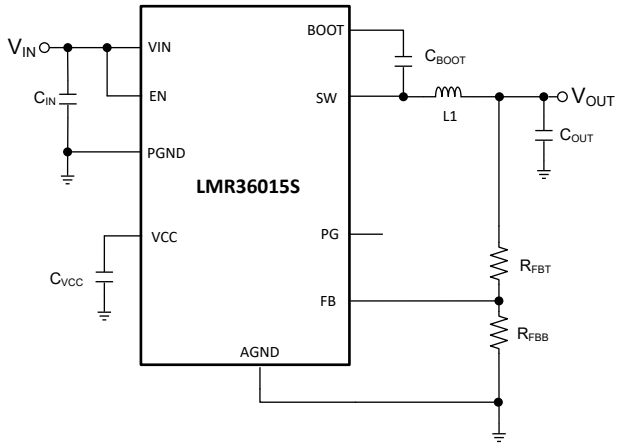


Figure 3-1. Simplified Schematic of LMR36015S

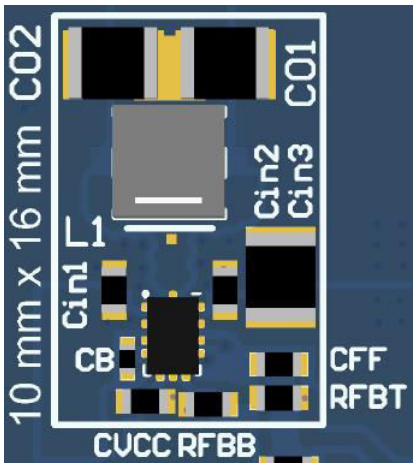


Figure 3-2. Solution Size of LMR36015S

3.1 Efficient PCB Thermal Design

The PCB copper planes act as heat sinks for the regulator. The area and thickness (weight) of the copper is important. Most of the heat will be dissipated to ambient through the layer that is on the same side as the converter. Figure 3-3 demonstrates a typical thermal performance curve for LMR36015S across different copper board area and a typical start-up waveform is shown in Figure 3-4.

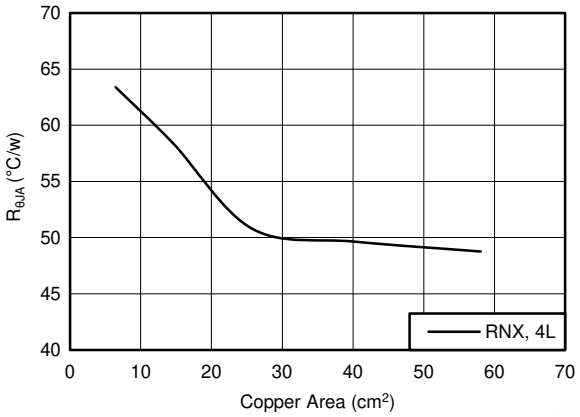


Figure 3-3. $R_{\theta JA}$ versus Copper Board Area for the VQFN (RNX) Package

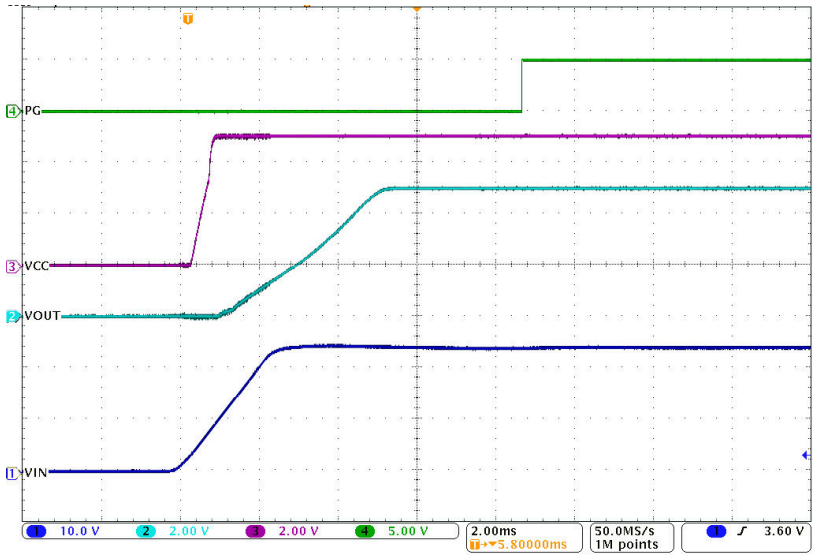


Figure 3-4. Start-Up Behavior at V_{IN} = 24 V, V_{OUT} = 5 V, I_{OUT} = 1.5 A at -55°C

3.2 Package Type

The type of package has a major impact on the thermal performance. TI offers many package types that provide the advantage of both good thermal performance and small size. For instance, HotRod is a thermally enhanced plastic package that uses a copper leadframe technology. It eliminates power device wire bonds by attaching the power device and/or die directly to the leadframe. This construction results in a cost effective advanced packaging that improves electrical performance over traditional leaded packages.

3.3 Power Modules

Power modules aim to simplify power supply design by integrating the power converter IC along with an inductor(s), a capacitor(s) and other passive components into a single package. The modules come in different type of packages depending on their voltage ratings, current ratings, and target applications.

For solutions using power modules, thermal characterization is greatly simplified since all relevant power dissipation components are integrated into the module package. TI's power modules are already thermally characterized to be reliable in many designs. The detailed characterization is provided in the data sheet, highlighting thermal capabilities at different power conditions, potential de-rated performance at higher output power conditions and ambient temperatures. The power module solution can greatly simplify the thermal design process and achieve faster time to market.

For example, the TPSM5601R5HE is 4.2-V to 60-V input, 1-V to 16-V output, 1.5-A power module in a Enhanced HotRod™ QFN package. Figure 3-5 and Figure 3-6 demonstrate a typtical thermal performance curve for the device.

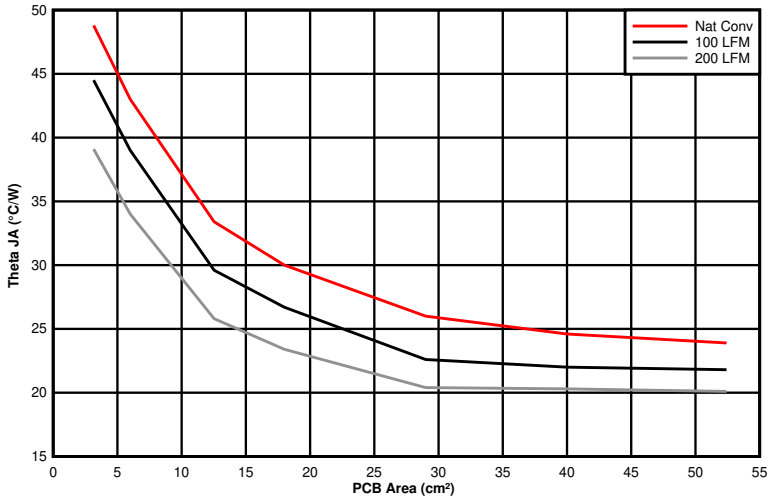
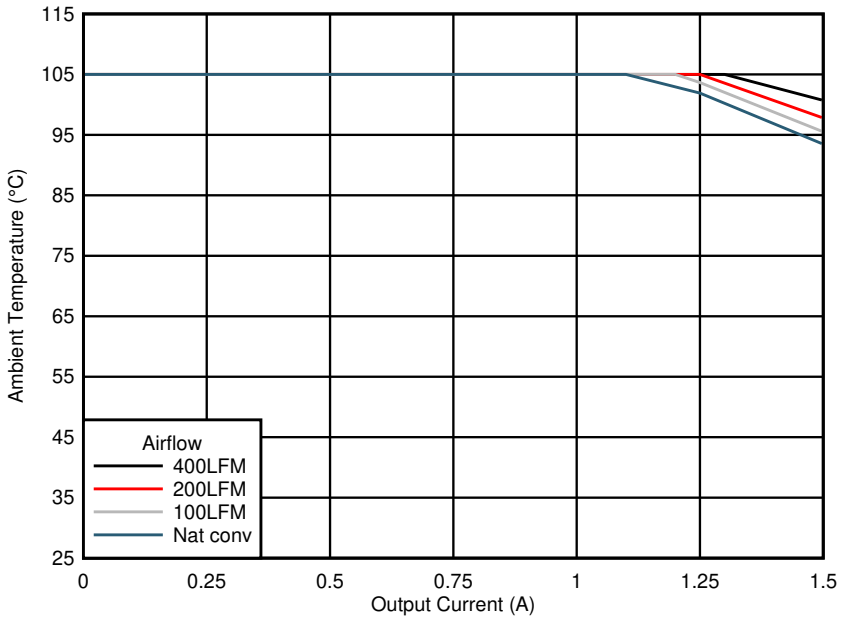


Figure 3-5. θ_{JA} vs PCB Area



Device soldered to a 63.5 mm × 82.5 mm, 4-layer PCB

Figure 3-6. Safe Operating Area (V_{IN} = 24 V, V_{OUT} = 5.0 V)

4 Summary

Every DC/DC switching regulator dissipates some amount of heat during the conversion process. A good thermal design will keep the junction temperature at a safe value under all operating conditions, but even in some applications the best thermal designs will not allow for the device to stay within its rated operating temperatures. It's important to note that the operating junction temperature and ambient temperatures are interrelated. Ambient temperatures have a great effect on convective and radiative heat transfers. That is why a switching regulator is not only being limited by its rated operating junction temperature, but also ambient temperature. An extended temperature rated device is a perfect solution for applications where temperatures are outside the standard industrial operating range of -40°C to 85°C and/or designed in a small solution size.

5 References

- Texas Instruments, *Semiconductor and IC Package Thermal Metrics* application report.
- Texas Instruments, *PCB Thermal Design Tips for Automotive DC/DC Converters*application report.
- Texas Instruments, *Bang For Your Buck - An Introduction to Buck Converter vs. Buck Power Module Comparison* application report.
- Texas Instruments, *Practical Thermal Design With DC/DC Power Modules* application report.
- Texas Instruments, *Soldering Considerations for Power Modules* application report.

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