Application Note

LM501x Thermals and Example PCB Design

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ABSTRACT

High-voltage, high-output power regulators require special attention when it comes thermal management. This application note highlights PCB copper area impact on power regulators' (for example, LM5013) thermal rise, in addition to, determining application limits.

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Trademarks

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1 Introduction

Thermal performance of power regulators often improves with increased copper area connected to its pins. The connection can be made in the component layer and inner layers. The metric which describes the increased PCB thermal performance with larger copper area is the $R_{\Theta JA}$. (see Section 5).

This application note serves as a resource to illustrate how increased PCB copper area (lower $R_{\Theta JA}$) results in a lower temperature rise of a power regulator. The LM5013 is used as example, but, these principles can be applied to most power regulators.

2 LM5013 PCB Comparison and Thermal Capability

The LM5013-Q1EVM was designed to showcase the small solution size shown in Figure 2-1 that Texas Instruments can offer for a high-voltage regulator. A consequence of the small Figure 2-2, is reduced thermal performance. The LM5013-Q1 100-V Input, Automotive 3.5-A Non-Synchronous Buck DC/DC Converter with Ultra-low IQ includes plots (Figure 2-3) that demonstrate how increased PCB copper area results in reduced $R_{\Theta JA}$. The equations used to perform the thermal analysis are also shown in the data sheet.

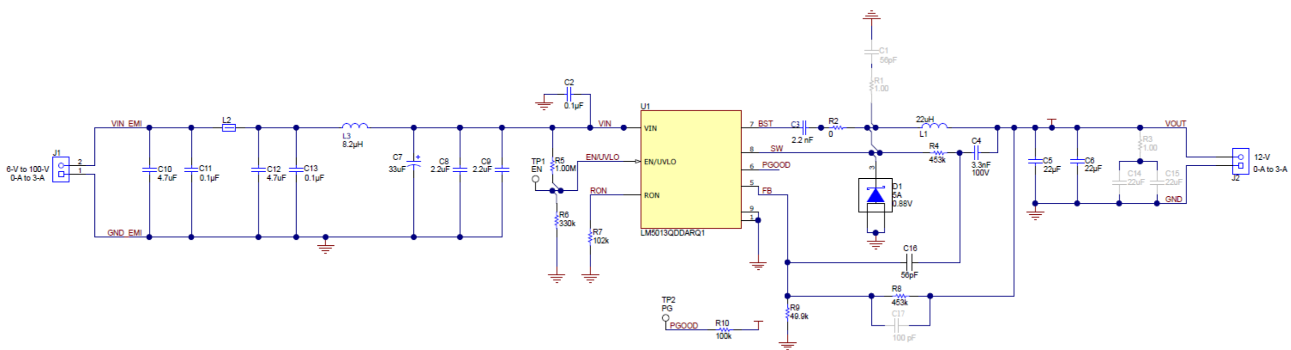

Figure 2-1. LM5013-Q1EVM Schematic

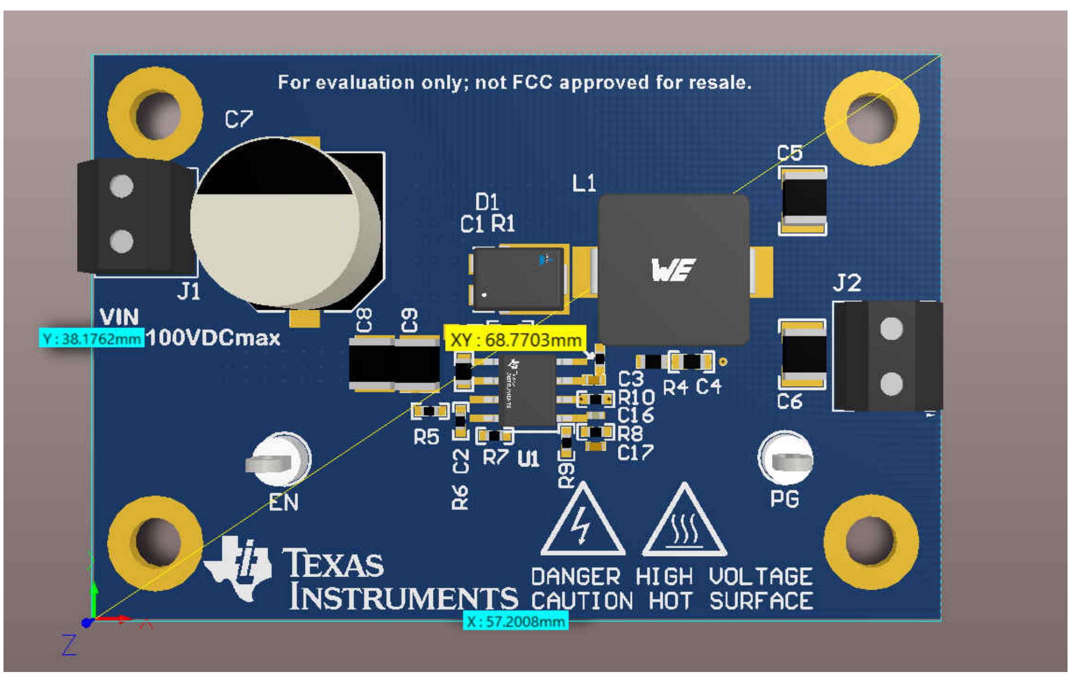

Figure 2-2. LM5013-Q1EVM 3-D image

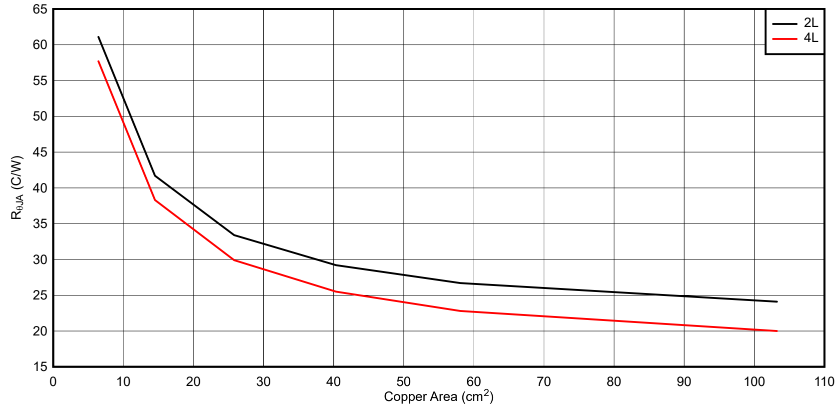

Figure 2-3. LM5013 $R_{\Theta JA}$ vs. Copper Area

Figure 2-4 shows the corresponding thermal rise on the LM5013-Q1EVM with a 48-V input and a 1.75-A load. The IC power loss is determined to be 1.02W, corresponding to an approximate 32.83°C/W $R_{\Theta JA}$ for the 21.6cm^2 , 4-layer board. This calculation was based on the estimated junction temperature (top case temperature) of the IC from the thermal capture taken.

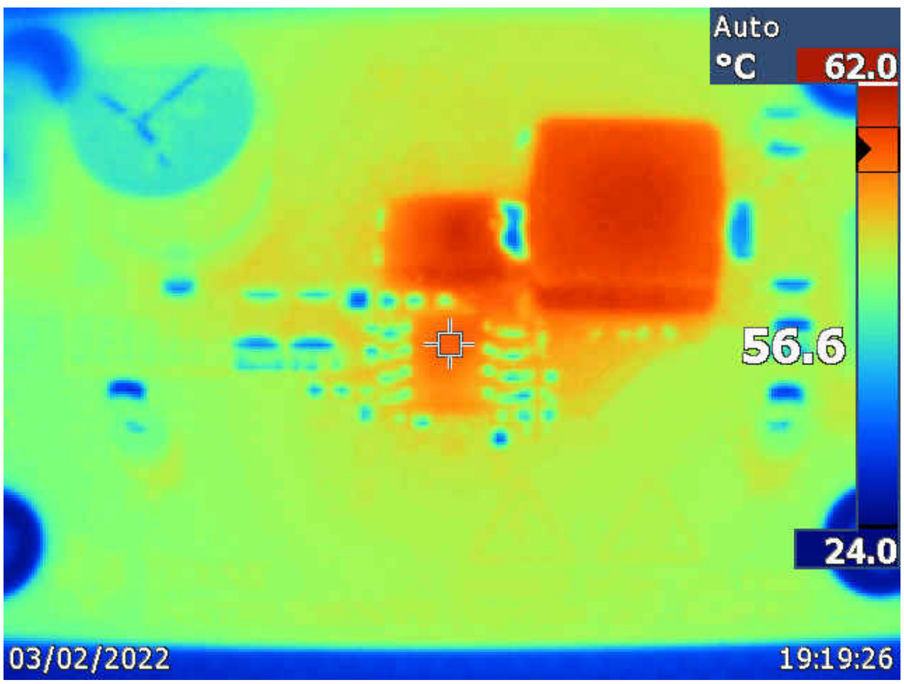

Figure 2-4. Thermal Rise on LM5013-Q1EVM (21.6cm^2 , 4-layer board)

Figure 2-4 shows the corresponding thermal rise on an experimental LM5013-Q1 PCB design with a 48-V input and a 1.75-A load. The layer stackup of the PCB is identical to LM5013-Q1EVM, though, the corresponding board size changes from 5.7 cm by 3.8 cm to 8.7 cm by 12.7 cm. In addition, the inductor physical cubic area remained similar, though, the typical DCR was reduced from 64 mΩ (Wurth 74437368220) to 55 mΩ (Coilcraft XAL6060-223ME). The IC power loss of 1.05 W equates to an approximate 21.40°C/W $R_{\Theta JA}$ for the 110cm^2 , 4-layer board.

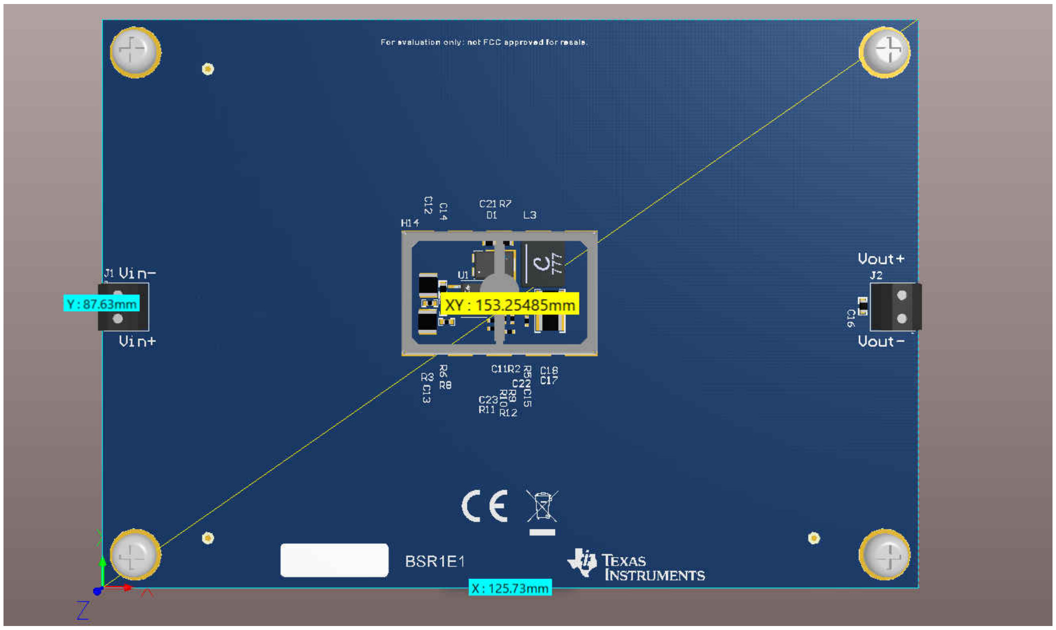

Figure 2-5. Experimental LM5013 PCB 3-D image

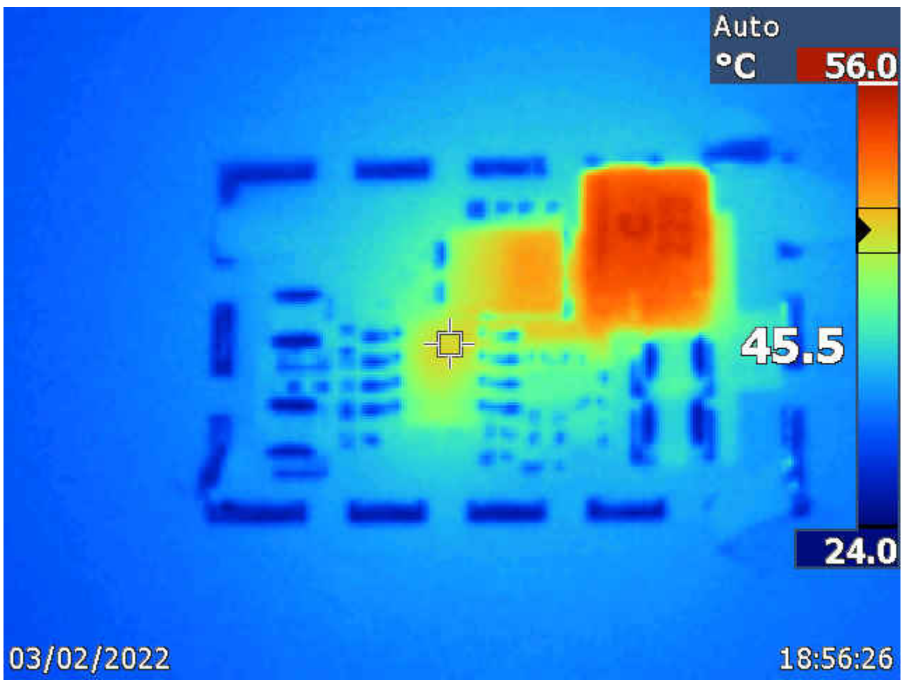

Figure 2-6. Thermal Rise on Experimental LM5013 PCB (110cm^2 , 4-Layer Board)

As shown, the increase in copper area of the experimental PCB reduces the case temperature, and therefore the approximate junction temperature, by 11°C. Additional considerations need to be taken into account when considering thermal optimization or analysis, namely the power inductor used in the design, as well, the buck diode.

3 Buck Inductor and Asynchronous Diode Impact on Thermals

Data sheets of DC/DC regulators recommend the buck diode and inductor to be in close proximity to the regulator. Closely placed components aids in reduction of EMC by the fact the high amplitude and high frequency AC current, whose loop is formed by these external components, are minimized, as well, their copper area which is proportional to radiated noise, is reduced. With these components conducting substantial DC current, in the case of a low duty cycle application for the asynchronous diode and high load current applications for the inductor, their power dissipation and corresponding temperature rise can influence the temperature rise in the neighboring regulator.

One main, targeted application for this device is 48-V to 12-V conversion. In a buck topology, the corresponding AC losses (of the inductor and diode) are not as of high importance in comparison to DC losses considering they are often small with correct component selection. The corresponding conduction loss (DC) in the inductor would be: L_{DCR} *I_{out} ^{2} , with L_{DCR} being the diode series resistance and I_{out} being the load current. Figure 3-1 shows the corresponding temperature rise on the LM5013-Q1EVM's for the buck inductor passing 1.75-A, a 1.75-A continuous load. As illustrated, that the PCB which was evaluated at ~23°C ambient exhibits about ~7°C rise in the buck inductor which constitutes ~1.5°C rise in the regulator.

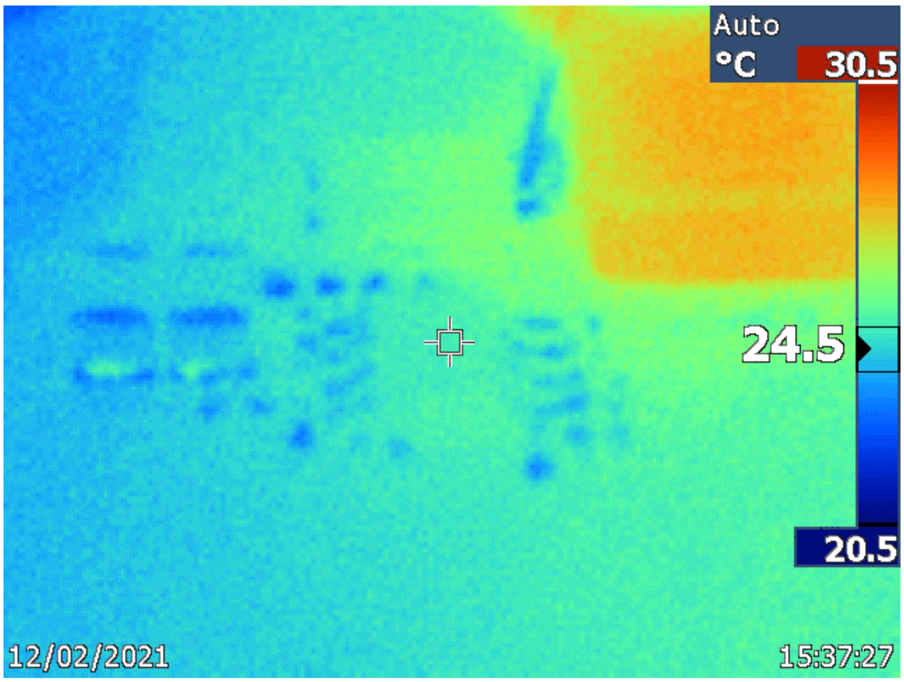

Figure 3-1. Inductor Self-Heating Impact on Neighboring Regulator

The other power component in close proximity to the regulator is the asynchronous diode. The corresponding conduction loss associated with it is: V_D *(1-D)*I_{out} , V_D being the forward voltage drop of the diode and D the duty cycle.

The average diode current ((1-D)*I_{out}) is 1.3-A for a 48-V to 12-V conversion with a 1.75-A continuous load. Figure 3-2 demonstrates that the PCB evaluated at ~23°C ambient with the inductor biased with 1.3-A. It shows about ~17°C rise in the buck diode which constitutes ~10°C rise in the regulator.

The diode (Vishay V8P12-M3/86A) was biased with 1.3-A, resulting in ~17°C rise in it and 10°C rise in the disabled regulator

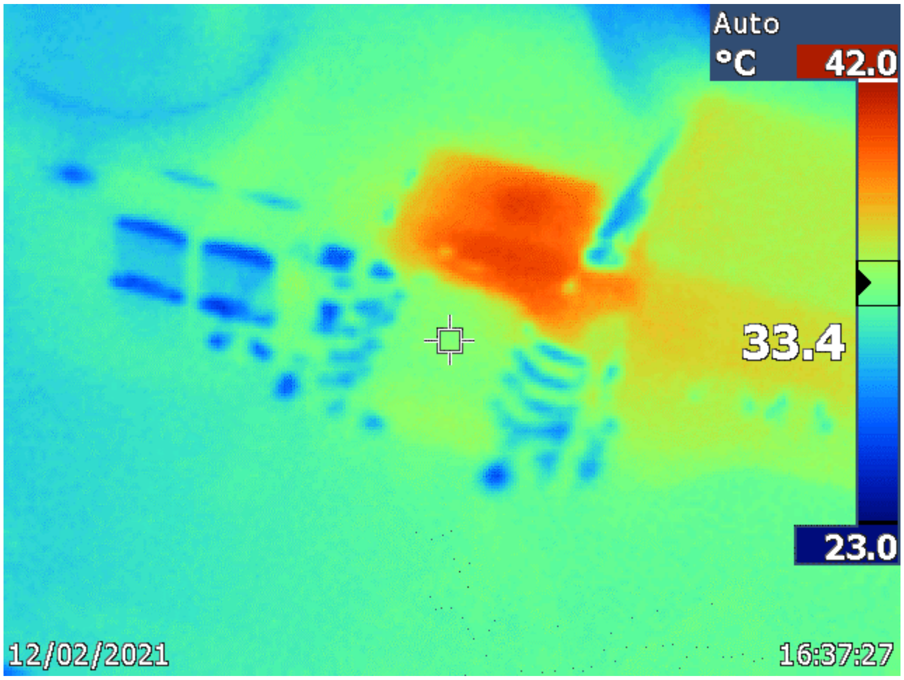

Figure 3-2. Diode Self-Heating Impact on Neighboring Regulator

4 Summary

This application note highlights that increased PCB copper area improves the thermal performance ($R_{\Theta JA}$) of LM5013. This enables more thermal margin in a given application, or higher output power capability, given that the PCB can better manage the power dissipation (heat). Additionally, it can be seen that additional losses occur in the buck topology other than that of power FET(s) which are integrated in a converter or module. In the LM5013-Q1EVM design, the buck inductor and diode both have non-negligible heat dissipation and constitute local temperature rise of the neighboring regulator.

Careful analysis and evaluation should be done to determine the impact of the components on thermal capability on the design. Please consult TI WEBENCH® or customer support channels such as E2E in the case you need further clarification on thermal design of a DC/DC, such as LM5013.

5 References

- Texas Instruments, PCB Thermal Design Tips for Automotive DC/DC Converters application note.
- Texas Instruments, Thermal Design Concerns for Buck Converters in High-Power Automotive Applications analog design journal.
- Texas Instruments, Thermal Design made Simple with LM43603 and LM46002 application note.

6 Appendix

Thermal Evaluation: 48V, 12Vout, 1.75A

$Eff := .922$	$Ldcr\_evm := .064$	(Typical)
$Ploss := 1.810$	$Ldcr\_exp := .055$	(Typical)
$Iout := 1.75$	$Vd := 0.45$	(Vd @ 1.3A)

$$D := \frac{12}{48}$$

Conduction loss of diode and inductor

$$Pdiode := Vd \cdot (1 - D) \cdot Iout = 0.591$$

$$Pind\_evm := Iout^2 \cdot Ldcr\_evm = 0.196$$

$$Pind\_exp := Iout^2 \cdot Ldcr\_exp = 0.168$$

Regulator loss only

$$Pic\_evm := Ploss - Pdiode - Pind\_evm = 1.023$$

$$Pic\_exp := Ploss - Pdiode - Pind\_exp = 1.051$$

Temperature rise from ambient

$$Prise\_evm := 56.6 - 23 = 33.6$$

$$Prise\_exp := 45.5 - 23 = 22.5$$

Calculated board theta at 48V, 12Vout, 1.75A

$$Rtheta\_evm := \frac{Prise\_evm}{Pic\_evm} = 32.833$$

$$Rtheta\_exp := \frac{Prise\_exp}{Pic\_exp} = 21.409$$

Figure 6-1. $R_{\Theta JA}$ Calculations