Power MOSFETs

TOLL and TOLT Comparison of Thermal Performance

About this document

This document compares the thermal performance of automotive power MOSFETs in the TOLL (TO-Leadless) package and its derivatives, including the TOLT (TO-Leaded Top-side Cooling) package. The information presented in this document is intended to serve as a comprehensive guideline for designing high-power automotive systems.

Target Device

- Renesas TOLL Power MOSFET
- Renesas TOLT Power MOSFET

Contents

1. Introduction

1.1 TOLL Package

The TOLL (TO-Leadless) package is a cutting-edge solution designed to optimize the performance of Power MOSFETs in power electronics applications. Its standout feature is its compact size, achieved by eliminating traditional lead components found in conventional packages like TO-220 or TO-247. This reduction in footprint is particularly advantageous in space-constrained environments.

Furthermore, the absence of leads enhances thermal performance by facilitating more efficient heat dissipation, crucial for high-power applications. Lower thermal resistance translates to reduced operating temperatures, enhancing the MOSFET's reliability and lifespan. The TOLL package also boasts improved electrical performance with low parasitic inductance and resistance, minimizing switching losses and improving efficiency, especially in high-frequency applications.

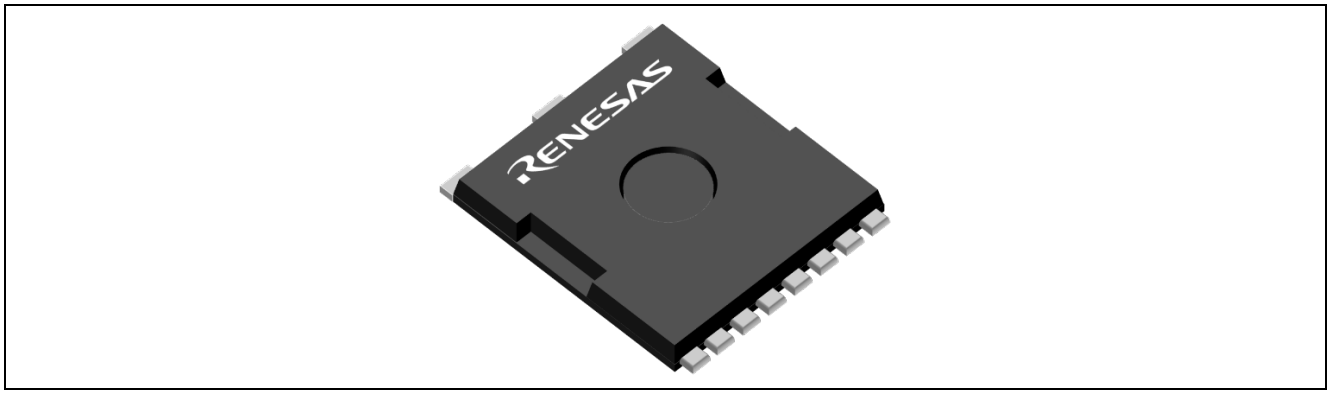


Figure 1. TOLL Package

1.2 TOLT Package

The TOLT (TO-Leaded Top-side Cooling) package represents an alternative approach to thermal management, particularly suited for high-power applications where efficient heat dissipation is paramount. Unlike the TOLL package, the TOLT package features a top-side cooling design, allowing for direct attachment of a heat sink or cooling apparatus to the MOSFET's top surface. This configuration significantly enhances thermal conductivity and heat dissipation, leading to lower operating temperatures and increased reliability.

Despite its top-side cooling arrangement, the TOLT package maintains a relatively compact form factor, making it suitable for applications where space is limited. Its compatibility with various types of heat sinks provides flexibility in thermal management strategies, allowing engineers to tailor cooling solutions to specific application requirements.

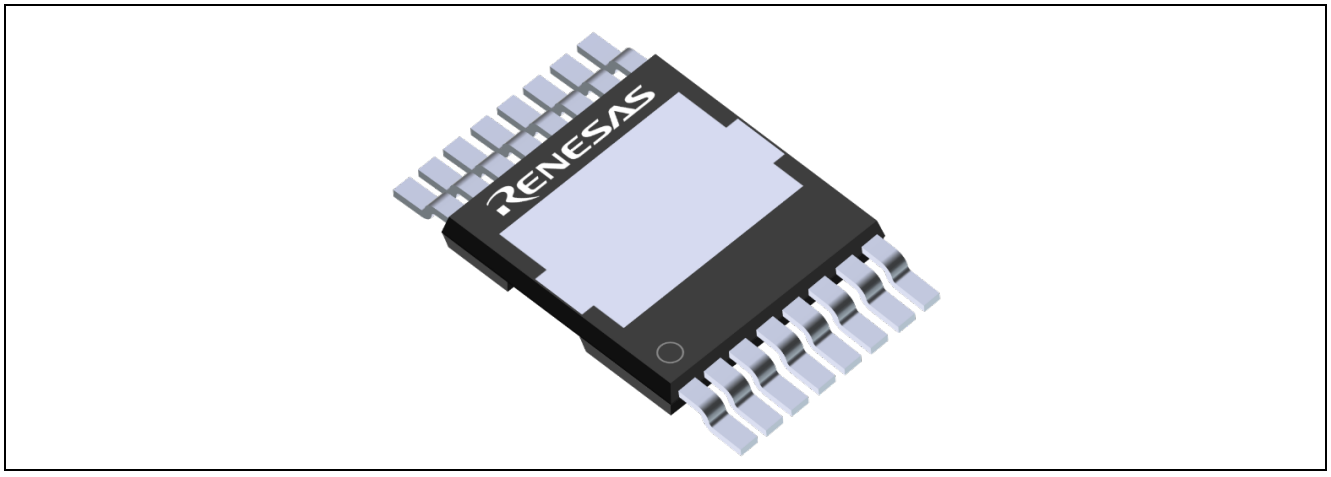


Figure 2. TOLT Package

2. Test Environment Setup

In this evaluation, both TOLT and TOLL evaluated samples are utilized with same chip. This evaluation is conducted with 48V power line evaluation board, the BLDC motor inverter board. The evaluation board used for TOLT and TOLL samples are different evaluation board where only the footprint of MOSFETs is different, while the circuitry is the same. The MOSFETs are soldered on the board as part of half bridge inverter configuration. The thermal performance of the MOSFET is captured during the operation. The ambient temperature is set at 25°C and without cooling fan is used throughout the evaluation carried out.

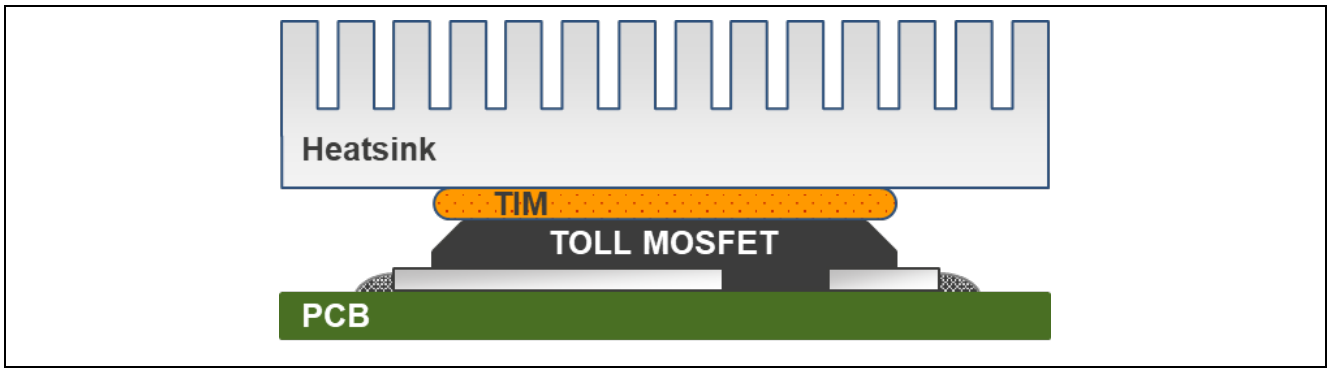


Figure 3. TOLL MOSFET Mounting Setup

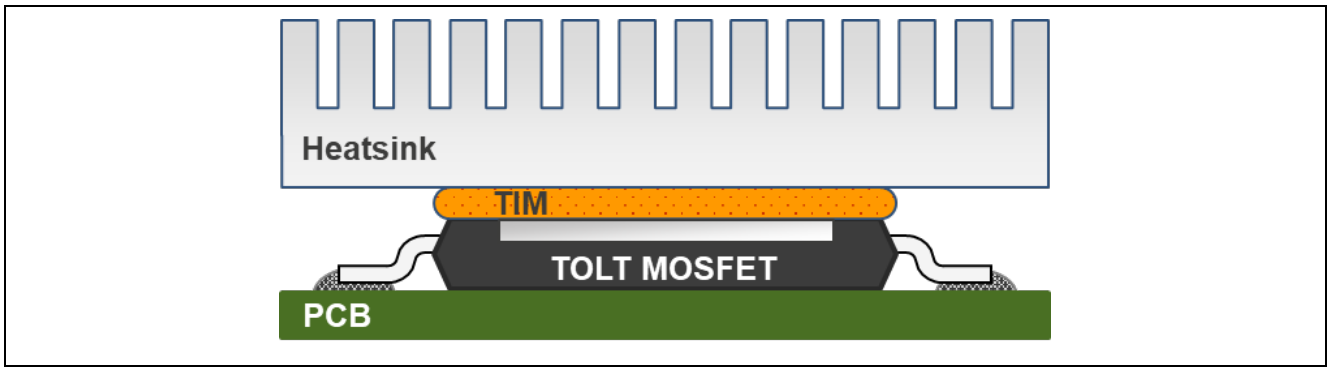


Figure 4. TOLT MOSFET Mounting Setup

The cooling setup of TOLL and TOLT MOSFET when soldered on evaluation board as shown in Figure 3 and Figure 4 respectively. The MOSFETs is cooled from 1 side only in this evaluation. The heatsink is attached to the evaluation board through screw tighten with torque force of 20cN·m. A layer of 2W/m·K thermal interface material (TIM) with thickness of 0.5mm is apply between the MOSFET and the heatsink. There are thermistors on the evaluation board located close to the MOSFET area as shown in Figure 5. The reading of the thermistors also being captured to monitor the heat dissipate to the surrounding especially to the PCB during operating the evaluation board.

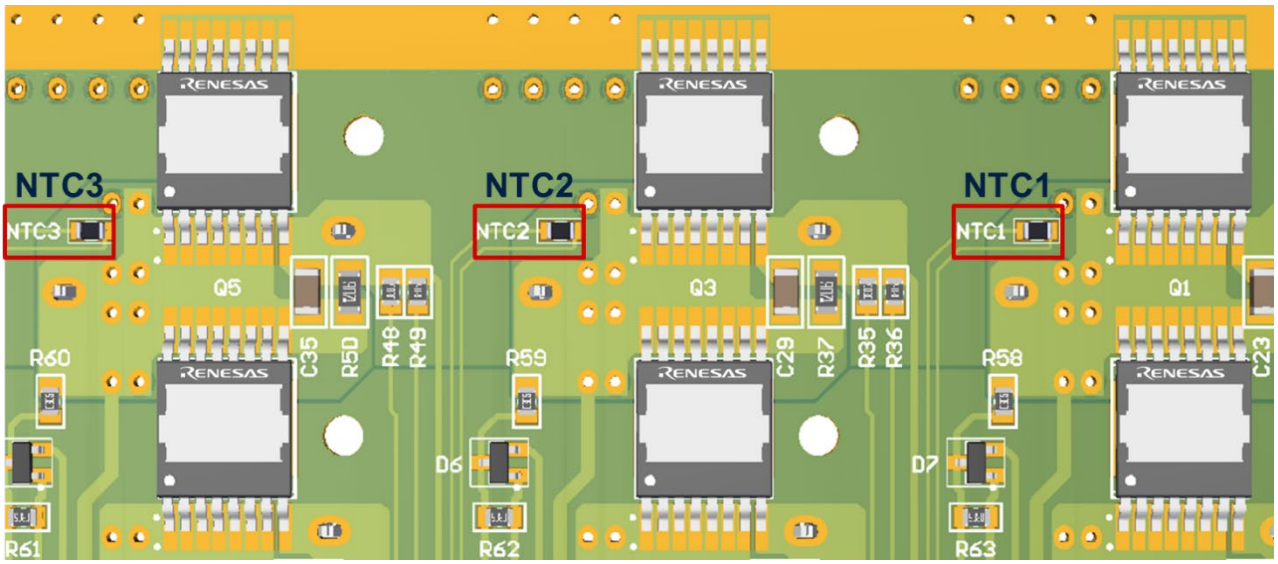


Figure 5. Thermistors (NTC1, NTC2 & NTC3) is located near to power MOSFET

2.1 Heat Dissipation Explained

The heat transfer pathways from the junction to the heatsink differ between TOLL and TOLT MOSFET, as illustrated in Figure 6. In the TOLL setup, heat generated at the junction first conducts through the drain plate, then traverses the mold compound encapsulating the MOSFET before reaching the Thermal Interface Material (TIM) layer. The TIM acts as a medium, connecting the MOSFET to the heatsink for efficient heat dissipation into the surrounding environment. Conversely, in the TOLT configuration, heat from the junction travels directly from the drain plate to the TIM layer, streamlining the transfer process. Subsequently, the heat dissipates into the heatsink and eventually into the ambient air.

While both configurations effectively facilitate heat transfer from the semiconductor junction to the ambient environment, TOLT generally offers a more direct and efficient pathway due to its structural design. However, it's crucial to ensure that the TIM used in the TOLT package is of high quality and applied correctly, as it significantly influences the efficiency of heat transfer from the MOSFET to the heatsink.

It's important to note that the heat generated is not only dissipated upwards to the heatsink but also towards the PCB. Compared to TOLL, TOLT dissipates less heat towards the PCB since it's separated by mold compound. Consequently, the PCB temperature of TOLL during operation will be higher compared to TOLT.

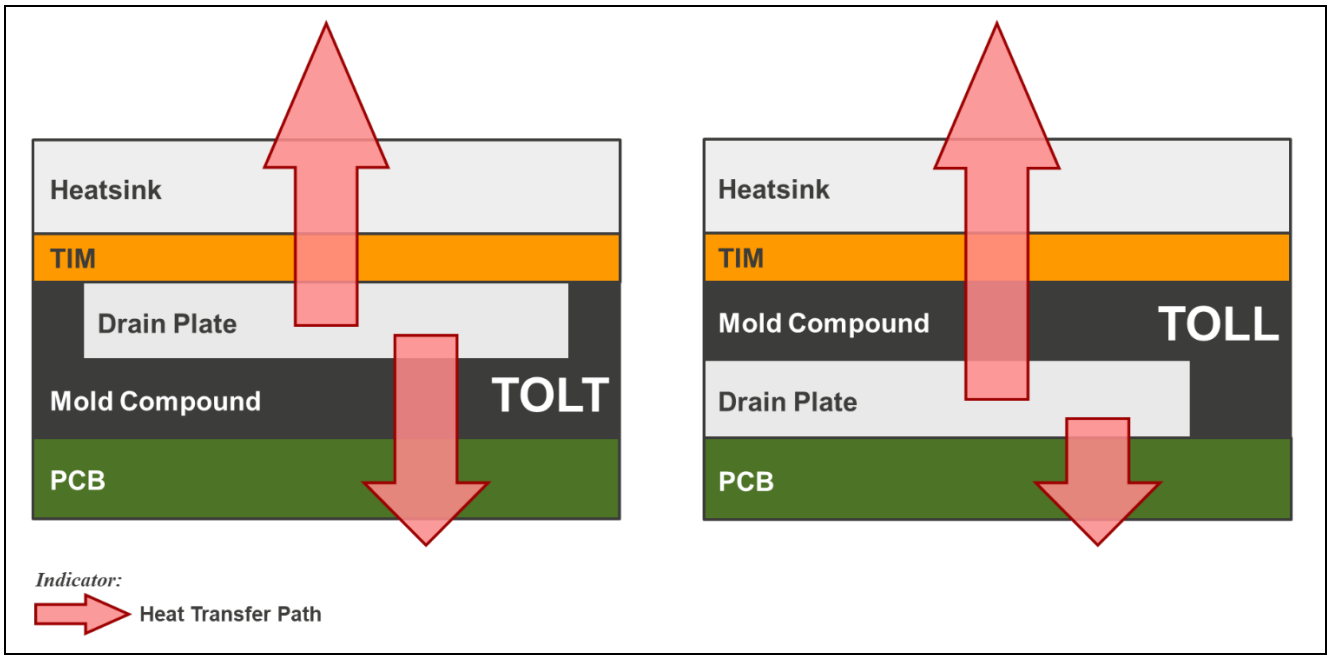


Figure 6. Cross sectional diagram of MOSFETs setup (Left: TOLT; Right: TOLL)

3. Thermal Result

3.1 MOSFET Operating Temperature

The temperature of the MOSFET is recorded during the operation of the inverter board. The inverter operates at a frequency of 10kHz and is powered by a 48V input. The main focus is on monitoring the temperature fluctuations of the MOSFET during operation, achieved by incrementally varying the load current from 10A to 50A in 10A intervals. Figure 7 shows the operating temperature of TOLL and TOLT during the evaluation.

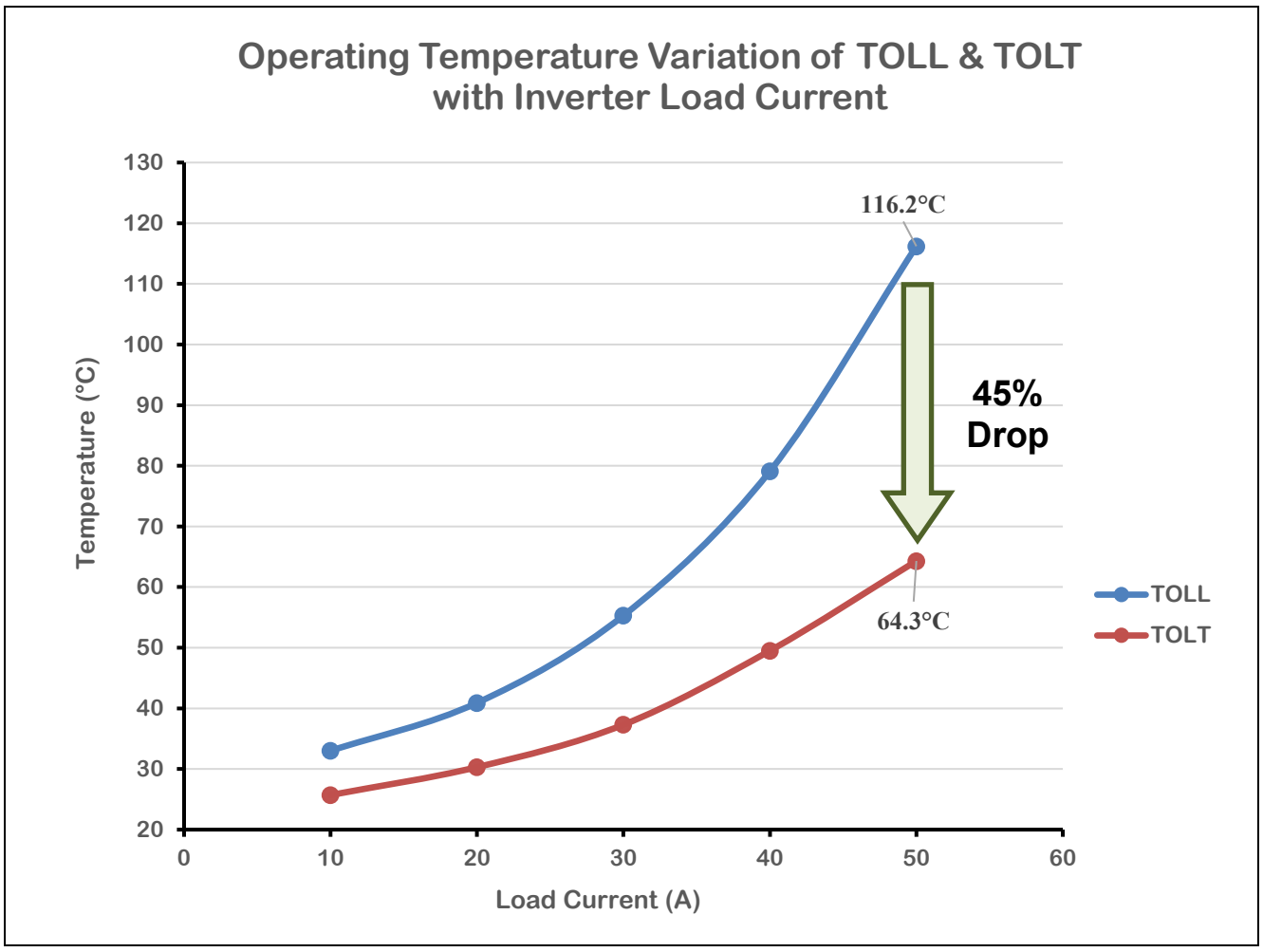
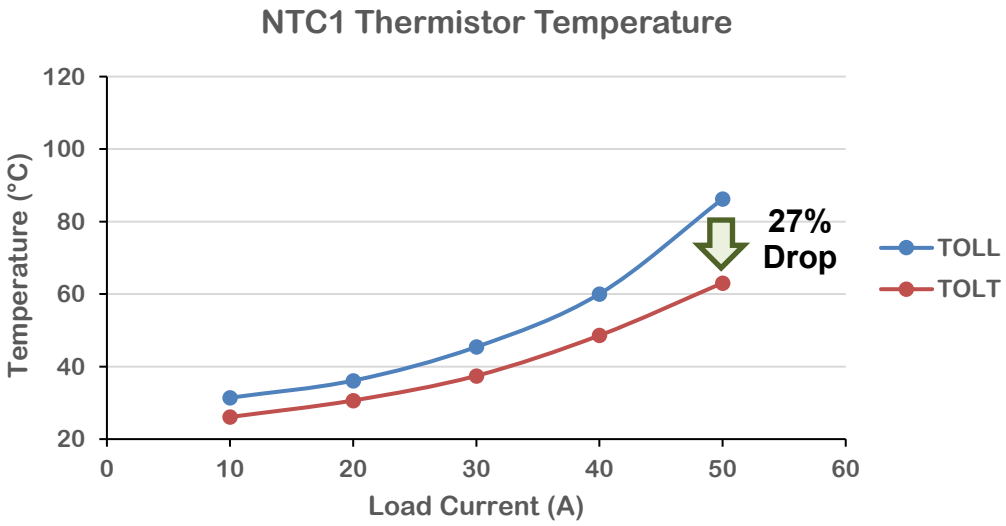


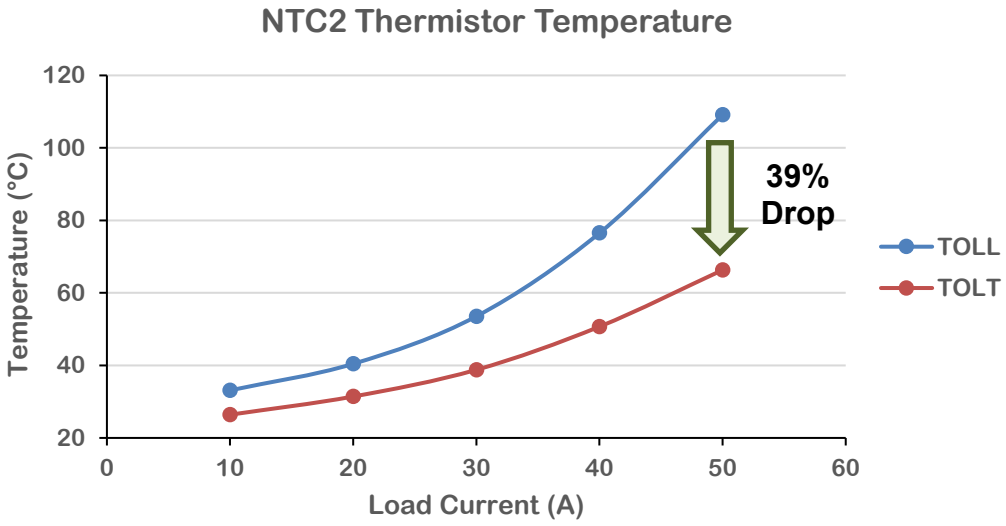
Figure 7. Temperature of TOLL and TOLT in response to inverter load current

The thermal performance analysis shows distinct trends in both MOSFETs. As the load current increases, temperatures rise for both components. However, TOLL consistently exhibits higher temperatures compared to TOLT across all load conditions. For instance, at a load current of 50A, TOLT registers a temperature of 64.3°C, which is 45% lower than TOLL's temperature of 116.2°C. This discrepancy can be attributed to the differing heat dissipation mechanisms. As elucidated in section 2.1, the heat generated in TOLL traverses through the mold compound, thereby increasing the thermal resistance for dissipating heat into the ambient environment. In contrast, heat from TOLT directly transfers to the thermal interface material (TIM) layer, facilitating efficient dissipation into the ambient environment through the heatsink. Consequently, the results underscore the superior thermal characteristics of TOLT compared to TOLL.

3.2 PCB Temperature

The PCB temperature reflect the rising in MOSFETs temperature. The heat generated in the MOSFET during operation disperses not only towards the heatsink but also transfers towards the PCB. Due to structural differences, the junction of TOLL is closer to the PCB compared to TOLT, whereas TOLT features a layer of mold compound before reaching the PCB. Figure 8 illustrates the PCB temperature at the MOSFET area on the inverter board during operation under similar conditions. Across load currents ranging from 10A to 50A, the PCB temperature of TOLL consistently exceeds that of TOLT. In particular the NTC2 thermistor reading, at a load current of 50A, TOLT's PCB temperature measures 66.3°C, a notable 39% lower than TOLL's temperature of 109.1°C. This indicates that TOLL dissipates more heat towards the PCB, resulting in less effective heat dissipation into the ambient environment.





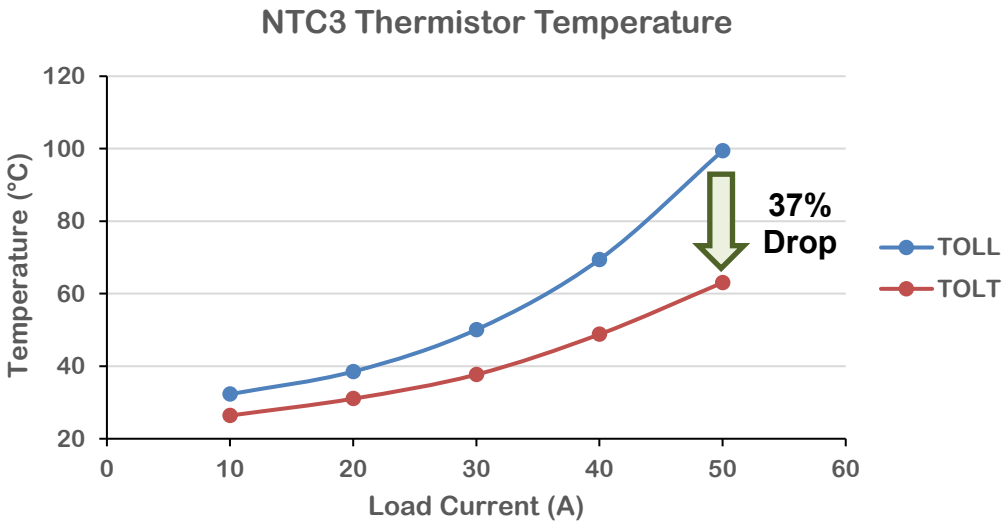


Figure 8. PCB temperature (thermistor reading) of TOLL and TOLT in response to inverter current load

4. Conclusion

TOLL and TOLT represent two distinct variants of MOSFET packages, each possessing unique thermal characteristics. TOLL packages are typically chosen for scenarios where space is at a premium and efficient heat dissipation is crucial. Their compact size makes them well-suited for applications demanding high power density. Despite their small footprint, TOLL packages still offer decent thermal performance by allowing direct mounting onto a PCB, facilitating heat dissipation through the board. However, their effectiveness may be somewhat limited compared to TOLT packages due to their reduced thermal mass. On the other hand, TOLT packages are commonly employed in situations where effective thermal management is paramount. Designed with top-side cooling in mind, these packages enable efficient heat transfer from the device to a heatsink or another cooling mechanism mounted on top. This design feature makes TOLT packages highly suitable for applications requiring robust thermal dissipation, particularly in high-power automotive scenarios.

In summary, the choice between TOLL and TOLT packages hinges on the specific requirements of the application. TOLL packages are favored for their compact size and moderate thermal performance, whereas TOLT packages excel in situations where superior thermal management capabilities are needed to handle high-power applications.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Apr.27.2026	-	First edition

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