 DOI:10.30420/566414016

Comparison of Junction Temperature Measurement Methods for Power Module

Andrew Yang[1], Yusi Liu[2], Juyoung Kim[1], Robbie Park[1]

[1] onsemi, Korea
[2] onsemi, USA

Corresponding author: Andrew Yang, Andrew.Yang@onsemi.com
Speaker: Andrew Yang, Andrew.Yang@onsemi.com

Abstract

Junction temperature (T_j) of power device within the module must be checked to prevent damage from exceeding the rated temperature. This paper shows four ways to measure this temperature. The first method is through calculation. The second method is through simulation with ICEPACK. The third and fourth methods check the T_j through actual measurements with thermo-coupler (TC) wire and thermal camera. Finally, the T_j obtained by four methods are compared and analyzed so that an appropriate method can be used for the situation.

1 Introduction

To ensure stable operation of the actual system using the power module, it is crucial to maintain a stable Tj of the device within the module [1]. However, directly measuring the temperature of the actual device can be challenging.

In the industry, there are four main methods used to check Tj. The first method involves calculation, where Tj can be estimated if the thermal resistance and power loss of the device are known. The second method utilizes simulation tools to predict Tj. The third method measures the actual temperature using a thermo-coupler (TC) wire. Lastly, the fourth method involves measuring the temperature of a blackened sample with a thermal camera. This paper describes these four methods and compares their results.

Actual measurements are conducted using the power module from onsemi, shown in Figure 1. This module package, known as F5+baseplate (F5BP), is designed in a large size for high-power applications. For instance, high-power solar systems utilize multi-level inverters like NPC type inverters for higher efficiency. These neutral point clamped (NPC) type inverters include many devices such as switches and diodes, which can all be mounted within this module. This enables the construction of a more compact system. Additionally, the larger area for heat dissipation improves thermal resistance.

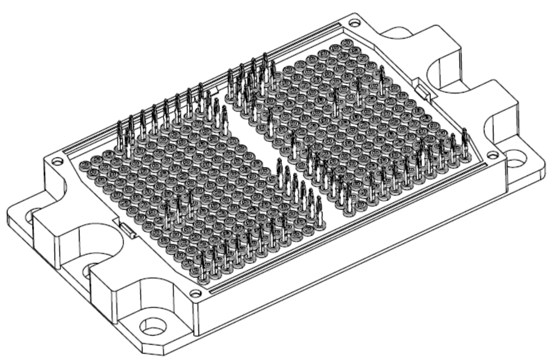

Fig. 1 NPC inverter power module from onsemi with F5+baseplate(F5BP) package

2 Junction Temperature Measurement Methods

onsemi's NPC type power module is tested by measuring the junction temperature (Tj) in four different ways. The experimental conditions are as follows: power loss (Ploss) of 150W, junction-to-heatsink thermal resistance (RthJH) of 0.167°C/W, and a heatsink temperature of 85 degrees Celsius. The target device information indicates that there are three parallel 200A devices.

2.1 Calculation

The first method estimates Tj through calculation using equation (1). Here, Rth represents the thermal resistance of the device, and delta T is the difference between the junction temperature and the temperature of the target area, such as the case or heatsink. Power loss, Ploss, refers to the loss of the device. Thermal resistance is typically measured as described in [2].

$$R_{th} = \frac{\Delta T}{Ploss} \tag{1}$$

ISBN 978-3-8007-6414-3

 DOI:10.30420/566414016

Equation (1) yields equation (2). Utilizing equation (2), equation (3) can be derived, allowing for the calculation of Tj. Considering the heatsink temperature, RthJH, and Ploss, Tj is calculated as 110.05 degrees Celsius. However, this calculation does not account for thermal coupling [3].

$$R_{thJH} = \frac{T_{Junction} - T_{Heatsink}}{Ploss} \quad (2)$$

$$T_{Junction} = R_{thJH} \times Ploss + T_{Heatsink} \quad (3)$$

2.2 Simulation

The second method involves using ICEPACK to estimate Tj. ICEPACK is a widely used simulation tool for predicting temperature. The target device is T1, which consists of the three parallel 200A devices mentioned earlier. In Figure 2, the circuit is the NPC inverter, and the red arrow indicates the direction of current flow. Considering the actual topology, the current needs to flow through both T1 and T2 [4]. In Figure 3, T1a is measured at 107.706 degrees Celsius, T1b at 109.831 degrees Celsius, and T1c at 109.047 degrees Celsius. Since T1b is located between T1a and T1c, its temperature appears relatively high due to the influence of thermal coupling.

2.3 Thermo-coupler Wire

The third method involves using a TC wire to measure temperature based on the characteristics of two different wires. Attaching the TC wire to the device is a straightforward process. First, prepare the target devices. As shown in Figure 4(a), after removing the gel,

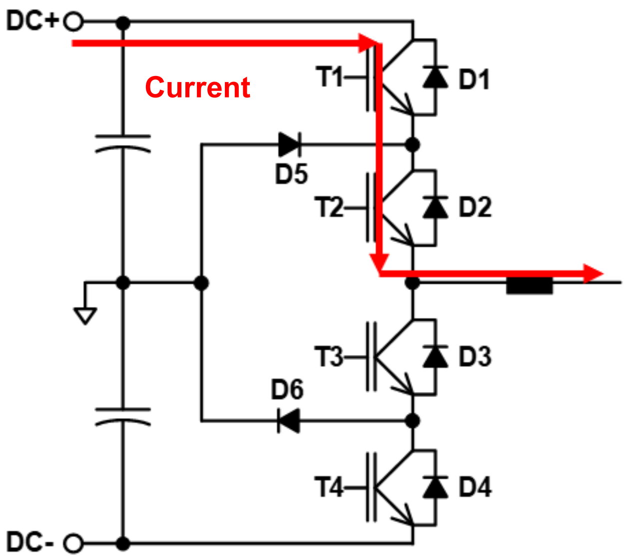

Fig. 2 Circuit diagram of NPC inverter and target current flow direction

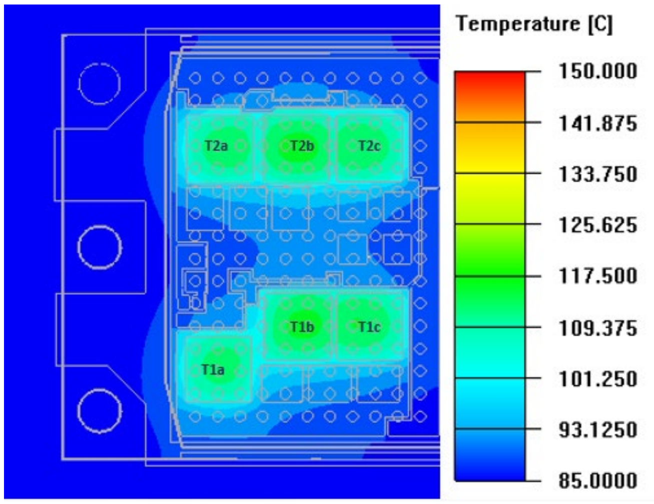

Fig. 3 Junction temperature with simulation

apply a thin layer of insulation with epoxy to prevent damage to the device. Next, put the TC wire on the insulation layer and fix it again with epoxy, as depicted in Figure 4(b). Using this method, attach the TC wire to T1a, T1b, and T1c, respectively.

Figure 5 illustrates the test setup. A continuous current of 135A is applied through thick wires to generate the target power loss of 150W. A chiller from Keenus maintains the heatsink temperature at 85 degrees Celsius. The power supply from Agilent applies a gate voltage of 15V to T1 and T2. A multimeter from FLUKE measures the collector-to-emitter voltage (Vce) drop to check the power loss. The thermal grease, TC5121 from Dow, is used.

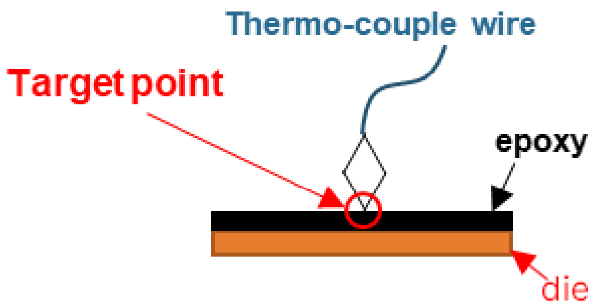

Fig. 4. (a) Insulation layer with epoxy

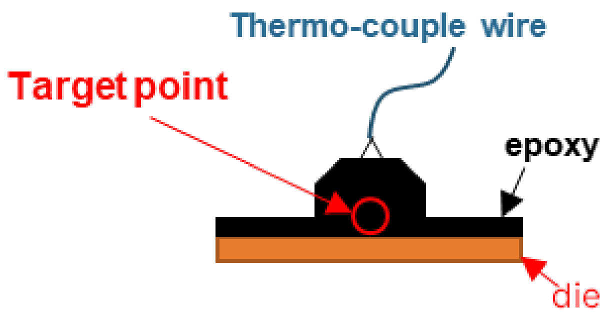

Fig. 4. (b) Fix thermo-coupler wire with epoxy

 DOI:10.30420/566414016

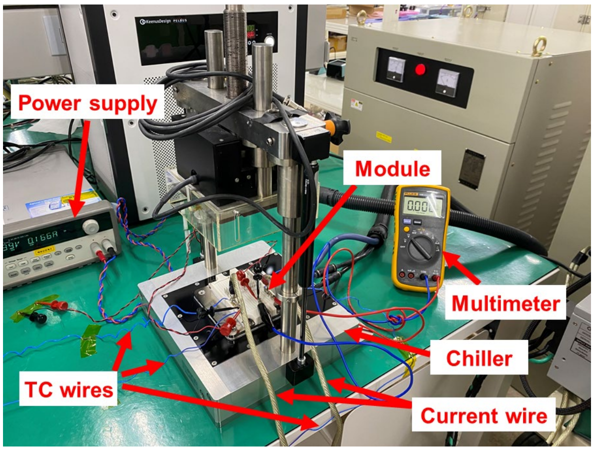

Fig. 5 Test setup for Tj measurement with thermo-coupler sample

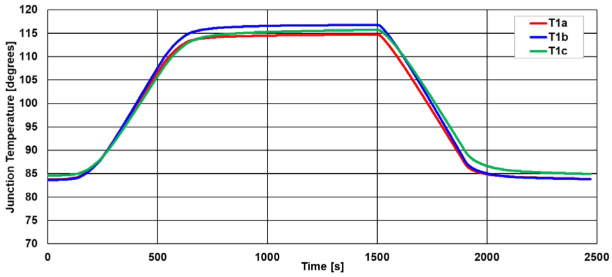

Fig. 6 Junction temperature of T1a, T1b, and T1c with thermo-coupler wire

Figure 6 shows the actual measured Tj of T1a, T1b, and T1c, with T1a measured at 114.7 degrees Celsius, T1b at 116.8 degrees Celsius, and T1c at 115.7 degrees Celsius. The Tj measured with tc wires shows a difference of about 6-7 degrees from the calculated value and the simulation result.

2.4 Thermal Camera

The fourth method measures Tj using a thermal camera. To capture Tj with the thermal camera, a blackened module is required. Blackened module can be made by removing the gel and using black spray. Figure 7 shows test setup using the thermal camera. The thermal camera from FLIR measures the Tj. The test equipment, except the thermal camera, is the same as the setup used with the TC wire. As shown in Figure 8, the Tj measurement results are 118.1 degrees Celsius for T1a, 120.8 degrees Celsius for T1b, and 119.7 degrees Celsius for T1c. The results obtained with the thermal camera show higher Tj values than those measured with the TC wire.

3 Comparison of Four Methods

Table 1 presents the Tj for each method. The Tj value obtained from the first method is 110.050 degrees Celsius. This value is calculated considering the RthJH, The Ploss, and the heatsink temperature in an ideal situation.

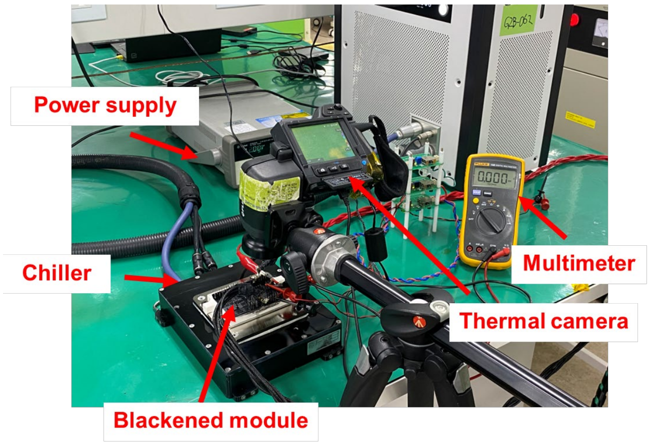

Fig. 7 Test setup for Tj measurement with blackened sample

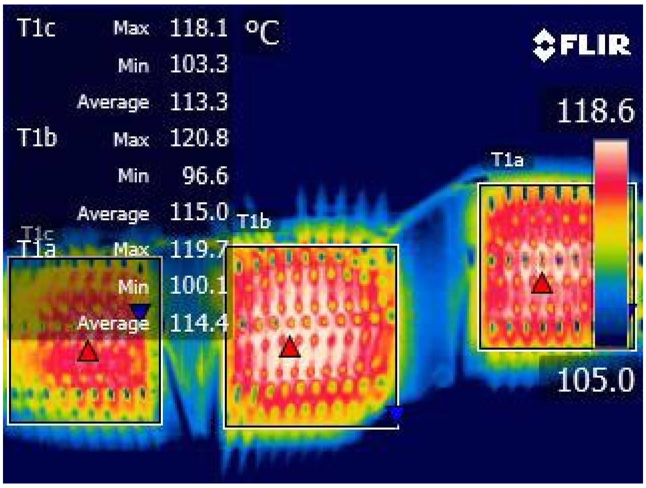

Fig. 8 Junction temperature of T1a, T1b, and T1c with thermal camera

Additionally, since the thermal coupling effect is not reflected, the individual temperatures of T1a, T1b, and T1c are unknown. The Tj predicted using the second method shows a range between 107.7 and 109.8 degrees Celsius. Due to the thermal coupling effect, T1b, which is in the middle, shows the highest value. However, since not all factors affecting the actual Tj are reflected, the actual Tj can be different. The Tj measured by the third method is 114.7-116.8 degrees Celsius. The highest temperature is 116.8 degrees Celsius, which is the Tj of T1b. However, since the surface temperature of the device is not uniform and only one TC wire is used for one device, it can be difficult to determine the highest Tj. Additionally, as mentioned above, the TC wire is mounted on the isolation layer, so the actual Tj could be slightly higher than Tj measured with TC wire. The Tj measured by the fourth method is 118.1-120.8 degrees Celsius. This fourth method also shows that the device in the center, T1b, has the highest Tj, 120.8 degrees Celsius. This method, like the third method, involves applying a material to the surface of the device, which results in a slight difference from the actual Tj. However, since it

ISBN 978-3-8007-6414-3

 DOI:10.30420/566414016

Table 1

<table>
<tr><th></th><th>Method 1</th><th>Method 2</th><th>Method 3</th><th>Method 4</th></tr>
<tr><td>T1a [degrees]</td><td rowspan="3">110.050</td><td>107.706</td><td>114.700</td><td>119.7</td></tr>
<tr><td>T1b [degrees]</td><td>109.831</td><td>116.800</td><td>120.8</td></tr>
<tr><td>T1c [degrees]</td><td>109.047</td><td>115.700</td><td>118.1</td></tr>
</table>

allows for checking the temperature distribution over the entire surface of the device, it is possible to measure the highest Tj. As a result, the measured results show 6-9% higher Tj compared to methods based on simulation or calculation, and they are expected to provide more accurate values considering various surrounding conditions. Between the two methods for measuring Tj, using a thermal camera appears to be more accurate.

4 Conclusion

There are various methods to obtain Tj. In this paper, Tj is determined using four different methods. Predicting Tj through calculation is simple, but many factors that affect Tj are omitted. Predicting Tj through simulation, ICEPACK, can be more accurate than calculation because it accounts for some thermal coupling effects and creates an environment like real condition; however, it is still difficult to consider all the factors that influence the actual Tj. Measuring Tj using a TC wire involves placing the TC wire on the target device and reflects the factors affecting Tj, resulting in a value closer to the actual Tj compared to calculation and simulation. However, due to the influence of the insulation layer, there can be a temperature difference from the actual Tj, and since the temperature measurement point is only one on the device, it is difficult to observe the temperature distribution across the device surface. Using a thermal camera to measure Tj allows for observing the entire temperature distribution on the device surface, even though applying other materials on the device to facilitate insulation and thermal camera measurement can cause a temperature difference from the actual Tj. This method provides a more accurate measurement of the highest Tj value.

In conclusion, if Tj can be measured directly, using a thermal camera is the most accurate method. However, if it's not possible to directly measure Tj, using a simulation built to closely resemble the actual operating environment is also acceptable. However, when using the simulation, the margin for Tj should be considered.

5 References

[1] H. Wang, M. Liserre, and F. Blaabjerg, “Toward reliable power electronics: Challenges, design tools, and opportunities,” IEEE Industrial Electronics Magazine, vol. 7, no. 2, pp. 17–26, 2013.

[2] JEDEC 51-14

[3] J. Cheng, X. He, X. Li, B. Zhou, H. Bao, L. Zhou, and Z. Wang, “Thermal coupling effects and thermal resistance matrix research of multi-heat sources MCM,” in 2014 10th International Conference on Reliability, Maintainability and Safety (ICRMS), Aug. 2014, pp. 715–719

[4] Application Note AN-11001, SEMIKRON

ISBN 978-3-8007-6414-3