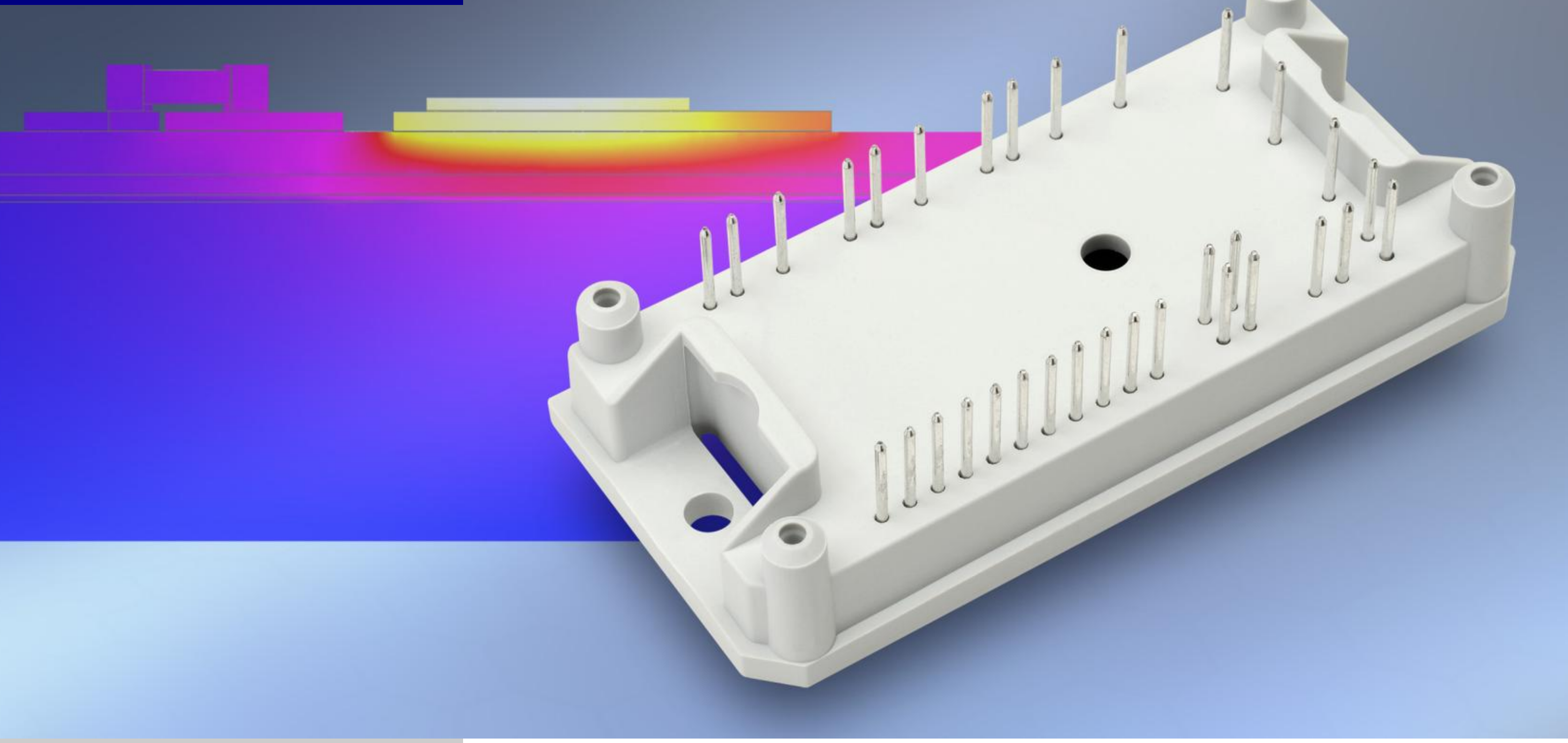
Vincotech

Application Note



Thermal Resistance, Thermal Spreading and Temperature Measurement

Thermal Characterization of a Power Module

Application Note no.:
AN_2013_09_001-v01

Vincotech

Table of Contents

Revision history:

Date	Revision Level	Description	Page number(s)
Sept. 2013	1	First release	9

1 Abstract

This paper describes the impact of a power module and heat sink assembly on thermal resistance. It explains how this resistance is calculated, shows how heat spreads within a power module and discusses why thermal resistance depends on the power module's design, the type of heat sink and the materials used in constructing these devices. Beyond that, it provides practical information on characterizing systems with power modules during their development and describes the use and benefit of the integrated NTC thermistor in Vincotech's power modules.

2 Introduction

A semiconductor's junction temperature increases in the course of standard operation. Thermal energy can rise beyond the component's tolerance threshold, which in turn can significantly reduce the semiconductor's lifespan. This is why heat buildup has to be counteracted with a cooling system, be it passive or forced.

Engineers need to know a semiconductor's junction temperature in operating mode to ensure component reliability. The junction is not directly connected to a heat sink, so it is imperative to include the thermal resistance between the junction and its cooling system in heat-sink calculations. The integrated NTC thermistor is a very important asset in the power module as it can be used to monitor temperature.

3 Heat distribution in power modules

Cooling elements' heat spreads in a radial pattern depending on the given geometry, the combination of materials and thermal characteristics. If two different materials are used, the way heat spreads within the first material will depend on the characteristics of the second material - the greater the conductivity of the second material, the higher the thermal resistance of the first material and the smaller the pattern of spread will be.

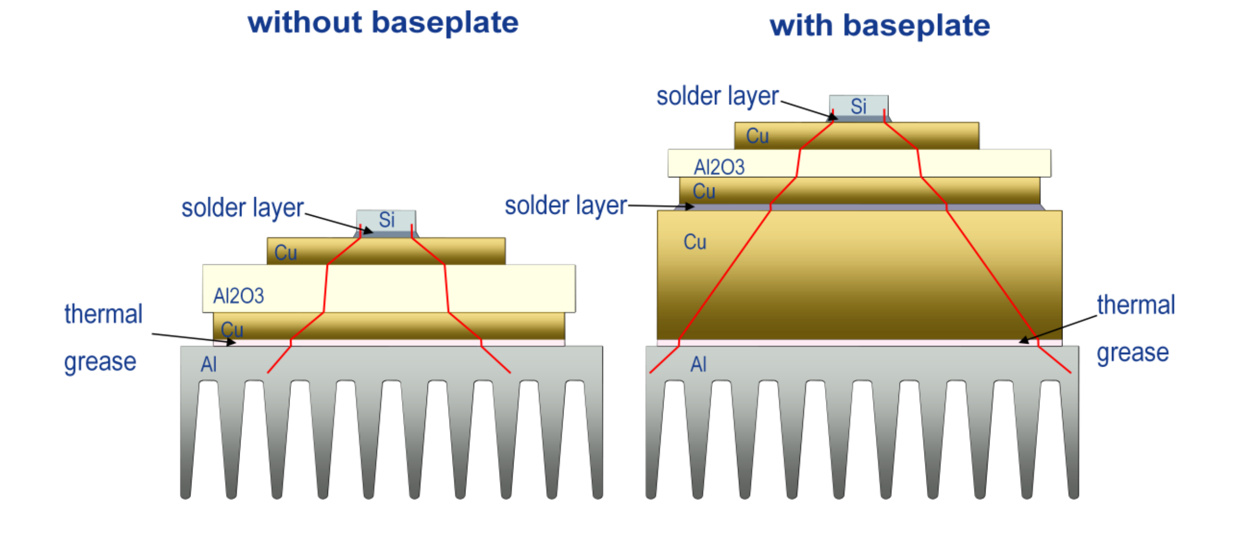


Figure 1: Power module setup with and without a baseplate

Pictured above are two variants of a power module setup, one populated with a baseplate and one without. The baseplate introduces an additional layer that has a direct influence on a power module's thermal characteristics. The thermal conductivity of a Vincotech module's baseplate is high, so thermal spreading within the module will be even more expansive than in modules without baseplates.

The connected heat sink also influences these characteristics. Thermal spreading within the module will decrease as the heat sink's ability to absorb heat increases, depending on how the heat sink is configured – that is, if it is passive or forced and if it cools with a fan or a liquid medium.

The quality of the heat sink connection also influences thermal behavior. Vincotech's power modules are pre-bent to achieve uniform pressure across the entire connecting surface, which reduces the resistance to heat transfer. However, thermal grease is still necessary to balance out local concavities on the surface. The coating is not very conductive, so it has to be as thin as possible.

A very convenient way of obtaining the optimal layer of grease is to use Vincotech's phase-change material, a pre-applied thermal conduction material. This phase-change material ensures a constant heat transfer rate (to learn more, please refer to "Power Modules with Phase-Change Material" at www.vincotech.com).

4 Classifying thermal behavior

Characterizing the thermal behavior of a power module involves taking complex measurements. The thermal resistance Rth describes thermal resistivity, which indicates the ability of a given material to resist heat flow. This key, quasi-static parameter for semiconductor applications is defined by the temperature difference between two points divided by a given power dissipation.

$$R_{th} = \frac{T_1 - T_2}{P_{th}} = \left[\frac{K}{W}\right]$$

T_1 – temperature at measuring point 1 in K (e.g. junction temperature)

T_2 – temperature at measuring point 2 in K (e.g. heat sink temperature)

P_{th} – power losses in W

Several measurements have to be taken to obtain all parameters needed for characterization.

4.1 Characterizing Rth

The R_{th} given in Vincotech datasheets is determined in four steps.

1. First heat the module passively while forcing a constant low current through the semiconductor: The temperature is increased step by step to monitor the forward voltage drop under varying temperature conditions until a thermal equilibrium is reached. This yields a graph that shows the temperature dependency at low currents as in the example below.

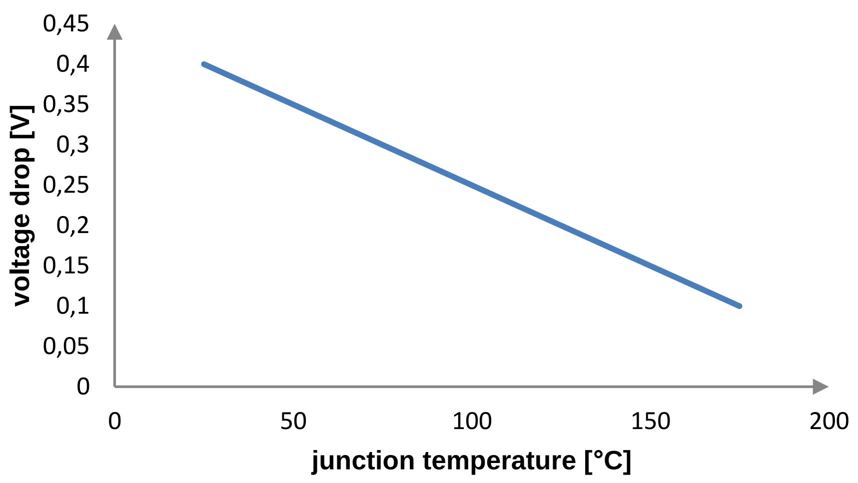


Figure 2: Cooling curve measurement of a semiconductor

2. Heat the module actively by way of static losses.
   The module is mounted to a water-cooled, copper heat sink during this measurement. The current is switched off once the heat sink temperature reaches a predefined constant level.
3. Determine the actual junction temperature.
   The third step takes place just a few micro seconds after the current is switched off. A constant low current is again forced through the semiconductor to determine the exact junction temperature Tj under the conditions defined for the temperature dependency graph.
4. Calculate Rth
   Now that the chip temperature T_j and the heat sink temperature T_s are known, ΔT can now be determined. A simple power analysis yield the power dissipation P_{th}. Thermal resistance can then be calculated as follows.

$$R_{th} = \frac{\Delta T}{P_{th}} = \frac{T_j - T_s}{U_{CE} \cdot I_C}$$

   U_{CE} – collector emitter voltage
   I_C – collector current

The benefit of this measurement method is that there are no other measuring probes that could influence chip temperature. What's more, it is not possible to obtain accurate results if the temperature dependence is determined by actively heating the component using high current. The subsequent voltage drop would not be linear enough and temperature sensitivity would be much lower than with low currents.

4.2 How different cooling methods influence Rth

In some cases, the calculated R_{th} varies from module to module even if the internal module setup is the same. The differences are attributable to the methods of measuring ΔT and the type of the heat sink. In Vincotech's test setups, modules are mounted on water-cooled, copper heat sinks so very little heat spreads within the semiconductors, the DCB and the baseplate. Accordingly, $R_{th(j\text{-}s)}$ is higher in measurement setups with non-forced cooling elements or other heat sink materials with lower heat conductibility, for instance, aluminum. The type of thermal grease and its layer thickness also have a huge influence on R_{th}.

Measurements have shown that $R_{th(j\text{-}s)}$ with Vincotech's Phase Change material is almost 30% lower than with common thermal grease when measured under identical conditions. Furthermore, $R_{th(j\text{-}s)}$ characterized in an air-cooled test setup is about 10% lower than in a water-cooled system.

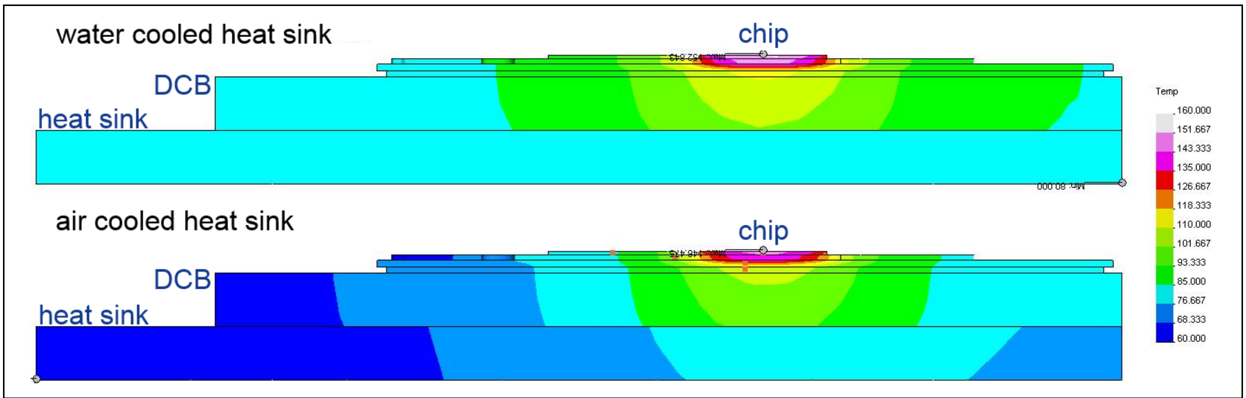


Figure 3: Simulation – water-cooled heat sink vs. air-cooled heat sink

As the picture above attests, the two cooling methods yield markedly different patterns of thermal spread. With a water-cooled heat sink, temperature spreads far more uniformly throughout the body so that heat is dissipated very well through a narrow channel. Heat dissipation within the air-cooled system is somewhat poorer, but with a wider thermal spread. This is why the air-cooled system yields a better R_{th} even though a water-cooled heat sink is the more effective method of cooling.

Another great benefit of Vincotech's measurement setup is that the worst-case R_{th} values are always published to provide a reliable basis for power module applications. In special cases where the worst-case values are not sufficiently accurate to define the cooling method, the entire measurement process should be repeated under the given conditions.

4.3 *The integrated NTC thermistor*

It certainly helps engineers to be aware of semiconductors' temperature during testing and in standard operation. Vincotech includes a NTC thermistor in most power modules to afford easy access to this value.

The integrated NTC thermistor is frequently located a good distance away from power components, and sometimes even not on the same DCB, so there will always be a discrepancy between the detected NTC temperature and the junction or heat sink temperature. This discrepancy has to be factored into the equation when monitoring an operating system.

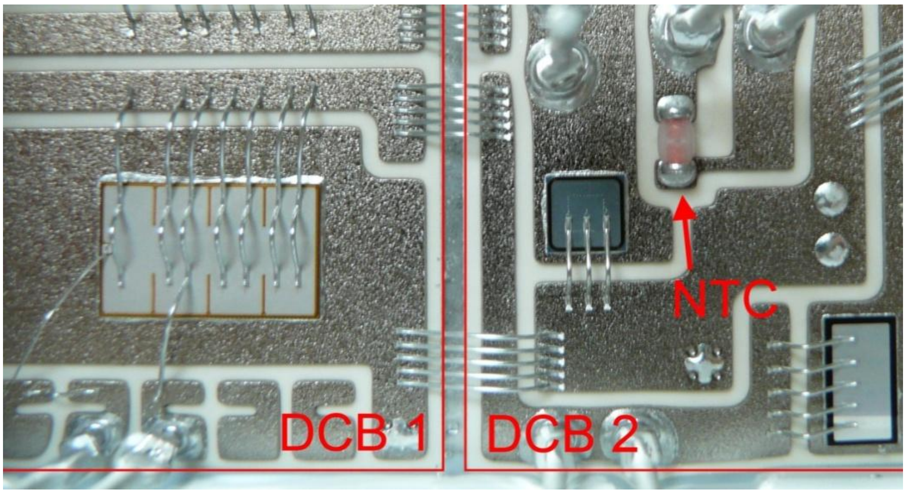


Figure 4: Typical NTC location

Moreover, the NTC value very much depends on thermal spreading. The mapped temperature is lower in a system where little spreading occurs than with cooling methods that spread heat in a wider pattern. It is important to analyze this behavior and gain a more accurate reading of the current temperature because this assessment will always be a combination of measuring and estimating.

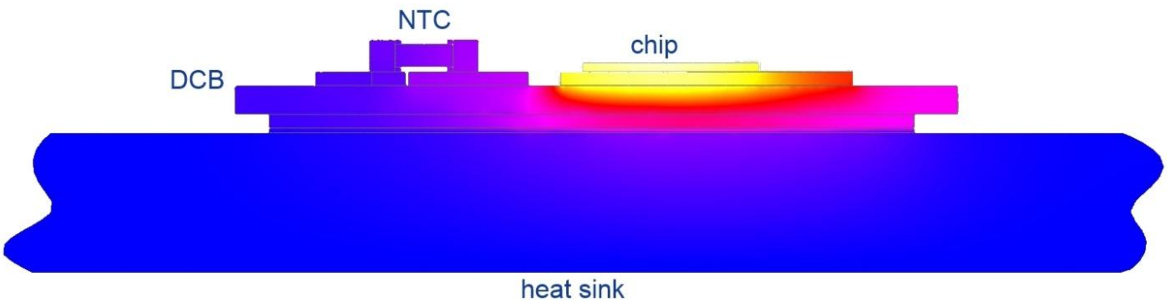


Figure 5: Heat spreading within a power module

Again, an NTC thermistor is already included in most Vincotech power modules. If not, a thermocouple ought to be placed right next to the module housing (to learn more, please refer to "Thermal measurement with an integrated NTC thermistor" on www.vincotech.com).

5 Thermal testing during development

It is recommended that devices be tested under thermal stress when developing power electronic systems. The datasheets of the combined components merely offer an initial impression of their behavior, so testing under worst-case conditions is imperative.

The thermocouples' location is very important in obtaining reliable results because of the different ways heat spreads in the combined materials. Even a minor variation in the couples' positioning will bring about a huge discrepancy in ΔT and subsequently in R_{th}.

Vincotech recommends measuring modules' temperatures in accordance with the IEC 60747-15 standard. A hole should be drilled from the bottom side in the heat sink to locate a thermocouple right beneath the midpoint of the contact surface and, depending on the inner circuit, at some other expected hotspots as well. The number of measuring points should be minimized to prevent interferences from the thermocouples.

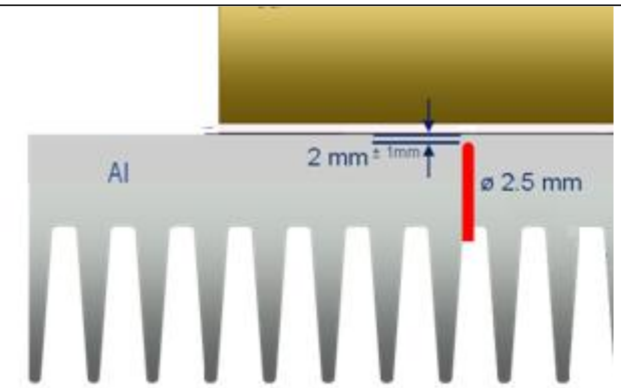


Figure 6: Recommended location for the thermocouple

6 Conclusion

Engineers are called upon to select electronic power components with great care. To this end, they have to gain fundamental insight into the designed system's thermal behavior. The thermal resistances given in Vincotech datasheets are worst-case values, so designed systems based on these parameters will certainly be reliable enough. It may be necessary to analyze thermal spreading and the resulting R_{th} accurately in some cases where the thermal environment is especially critical.

When a thermal survey is conducted of the entire system containing the power module and heat sink, the resulting R_{th} will differ from Vincotech's worst-case datasheet values. The extent of the variation will depend on how the different cooling methods change the pattern of spreading heat.

Monitoring the heat sink temperature with the internal NTC thermistor helps obtain insight into the thermal behavior and increase safety. The discrepancy between the NTC value and the actual temperature has to be considered when these readings are taken. It is advisable to mount an NTC thermistor close to the power module if an integrated thermistor is unavailable in the chosen module.

The power module and its heat sink should also be tested thoroughly under worst-case conditions.