Influence of Thermal Cross Coupling at Power Modules

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Abstract

The thermal impedance of the semiconductors in Power Modules is always measured for a single chip, without the influence of other surrounding dies. This article describes the increase of the junction temperature of power-semiconductors due to the cross coupling of the Rth of components placed close to each other. The influence of different module structures, such as baseplate-less modules, modules with baseplate, material-thicknesses and different materials is provided.

Introduction

Today power-applications are getting more and more compact to save cost, space, and weight. For the same reason the layout of Power-Modules has to be optimized. Also the integration factor is getting higher. In the past single half bridges and separated rectifiers were used, nowadays PIM´s are used. But this trend is leading to a high concentration of thermal losses, associated with a high influence of the thermal cross coupling to the real thermal impedance of the application. Since the thermal impedance for the semiconductor of a power-module is given only for single semiconductors without cross coupling, it is important for the designer of power electronic equipment to know how much the thermal resistance will increase, by chips and modules placed close together. As integration and power concentration is going forward it becomes more and more important for the designer of frequency converters to deal also with the influence of cross coupling. Therefore, as long as no thermal cross coupling is provided for Power Modules, the increase of thermal impedance for the application has to be estimated based on the internal distances of semiconductors in the module.

0. Basic Module Construction and Simulation Considerations

For the simulation the following basic module constructions were used. The used chipset is a 150A – 158mm2 IGBT loaded with 85W and in the case of a half-bridge configuration a 150A FRED, loaded with 25W is used, which can be estimated as typical for a fully loaded 150A module in drive applications. For the different simulations mainly the number of chips and the position at the heatsink was alternated. In some cases also the thickness of the substrate and the thermal grease.

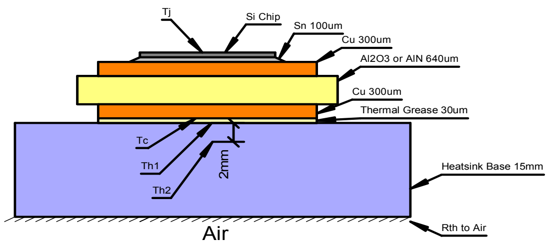

Figure 1: Module without baseplate

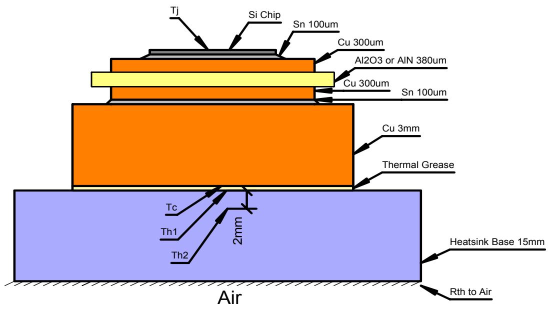

Figure 2: Module with baseplate

1. Datasheet Values of the Thermal Impedance Zth

The thermal impedance is highly influenced by the used measurement method and used interface materials for the characterization. It can be measured as Tj-Tc, Tj-Th with temperature measurement at module-back-side or heat-sink-surface or Tj-Th with temperature measurement inside the heat sink in a depth of 1-2mm under the module. Each method has his pros and cons. Tj-Tc describes the module most exact, but is highly influenced by the method of measurement of the module backside temperature. Tj-Th characterizes in addition the thermal resistance from the module to the heatsink, which it is closer to the real application, but it is also influenced by the thickness and material, which is used for the thermal interconnection of the module to the heat sink.

- Measurements and simulations for datasheets were done under the following conditions:Fluid cooled copper heat sink
- Measurement of Tc at bottom surface of module in the chip center
- Measurement of Th1 at surface of heatsink, center of the chip
- Measurement of Th2 2mm deep in the heat sink.

	Rth Tj-Tc	Tj- Th1	Tj- Th2
Al2O3 0,64mm without baseplate			
grease (d=30 µm, λ=1 W/mK) best case	0,167	0,310	0,336
grease (d=50 µm, λ=0,6 W/mK) - typical	0,156	0,479	0,501
foil (d=70 µm, λ=1,2 W/mK) - typical	0,160	0,407	0,430
Al2O3 0,38mm wo baseplate,			
grease (d=30 µm, λ=1 W/mK) best case	0,112	0,255	0,281
AIN without baseplate			
grease (d=30 µm, λ=1 W/mK) best case	0,049	0,185	0,211
grease (d=50 µm, λ=0,6 W/mK) - typical	0,047	0,342	0,362
foil (d=70 µm, λ=1,2 W/mK) - typical	0,048	0,276	0,298
Al2O3 with baseplate			
grease (d=30 µm, λ=1 W/mK) best case	0,159	0,220	0,230
grease (d=50 µm, λ=0,6 W/mK) - typical	0,154	0,267	0,273
foil (d=70 µm, λ=1,2 W/mK) - typical	0,156	0,248	0,256

Table 1: comparison of construction, interface materials, and location of temperature measurement

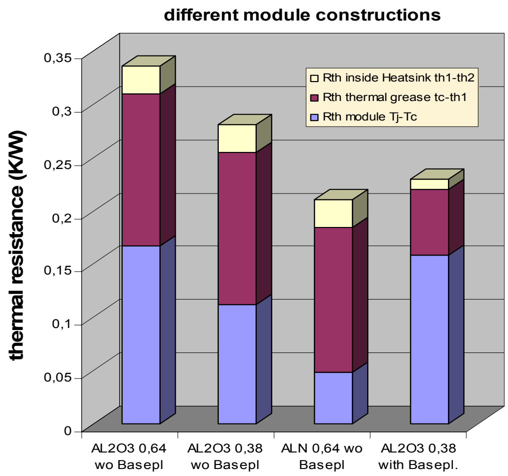

Figure 3: comparison of construction and interface materials

Type and thickness of the ceramic material mainly influences the internal Rth of a module. The internal resistance of a module with AL203 0,64mm without baseplate and 0,38mm AL2O3 with baseplate is nearly the same. For all modules without baseplate the thermal resistance of the thermal interface material is the same. Here the module with base plate behaves much better due to the thermal spreading of the base plate. Also the internal Rth of the heatsink is lower for modules with baseplate due to the spreading of the base plate.

With a simulation in cross section the thermal spreading of a base-plate can be clearly seen.

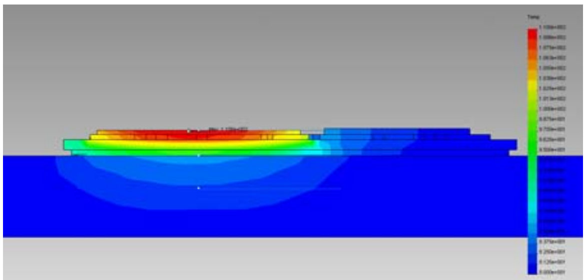

Figure 4: Al2O3 0,64mm

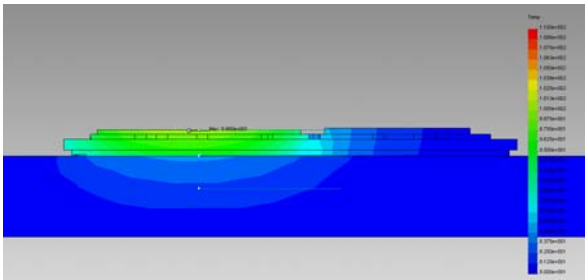

Figure 5 AIN 0,64mm

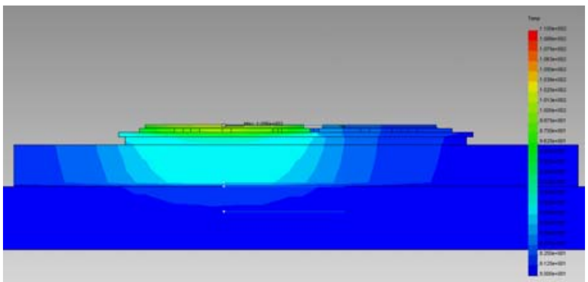

Figure 6 Al2O3 0,38mm, with baseplate 3mm

2. Thermal System Resistance of Distributed and Close Chips

Six IGBT's were mounted on Daces with and without base plate. The arrangement was altered from well distributed to compact packed. The module was placed on an aluminum heat sink 200*300mm with a base thickness of 15mm and a thermal resistance of 0,078K/W to air, which would lead to a calculated heat sink temperature of 80°C at 40°C ambient.

Between the chips the distance was reduced from 100mm, to 50mm, 25mm, 10mm, 7,5mm, 5mm, and 2mm. The size of the base plate was reduced in the same way for the modules with base plate and DBC size respectively.

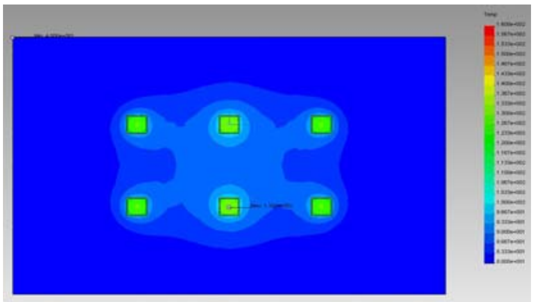

Figure 7: Al2O3 wo. baseplate, distance 50mm

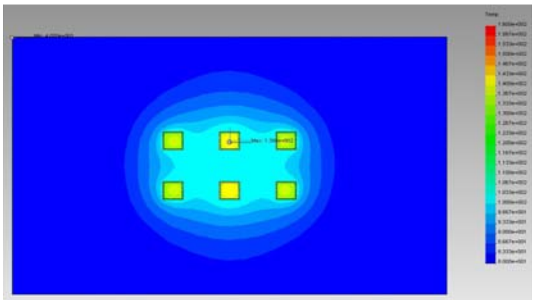

Figure 8: Al2O3 wo. baseplate, distance 25mm

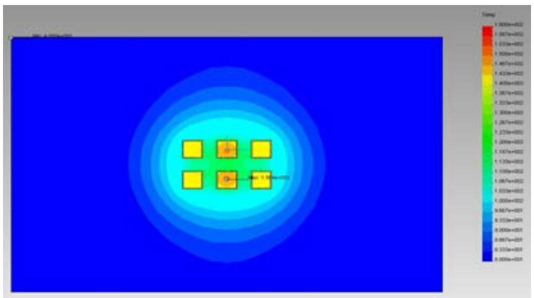

Figure 9: Al2O3 wo baseplate, distance 10mm

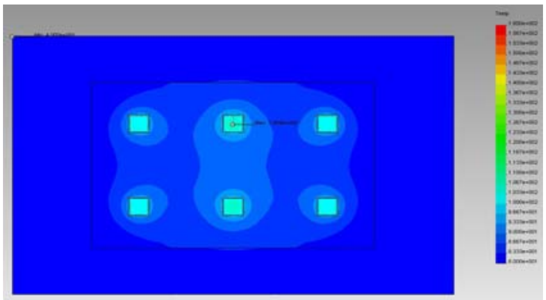

Figure 10: Al2O3 with base plate, distance 50mm

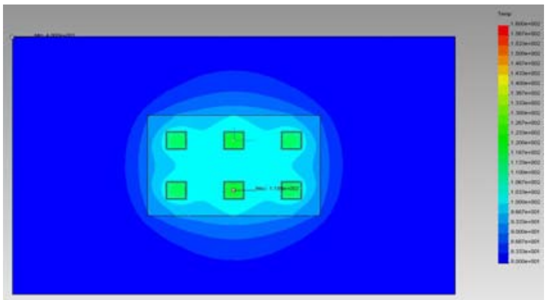

Figure 11: Al2O3 with base plate distance 25mm

At a distance of 25mm there is a overlapping of the spreading area with equal temperature of the baseplate between the chips.

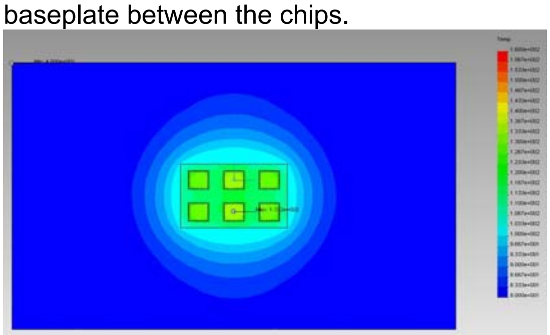

Figure 12: Al2O3 with base plate, distance 10mm

At a distance of 10mm the baseplate temperature got homogenous. A further reduction of the distance would reduce the spreading area around the chips and drastically increase the thermal resistance between base plate and heatsink.
Figure 15 will confirm the estimation. Between 100mm and 50mm distance the slope is the same for all graphs. For less then 50mm the slope off the chips on base plate is increasing more compared to the modules without base plate.

	absolute value				**percent to 100mm distance**			
	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth
dist.	Tj-	Tj-	Tj-	Tj-	Tj-	Tj-	Tj-	Tj-Th

	Tc	Th1	Th2	Th	Tc	Th1	Th2	
mm	K/W	K/W	K/W	K/W	%	%	%	%
ALN wo basepl.								
100	0,05	0,19	0,23	0,39	0%	0%	0%	0%
50	0,05	0,19	0,23	0,47	0%	0%	0%	20%
25	0,05	0,19	0,23	0,58	0%	0%	0%	47%
10	0,05	0,19	0,23	0,70	0%	0%	0%	80%
7,5	0,05	0,20	0,23	0,74	0%	0%	0%	88%
5	0,05	0,20	0,24	0,77	0%	1%	2%	98%
2	0,05	0,20	0,25	0,83	1%	2%	7%	112%
Al2O3 wo basepl.								
100	0,17	0,32	0,35	0,51	0%	0%	0%	0%
50	0,17	0,32	0,35	0,59	0%	0%	0%	15%
25	0,17	0,32	0,35	0,70	0%	0%	0%	36%
10	0,17	0,32	0,35	0,83	0%	0%	0%	61%
7,5	0,17	0,32	0,35	0,86	0%	0%	0%	67%
5	0,17	0,32	0,36	0,90	0%	1%	2%	75%
2	0,17	0,32	0,37	0,95	1%	1%	5%	86%
Al2O3 with basepl.								
100	0,16	0,20	0,22	0,27	0%	0%	0%	0%
50	0,15	0,20	0,22	0,34	0%	0%	1%	25%
25	0,15	0,20	0,22	0,46	0%	0%	2%	67%
10	0,15	0,22	0,23	0,62	0%	7%	6%	129%
7,5	0,15	0,23	0,25	0,67	0%	11%	14%	147%
5	0,16	0,24	0,25	0,74	1%	17%	16%	171%
2	0,16	0,26	0,30	0,85	4%	30%	36%	210%

Table 2: decreased distance between chips

All modules showed a strong increase of Rth Tj-Th due to the bad spreading of the heatsink. Modules without base-plate have no increase of Rth down to Thj2, whereas modules with base-plate have an increase due to the reduced possible spreading of the baseplate as expected.

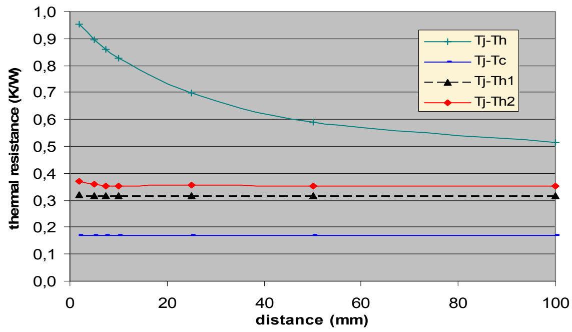

Figure 13: Al2O3 without baseplate

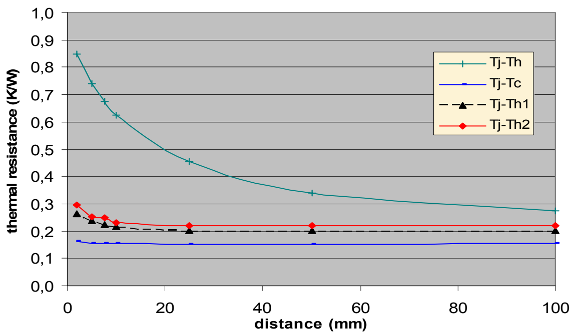

Figure 14: Al2O3 with baseplate

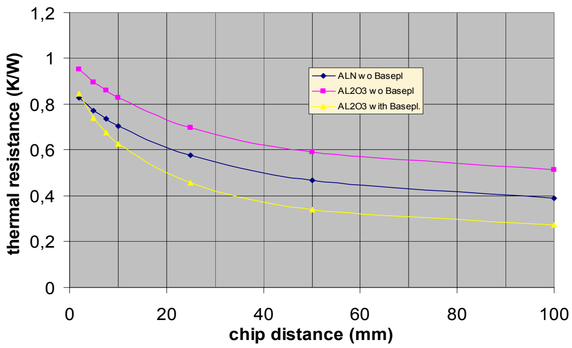

Figure 15: comparison of AIN, Al2O3 with, and without base-plate

3. Thermal Resistance of a 1/2-Bridge IGBT Module

The half-bridge simulation was carried out under following conditions:
2* IGBT 158mm^2 (Pv=85W each)
2* FRED 53mm^2 (Pv=25W each)
Tested configurations:

- Al2O3 without baseplate
- ALN without baseplate
- Al2O3 with baseplate, Al2O3 0,38mm, Cu-base plate 3mm thickness

Aluminum heatsink 100*200mm*15mm, Rth to ambient 0,18K/W, which leads to 80°C calculated heatsink temperature at 40°C ambient temperature.

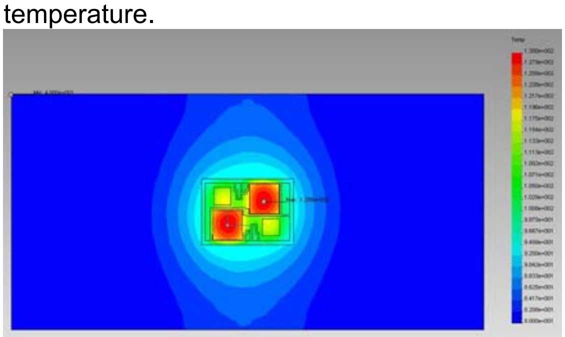

Figure 16: Half Bridge without baseplate, simulation

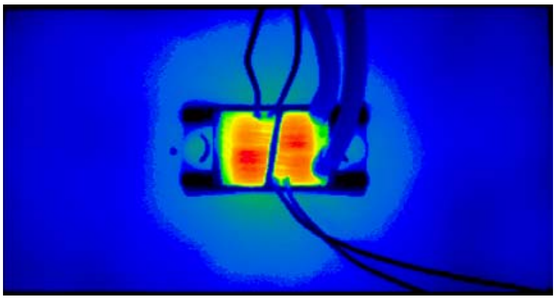

Figure 17: Half bridge without baseplate, thermal measurement

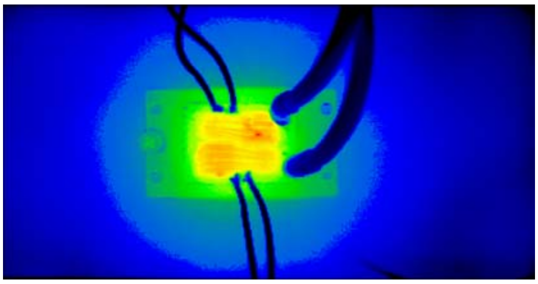

Figure 18: Half Bridge with baseplate, thermal measurement

The module with base-plate, is a better spreading in the base-plate compared to the spreading in the Al heatsink. This decreases also the thermal resistance of the spreading inside the heatsink. It can be seen at the low Th2-Th value of the baseplate module compared to the modules without baseplate. The other resistances kept nearly the same values as in the datasheet simulation.

	Rth Tj-Tc (K/W)	Rth Tj-Th1 (K/W)	Rth Tj-Th2 (K/W)	Rth Th2-Th (K/W)
Al2O3 wo basepl	0,157	0,287	0,326	0,259
AlN wo basepl	0,046	0,168	0,206	0,254
Al2O3 with basepl	0,153	0,217	0,241	0,186

Table 3: Rth of Half-Bridge

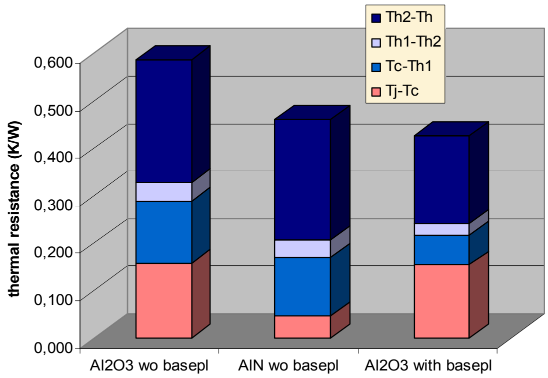

Figure 19: Rth of Half-Bridges

4. Thermal Resistance of a Six Pack Configuration

In the following 3 * Half-Bridges, with 2* IGBTs (Pv 85W each) and 2*FREDs (Pv 25W each) are tested.
Tested configurations:

- ALN without baseplate
- Al2O3 without baseplate
- Al2O3 without baseplate.
- Al heat sinks 0,06K/W, 200*300mm*15mm.

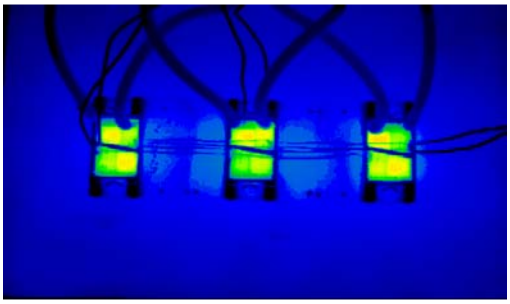

Figure 20: 3 Half-Bridges w/o baseplate, distance 50mm, thermal measurement

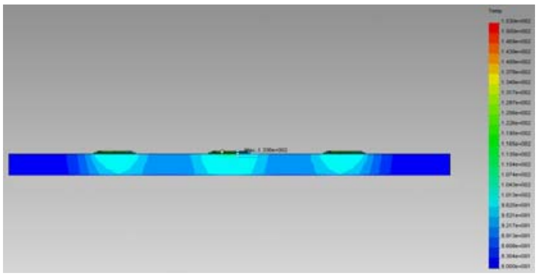

Figure 21: cross cut of 3 Half-Bridges w/o baseplate simulation

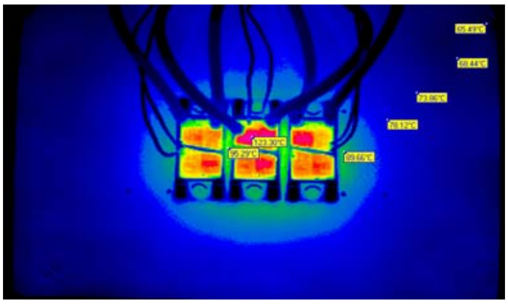

Figure 22: 3 Half-Bridges, distance 5mm, thermal measurement

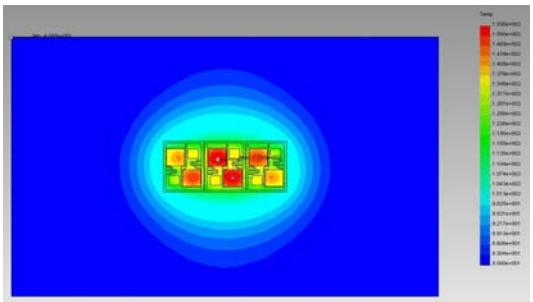

Figure 23: 3 Half-Bridges dist. 1mm, simulation, simulation

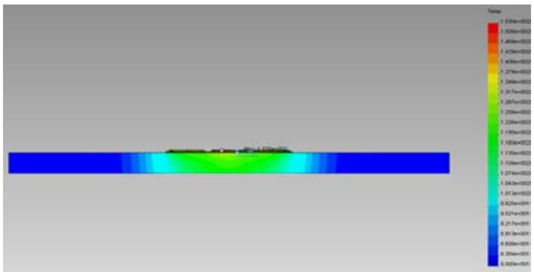

Figure 24: cross-cut, 3 Half-Bridges, dist. 1mm, simulation

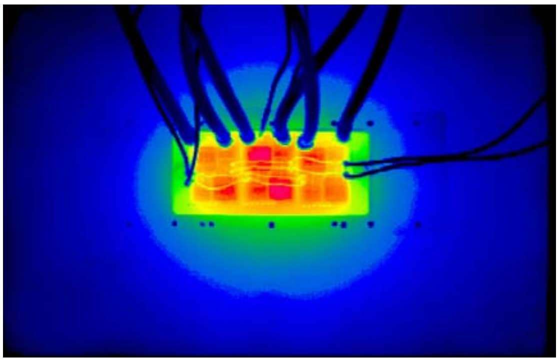

Figure 25: Six-Pack with 3mm base-plate, DBC distance 1mm, thermal measurement

The temperature values of this simulation show for the Rth Tj-Tc, Rth Tj-Th1 and Rth Tj-Th2 nearly the same values as specified in the datasheet and the Half-Bridge. Only the thermal resistance for the spreading within the heatsink was increased depending on the distance of the Half-Bridges.

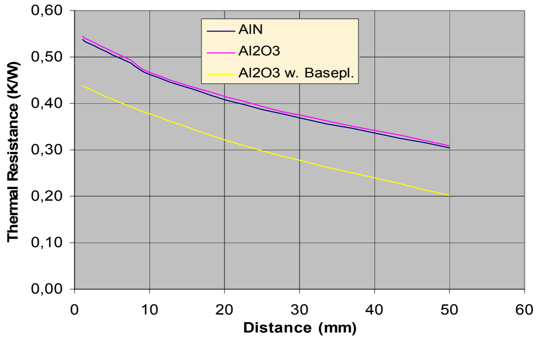

Figure 26: spreading of heat-sink Th2-Th

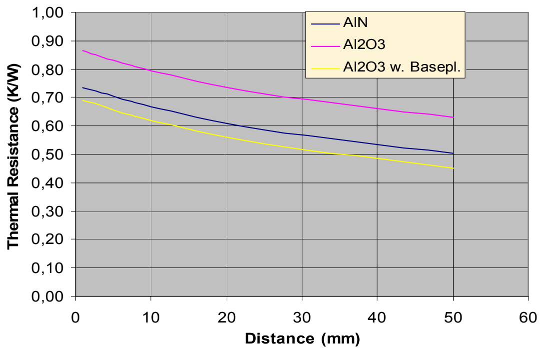

Figure 27: total Rth, Tj-Th

The cross-section in figure 24 shows that the temperature doesn't decrease so much vertically, but in horizontal direction it decreases rapidly. This leads to the estimation, that increasing of the thickness of the heat-sink base or the usage of a better thermal conducting material could reduce the thermal resistance.

In order to proof this, a three-phase inverter bridge with 3mm base-plate was mounted on heat-sink bases with different thicknesses, and different materials.

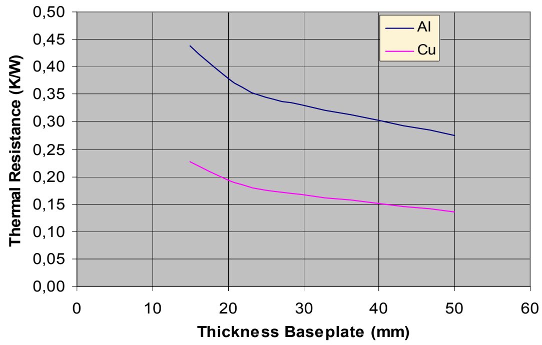

Figure 28: increased thickness of heat-sink-base

Increasing the base of the heat sink up to 25mm lead to a strong reduction of the spreading Rth inside the heatsink. Increasing the thickness up to 50mm still decreased the Rth but the slope was getting less steep.

5. Conclusion

For modules in the tested power range / chip size (1200V / 150A /158mm^2) without baseplate no cross coupling within the module itself was found.
For modules with baseplate, the cross coupling is influencing the Rth for chips side by side at a distance less than 5mm. The spreading of the heat sink base is the major limiting factor and must be considered.

If a distributed mounting of modules is not applicable, the thickness of the heat-sink base should be increased to values > 20mm or copper should be considered instead of alumina.

Modules with baseplate provide the lowest thermal resistance, since the baseplate provides a thermal spreading before the thermal flow has to pass the thermal interface module – heat sink with a relative low thermal conduction. The spreading of the base plate also improves the spreading of the heat sink base.

However, three half-bridges without base-plate, mounted well distributed are able to provide the same or better performance than a dense Six-Pack with baseplate.