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Thermal resistance of IGBT Modules - specification and modelling

1. Introduction

For selecting a suitable IGBT module it is essential to know its thermal performance in conjunction to the thermal properties of the cooling system and the requirements given by the application (power, ambient temperatures, load cycle stress/required lifetime).
Main issues for the comparability of thermal characteristics of different modules are:

- Different module packaging technologies (with/without baseplate, with integrated heatsink),
- manufacturer specific, different choices of reference points for measuring temperatures,
- differences in specification thermal resistances (measuring conditions, specification per module or per switch, with or without thermal coupling between module's switches, modelling),
- thermal conductivity and thickness of TIM (thermal interface material) between module and heatsink,

This application note describes usual specification methods for thermal characteristics of IGBT modules and its impacts on data sheet parameters. It outlines the actual and future methods of R_{th} specification of SEMIKRON components. A detailed overview of the physical principles of heat transfer and its usage to improve power electronic systems is given in the Application Manual of SEMIKRON [2].
R_{th} and temperature measurement results presented here are exemplary to show different effects. They may deviate from datasheet values which are valid to describe the product.

2. Methods for Determining Thermal Resistances

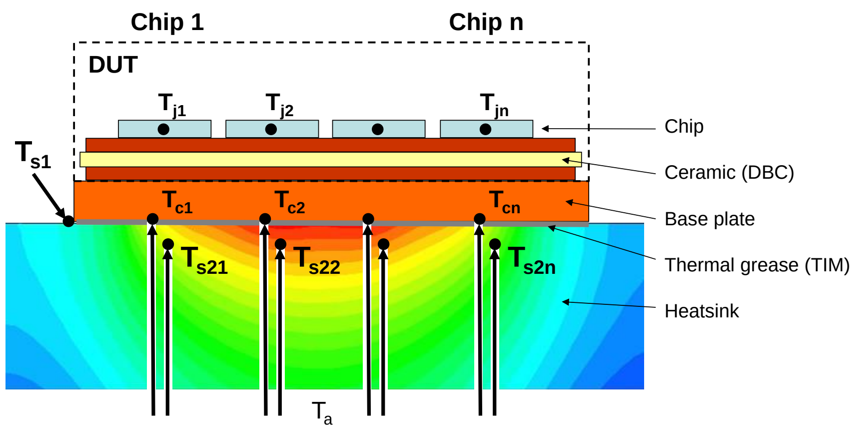
2.1 Definitions with Regards to this Application Note

IGBT module: contains one or more power electronic switches, isolated from the cooling surface called "case" with the assumption that the total heat is dissipated via this surface;
Switch: electrical circuit element, here the IGBT with its antiparallel diode;
IGBT-switch: IGBT part of the switch made of one or by parallel connection of more chips inside of a module operating as one functional circuit element;
Diode-switch: Diode part of the switch made of one or by parallel connection of more chips inside of a module operating as one functional circuit element;
Case rated module: module where the rated current is specified for a certain case temperature, which requires the specification of a thermal resistance from IGBT-switch and diode-switch to the case, normally modules with a thick baseplate;
Heatsink rated module: module where the rated current is specified for a certain heatsink temperature, which requires the specification of a thermal resistance from IGBT-switch and diode-switch to the heatsink and the mounting conditions for which this resistance is valid, normally modules without baseplate;

2.2 Chip T_j, Case T_c and Heatsink Temperature T_s Measurement

There are different possibilities to measure the temperatures of IGBT and diode chip, for example using infrared cameras or thermocouples at chip surfaces or using temperature dependence of semiconductor properties like the forward voltage drop. Latter is proposed by IEC 60747 standard [3] because this method is applicable without special prepared modules for its user: When operating with a small measurement current, bipolar semiconductors show a linear dependency between the forward voltage drop and the chip temperature. A calibration curve $V_{ce}=f(T_j)$ or $V_f=f(T_j)$ is generated using this effect by passive heating and measuring the forward voltage at the measurement current and different temperatures. Than the switch X (IGBT or diode) is operated at a constant load current to heat it until thermal equilibrium is reached. The power dissipation is calculated by $P_X=V_X*I_{DC}$. After switching off the load current the small measurement current is applied again to the switch. T_j can be derived from the measured voltage drop by the calibration curve a few 100 µs after turning off. The short brake is necessary to allow semiconductor charge carrier effects to decline. The result is an area related average junction temperature of that switch.
Case temperature measurement for case rated modules is made by thermocouples from underneath in the center position of the chips. For heatsink temperature measurements leaves the IEC 60747-15 [4] two options, beside the module T_{s1} or from below the chip center position T_{s2} as well (see Figure 1 and Table 1).

Figure 1: Cross section of a case rated device with reference points for temperature measurement of T_c and T_s [4]



To measure T_{cn} and T_{s2n} at the same vertical position underneath the chips different options can be used. The first two have the disadvantage of disassembly and remounting of the module, which is a source for failure where the third has a low failure by a deviation from the chip center position:

- either two heatsinks where one has the holes drilled through underneath the chips to measure T_{cn} and a second heatsink with blind wholes at the same positions to measure T_{s2n}

- or in case of symmetrical chip position of the switches one heatsink with the half number of holes to measure $T_{c1\ldots n/2}$ and the other half to measure $T_{s2n/2\ldots n}$. After the first measurement the device is turned by 180° and in a second measurement the other temperatures are measured
- or a slightly shifted drill hole for T_s measurement beside of T_c measurement

In heatsink rated modules without baseplate it is not possible to measure the case temperature without disturbing the heat flow from chip to heatsink. Here only the heatsink temperature is measured either from below T_{s2n} or beside T_{s1} of the module.

Table 1: Definition of temperature reference points according IEC 60747-XX [3] [4]

Measured temperature	Symbol	Temperature reference point
junction temperature of chip 1 to n	$T_{j1\ldots n}$	determined for the chips of measured switch, usually by means of methods as described in the individual documents (diode -2; IGBT -9)
case temperature below chip 1 to n	$T_{c1\ldots n}$	at manufacturer specified point of case, measured from underneath through a 1…2.5 mm small hole through the heatsink and any thermal interface material underneath the chip
heatsink temperature at a specified surface point	T_{s1}	**method 1:** T_s is taken at the heatsink surface from above at hottest accessible point nearest to the chip
heatsink temperature below chip 1 to n	$T_{s21\ldots 2n}$	**method 2:** T_s is taken from underneath through a 1…2.5 mm blind hole ending at 2±1 mm below the heatsink surface

2.3 Specification of Thermal Resistance

The formulas to calculate the thermal resistances $R_{th(j-c)}$, $R_{th(c-s)}$ or $R_{th(j-s)}$ per switch or per module M by using the temperature differences and power dissipation derived by the measurements from above is shown in Table 2. The variable X stands for IGBT or diode and is applicable to any other power semiconductor inside a module. The highlighted formulas are used by SEMIKRON up to now.

Table 2: Definition of $R_{th(j-s)}$, $R_{th(j-c)}$ and $R_{th(c-s)}$ according IEC 60747-15 [4]*

Thermal resistance R_{th}	case rated modules	heatsink rated modules
per IGBT- or diode switch for modules with single chip switches	$R_{th(j-c)} = \frac{T_j - T_c}{P}$ $R_{th(c-s)1} = \frac{T_c - T_{s1}}{P}$ **or** $R_{th(c-s)2} = \frac{T_c - T_{s2}}{P}$	$R_{th(j-s)1} = \frac{T_j - T_{s1}}{P}$ **or** $R_{th(j-s)2} = \frac{T_j - T_{s2}}{P}$
per IGBT- or diode switch of modules using n chips in parallel	$R_{th(j-c)} = \frac{T_j - \sum_{i=1}^{n} T_{ci}/n}{P}$ $R_{th(c-s)1} = \frac{\sum_{i=1}^{n} T_{ci}/n - T_{s1}}{P}$ **or** $R_{th(c-s)2} = \frac{\sum_{i=1}^{n} T_{ci}/n - \sum_{i=1}^{n} T_{s2i}/n}{P}$	$R_{th(j-s)1} = \frac{T_j - T_{s1}}{P}$ **or** $R_{th(j-s)2} = \frac{T_j - \sum_{i=1}^{n} T_{s2i}/n}{P}$
per module M (losses $P_M = \Sigma P_m$) with n chips	$R_{th(c-s)M1} = \frac{\sum_{i=1}^{n} T_{ci}/n - T_{s1}}{P_M}$ **or** $R_{th(c-s)M2} = \frac{\sum_{i=1}^{n} T_{ci}/n - \sum_{i=1}^{n} T_{s2i}/n}{P_M}$	n.a

** Note: the IEC does not clearly distinguish between single chip and multiple chip switches and how to deal with different case or heatsink temperatures at different chip positions of one switch. Amendatory to the international standard is the average of the measured temperatures used here (see 2.4).*

The standard leaves to the module manufacturer the choice of reference point location for heatsink temperature T_s, but the location should be specified in the data sheet or in technical explanations. This free choice leads to a variety of heatsink related R_{th} values depending on manufacturer and for different products and makes a comparison difficult.
The reasons for these difficulties are different portions of thermal resistances in the heat path from junction to ambient, see Figure 2. Reference point T_{s1} at heatsink surface is far cooler than T_{s2} underneath the module with the consequences described in Table 3. The better the heatsink dissipates the power the larger the difference of measuring results. Related to fixed T_a, thermal properties and measuring conditions, $R_{th(s-a)}$ varies with the selection of reference point T_s, but $R_{th(j-a)} = R_{th(j-c)} + R_{th(c-a)}$ will remain constant.

Figure 2: Fractions of calculated thermal resistances in a module with baseplate

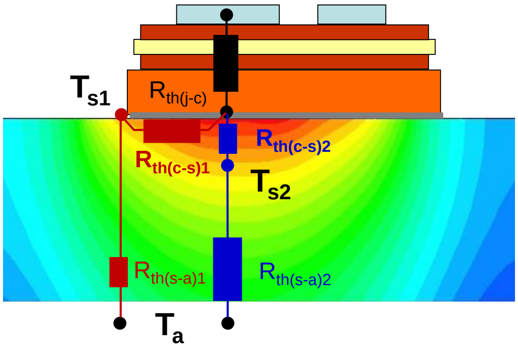


Table 3: Effects of reference point for T_s at $R_{th(c-s)}$ and $R_{th(s-a)}$

Measuring method for T_s	Reference Point	Relation $\Delta T_{(c-s)}$, $R_{th(c-s)}$	Relation $\Delta T_{(s-a)}$, $R_{th(s-a)}$	Advantage	Disadvantage	used by SEMIKRON
method 1	T_{s1}	higher	lower	accessible Measuring point, one measurement	strong heatsink depending	for case rated modules with release date before 2014
method 2	T_{s2n}	lower	higher	less heatsink depending,	special prepared heatsink, two measurements	for heatsink rated modules; for case rated modules from 2015 onwards

2.4 Multi Chip Devices

All switches of IGBT modules for high power applications are made of multiple IGBT/diode chips in parallel. The chips are soldered or sintered to isolating substrates, in most cases DBC substrate (Direct Bonded Copper). Due to electrical and mechanical unbalances each chip has different power dissipation and its own individual temperature. The IEC standard leaves also here some determinations to the module manufacturers, such as which couples of case and heat sink temperature reference points are to be used for datasheet specification, e. g. case temperatures underneath the hottest chip or medium values of all chip-specific case temperatures. Datasheets and technical explanations often do not contain information on whether the specified thermal properties were calculated from peak or mean values of chip-individual case temperatures.
Using the junction temperature measurement method from above, the voltage drop of all parallel IGBT or diode chips of a switch is measured. That means the derived T_j is an area related average temperature including thermal coupling effects of the parallel chips of that IGBT- or Diode-switch. So the measurement result is not exactly the temperature equivalent voltage of one quite specific or the hottest chip.

In contradiction to this provides the baseplate measurement a position-related case temperature T_c. For determination of a switch-related case temperature it is necessary to measure T_{cn} under each chip and use the average T_c together with T_j to calculate the $R_{th(j-c)}$ per switch. Otherwise the thermal resistance will be position dependent and **the position underneath the hottest chip provides the smallest thermal resistance $R_{th(j-c)}$**. An example for Semix3 is shown in Figure 3, a deviation in the temperature difference between the single positions 1 to 3 of 10% …15% is common. The same applies to the sink temperatures and the determined $R_{th(c-s)21…23}$. Here as well the averages of all temperatures should be used.

Figure 3: View into a SEMiX module with 2 IGBT- and diode-switches, each made of 3 parallel chips and a temperature profile at module baseplate when heated by IGBT losses

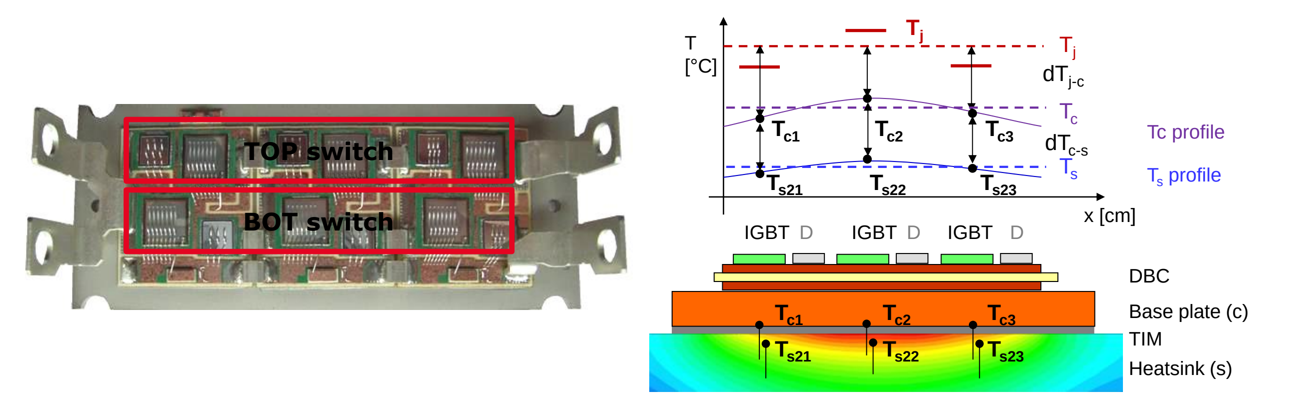
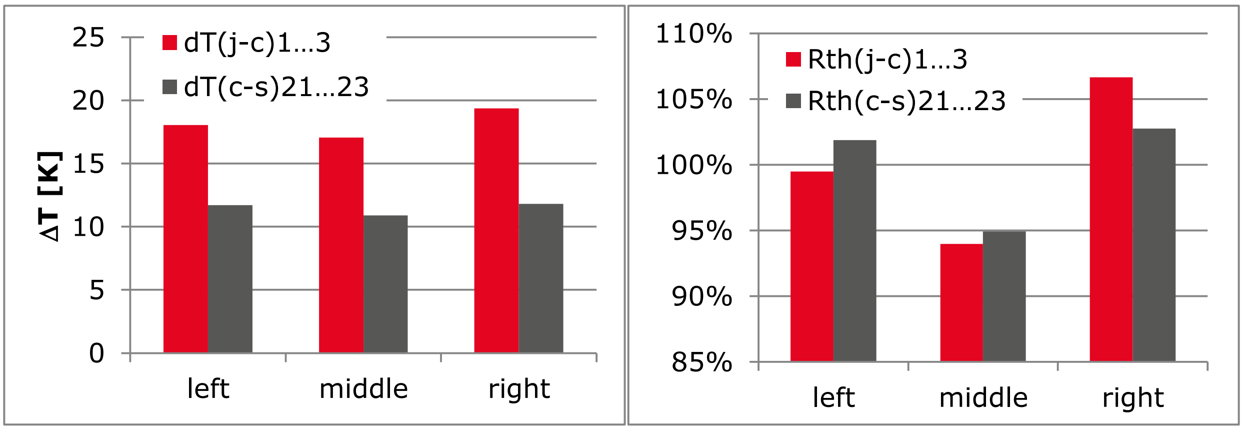


Figure 4: Measured temperature differences at the three individual TOP switch chip positions and derived $R_{th(j-c)n}$ and $R_{th(c-s)n}$ values relative to the average value (100%)



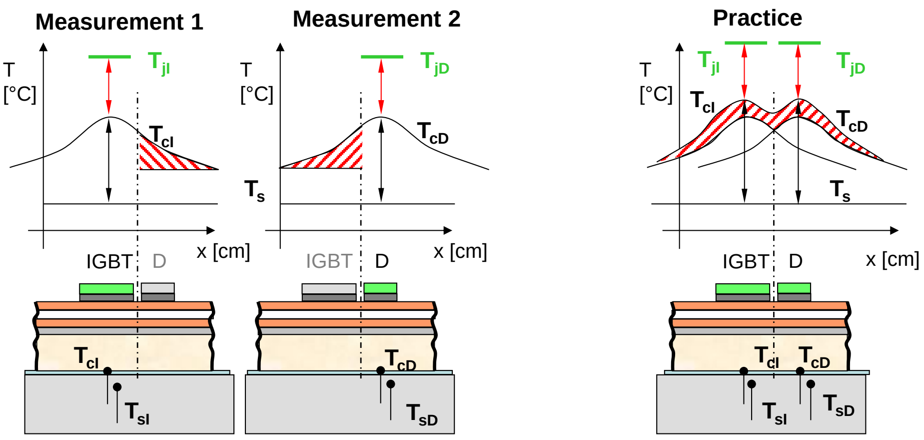
In heatsink rated modules without baseplate are temperature gradients on the heatsink even higher due to the lack of the baseplate's heat spreading effect. Here as well would the position underneath the hottest chip provide the smallest $R_{th(j-s)}$. Therefore, the mean values of heatsink temperatures beneath all parallel chips should be used for determination of a switch-related heatsink temperature.
As depicted above is it necessary to measure case and/or heatsink temperature underneath each chip and use average values per switch for case and heatsink temperature. For this reason SEMIKRON uses module type specific liquid cooled heatsink with holes at any chip position.

2.5 Thermal Coupling Between Switches

To which extend thermal coupling takes place depends on the distance between the chips of the switches and thickness + thermal conductivity of the layers underneath. In fully equipped modules with distances between the switches of less than 3 mm thermal coupling has to be considered in the DBC. But mostly does the heat spreading in the thermally more conductive layers underneath the DBC (base plate, heatsink root) generate effects of thermal coupling.
When using the above described measuring method losses can be only impressed in either IGBTs or diodes. Thermal coupling between IGBT and diode of one switch will not be detected but will heat up the devices to

higher temperatures in the application. The hatched area (see Figure 5 left) from the single measurement cannot longer be used for the heat transfer if both devices dissipate power leading to a higher temperature profile to the same extend (right).

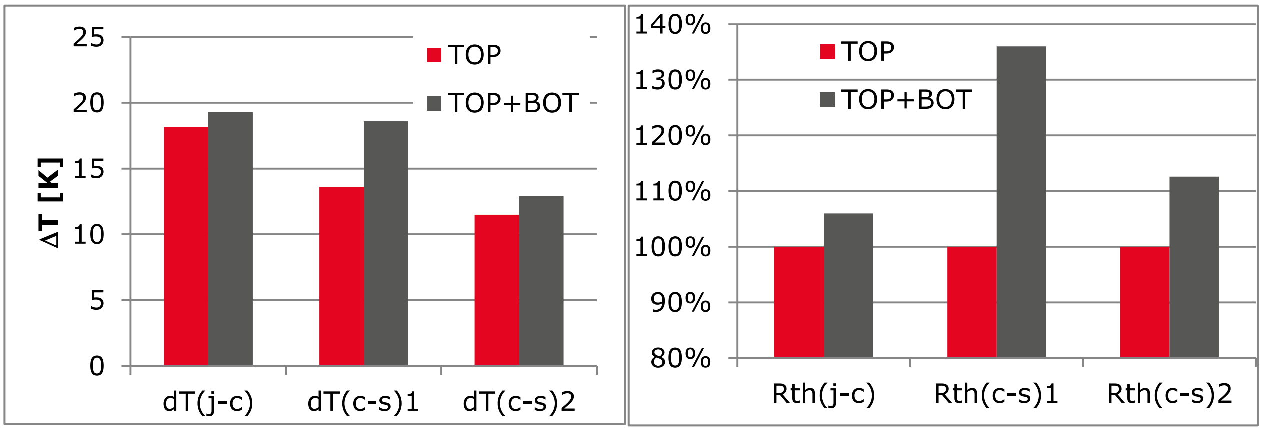
Figure 5: Neglected heat spreading at indirect measurement of chip temperature in an IGBT module with baseplate



2.5.1 $R_{th(j-c)}$

The effect of operation with two IGBT-switches on the same time is shown in Figure 6. This effect can be investigated easily with the measurement method described above, if the switches of the same kind are connected electrically in series, for example the two IGBT or two diodes of a half-bridge module. In case off SEMiX are the TOP and BOT IGBT-switches arranged only with a few millimeter distance (see Figure 3) and heating up each other. The measurement result shows that $R_{th(j-c)}$ changes only a few single percent. This can be explained with a low cross conducting within the DBC. The temperature of the copper base plate is increased by the same value as the chip temperature, when two switches are in operation instead of one. The ΔT and therewith the R_{th} stays constant. The specification of $R_{th(j-c)}$ per single IGBT- or diode-switch without considering coupling effect is acceptable.

Figure 6: Measured temperatures differences between T_j, T_c and T_s for operation of only TOP IGBT compared to the situation of losses in TOP + BOT IGBT simultaneous and derived relative values of $R_{th(j-c)}$ and $R_{th(c-s)}$ (single switch = 100%) of a 450 A SEMiX module



2.5.2 $R_{th(j-s)}$

The resistance is specified normally for modules without baseplate. Here is only a very limited thermal coupling between the switches inside the DBC. The value is specified for a single IGBT- or diode-switch for a sink temperature measured underneath the module. There is no adaptation of the measurement procedure or specifications necessary.

2.5.3 $R_{th(c-s)}$ with Thermal Coupling of Switches

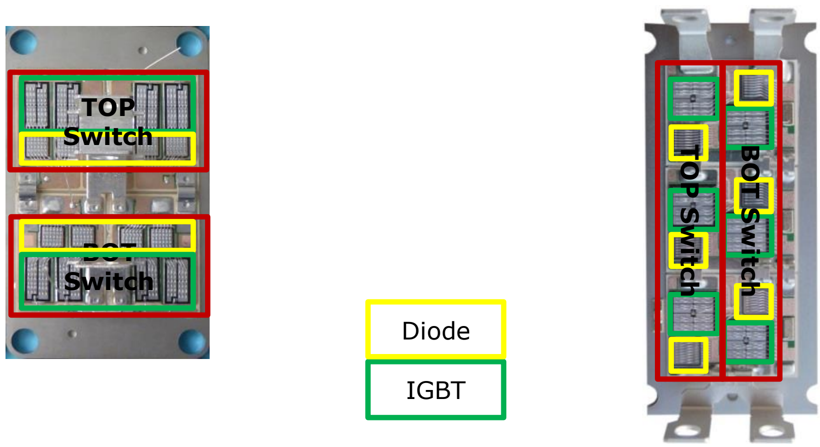
In Figure 6 can be seen that $R_{th(c-s)I}$ changes from 15% (two IGBT-switches in operation and T_s measured underneath the module) up 35% if T_s is measured beside the module. The results below show that it can rise up to 100% if the diode-switches dissipate power as well. Specifying only a $R_{th(c-s)X}$ per switch without any coupling factor will lead to a too low temperature prediction in case of losses in all switches. Table 4 shows the conditions for simulation and measurement of thermal coupling effects on $R_{th(c-s)}$ of a SEMiX3 and SEMITRANS3 half bridge module.

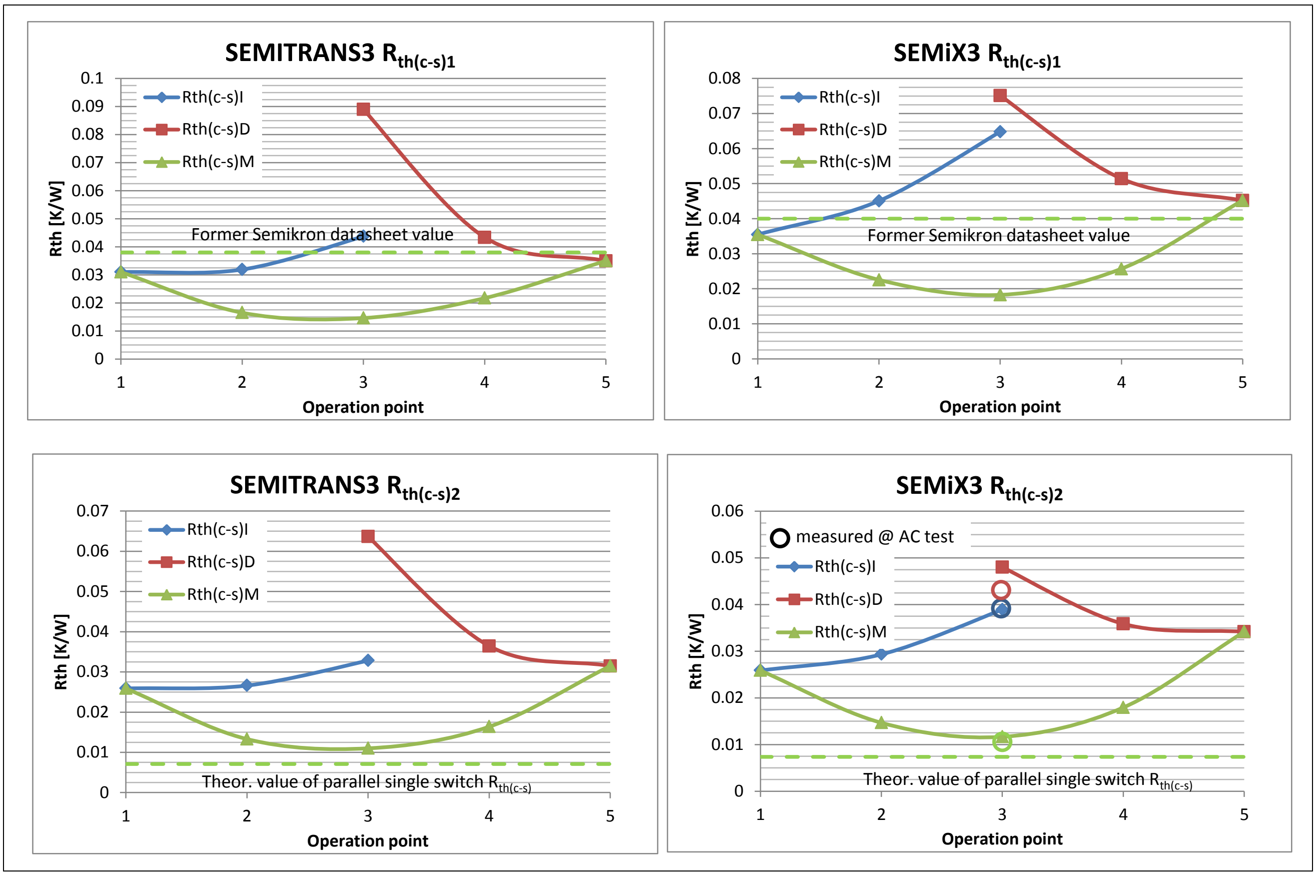
Table 4: Specification of working points for simulation and measurement of thermal coupling influence on the $R_{th(c-s)}$; 100% stands for about 1 W/mm² used chip area

#	Practical relevance	Power losses per IGBT and diode			
		T TOP	T BOT	D BOT	D TOP
1	Half bridge module in brake chopper or stall mode of a motor inverter	100%	0	0	0
2	Inverter operating with max. AC voltage, power factor cos(ϕ)=1, low switching frequency	100%	100%	0	0
3	Inverter operation with lower output voltage, power factor cos(ϕ)=-0.8….+0.8, high switching frequency	50%	50%	50%	50%
4	Inverter operating with max. AC voltage, power factor cos(ϕ)=-1, low switching frequency	0	0	100%	100%
5	Booster with input voltage almost equal to output voltage	0	0	0	100%

Figure 7 shows the calculated variation of $R_{th(c-s)I}$ per IGBT-switch, $R_{th(c-s)D}$ per diode-switch and $R_{th(c-s)M}$ per module. To calculate $R_{th(c-s)M}$ the highest temperature difference $dT_{(c-s)X}$ determined for one switch was divided by the total losses of the module. Operation points 1, 2 and 3, 4 are equal to results of measured values and used to validate the model. Operation point 3 represents a condition with losses in IGBT and diode at the same time. It was verified for the SEMiX by an AC test with alternating current through IGBT and diode at a 50 Hz high current power supply.

Figure 7: Thermal resistances $R_{th(c-s)}$ of 450 A-SEMITRANS (left) and 450 A-SEMiX (right) for different situations of thermal coupling between switches accordingly Table 4



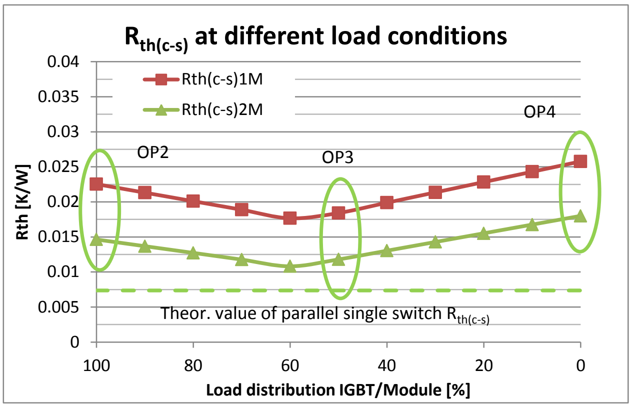


For the different operation conditions following conclusions can be made, taking into account that R_{th} is inverse proportional to the area A used for heat transfer ($R_{th} \sim 1/A$):

- The module has the highest $R_{th(c-s)M}$ if only one IGBT- or diode-switch dissipates power **(OP1 and OP5)** because only a small part of the modules mounting surface is used for heat transfer. $R_{th(c-s)X} = R_{th(c-s)M}$ because only one heat source is inside the module. This worst case condition corresponds roughly to the SEMIKRON datasheet statement for product release before 2014. Using this value for T_j calculation gives a good agreement between calculation and reality for OP1 and OP5 but overestimates the $dT_{(c-s)}$ for OP2…4.
- The $R_{th(c-s)M}$ decrease if two IGBT-switches or two diode-switches **(OP2 and OP4)** dissipate power, because the two switches use a larger case area to transfer heat. How much it will decrease depends on the distance between the switches, for example the two IGBT-switches inside the SEMITRANS are far away and not thermally coupled. In that case the heat transfer area is doubled, therefore is $R_{th(c-s)M}$ reduced here to 50%. $R_{th(c-s)I}$ is constant, independent if one or two switches are used. The coupling inside the SEMIX is stronger, the $R_{th(c-s)M}$ is reduced only to 60% when two switches are used and the $R_{th(c-s)I}$ is increased by 15…30% because TOP and BOT IGBT are close to each other and share a fraction of the same area for heat transfer which they could use before for its own.
- The modules $R_{th(c-s)M}$ has its lowest value if all switches are in operation **(OP3)** because the largest area of the modules mounting surface is used for heat transfer. The $R_{th(c-s)M}$ value of measuring method 1 (T_s taken beside the module) is 30% lager for SEMITRANS and 50% larger for SEMIX than those of method 2 (T_s taken from below). The individual $R_{th(c-s)X}$ increase much more at OP3 compared to OP2. The highest effect can be seen at the antiparallel diode inside the SEMITRANS because it is heated by the nearby IGBT.
- A specification of $R_{th(c-s)X}$ per single IGBT- and diode-switch alone is not sufficient to describe thermal conditions for a power module. A description of coupling effects either per switch or per module is mandatory.

The $R_{th(c-s)}$ depends furthermore on the distribution of power dissipation between the switches inside a module. OP3 represents a condition with similar losses per mm² used chip area. But depending on power factor, modulation ration or switching frequency of an inverter this loss share can vary between 80% IGBT losses (20% diode losses) and 40% IGBT losses (60% diode losses) under practical relevant conditions. Figure 8 shows this effect. The lowest value is reached where IGBT and diode have similar junction temperatures, which is in the example at 60% of the module losses in the IGBT and 40% in the diodes. By using the $R_{th(c-s)M}$ derived from OP3 it is possible to describe the temperature difference "case-to-sink" for the whole range of typical inverter operation conditions with a failure of less than 10%.

Figure 8: Influence of loss share between IGBT and diode on $R_{th(c-s)M}$ with SEMiX453GB12E4



2.5.4 $R_{th(c-s)}$ Without Thermal Coupling

If $R_{th(c-s)}$ is specified separately for each single IGBT- and Diode-switch, thermal coupling between switches is neglected. A theoretical $R_{th(c-s)M}$ per module is calculated by some manufacturer by a virtual parallel connection of all $R_{th(c-s)}$ of the module.

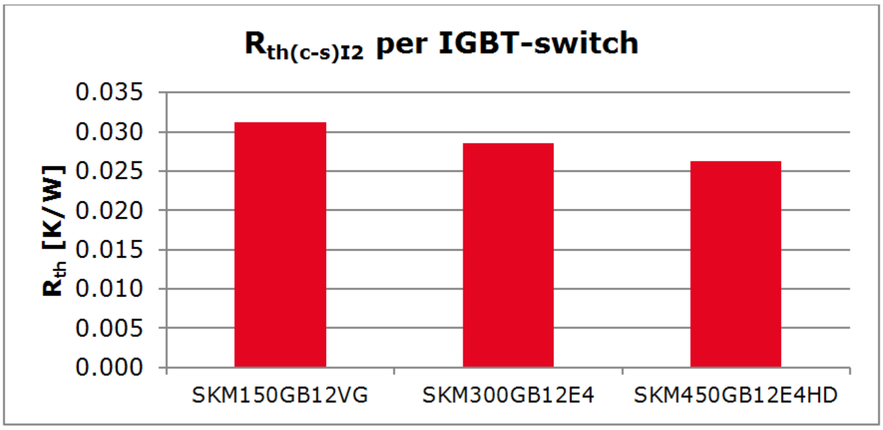
$$R_{th(c-s)M} = \left(\frac{n}{R_{th(c-s)I}} + \frac{n}{R_{th(c-s)D}}\right)^{-1} \quad | \; with\ n = number\ of\ switches\ per\ module$$

This theoretical value could be reached only if the distance between all switches is wider than 3…4 times the thickness of the material stack "chip-to-sink" (15…20 mm), but this is never the case in today's available power modules. This theoretical value can therefore never be reached (see dashed line in Figure 7 and Figure 8).

2.6 $R_{th(c-s)}$ per Switch as a Function of Chip Size

In the past Semikron has specified the $R_{th(c-s)M1}$ for a module family of the same size, independent from the current rating of the module. A more detailed system design considering different operation conditions requires a specification of $R_{th(c-s)X2}$ per switch. And this value depends also on the chip area used inside a module. The thermal resistances values for IGBT-switches of SEMITRANS3 modules with current ratings from 150A to 450A are shown below as an example.

Figure 9: Influence of current rating respective chip area on $R_{th(c-s)I2}$ in a SEMITRANS3



2.7 Effects of Mounting Conditions on $R_{th(j-s)}$ and $R_{th(c-s)}$

These thermal resistances depend on module assembly, e.g. screw tightening torque, heatsink performance and quality, thickness and heat conductivity of TIM. For specification of IGBT modules with baseplate the manufacturer uses not only different reference points but also different assumptions on thermal conductivity of TIM and quite different possibilities for specifying $R_{th(c-s)}$ with or without respect to thermal coupling of switches inside modules, see Table 5.

Table 5: $R_{th(c-s)}$ specifications from IGBT modules manufacturer's datasheets

Manufacturer	TIM thermal conductivity λ	Specification of $R_{th(c-s)}$ per IGBT/Diode	Specification of $R_{th(c-s)}$ per module	Respect to thermal coupling of switches
SEMIKRON	0.81 W/(m∗K)		x	Yes
Infineon	1.0 W/(m∗K)	x		No
ABB Semiconductors	1.0 W/(m∗K)	x		No
Mitsubishi	0.9 / 1.0 W/(m∗K)		x	Yes
Fuji	no information		x	Yes

The $R_{th(j-s)}$ and $R_{th(c-s)}$ data sheet statement of SEMIKRON IGBT modules are valid only if the modules are mounted according to the mounting instructions using the specified thermal grease material and layer thickness. Three temperature cycles should be done before reaching the full thermal performance of the power module. The values are measured at liquid cooled heatsinks, at less effective air cooled heatsinks is the $R_{th(c-s)M}$ lower due to a wider heat spreading in air cooled systems.

3. Modelling with Thermal Equivalent Circuits

For modules without baseplate an individual $R_{th(j-s)X}$ per IGBT- or diode-switch is specified. This kind of modelling is approved and does not need to be changed. The thermal coupling inside the module is low and is modeled inside the heatsink.
The two today's commonly used ways of modelling of modules with base plate are

a) a switch specific value $R_{th(j-c)X}$ + common $R_{th(c-s)M}$ for the complete module (see Figure 10) or
b) switch specific values of $R_{th(j-c)X}$ and $R_{th(c-s)X}$ (see Figure 11).

Both methods have advantages and disadvantages and are only valid for certain operation conditions. Three-dimensional structures are mapped to one-dimensional models. This will inevitably result in errors in temperature calculation. Methods like Finite Element simulations are preferred for more accurate results.
Model a) includes full thermal coupling between all switches where b) neglects fully the thermal coupling. If for example a common $R_{th(c-s)M}$ is used and the losses are well distributed between the chips, the model can

show a good agreement to the temperature conditions inside a module. In case of very asymmetric load with losses only in one switch the model would show to low temperatures for a realistic value of $R_{th(c-s)M}$. To minimize this risk SEMIKRON has specified in the past a maximum value of $R_{th(c-s)M1}$ for the module, which was almost the value of a single switch. It would have been more accurate to use a value for a single switch $R_{th(c-s)X}$ in that case. On the other hand does a single switch $R_{th(c-s)X}$ not reflect the effect of thermal coupling and results in a too low calculated junction temperature if the other switches have losses as well. This can become critical with regards to the maximum junction temperature but will also result in a lower temperature swing with pulsed load or mission profiles. A lower temperature swing leads to higher calculated numbers of power cycles and lifetime than it will be reached in reality in inverter applications.

Figure 10: Thermal equivalent circuit with common thermal resistance case to heatsink per module

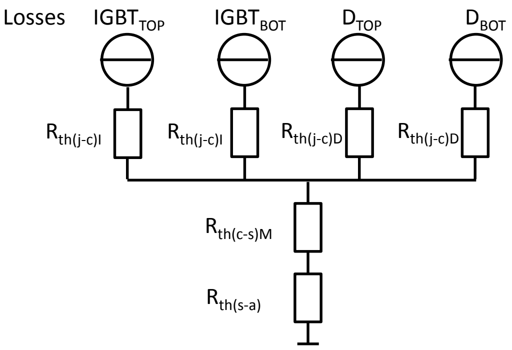
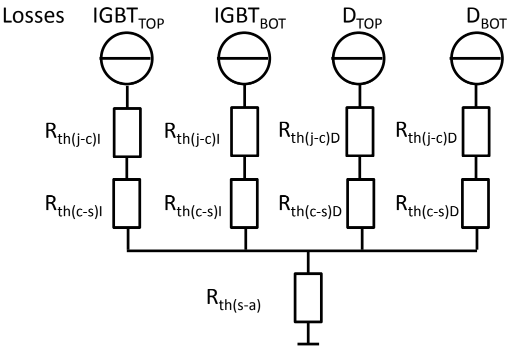


Figure 11: Thermal equivalent circuit with separate thermal resistance case to heatsink of IGBT- and diode-switch used also for modules without base plate with $R_{th(j-s)}=R_{th(j-c)X}+R_{th(c-s)X}$



To make the systems more and more cost effective designers needs to decide by itself where to put safety margin in. This requires a case sensitive modeling with an adaptation of parameter on different operation condition. Following this requirement SEMIKRON will specify its IGBT modules in a new way for new products released starting from 2015. A switch specific values of $R_{th(j-c)X}$ and $R_{th(c-s)X}$ is specified per IGBT- or diode-switch, which can be used for single switch operation of modules. Additional an $R_{th(c-s)M2}$ including full thermal coupling is specified which can be used for inverter operation with a distribution of losses between all switches inside the module. For the purpose of comparison with competitor datasheets the theoretical value is specified as well.

4. Today's and Future Data Sheet Specification of R_{th} Values for SEMIKRON Products

Product group related information about the position of reference points of actual SEMIKRON IGBT modules is included in the specific Technical Explanations [5]…[10]. The position of T_s is different between heatsink rated modules without baseplate (method 2, T_{s2}) and case rated modules with baseplate (applied method 1, T_{s1}: at the heatsink surface beside the module at its longitudinal side, nearly 1/3 of the module length away from the module corner).
For multiple chip switches the average values of T_j, T_{cn} and T_{s2n} of that switch is used for R_{th} calculation.

4.1 Heatsink Rated Module

Sink temperature measurement point underneath the switch position does not change. The modules are 3 times temperature cycled before R_{th} measurement to guaranty a good distribution of thermal grease. The forward voltage drop to calculate power dissipation is measured as close as possible to the chips at the main terminals. $R_{th(j-s)}$ values are given for single switch operation.
Past: All switches in a low number of modules are measured; the highest value is given as typical value with some safety margin
Future: all switches of a module are measured; the switch with the highest $R_{th(j-s)}$ is determined and measured in a higher number of modules. The average $R_{th(j-s)}$ of that worst case switch is given as a typical value in the data sheet.

4.2 Case Rated Modules

The $R_{th(j-c)}$ measurement is equal to the past, the value is derived from a single switch measurement with power dissipation measured at the main terminals. For modules with more than one switches of the same kind (e.g. 2 IGBT-switches of a half bridge) the switch with the highest $R_{th(j-c)}$ is specified in the data sheet and given as a maximum value on the basis of a higher number of measurements.
Past: $R_{th(c-s)M}$ on module basis was given for method 1 (beside of the module) for a worst case of a very asymmetric distribution of power dissipation between the switches;
Future: $R_{th(c-s)}$ is given for method 2 (underneath the module) for a single switch $R_{th(c-s)X}$ and additional for the module $R_{th(c-s)M}$ including the effect of thermal coupling between the switches for a typical distribution of power dissipation between the switches. For comparison reasons to competitor products also the theoretical value is given.
The new description of the modules thermal properties offers the user three main advantages:

- The reference point for T_s measurement underneath the module depends less from the cooling conditions like cooling medium (air, liquid) heatsink design and heatsink material than the former used position beside the module.
- SEMIKRON uses now the same reference point T_s for case rated and heatsink rated modules which makes a comparison easier between the different product lines.
- Using the reference point for T_s underneath the module is the common way of $R_{th(c-s)}$ specification for the most modules on the marked. That makes a comparison between modules of different manufacturers easier. As an additional service is $R_{th(c-s)M}$ given including full thermal coupling between the switches inside the module.
- The datasheet specification of $R_{th(c-s)}$ per IGBT- and diode-switch and also for the module allows distinguishing between different operation conditions and using the most appropriate model according to this.

It is necessary that the user applies the heatsink properties which are valid for the new reference point of T_s measurement. For those modules described in the new way (indicated in the conditions of datasheet characteristic $R_{th(c-s)}$ with the note "Ts from underneath") the heatsink $R_{th(s-a)}$ has to be specified for a measurement point under the module as well (see 2.3).

5. Conclusions

For reliable operation a proper thermal design is crucial. An IGBT module comparison just by datasheet information could be misleading when comparing products from different manufacturers without careful consideration. Wrong conclusions can easily be drawn concerning power dissipation and junction temperatures which may only be related to different methods of measurement. Only by using identical reference points T_c and T_s, identical measuring conditions and methods ranking and selection of suitable power modules will be correct. Since also other parameters such as cooling conditions, use of thermal interface material etc. vary for different manufactures, it is recommended and necessary to evaluate the thermal resistances with own measurements.

Symbols and Terms

Letter Symbol	Term
D	Diode (also as subscript)
I_C, I_F	Collector current of IGBT, forward current of diode
M	Module (as subscript)
P, P_x	Power losses (general), power losses of a switch x
$R_{th(c-a)}$	Thermal resistance between baseplate and cooling media
$R_{th(c-s)x}$	Thermal resistance between baseplate and heatsink per IGBT- or diode-switch
$R_{th(c-s)M}$	Thermal resistance between baseplate and heatsink specified for a module
$R_{th(j-a)}$	Thermal resistance between chip and cooling media
$R_{th(j-c)x}$	Thermal resistance between chip and baseplate per IGBT- or diode-switch
$R_{th(s-a)}$	Thermal resistance between heatsink and cooling media
T_a	Temperature of cooling media
T_c	Baseplate temperature
$T_{cD1...n}$, $T_{cI1...n}$	Baseplate temperature underneath diode/IGBT chips 1…n
T_j	Average value of chip temperature
T_s, T_{s1}, T_{s2}	Heatsink temperature, 1- beside the module, 2- underneath a chip position
V_{CEsat}, V_F	Collector-emitter saturation voltage drop of IGBT, forward voltage drop of diode
λ	thermal conductivity of TIM between baseplate or DBC of modules without baseplate and heatsink

A detailed explanation of the terms and symbols can be found in the "Application Manual Power Semiconductors" [2]

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HISTORY

SEMIKRON reserves the right to make changes without further notice herein

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