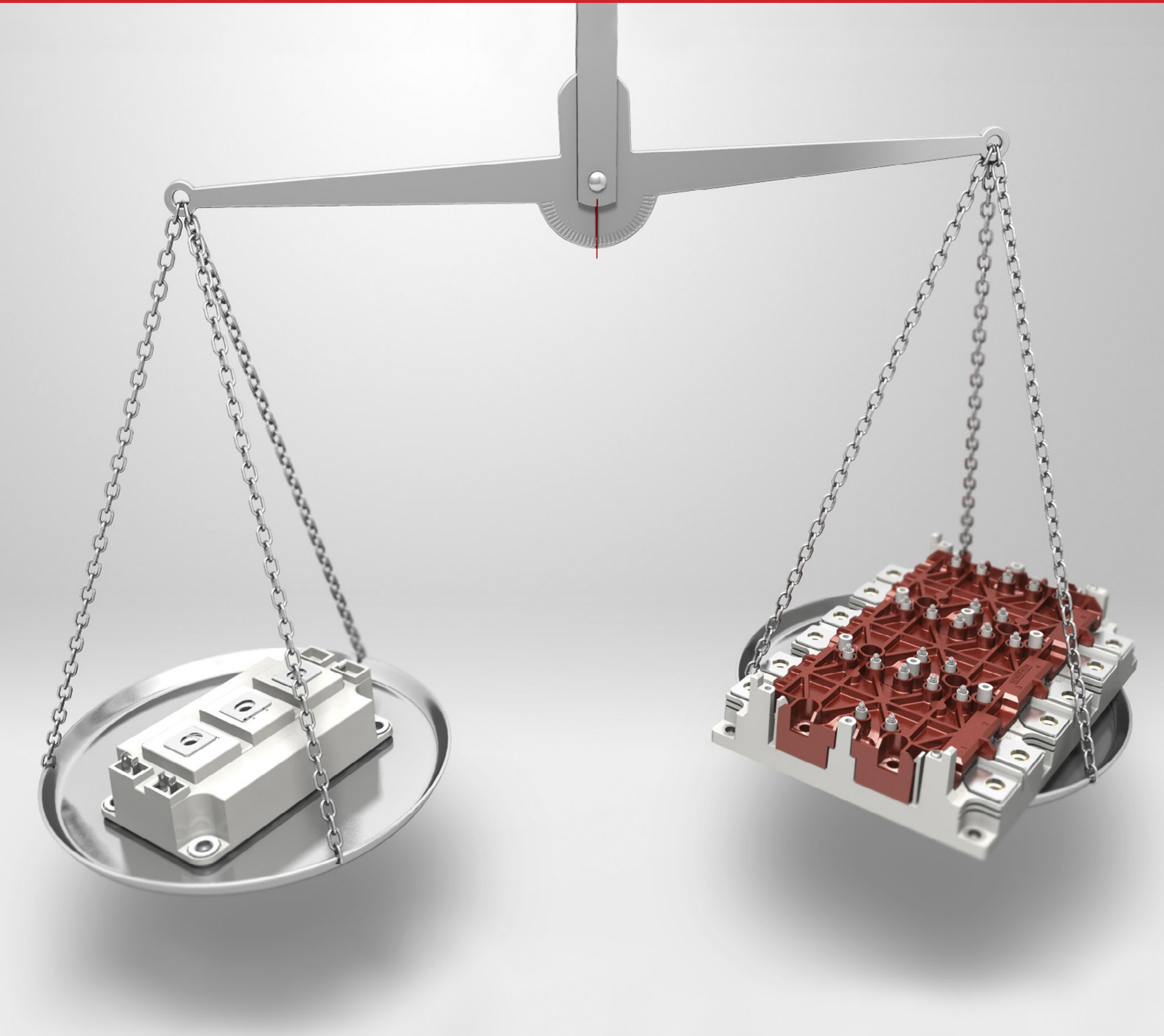
COMPARING THE INCOMPARABLE

Understanding and comparing IGBT module datasheets



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Understanding and comparing IGBT module datasheets

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This might sound somewhat overdone but comparing IGBT modules using datasheets is not as easy at is might appear. A rough comparison can, of course, be made using the component blocking voltage (V_{CES}, e.g. 1200V) and the nominal current (I_{Cnom} = 100A, 200A…). On closer inspection, however, the user might be confused by the different measurement conditions, as well as different definitions and designations.

This article is intended to explain the component parameters in more detail, point out possible differences in how the different parameters are determined and help users analyse data.

Conducting current

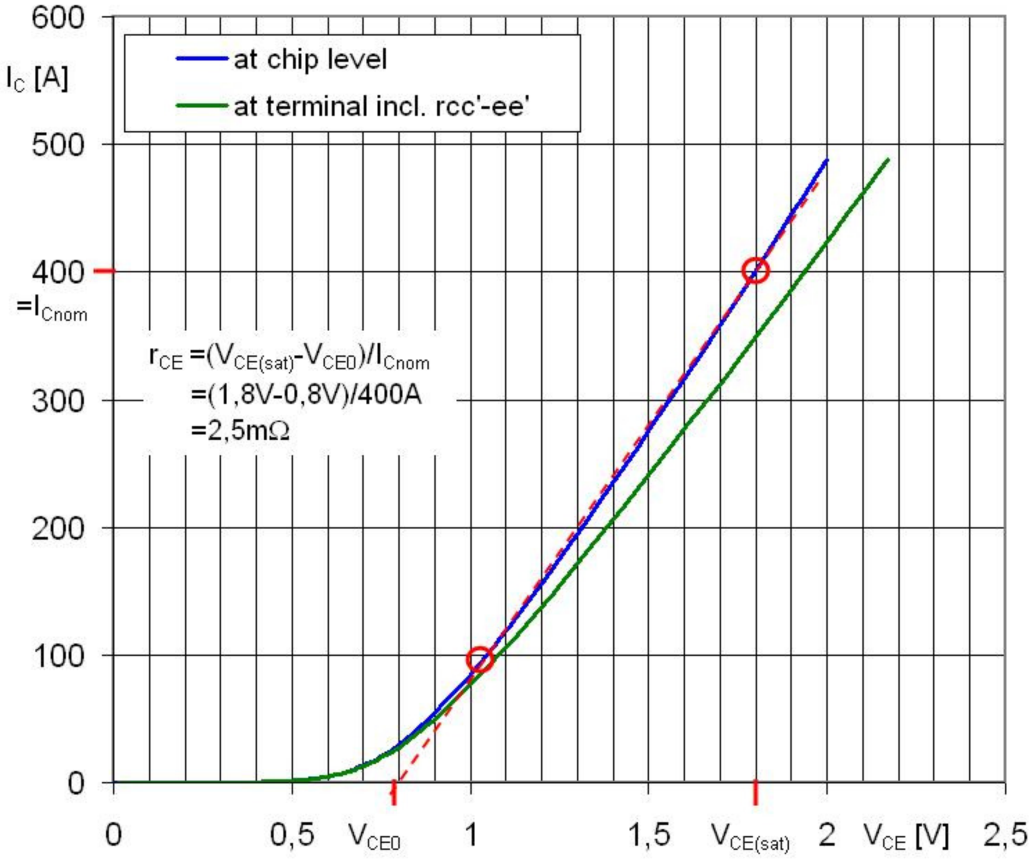
Normally, comparisons are done on the basis of the nominal IGBT current. What must be borne in mind here, however, is that different current data exist, which, if incorrectly interpreted, may lead to misunderstandings. The “nominal current” I_{Cnom} is the nominal current of the chip area used and is calculated from the current density per mm² defined by the manufacturer for the chip technology. None of the properties relating to the module design are factored into this calculation. The forward voltages and switching losses are given for this current. The I_C specified in the “maximum ratings”, in contrast, refers to the direct current which can be continuously conducted by the IGBT at a certain case temperature. This value of current is determined for a component with maximum forward voltage and using the maximum junction temperature. This specification includes both the electrical and the thermal properties (R_{th}) of the module. As a result of additional switching losses and a safety margin in junction temperature, this value can seldom be achieved in practice. For some modules, the maximum current is limited by the terminals rather than the chips; in such cases, the maximum terminal current ($I_{t(RMS)}$) must be specified.

The data specified for the forward voltages $V_{CE(sat)}$ for the IGBT and V_F for the freewheeling diode should actually relate to the main terminals of the modules, i.e. they should be specified at terminal level. This includes voltage drops across the terminals. Owing to higher power densities and improved semiconductor properties, the terminal losses are no longer negligible as compared with semiconductor losses. For thermal dimensioning, it therefore makes sense to specify the voltage drop across the chips (i.e. at chip level) and across the terminals ($r_{CC'\text{-}EE'}$) separately. The voltage across the terminals is as follows:

$$V_{CEterminal} = V_{CEchip} + I_C \cdot r_{CC'-EE'} \ .$$

The separate specification offers the user the advantage that he can calculate chip losses and terminal losses separately. For instances, a 300A current causes in a module with $r_{CC'\text{-}EE'}$ = 1mΩ terminal losses of 90W. In comparison: the four semiconductors in this half bridge module (2 x IGBTs + 2 x diodes) cause, for this current, around 700… 800W losses. Only the losses in the chip are relevant for chip heating.

$$P_v = I_{C(av)} \cdot V_{CE0} + I_{C(rms)} \cdot r_{CE}$$



[Fig. 1 Different forward characteristics of a 400A SEMITRANS module at chip level and terminal level, incl. the equivalent straight line resulting from V_{CE0} and r_{CE}]

The data specified for V_{CE0} and r_{CE} come from a straight line approximation of the forward characteristic, generated through the points at 25% and 100% of the I_{Cnom}, as shown in the example in Fig. 1. These are auxiliary values that are obtained by calculation and are intended to help users calculate power losses. A comparison of forward voltages is to be performed for the same, high chip temperature, the same measuring point (chip or terminal) and same measuring current (I_{Cnom}). Not all manufacturers include the measuring point is the datasheet. A tip for chip-level measurements is that here the values for $V_{CE(sat)}$ for all IGBT modules of one chip technology are largely the same. For terminal-level measurements, the data specifications depend on I_{Cnom}.

Switching

Switching energy (E_{on}, E_{off}, E_{rr}) and switching times ($t_{d(on)}$, t_r, $t_{d(off)}$, t_f, t_{rr}) are not only dependent on the semiconductor itself, but also on the surroundings. Stray inductance, driver output or motor cable and filter capacities affect the switching behaviour. The datasheet values are therefore to be regarded as typical values only. When comparing different datasheets, or even when looking at lab measurements in comparison to practical results, a number of essential factors must be taken into account. The majority of manufacturers, including SEMIKRON, refer to switching behaviour under inductive load, since this is closest to actual usage in drive applications. A few manufacturers specify data for ohmic load, resulting in far lower switching losses and switching times. A further reason why differences occur lies in the different limits of integration, between which the switching energy is determined from the switching losses as a function of time. These limits should start and finish at 1…2% of the increasing or decreasing value, respectively. The use of 10% limits, as is the case when defining switching times, results in too low a result for switching losses.

Data relating to load conditions and integration limits can be found in manufacturers' technical explanations or application notes.

Comparisons of switching energies are often done for identical gate resistance R_G, because the switching speed is related to R_G. This is, however, not always possible, even for the same chip technology, since both positive and negative feedback effects in the control circuit determine the switching speed. A better approach would be to perform a comparison for identical di_C/dt and dv_{CE}/dt, since here the interference levels are comparable. When looking at the power losses, a change in gate resistances has to be taken into account in accordance with the curve $E_{sw}= f(R_G)$. This curve begins at a value that is not specified directly as the minimum gate resistance, but at which the IGBT can still be safely switched. Smaller R_G values are not ruled out, but ought to be verified with the manufacturer first.

Stray inductance in the commutation circuit means a reduction in turn-on load and, especially in the case of low DC link voltages (e.g. 300V), ensures very low turn-on losses. This is largely offset by a turn-off overvoltage, which is why in hard switching applications the sum of the turn-on and turn-off losses has to be considered. Switching losses normally specified only depend on the current. Other parameter that are important for switching energy comparisons are the voltage applied and the junction temperature. The following formulae can be used to apply the point of reference "ref" to other conditions, resulting in an acceptable approximation:

$$\mathrm{IGBT}: E_{sw} = \left(E_{on} + E_{off}\right)_{ref} \cdot \frac{I_C}{I_{Cref}} \cdot \left(\frac{V_{CC}}{V_{CCref}}\right)^{1,35} \cdot (1 + 0{,}003 \cdot (T_j - T_{ref}))$$

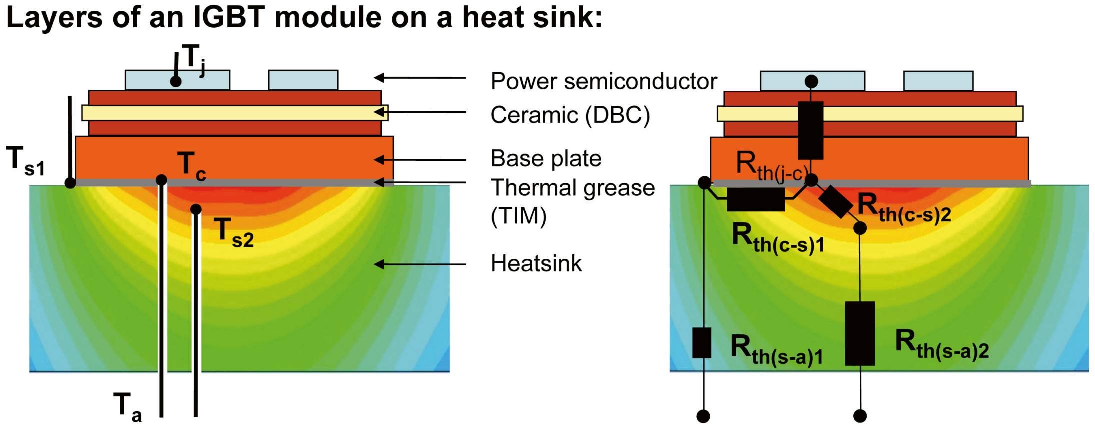
$$\mathrm{FWD}: E_{rr} = \left(E_{rr}\right)_{ref} \cdot \left(\frac{I_F}{I_{Fref}}\right)^{0,6} \cdot \left(\frac{V_{CC}}{V_{CCref}}\right)^{0,6} \cdot (1 + 0{,}006 \cdot (T_j - T_{ref}))$$

Gate charge Q_G may be specified in the datasheet for different turn-off voltages (negative driver voltage -15V/-8V/0V). If a curve is given for positive voltages only, the curve can be extended into the negative area from voltage rise above the voltage plateau. Q_G is only slightly dependent on the DC link voltage, since this voltage is needed to charge the Miller capacitance. For high voltages, the capacitance is very low, which is why the influence on the gate charge is minimum, too. Temperature dependency is negligible.

Heat dissipation

The ability to dissipate heat is specified by the value R_{th}. In power semiconductor modules, the assumption is made that the total heat losses are dissipated via the assembly (module) surface. The thermal resistances are calculated from the temperature difference between two measuring points (T_1, T_2) and the power dissipation (P_v).

$$R_{th(1-2)} = \frac{T_1 - T_2}{P_v}$$



[Fig. 2: Possible reference points for temperature measurement in IGBT module and the resultant, different shares in the calculated thermal resistances]

Different choices of measuring points can lead to variations in the shares in the thermal resistances (see T_{s1} and T_{s2} in Fig. 2). For the specification of R_{th} for chip (junction) to base plate (case) $R_{th(j-c)}$, this is still relatively uniform. Here, the measuring point for base plate temperature is directly beneath the chip. For the specification of R_{th} between base plate and heat sink ($R_{th(c-s)}$), however, there are a variety of definitions. The temperature of the heat sink surface is higher underneath the module than beside it. SEMIKRON specifies the $R_{th(c-s)}$ for a measuring point T_{s1} beside the module. The relatively high temperature difference at this point leads to a high value for R_{th}. Other manufacturers' specifications for this value are based on the measuring point T_{s2}. The low temperature difference from the base plate to this hot spot results in a low value for R_{th}. This is why the R_{th} values specified for identical-sized, standard module cases are often very different.

$R_{th(c-s)}$ can continue to be specified per module or per semiconductor. One-dimensional modelling using thermal resistances always leads to an error with regard to the thermal coupling between the individual components in a module. For specification of $R_{th(c-s)}$ per semiconductor, thermal coupling between the semiconductors is, despite good conducting copper base plate, completely neglected. If $R_{th(c-s)}$ is given for the entire module, this means full coupling between the semiconductors of one module. In addition, $R_{th(c-s)}$ is, of course, also dependent on the module assembly, for example the screw tightening torque, the heat sink quality or the thickness and heat conductivity of the thermal paste, which is why this value can be given as a typical value only.

For modules with no base plate, the “base plate temperature” point is not accessible for measurements, which is why in this case $R_{th(j-s)}$ is specified directly from chip to heat sink underneath the chip. As a result, the total $R_{th(j-s)}$ to heat sink is to be used when comparing modules with and without base plate.

$$R_{th(j-s)} = R_{th(j-c)} + R_{th(c-s)}$$

Conclusion

A comparison of the static IGBT parameters of different manufacturers and modules may well be done if a number of steps are followed. With a number of restrictions, the same applies to thermal resistances, provided the relevant measuring points are known and the entire path from chip to cooling medium is factored in. The most difficult comparison is that of the switching properties. Here, it is vital that the di/dt or dv/dt is taken into account. The ideal situation would be to perform a direct comparison in actual application, factoring in temperature, losses and interference radiation measurements.

Manufacturers of IGBT modules offer users support in the form of tools which can be used to calculate power losses and temperature [http://semisel.semikron.com/] under application-like conditions. Such calculations provide more meaningful results as regards the suitability of a module than pure datasheet-based considerations.