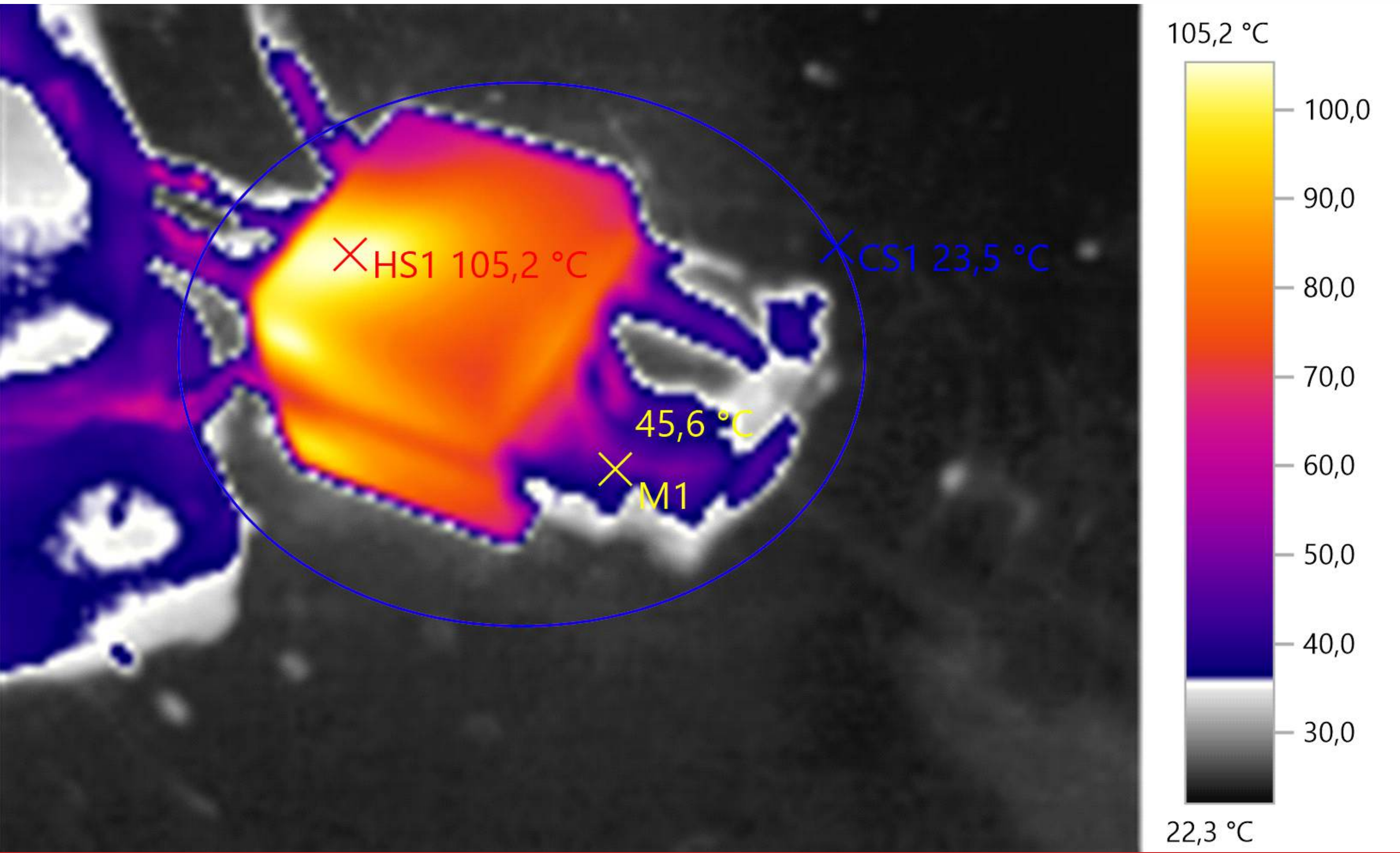
APPLICATION NOTE



Thermal Considerations

On Power Semiconductors

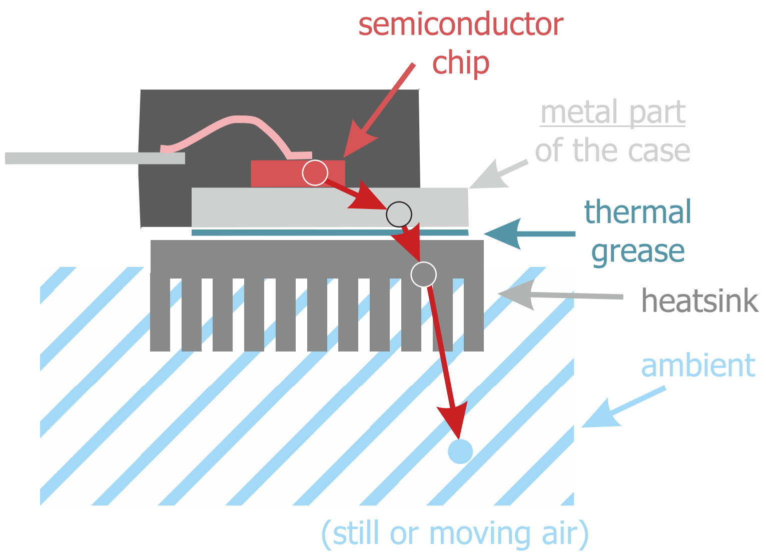
- Calculation and Measurement
- Thermal Paste Appliance
- Heatsink Assembly

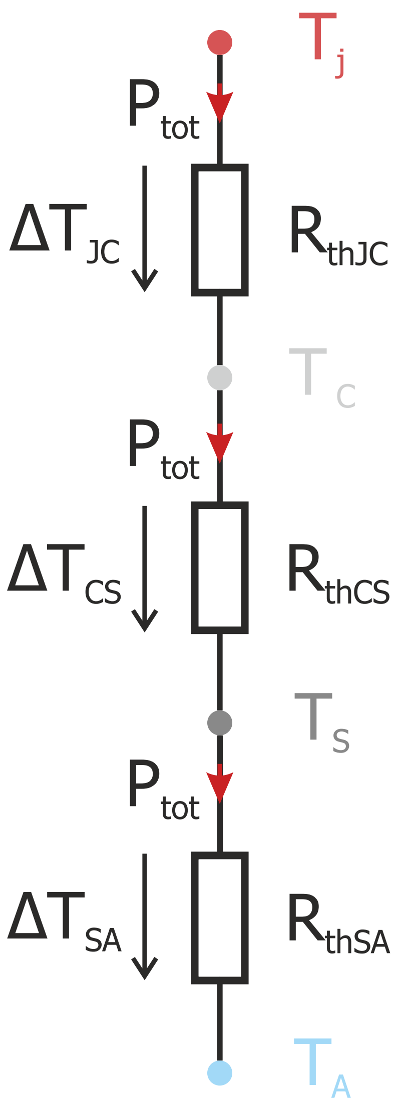
1. Why Temperature Matters

The so called „Law of Arrhenius" states - shortly spoken - the fact that every 10K temperature increase reduces lifetime of a physical device by 50%! In other words: When a „good" design for an electronic circuit heads for a lifetime of 20 years, a „simple" temperature increase (caused by poor thermal considerations) from 80°C to 110°C (30K) leads to an early failure after 2.5 years! While commercial applications run typically in 25°C ambient, industrial ones must operate minimum at 50°C and automotive environments call for safe operation at 75°C or even higher. This explains why spending a bit of time in thermal considerations is helping a lot to make a power design reliable and successful.

2. Thermal Equivalent Circuit

A thermal path can be easily transferred into an electrical circuit, allowing for simple calculations and even SPICE modelling. Equation 1 shows how it works. Temperature equals to voltage or better say potential. Power losses becomes current and thermal resistance is electrical resistance.





$$T_J = P_{tot} * (R_{thJC}{}^{1)} + R_{thCS} + R_{thSA}) + T_A \qquad (1)$$

R_{thJC} is a fixed parameter of the component. While R_{thCS} and R_{thSA} are under the control and influence of the user. The following pages explain what needs to be considered to get as low as possible values, in order to achieve low junction temperatures and thus high reliability.

We further show how Ptot is derived for different types of components.

[1] For reasons of better readability, the Diotec data sheets show R_{thC} instead R_{thJC}

3. Calculation of P_{tot} at Diodes & Rectifiers

For most diodes and rectifiers, the reverse leakage is negligible. Only at Schottky diodes, the leakage can form a significant part of the overall losses. Switching losses are relevant for power rectifiers operated at high frequencies > 50 kHz. Since the reverse recovery current depends highly on the application, we recommend to measure it in the circuit.

$$P_{tot} = V_F * I_{FAV} \, (+ V_R * I_R * [D-1] \, (+ 1/4^{1)} * t_{rr} * I_{RM} * V_R * f_{sw})) \qquad (2)$$

Where
V_F = Forward voltage drop of the diode at I_{FAV} and T_J
(if unknown, take the value at 100°C [2])
I_{FAV} = Average current through the diode
V_R = Reverse voltage
I_R = Reverse leakage at T_J
(if unknown, take the value at 125°C [2])
D = Duty cycle (on time in %)
t_{rr} = Reverse recovery time
I_{RM} = Reverse recovery current
f_{sw} = Switching frequency

4. Calculation of P_{tot} at Bridge Rectifiers

For bridge rectifiers operated at 50/60 Hz, reverse leakage and switching losses can be neglected.

$$P_{tot} = V_F * I_{FAV} * n * m \qquad (3)$$

Where
V_F = Forward voltage drop of the single diode at I_{FAV} and T_J
(if unknown, take the value at 100°C [2])
I_{FAV} = Average current at the output of the bridge
n = 1/2 (for single phase bridge)
n = 1/3 (for three phase bridge)
m = 2 (if R_{th} is „per device")
m = 1 (if R_{th} is „per diode")

Isolation voltage terminals to case Isolationsspannung Anschlüsse zum Gehäuse	V_{ISO}	> 1500 V_{RMS}
Typical thermal resistance junction to ambient (per device) Typischer Wärmewiderstand Sperrschicht – Umgebung (pro Bauteil)	R_{thA}	18 K/W [2]
Typical thermal resistance junction to case (per device) Typischer Wärmewiderstand Sperrschicht – Gehäuse (pro Bauteil)	R_{thC}	2.7 K/W

[1] In the first half of trr, there is no reverse voltage present yet; the second 1/2 comes from triangular waveform
[2] This provides extra safety margin

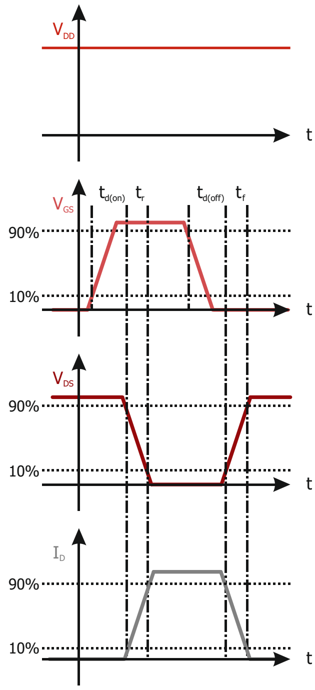
5. Calculation of P_{tot} at MOSFETs & IGBTs

For MOSFETs and IGBTs, the reverse leakage is mostly negligible. Switching losses are relevant at high frequencies and depend on free-wheeling diode characteristics and application itself, e. g. the Gate drive resistor. We therefore recommend to measure switching times in the circuit.

$$P_{tot} \sim R_{DSon} * (I_D * D)^2 + 1/2 * I_D * V_{DS} * (t_r + t_f) * f_{sw} \quad (4)$$

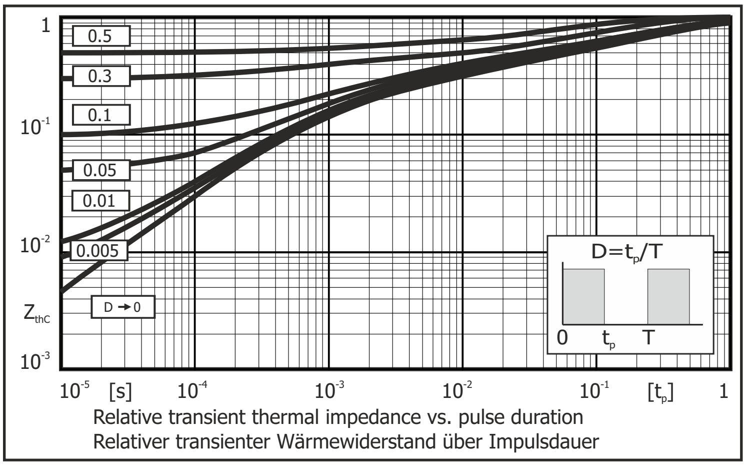
$$P_{tot} \sim V_{CEsat} * (I_C * D) + 1/2 * I_C * V_{CE} * (t_r + t_f) * f_{sw} \quad (5)$$

Where
(4) = valid for MOSFETs
(5) = valid for IGBTs
R_{DSon} = On-state resistance at I_D and T_J
(if unknown, take the value at I_{D25} and 150°C [2])
V_{CEsat} = Collector-Emitter saturation voltage at I_D and T_J
(if unknown, take the value at I_{C25} and 150°C [2])
I_D = Peak Drain current in the application
I_C = Peak Collector current in the application
D = Duty cycle (on time in %)
V_{DS} = Drain-Source voltage in the application
V_{CE} = Collector-Emitter voltage in the application
t_r = Rise time in the application
t_f = Fall time in the application
f_{sw} = Switching frequency



6. Transient Thermal Impedance

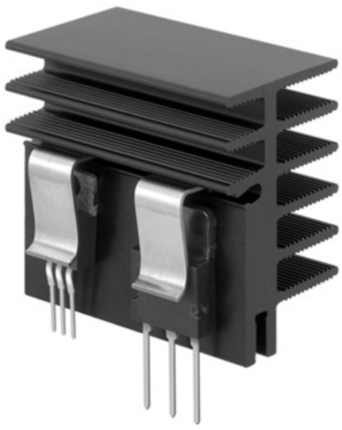
Bigger case outlines like D²PAK are built with massive copper baseplates, having a significant thermal capacity. At short pulses and duty cycles, the thermal resistance of such case outlines appears therefore reduced. This can be positively used for short but high power loads. Rather than using the steady-state thermal resistance R_{th}, designers can calculate with the transient thermal impedance Z_{th}. Most data sheet of power devices show the right-side curve providing that value at different duty cycles.



Relative transient thermal impedance vs. pulse duration
Relativer transienter Wärmewiderstand über Impulsdauer

7. Assembly onto Heatsink

There are many manufacturers for heatsinks and no preference from Diotec side. Assembly methods include screw mounting and clamping. Advantage of clamping is the fact that screws can get loose, while clamps will normally not. Forced air cooling can improve efficiency a lot but requires an additional fan.



Data sheets of the heatsink always provide the thermal resistance from assembly area to still air. This can be used in a first order for R_{thSA} in formula (1).

Admissible mounting torque
Please refer to the data sheet, admissible mounting torque is e. g. 1 +/- 10% Nm. If too high: The case can break! If too low: There will be poor heat transfer.

Admissible mounting torque Zulässiges Anzugsdrehmoment	M3	9 ± 10% lb.in. 1 ± 10% Nm

8. Application of Thermal Grease

There are many manufacturers for thermal paste and no preference from Diotec side. Applied between the thermal pad of the component case and the heatsink, this material improves the heat transfer at the contact area. Recommendations of the thermal paste manufacturer must be respected and the thermal resistance of the paste must be taken into account. The thermal resistance from case to heatsink can hardly be calculated, therefore a practical verification as shown on the last page is recommended.

Layer of paste must be in any case <u>rather thin</u>!

Recommended paste thickness
Needs to be defined empirically:
a) Start with a small amount of grease in the centre of the bridge.
b) Assemble the bridge, let it rest for short time and remove the bridge again.
c1) Is the full backside of the bridge covered with a thin layer of grease? Ok.
c2) Is the area not fully covered? Add more grease.
c3) Is the grease welling out at the sides of the bridge? Reduce the amount of grease.

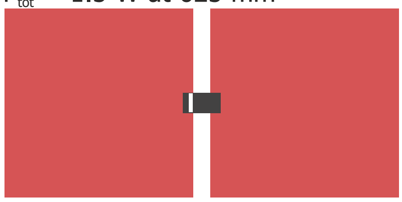
9. Influence of Solder Pad Size

Some competitors offer real low thermal resistance values and thus impressively high-power dissipations. But this is only possible for impractically large solder pad areas. Diotec has to follow sometimes these marketing driven specifications, in order to demonstrate compatibility of the parts. We recommend however to always to specify and judge any semiconductor device on realistic pad sizes.

P_{tot} = 1 W at 25 mm²

Realistic pad size

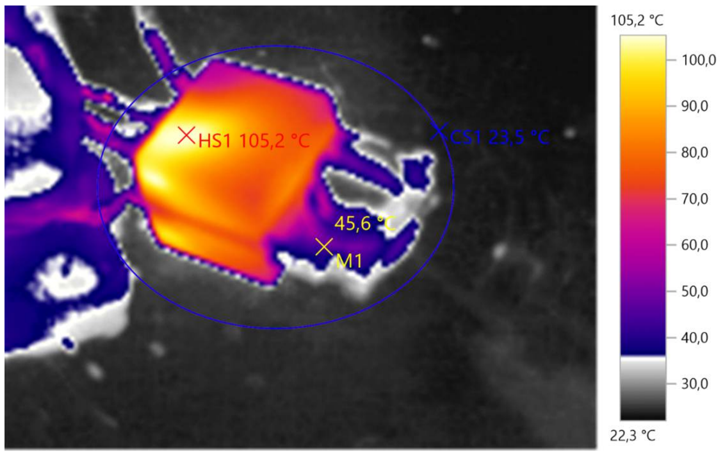
P_{tot} = 1.5 W at 625 mm²



Very unrealistic!

10. Practical Verification

When calculations are done and a first heatsink or pad size is defined, we recommend to perform a verification check. Thermal cameras are a good and easy to use tool, but one has to consider that shiny metallic surfaces have a rather low thermal emission coefficient. When checking therefore the terminal, metallic heat-flange or „case" of a power device, it needs to be coloured black before. A simple permanent marker has proven to be good enough for such purpose. A junction temperature of about 80°C is a good value for high reliability and desired long lifetime. Values bigger than 100°C should not last too long for a semiconductor part, even if these parts are rated for T_{jmax} = 175°C. That is always to be considered as a very short peak value, but never for permanent operation.



Do not hesitate to contact us for further questions:

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