Cooling concepts for CanPAK^{TM}* package

IMM PSD LV
Peinhopf Wolfgang

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1 Introduction

Cooling capability is the major disadvantage for SMD based power electronics. However, SMD based systems can't be avoided when it comes to high efficiency. The CanPAK^{TM} package is a package with a very low thermal resistance to the top and bottom side of the package. This allows using efficient cooling concepts and thus solves the issue of limited cooling capability in SMD systems. This document gives an overview of different cooling concepts and also provides thermal measurement and simulation results to see the improvement in thermal performance by employing such new concepts.

2 CanPAK^{TM} package

CanPAK^{TM} is a surface mount semiconductor technology designed for board mounted power applications. It optimizes elements of packaging to improve the thermal performance. CanPAK^{TM} devices no longer use bond wire or clip interconnect but use solder bumps for source and gate connections. The drain connection is formed by a plated copper can, which is bonded to the drain side of the silicon die. There are two can sizes available, medium can M and small can S (Fig. 1)

Fig. 1 CanPAK^{TM} medium can M and small can S

As the CanPAK^{TM} uses a copper can it features a very low thermal resistance to the top side of the package and hence is very suitable for cooling through the top side of the package ('double sided cooling'). The top side of the can dissipates heat to the ambient, which is maximized if a heatsink is used. In addition to the source and gate pads the can construction provides a parallel thermal path to the board via the edges of the can. The heat flow paths are shown in Fig. 2.

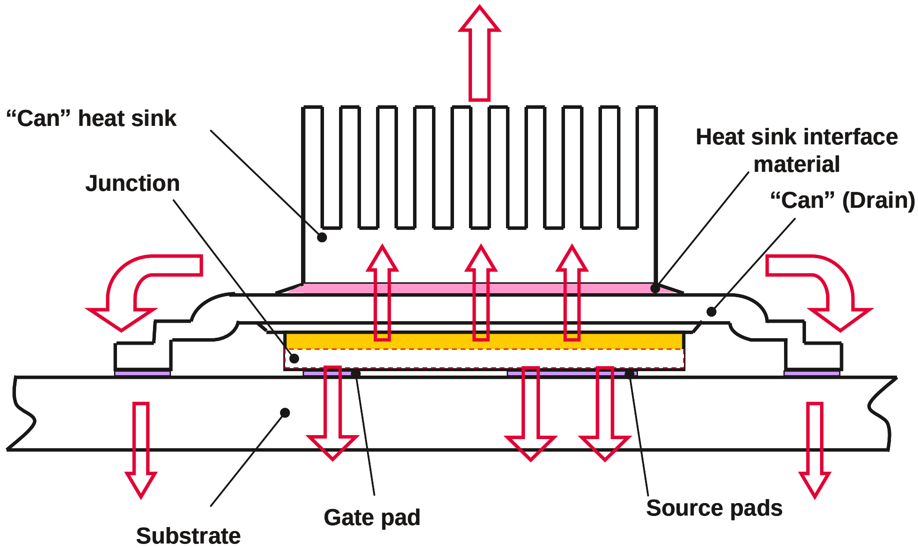


Fig. 2 CanPAK showing heatflow directions (red arrows)

3 Thermal resistance

When a Power MosFET operates in a system under steady-state condition, the maximum power dissipation is determined by the maximum junction temperature rating, the ambient temperature, and the junction-to-ambient thermal resistance.

$$P_{\max} = \frac{T_{J,\max} - T_A}{R_{th\,\mathrm{JA}}} \qquad (1)$$

T_J is the temperature of the device junction. The term junction refers to the point of thermal reference of the semiconductor device. T_A is the average temperature of the ambient environment. P is the power dissipated in the device which changes the junction temperature. R_{thJA} is a function of the junction-to-case R_{thJC} and case-to-ambient R_{thCA} thermal resistance:

$$R_{th\,\mathrm{JA}} = R_{th\,\mathrm{JC}} + R_{th\,\mathrm{CA}} \qquad (2)$$

For the CanPAK™ one has to distinguish between the R_{thJC} – bottom (resistance to the PCB board) and the R_{thJC} – top (resistance to the heatsink). R_{thJC} can be controlled and measured by the component manufacturer independent of the application and mounting. The main influence factor on the R_{thJC} is the chip size.

On the other hand, it is difficult to quantify R_{thCA} due to strong dependence on the application. R_{thCA} is influenced by many variables such as ambient temperature, board layout, and cooling method (Table 1). In the datasheet usually R_{thJA} values are given for a device on 40 mm x 40 mm x 1.5 mm epoxy PCB FR4 with 6 cm² (one layer, 70 µm thick) copper area for drain connection. The PCB is vertical in still air. Before using the data sheet thermal data, the user should always be aware of the test conditions and justify the compatibility in the application.

Table 1 Influence factors R_{thJC}, R_{thCA}

R_{thJC} (product variables)	R_{thCA} (application variables)
• Leadframe size & material • Die size • Die attach material • Mold compound size & material	• Mounting pad size, shape and location • Placement of mounting pad • PCB size & material • Use of heatsink • Amount of thermal vias • Traces length & width • Adjacent heat sources • Air flow rate and volume of air • Ambient temperature, etc.

4 CanPAK™ – Double sided cooling package

The metal can provides a very low thermal resistance between junction and the package topside. With the use of heatsinks and cooling air flow, the CanPAK™ package can dissipate more heat out of the top of the package than regular molded packages, reducing the operating temperature of the device. Effective top-side cooling means that heat dissipated can be pulled away from the circuit board, increasing the currents that the device can safely carry.

With the CanPAK™ effective cooling can be achieved by:

- Regular SMD
- Top side sinking
- bottom side sinking
- dual sided sinking

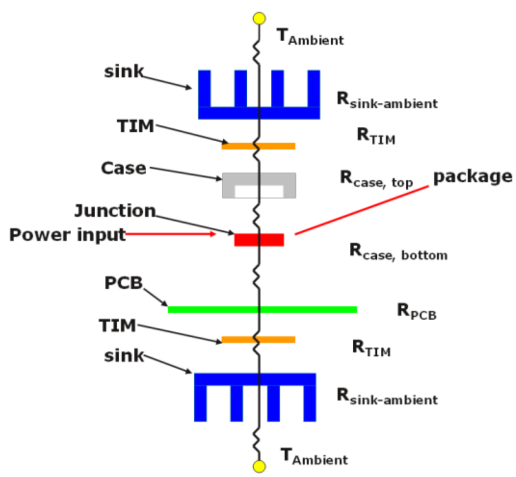


Fig. 3 Different options for usage of a heatsink.

When using a heatsink three points have to be considered (Fig. 4)

- heatsink
- thermal interface material (TIM)
- board attachment of heatsink

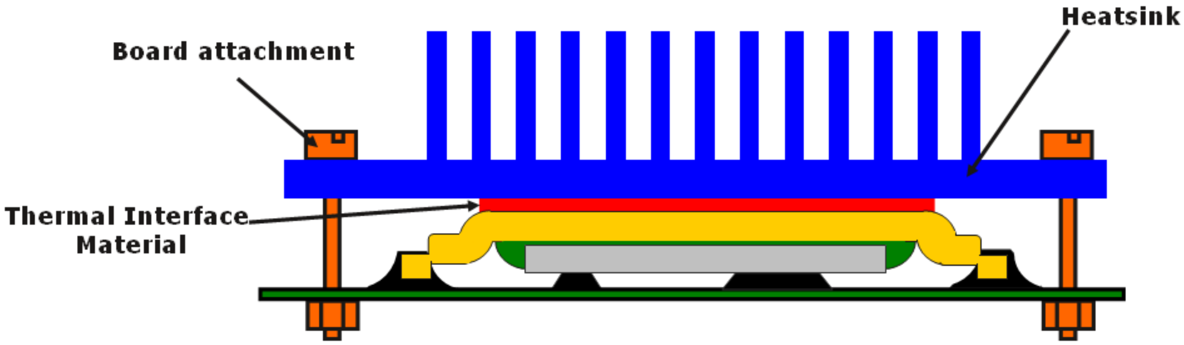


Fig. 4 Using a heatsink (heatsink, thermal interface material (TIM) and board attachment)

4.1 Heatsink

The size/shape of the heatsink will depend on the customers requirement for R_{thCA} case - ambient and required thermal capacity. The heatsink can be designed to sink single or multiple devices.

A heat sink lowers the thermal resistance mainly by increasing the surface area that is in direct contact with the package. This allows more heat to be dissipated and/or lowers the device operating temperature. Several vendors publish performance graphs for heatsinks as shown in Fig. 5. One can use the performance graphs to identify the heat sink and, for forced convection applications, determine the minimum flow velocity that satisfy the thermal requirements.

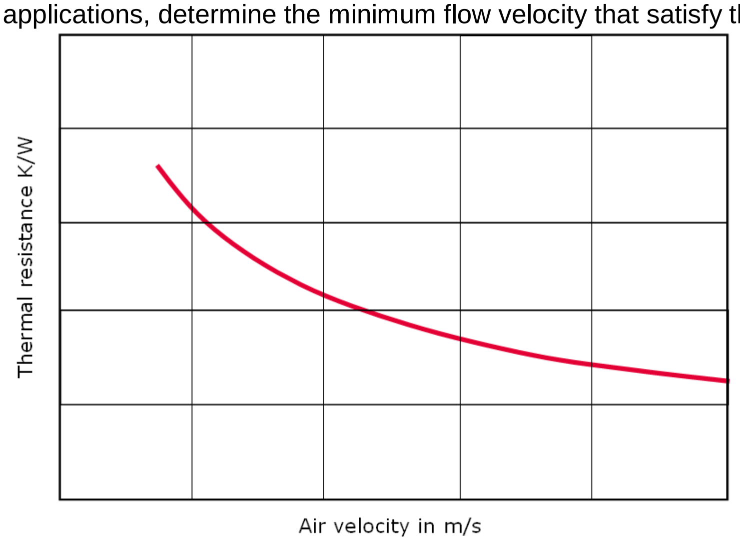


Fig. 5 Typical performance graph of a heatsink

4.2 Thermal interface materials (TIM's)

Interface material provides two functions. It fills the gap between device and heatsink and so

1. improves the intimacy on the thermal contact of the CanPAK™ and the heatsink.
2. provides electrical isolation between the drain clip which is at drain potential and the heatsink (not required if only one device is to be heatsunk or all devices are running at the same potential and phase).

There are different types of thermal interface materials available (Table 2). One has to distinguish between liquid (like grease) and solid interface (like silicone pads) materials

There are two key factors that impact the performance of the TIM's
- Thermal conductivity of the material
- Surface wetting/conforming characteristics of the material

Table 2 Comparison of different types of thermal interface materials (TIM's)

Material class	Description	Benefits	Drawbacks	Thermal condcutivity	surface wetting	surface conforming
Grease	TIMs filled with conductive particles of AL2O3, etc.	- Can achieve very thin bondlines < 10 µm	- Difficult to preapply to assemblies, - messy - Requires controlled dispensing - Typically pumps out, effecting long term reliability - No electrical isolation	0.3 - 2 W/mK	very good	very good
Gel	Grease replacement that crosslinks during cure to form a gel-like substance	- Can achieve very thin bonlines < 10 µm - Does not pump out	- Can't be preapplied to assemblies - Requires cure which can be from burn-in - Messy - Requires controlled dispensing	0.3 - 2 W/mK	very good	very good
Adhesive	Heat cured adhesives with conductive particles	Can achieve very thin bonlines < 10 µm - Mechanical and thermal attach	- Can't be preapplied to assemblies - Typically requires process oven curing - Messy - Requires controlled dispensing	0.3 - 1.3 W/mK	very good	very good
Tape	Usually pressure sensitive adhesive filled with conductive particles on a fiberglass or plastic carrier	- Mechanical and thermal attach - Can be cut and preapplied - Clean and simple processing - Typically electrical isolating	- Typically thick bondlines with low thermal conductivity	0.7-1.5 W/mK	moderate	poor
Phase Change	A waxy type material that changes to a gel at approx. 50°C allowing it to conform to surface irregularities Can be preapplied or supplied on a carrier	- Can achieve very thin bondlines < 10 µm - Fairly clean process - Can be cut and preapplied - Clean process	- Typically low thermal conductivity - The phase change material itself is usually very thin and does not conform to large irregularities	0.8-1.5 W/mK	moderate	poor
Pads	Typically thick materials 100 - 300 µm	-simple to use - Can typically be re-used - Can be cut and preapplied - clean process	- Typically requires moderate to high pressure to achieve reasonable performance - Typicall does not conform well to small irregularities	0.8 - 4 W/mK	Poor	Very good for large irregularities, very poor for small

Testing of interface materials in the application is critical. Initial first material selection can be based on the data sheet, however to optimize performance, empirical testing must be performed.

4.3 Board attachment

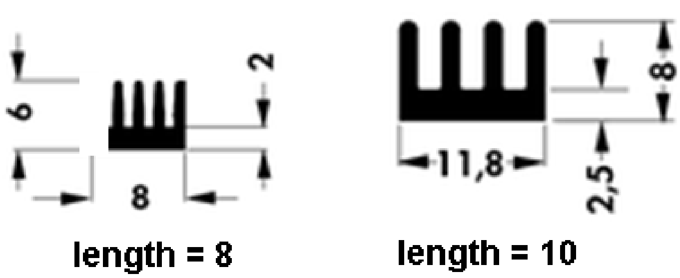
In the majority of cases the method of attachment is a compression fit of the heatsink onto the device. This is either achieved by screw mounting of the heatsink or through the use of a clip to affix the heatsink to the board. In both cases the interface material is sandwiched between the heatsink and the board.

5 Thermal measurements and simulation

The thermal performance in the application depends on boundary conditions like copper area on PCB, air flow velocity, etc. To show the influence of these parameters a typical board configuration for computing applications was used for thermal measurements and simulations. The PCB design is shown in Fig. 7 and Fig. 14. The measurements were done with test boards in a wind tunnel with airflow between 0 and 3 m/s. To show the influence of a heatsink the CanPAK™ investigations were done with two different heatsinks (Fig. 6). The small heatsink HS1 has twice the footprint of the CanPAK™ and the big heatsink HS2 has 4 times the footprint of the CanPAK™. The surface area of HS2 is approximately twice the area of HS1 which results in double heat transfer performance.

The advantage of using a heatsink can be seen in Fig. 8. Depending on the heatsink size a decrease of Rthja up to 30% was reached, which means that accordingly more power can be dissipated or a lower PCB temperature can be achieved (Fig. 11). The measurements also show a dramatic influence of forced convection which decreases the thermal resistance by approximately 50 % compared to still air (Fig. 8, Fig. Fig. 9, Fig. 10). The investigations show a very good agreement of measurement and simulation results.

Comparing different heatsink arrangements the arrangement on top of the package is better than arrangement beneath the PCB. Arrangement on top and bottom side yields the best performance (Fig. 9, Fig. 10).



Thermal interface material:
- Adhesive tape
- Thickness: 127 µm
- Thermal conductivity: 0.37 W/mK

Fig. 6 Heatsinks used for measurement and simulation (left: heatsink HS1, right: Heatsink HS2, dimensions in mm)

Fig. 7 Measurement boards (dimensions in mm)

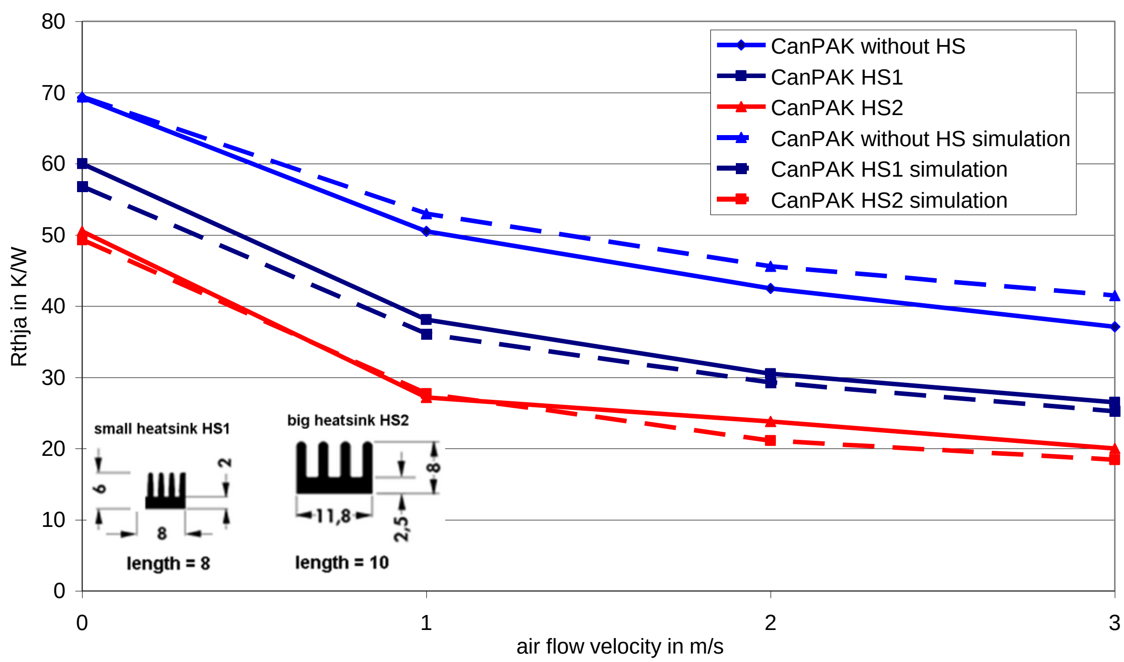


Fig. 8 Measurement and simulation results R_{thJA} – CanPAK™ with and without heatsink

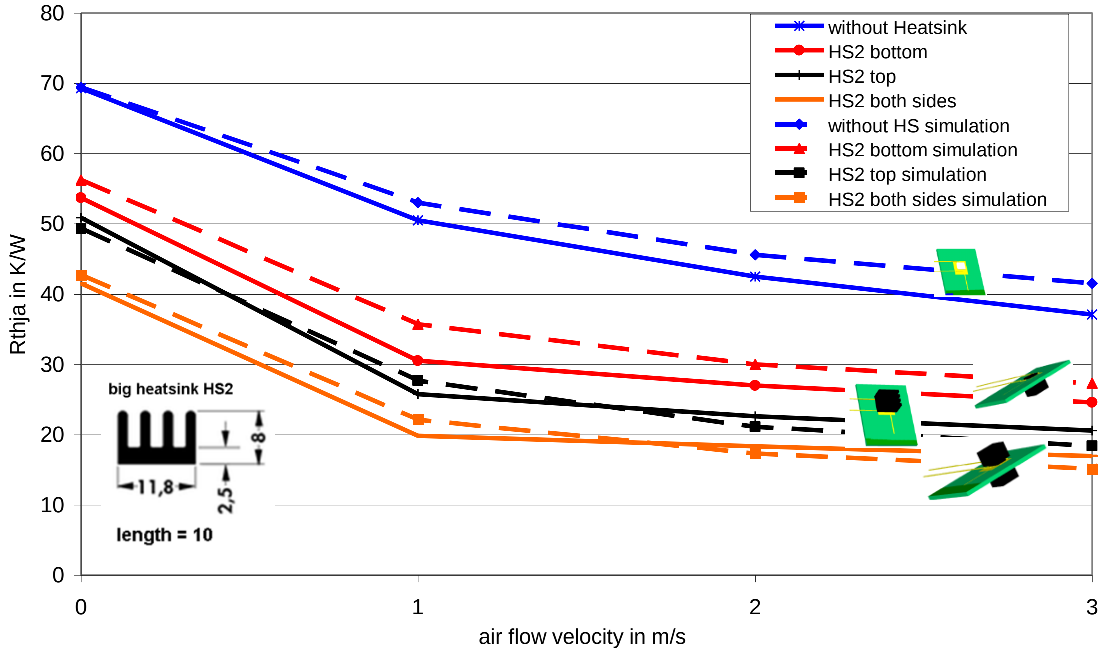


Fig. 9 Measurement and simulation results R_{thJA} – CanPAK™ with and without heatsink and different arrangements of the heatsink

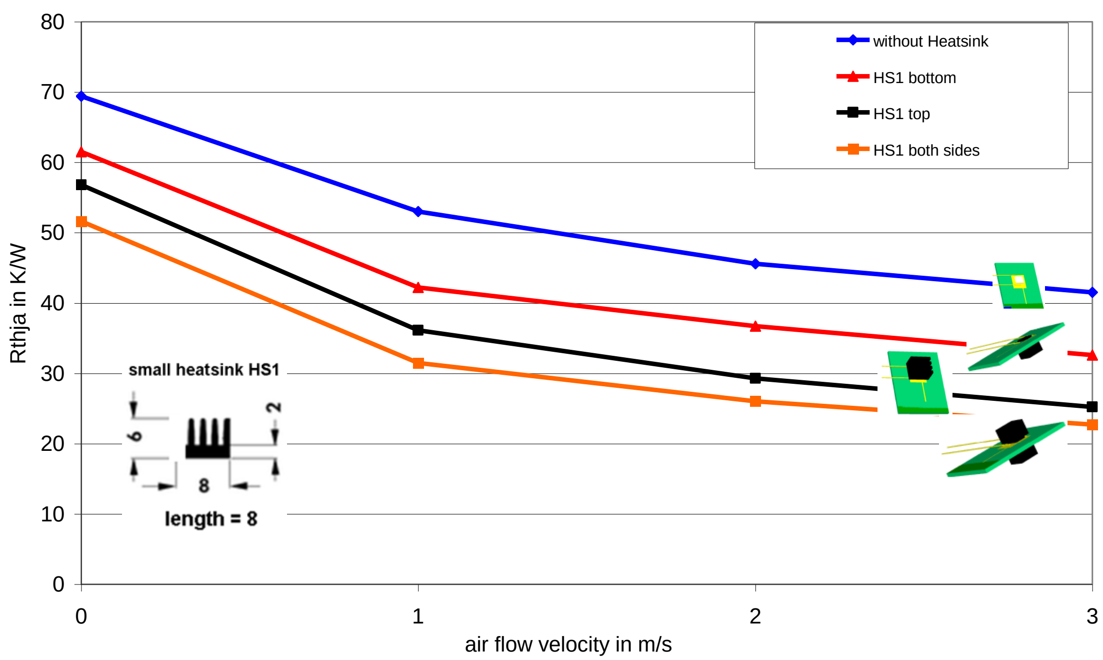


Fig. 10 Simulation results R_{thJA} – CanPAK™ with and without heatsink and different arrangements of the heatsink

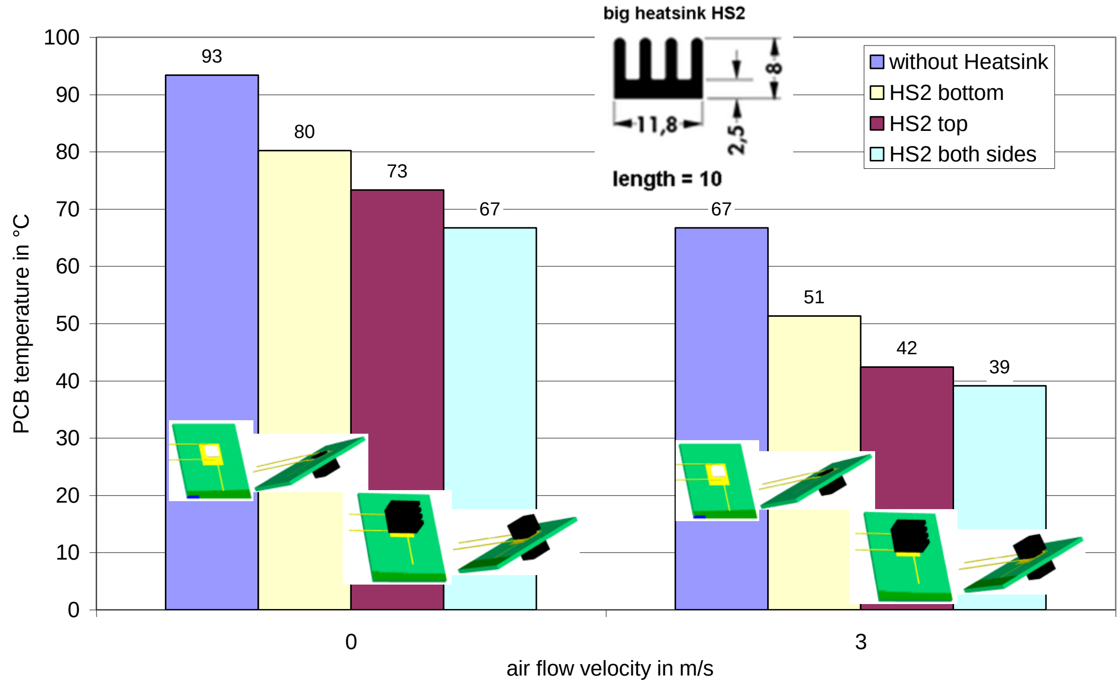


Fig. 11 Simulation results for PCB temperature (Power dissipation 1 W, ambient temperature 25°C)

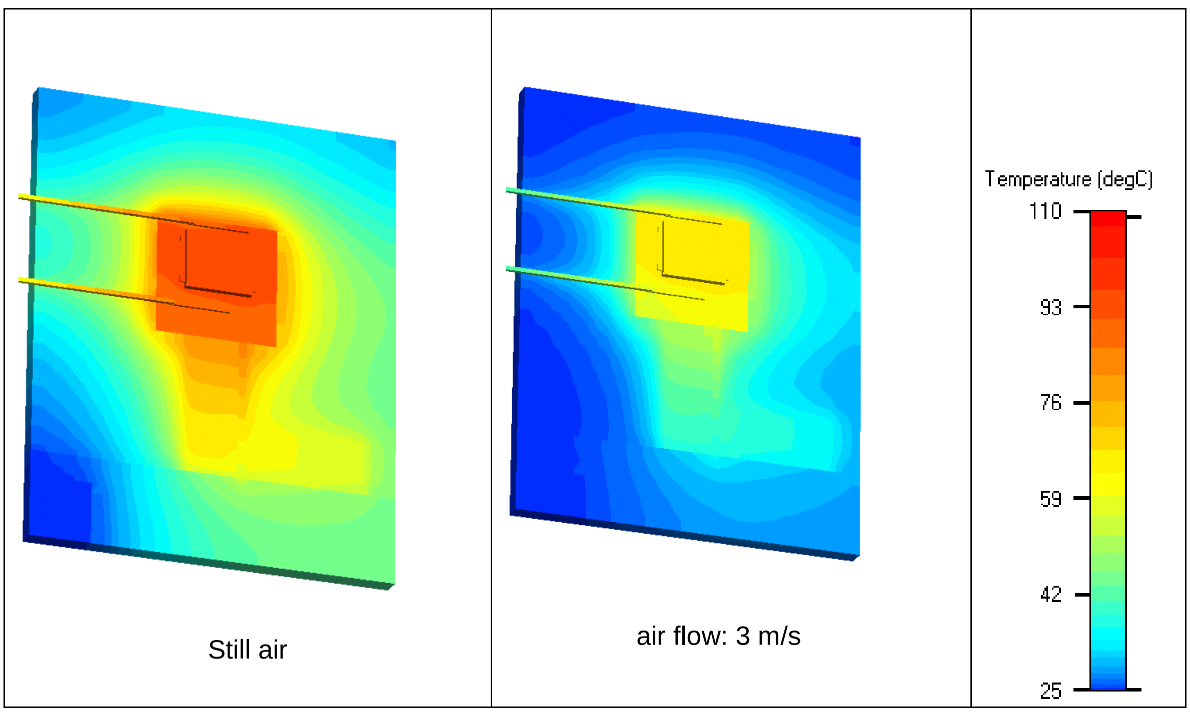


Fig. 12 Simulation results for PCB temperature (Power dissipation 1 W, ambient temperature 25°C)

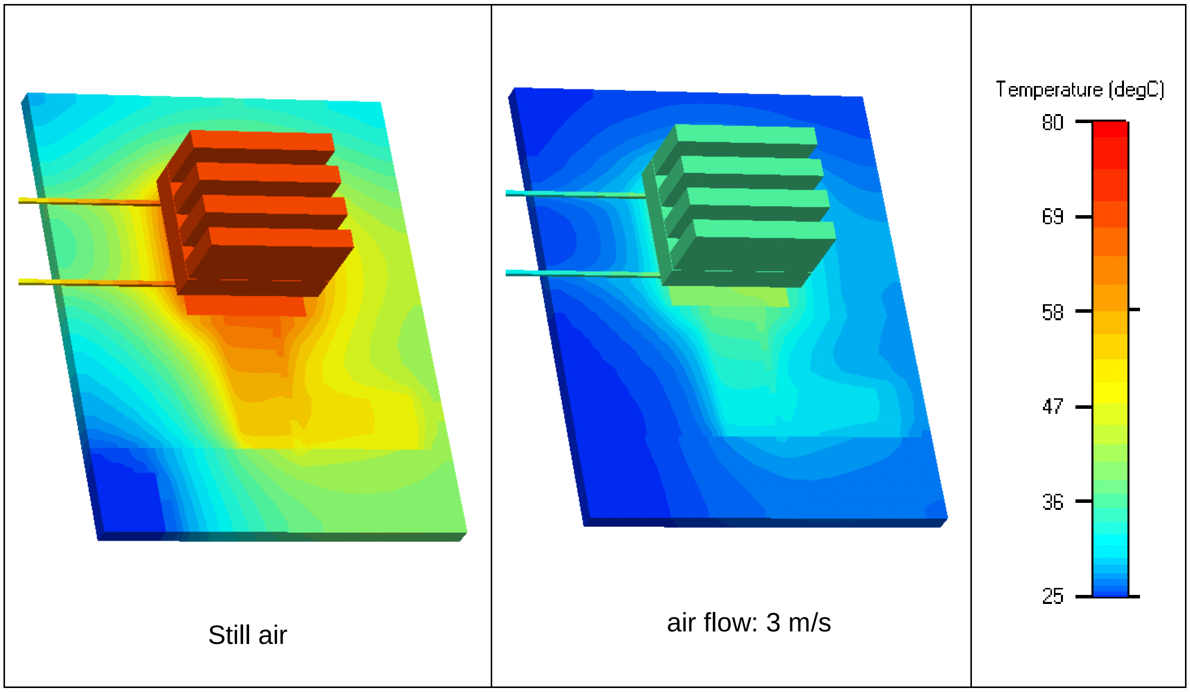


Fig. 13 Simulation results for PCB temperature (Power dissipation 1 W, ambient temperature 25°C, heatsink HS2)

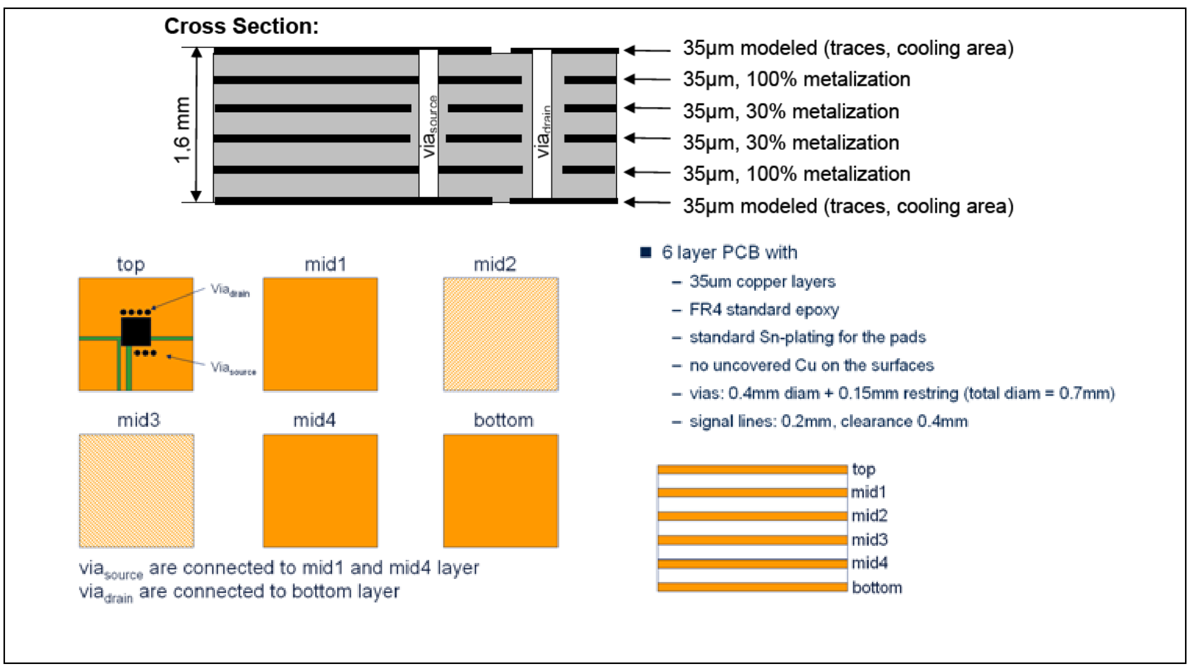


Fig. 14 PCB board used for thermal measurement and simulation

6 Summary

This document outlines different cooling concepts for the CanPAK™ package. Measurements and simulations show a significant thermal improvement by using heatsinks and by forced convection. There is a good agreement between measurement and simulation results.

In the appendix a simple method for an analytic calculation of the thermal resistance is shown.

7 Appendix

Analytic calculation of the thermal resistance Rth_JA

The thermal resistance R_{th_JA} can be calculated using a one dimensional model. As heat is transferred via the top and bottom side the thermal resistance to the top and bottom side have to be considered. The R_{th_JA} can be calculated using the formula for parallel connection of thermal resistances:

$$R_{th\_JA} = \frac{R_{th\_top} \times R_{th\_bottom}}{R_{th\_top} + R_{th\_bottom}} \quad (3)$$

R_{th_top} = thermal resistance top-side

R_{th_bottom} = thermal resistance bottom side

R_{th_JA} = thermal resistance junction-ambient

Case 1: Without heatsink

$$R_{th\_top} = R_{th\_JC\_top} + R_{th\_conv\_rad\_top} \quad (4)$$

$$R_{th\_bottom} = R_{th\_JC\_bottom} + R_{th\_PCB} \quad (5)$$

$R_{th\_JC\_top}$ = thermal package resistance bottom-side (datasheet)

$R_{th\_conv\_rad\_top}$ = convection and radiation resistance package top-side

$R_{th\_\_JC\_bottom}$ = thermal package resistance bottom side (datasheet)

R_{th_PCB} = thermal resistance PCB

Case 1: With heatsink

In case of using a heatsink the R_{th_top} resistance has to be calculated differently.

$$R_{th\_top} = R_{th\_JC\_top} + R_{th\_TIM} + R_{th\_heat\,sink} \quad (6)$$

$R_{th\_\_JC\_bottom}$ = thermal resistance thermal interface material (TIM)

$R_{th\_heat\,sink}$ = thermal resistance heatsink

Calculation Example 1:

package	CanPAK M
Heatsink	no
Boundary condition	Natural convection

$$R_{th\_top} = R_{th\_JC\_top} + R_{th\_conv\_rad\_top}$$

$$R_{th\_JC\_top} = 1.4K/W \text{ (datasheet value)}$$

The $R_{th\_conv\_rad\_top}$ can be calculated using equation (8). As a rule of thumb the heat transfer coefficient for convection and radiation is about 10 W/m²K. The contact area is calculated by using the package drawing in the datasheet (~ 30.9 mm²)

$$R_{th\_conv\_rad\_top} \approx \frac{1}{10 W/_{m^2K} \times 30.9mm^2} = 3239.4 K/_W$$

$$R_{th\_top} = 1.4 + 3239.4 = 3240.8 K/_W$$

$$R_{th\_JC\_bottom} = 1.0 K/_W \text{ (datasheet value)}$$

As the R_{th_PCB} is difficult to calculate with a one-dimensional model this value is estimated based on the measurement results.

$$R_{th\_PCB} \approx 70 K/_W$$

$$R_{th\_bottom} = 1.0 + 70 = 71 K/_W$$

The R_{thJA} is calculated using equation (3)

$$R_{th\_JA} = 69.5 K/_W$$

The ratio of power dissipation top side and overall dissipation gives:

$$\frac{P\_top\_side}{P} \times 100 = \frac{R_{th\_JA}}{R_{th\_top}} \times 100 = \frac{69.5}{3240.8} \times 100 = 2\%$$

Calculation example 2:

package	CanPAK M
Heatsink	HS1
TIM	WLFT 404 Thickness: 127 µm Thermal conductivity: 0.37 W/mK
Boundary condition	Natural convection

$$R_{th\_JC\_top} = 1.4K/W \text{ (datasheet value)}$$

The $R_{th\_JC\_TIM}$ can be calculated with equation (7) for the thermal resistance.

$$R_{th\_JC\_TIM} = \frac{127\mu m}{0.37 W/_{mK}\ 21.45\,mm^2} = 16.0\,K/_W$$

For the thermal resistance of the heatsink $R_{th\_heatsink}$ the conduction resistance is neglected as its contribution is small compared to the convection resistance. The convection resistance is calculated using equation (8). The contact area is roughly calculated as area of the fins and the area of the fillets between the fins (~ 280 mm²).

$$R_{th\_heatsink} \approx \frac{1}{10 W/_{m^2K} \times 344mm^2} = 290.7\,K/_W$$

$$R_{th\_top} = 1.4 + 16.0 + 290.7 = 308.1\,K/_W$$

$$R_{th\_bottom} = 71\,K/_W$$

$$R_{th\_JA} = 57.7\,K/_W$$

The ratio of power dissipation top side and overall dissipation gives:

$$\frac{P\_top\_side}{P} \times 100 = \frac{R_{th\_JA}}{R_{th\_top}} \times 100 = \frac{57.7}{308.1} \times 100 = 19\%$$

<u>Calculation example 3:</u>

package	CanPAK M
Heatsink	HS2
TIM	WLFT 404 Thickness: 127 µm Thermal conductivity: 0.37 W/mK
Boundary condition	Natural convection

The calculation is the same as for calculation example 2. The only difference is the contact area for the heatsink which gives roughly 500 mm².

$$R_{th\_JC\_top} = 1.4K/W \text{ (datasheet value)}$$

$$R_{th\_JC\_TIM} = \frac{127\mu m}{0.37 W/_{mK} \; 21.45 mm^2} = 16.0 K/_W$$

$$R_{th\_heat\,sink} \approx \frac{1}{10 W/_{m^2 K} \times 610 mm^2} = 163.9 K/_W$$

$$R_{th\_top} = 1.4 + 16.0 + 163.9 = 181.3 K/_W$$

$$R_{th\_bottom} = 71 K/_W$$

$$R_{th\_JA} = 51.0 K/_W$$

The ratio of power dissipation top side and overall dissipation gives:

$$\frac{P\_top\_side}{P} \times 100 = \frac{R_{th\_JA}}{R_{th\_top}} \times 100 = \frac{51.0}{181.3} \times 100 = 28\%$$

Calculation of thermal resistances

Conduction Resistance

$$R_{cond} = \frac{L}{\lambda \times A}$$

$$L = \text{material thickness} \qquad (7)$$
$$\lambda = \text{thermal conductivty}$$
$$A = \text{contact area}$$

Convection and radiation resistance

$$R_{conv\_rad} = \frac{1}{\alpha \times A} \qquad (8)$$

$$\alpha = \text{convection and radiation heat transfer coefficient } (\alpha = \alpha_{conv} + \alpha_{rad})$$
$$A = \text{contact area}$$

Typical values for convection and radiation resistance

Cooling by free convection in air and radiation
$\alpha \approx 10$ W/(m²*K)

Cooling by forced convection in air and radiation
$\alpha \approx 20 - 50$ W/(m²*K)