AVL Software and Functions GmbH

AVL e-Drive

Air cooled Power electronic design

PDiM 2018 Sweden - Göteborg

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Development services and competences for advanced e-Drives

Concepts

Components

Hardware

Software

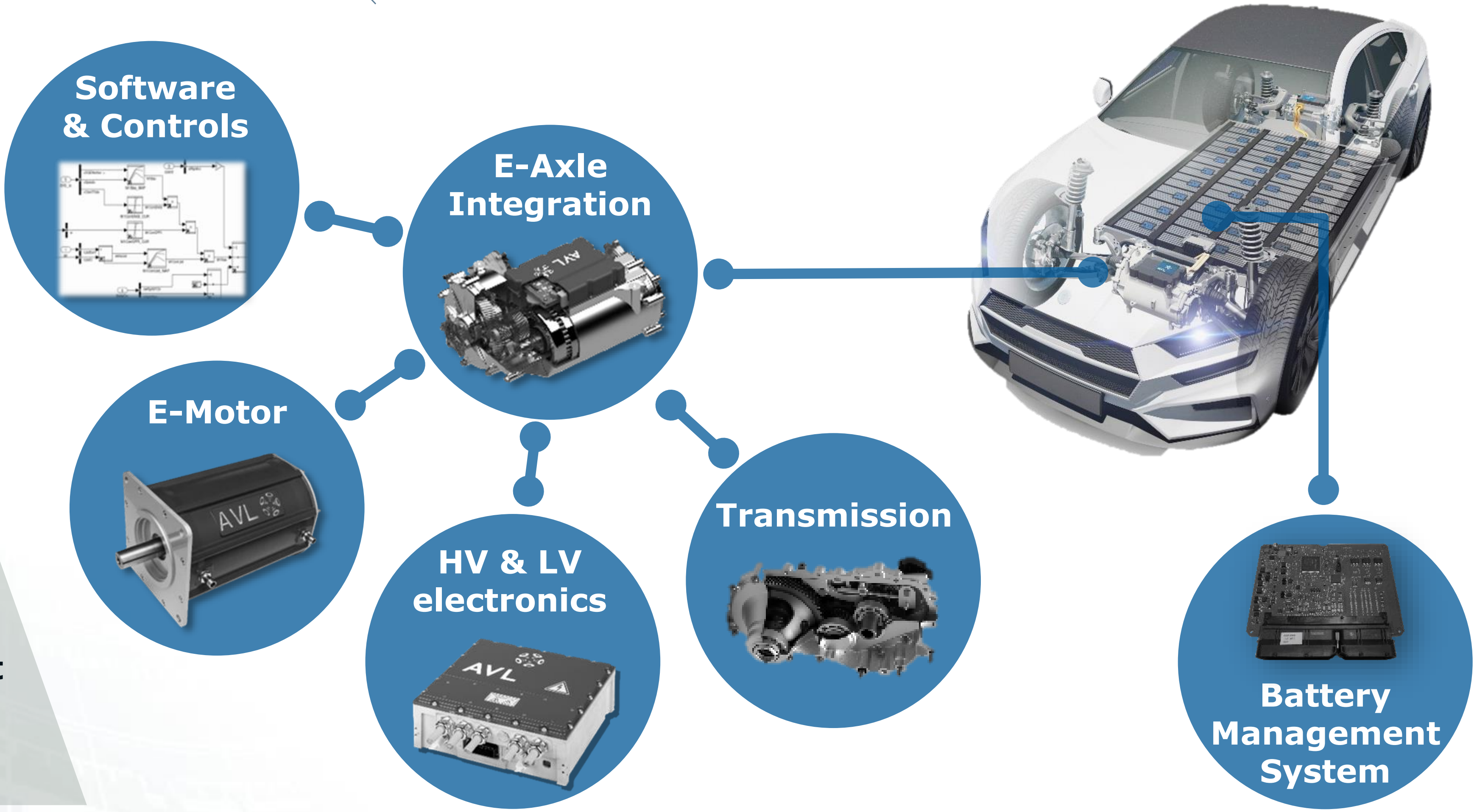
Integration

Benchmarking

Technology consulting

Industrialization support

SOP development



Full solution offering from concept, components to fully integrated E-Drive systems

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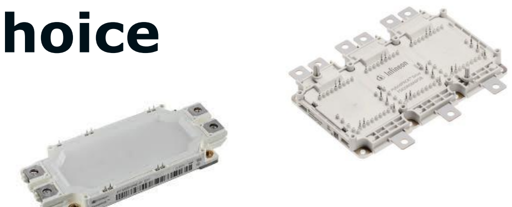
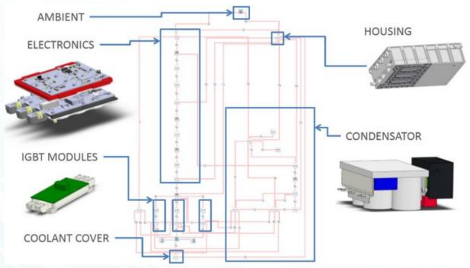
How to select a cooling system for power electronics?

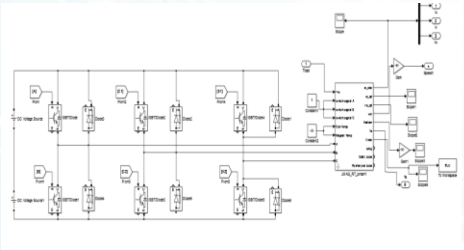
Module choice

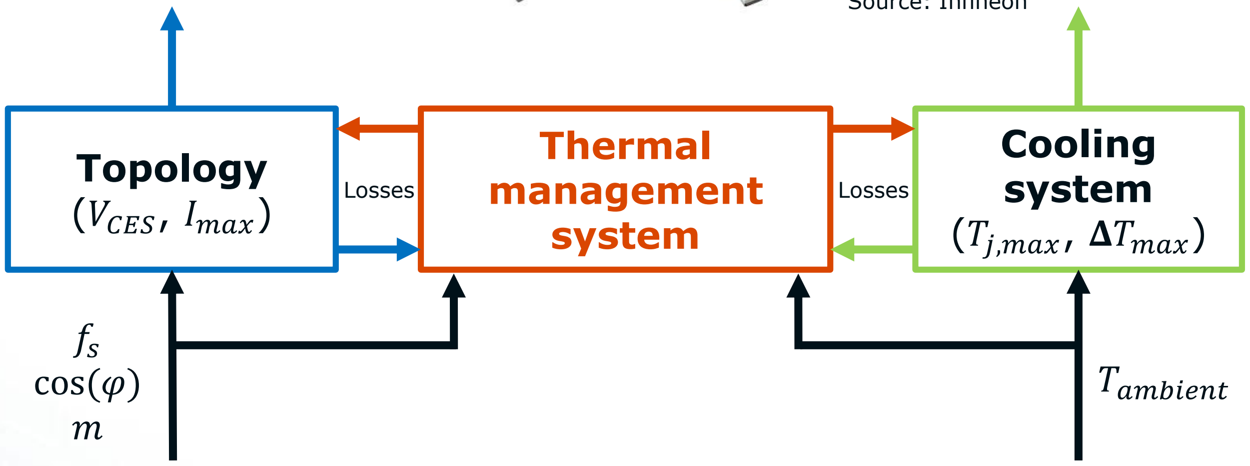


Source: Infineon

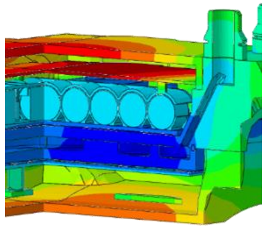
Electrical design

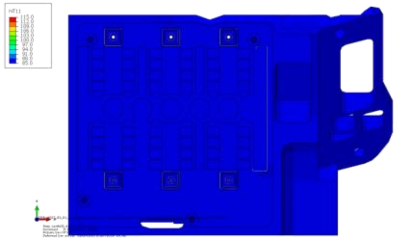






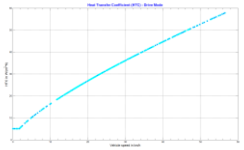
Thermal design





Requirements & Load profile

- Ambient air
- HTCs
- Vehicle parameters
- …



Cooling of power electronics is a system topic

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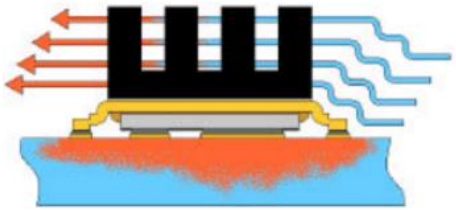
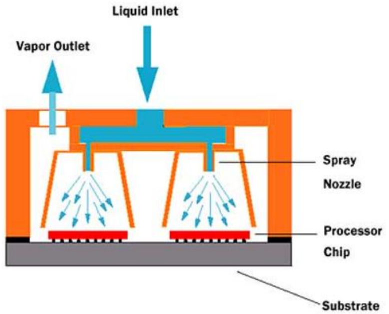
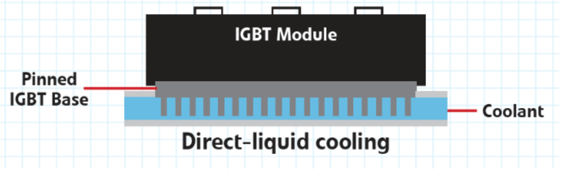
Cooling solutions for power electronics in today´s use



Source: electronics-cooling

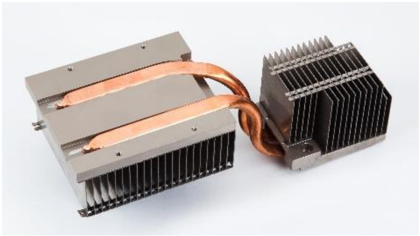
Natural and forced convection air cooled head sinks





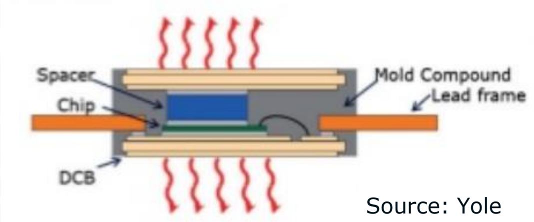
Source: zuerich-ibm

Jet impingement and direct contact liquid cooling of module base plates or DBC substrates



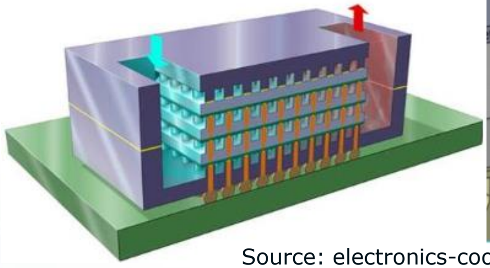
Source: luscombe

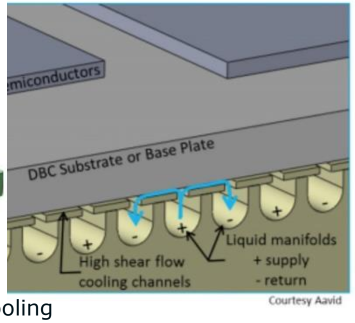
Two-phase liquid cold plates with boiling of dielectric refrigerant coolant



Source: Yole

Single and double sided cooling with liquid cold plates





Source: electronics-cooling

Micro-channel liquid coolers built into power module base plates or integrated with the DBC substrate

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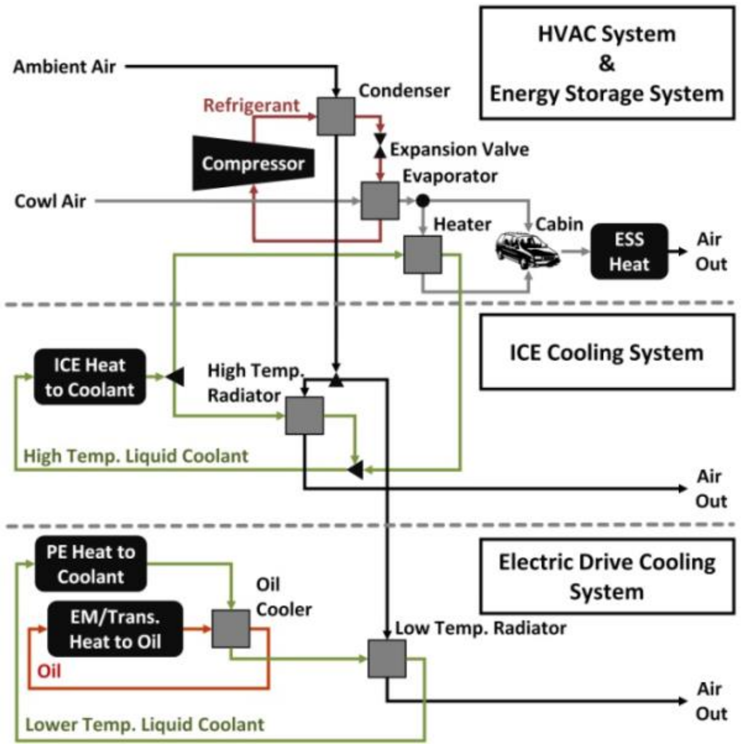
Why air cooling?

Natural or forced air cooling has several benefits such as…

- ✓ Lower system complexity by removing of water pumps, pipes, interfaces, etc.
- ✓ Cost benefit and reduction on system level
- ✓ No leakage compared to liquid cooling possible
- ✓ Good integration possibilities especially in (P)HEVs because of no interfacing of existing cooling system necessary

Todays vehicles are indirect air cooled (heat exchanger)



Example of vehicle cooling system

High potential of air cooling for lower system complexity and cost reduction

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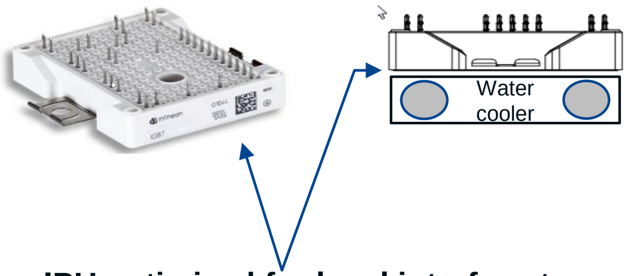
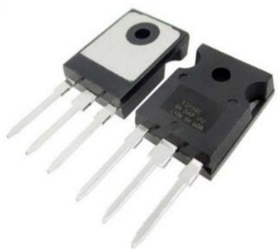
What package of semiconductors for air cooling?

IPU Cooling Interface
@ WATER- and AIR-COOLING

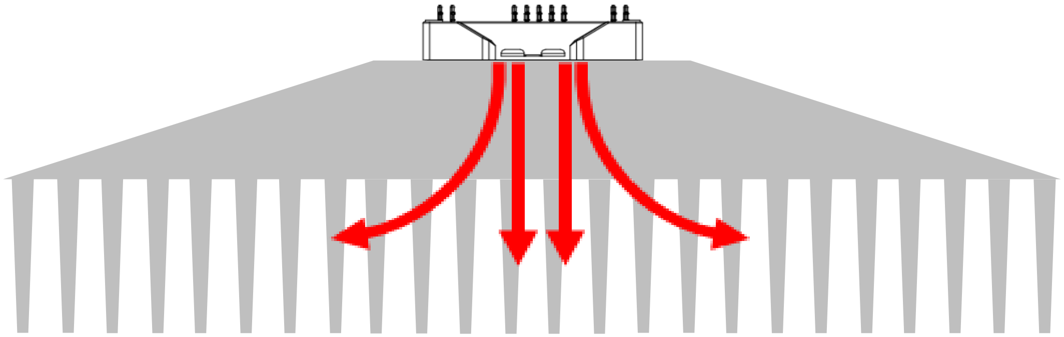


IPU optimized for local interface to heatsink (water-cooler)

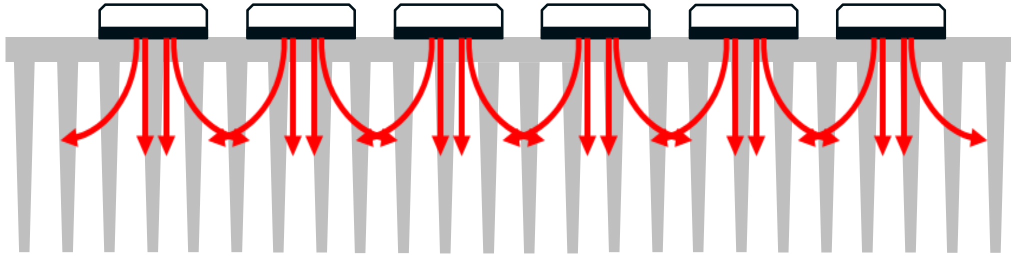
Discrete Semiconductors
@ AIR-COOLING application



discrete components to distributed thermal losses homogenously



massive heat-spreader required to use IPU in passive air-cooler applications



distributed, discrete components support passive air-cooler applications

Especially for air cooling discrete semiconductors supports better equal heat distribution

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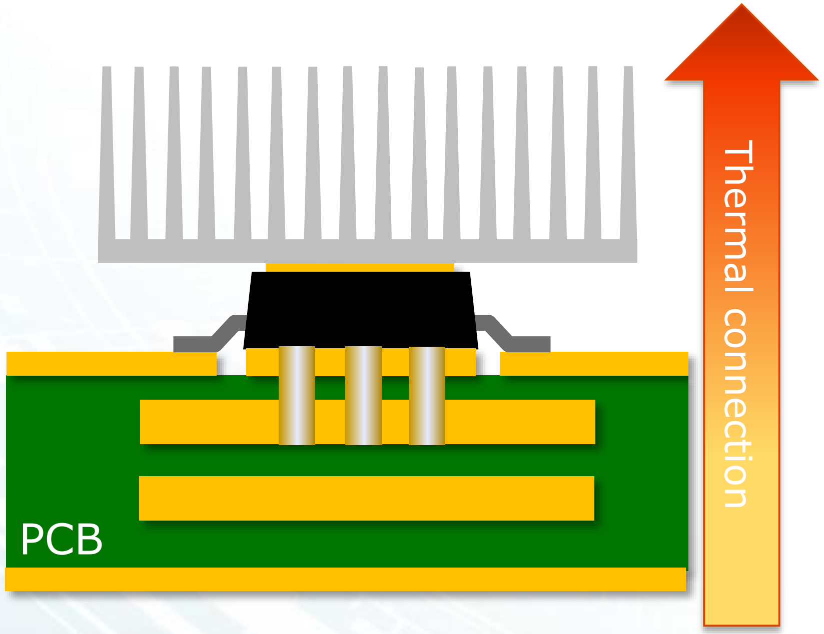
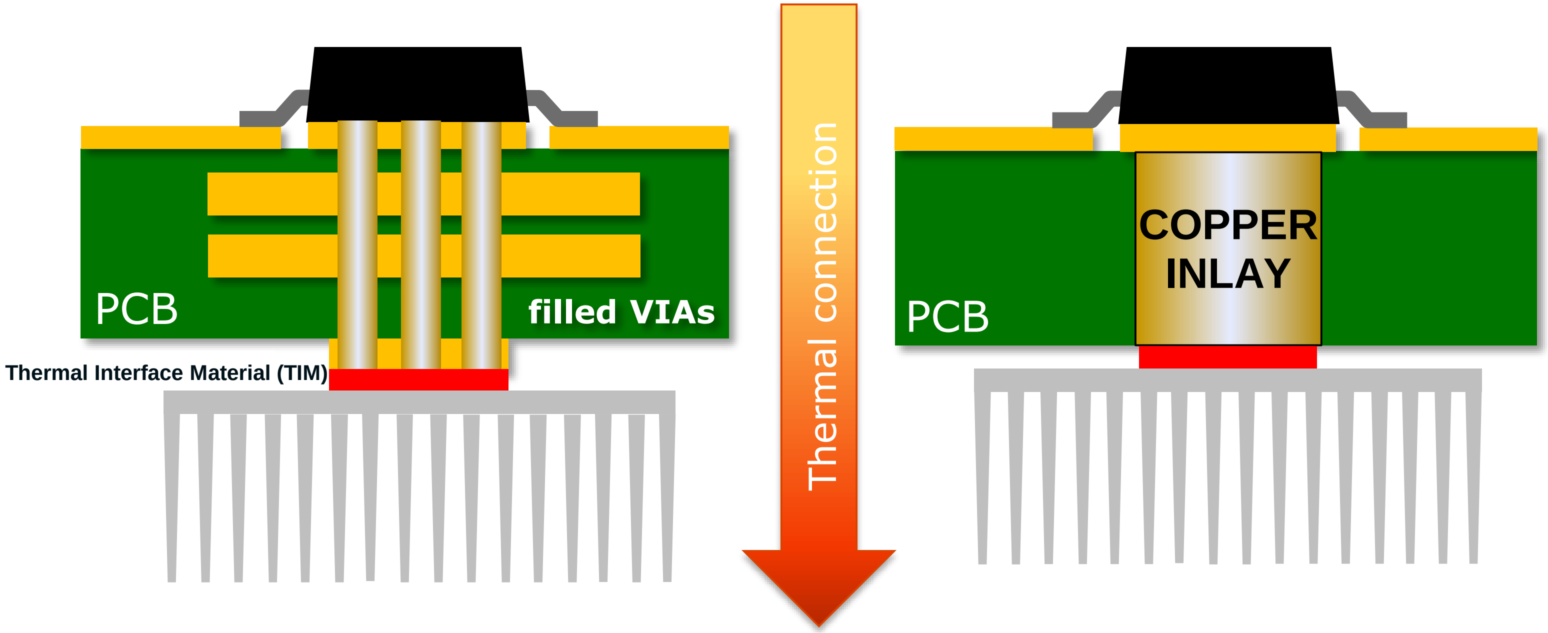
Design options for power electronic boards for air cooling

Typical thermal connection



Alternative thermal connection



Integration of busbars possible → cooling of busbars

Thermal design also effects the PCB design and layout

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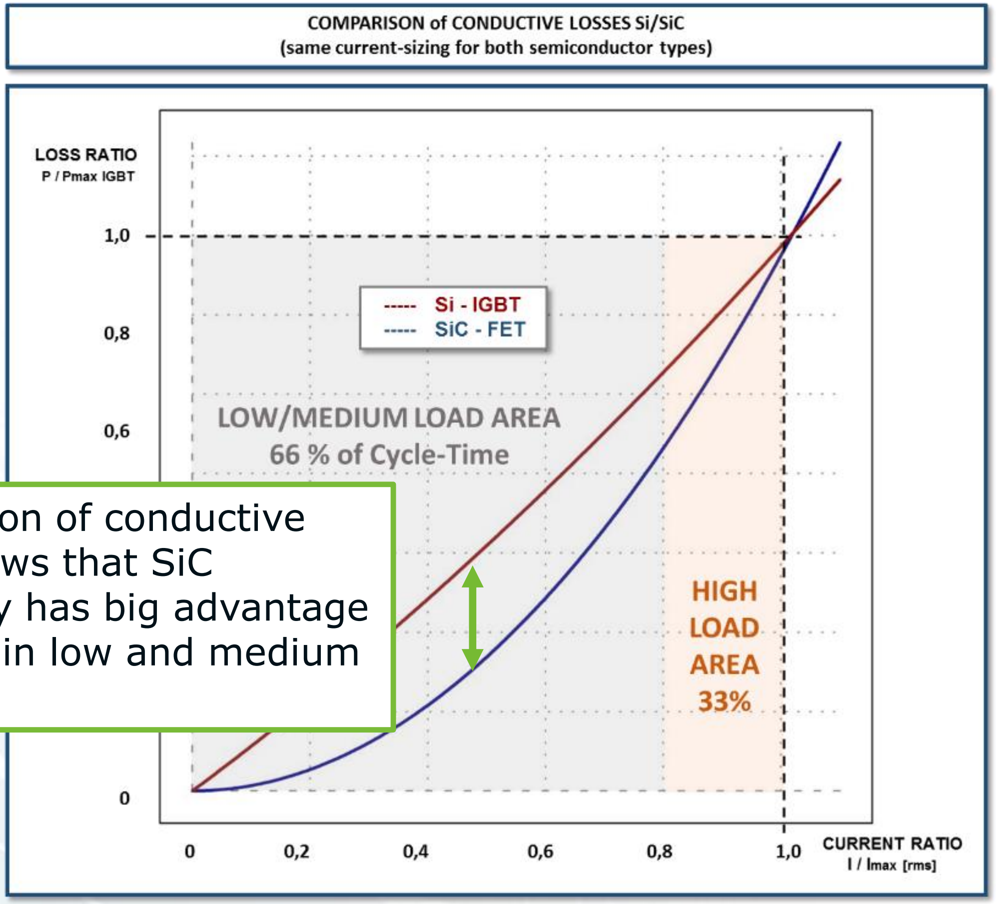
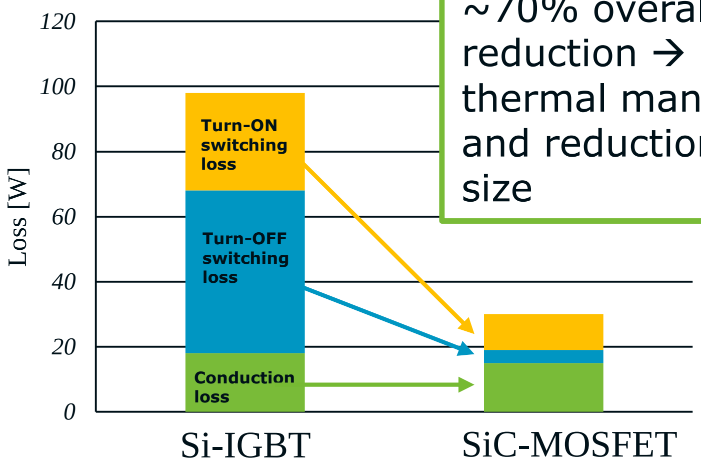
What type of semiconductor technology? Advantages of SiC for air cooling



Visualization of conductive losses shows that SiC technology has big advantage especially in low and medium load area

At a switching frequency similar to current IGBT inverter applications a SiC Converter shows

- Lower losses -> less internal temperature increase **AND**
- Better thermal conductivity
- Accepts higher junction temperature up to 200°C



~70% overall loss reduction → better thermal management and reduction of cooler size

SiC has better thermal properties and therefore big advantages for air cooled applications

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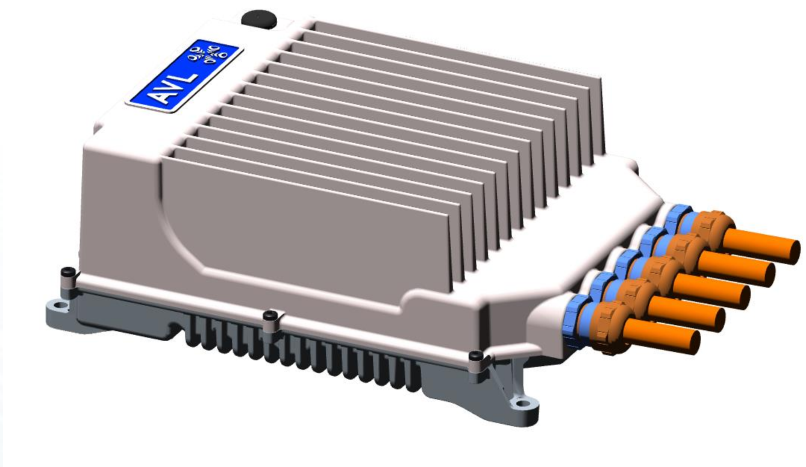
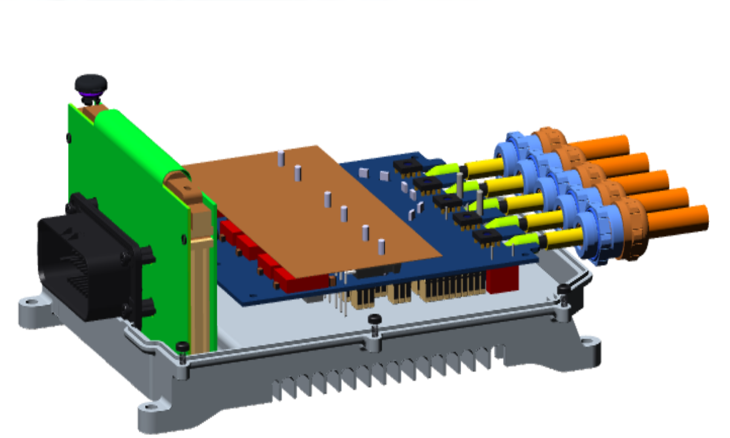
Air cooling example: 800V SiC Inverter for auxiliary applications





- **Development of 800V SiC inverter for auxiliary components like e-charger, e-compressor**
- **Design to Cost**
- **Separated Control and Powerboard for better EMC-charcteristics**
- **Key specifications**
  - No. of phases 3
  - V_{DC} 485-920V
  - V_{nom} 800V
  - $P_{out,\ max}$ 22kW
  - I_{nom} $15A_{rms}$

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Semiconductor loss calculation

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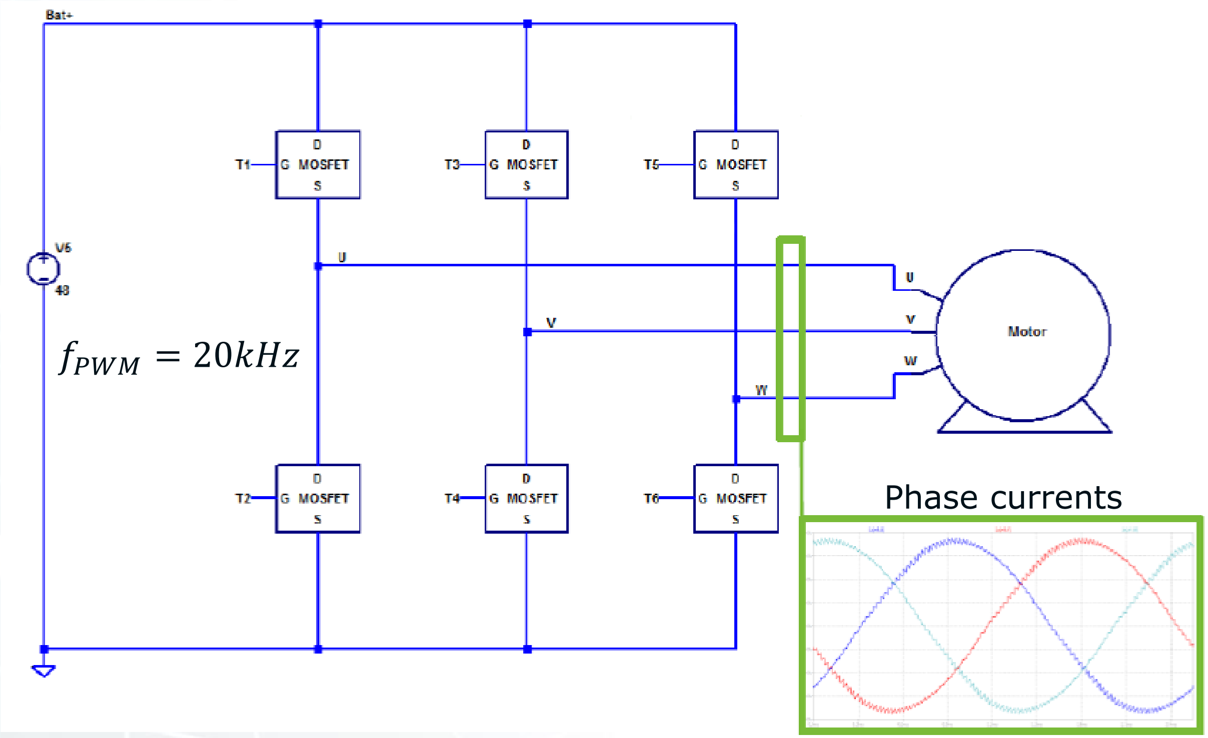
- Loss simulation based on critical load points
- Mosfet model from supplier for simulation



Inverter conductive losses are defined as:

$$P_{loss,conductive} = I^2 R_{DSon} + 2\left(\frac{I}{2}\right)^2 R_{DSon}$$

Inverter switching losses are defined as:

$$P_{loss,switching} = 6 f_{PWM}\left(E_{on} + E_{off}\right)$$

Total losses of Inverter:

$$P_{loss,total} = I^2 R_{DSon} + 2\left(\frac{I}{2}\right)^2 R_{DSon} + 6 f_{PWM}\left(E_{on} + E_{off}\right)$$

Mean value of losses per Mosfet:

$$P_{loss,Mosfet} = \frac{1}{2} I^2 R_{DSon} + f_{PWM}\left(E_{on} + E_{off}\right)$$

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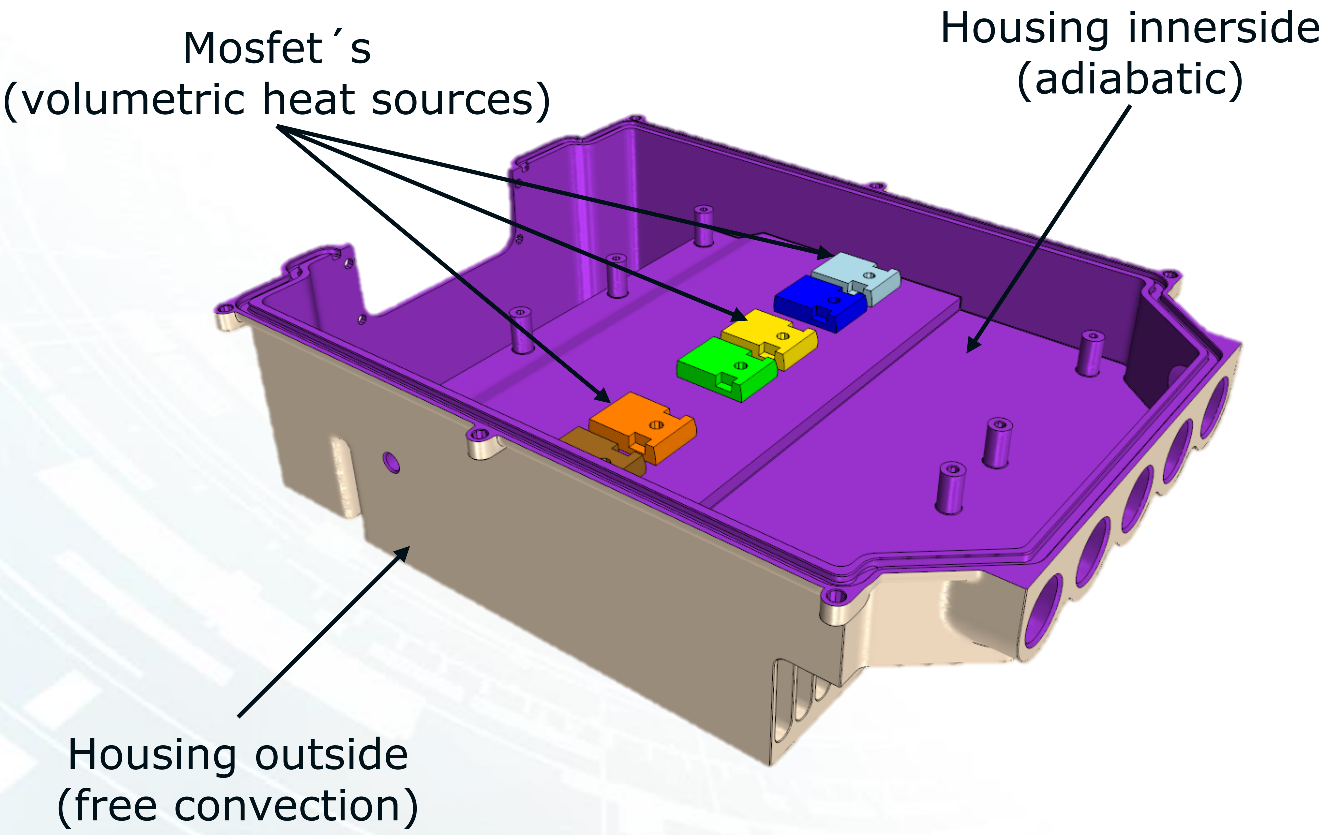
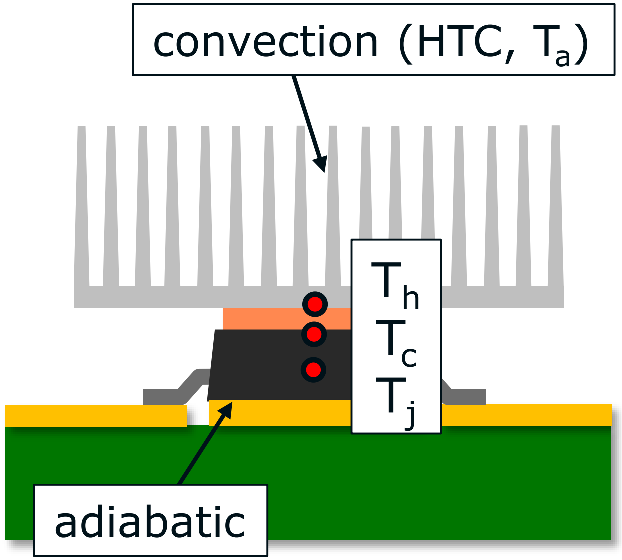
Thermal model of inverter



Gappad between Mosfet and housing is modelled as heat resistance

- Heat transfer coefficent of the housing: $HTC = 10\frac{W}{m^2K}$, (free convection)
- Ambient temperature: $T_{ambient} = 20°C$
- Gappad (Kerafol U90 s=0,2mm): $d = 0.2mm, k = 6\frac{W}{mK}$
- Housing (AlMg4.5Mn0.7 EN AW – 5083): $k = 125\frac{W}{mK}$
- R_{mosfet}: $0.55\,°C/W$ (junction-case resistance)



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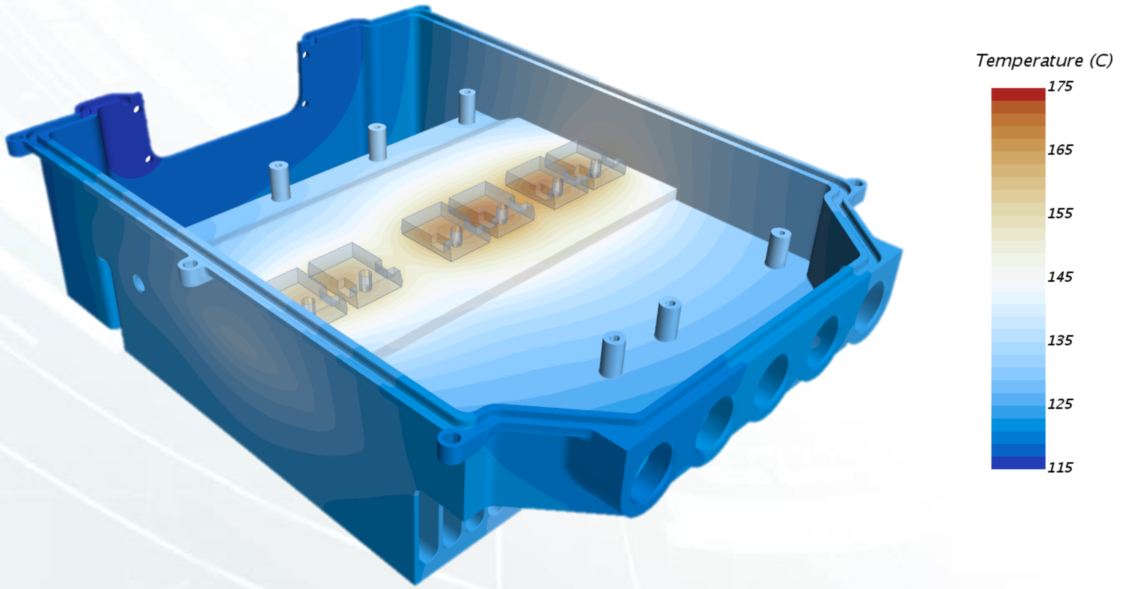
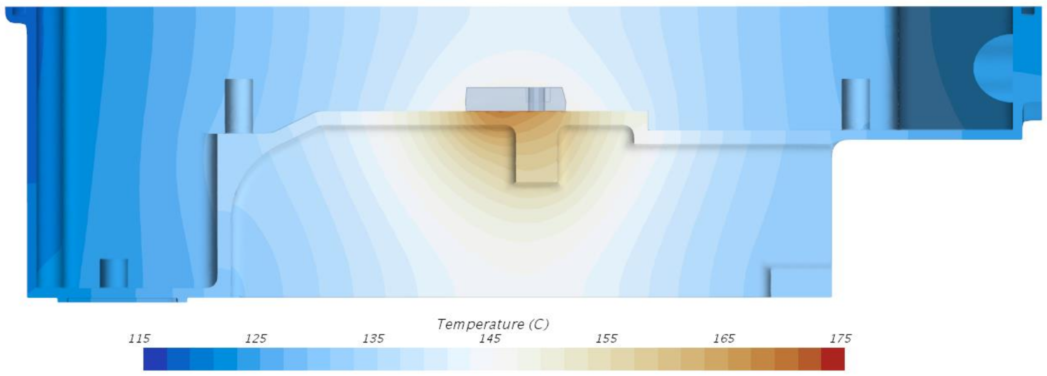
Results of the thermal simulation

- Max. power at **200°C** junction temperature is **26.4kW** based on the numerical simulation
- The Mosfet´s have a power losses of **270W**
- Max. surface temperature of Gappad is **176 °C**.





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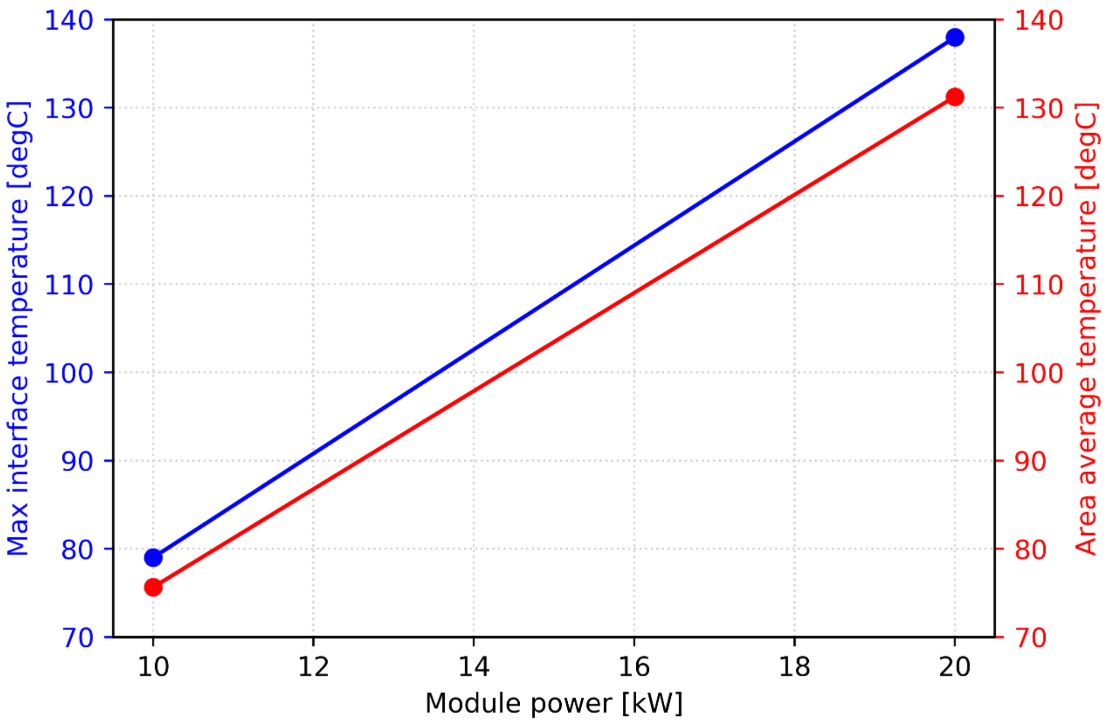
Results of the thermal simulation and influence of module power

- Max. temperature at the Gappad is **79 °C and 138 °C for 10 and 20 kW** module power
- The corresponding junction temperature is **88.2 °C at 10 kW** and **156 °C at 20 kW**
- The average surface temperature is for **10 and 20 kW** module power a surface temperature of **76 °C and 131 °C**.



For the planned operating performances, the power module is at a safe distance from its max. allowed limit temperature

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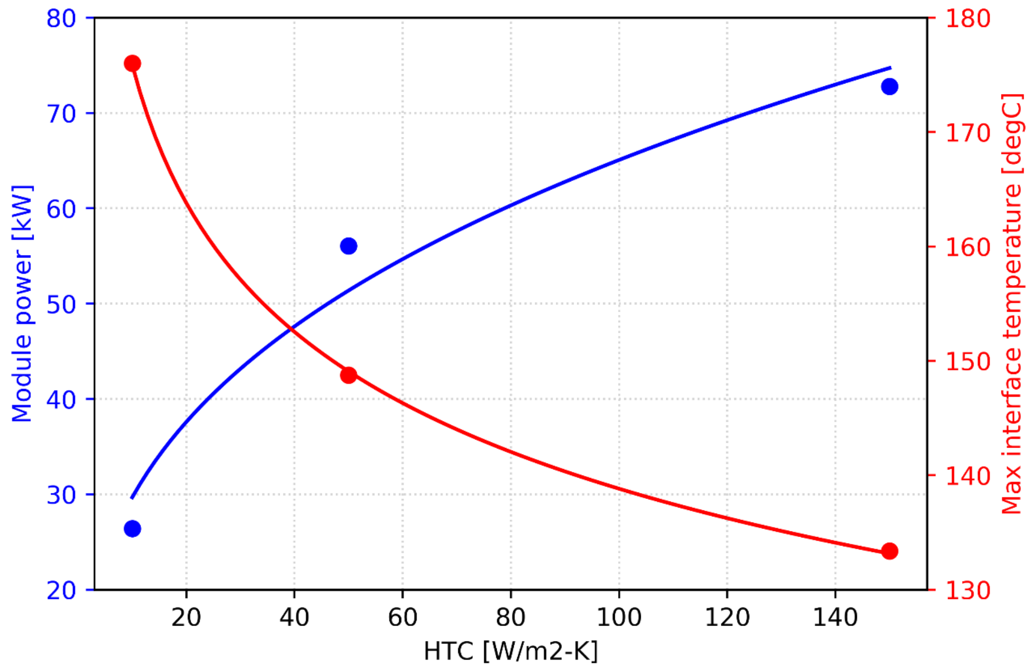
Results of the thermal simulation and influence of module power

- Investigation of different HTCs:
  10 W/m²-K (free convection) **26.4 kW**
  50 W/m²-K (low air flow) **56.1 kW**
  150 W/m²-K (High air flow) **72.8 kW**

- Erhaltene Equations for module power and max. temperature of gappad:

$$P_{Module} = 13.541 \cdot HTC^{0.341}$$

$$T_{Max\_if} = 222.841 \cdot HTC^{-0.103}$$



The air flow has the biggest impact for the max. possible power of the inverter

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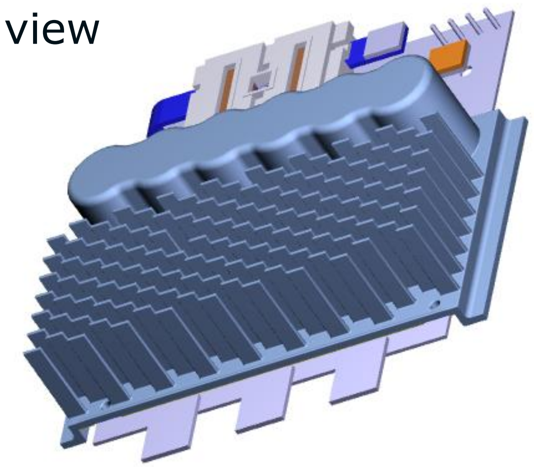
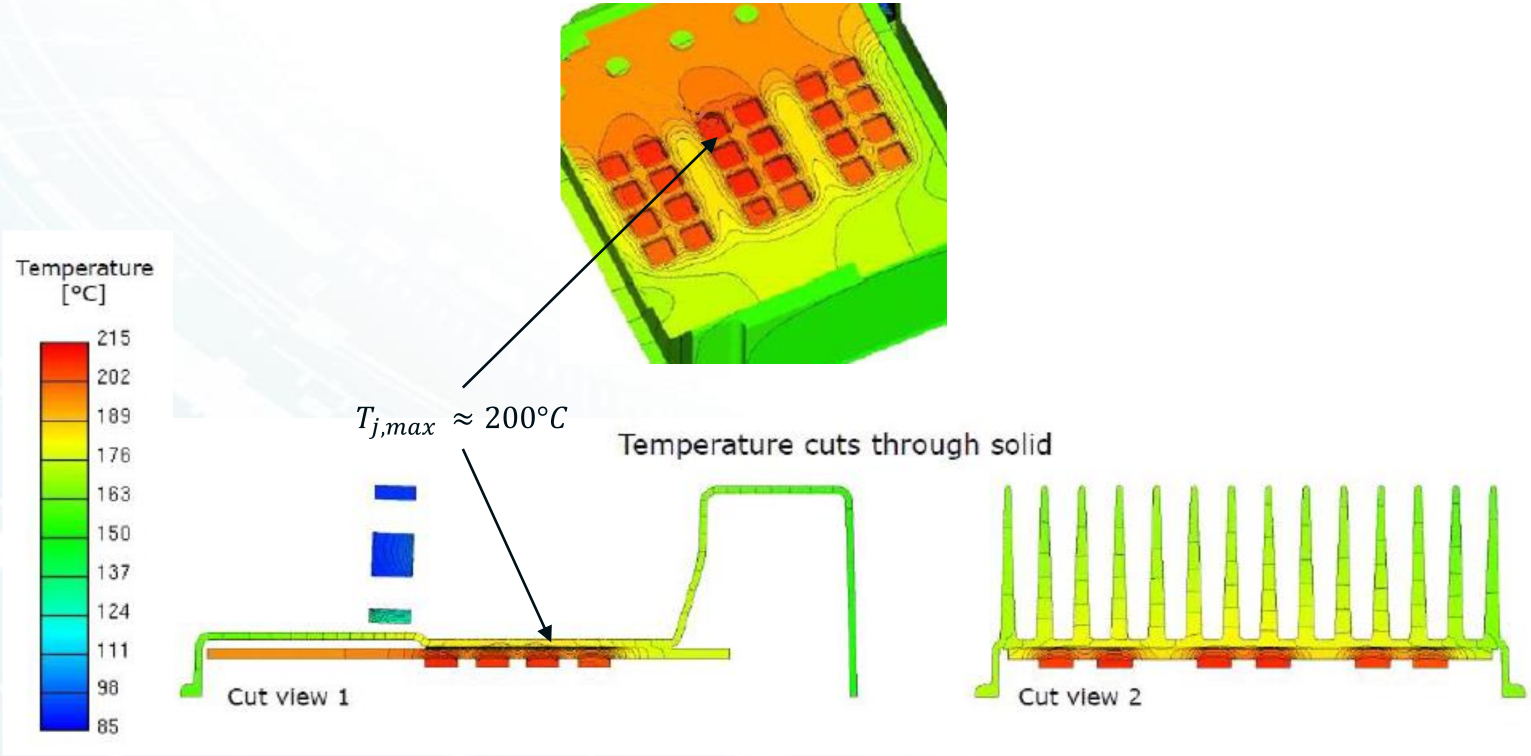
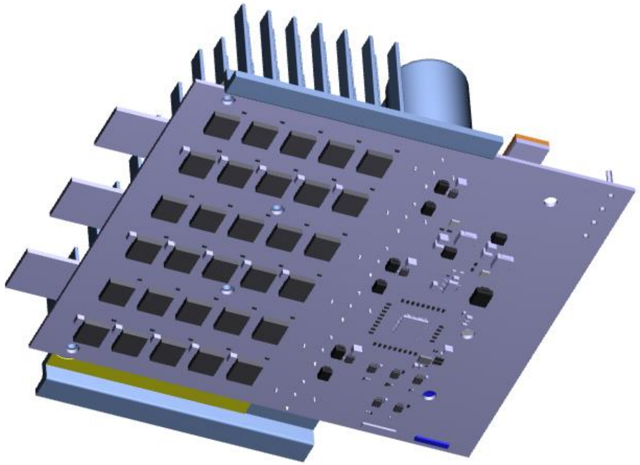
Air cooled Example: 48V Crosscharger

- For the ideal vorticity (turbulent air flow) of the air the housing is designed as "pin fin"
- 4 parallel Mosfets per single switch







Thank You

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