

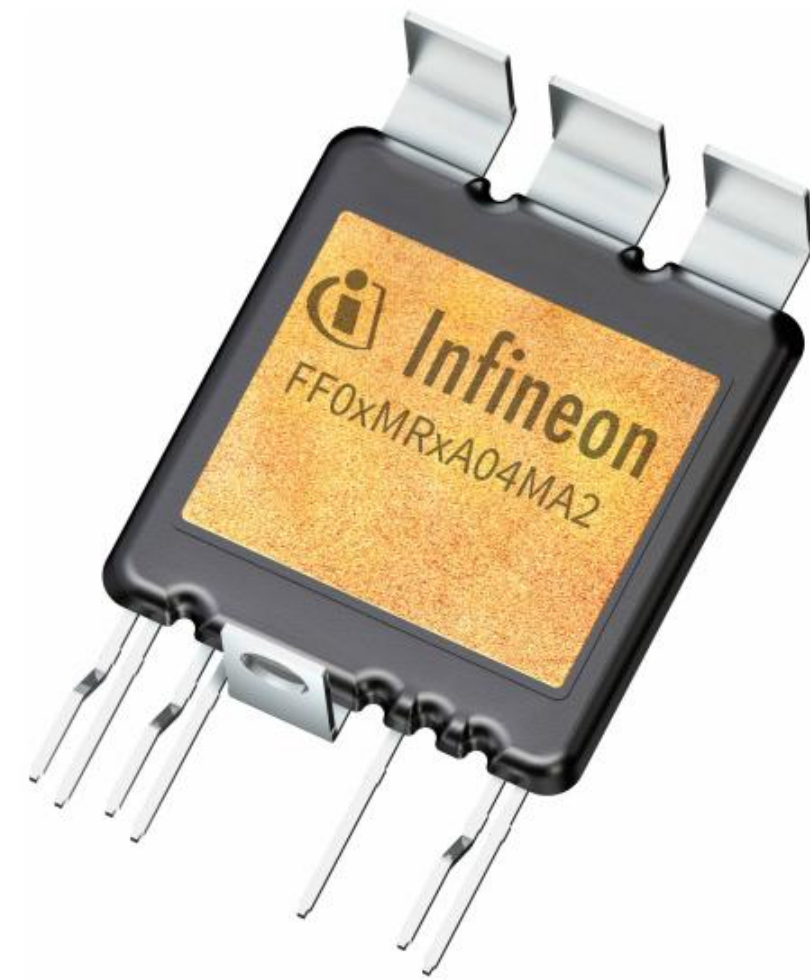
Thermal Characterization and Design Optimization of a Double Sided Cooled SiC Power Module for Automotive High Power Density Inverters

Alex Widhalm¹⁾, Waldemar Jakobi¹⁾ and Christian Muller¹⁾

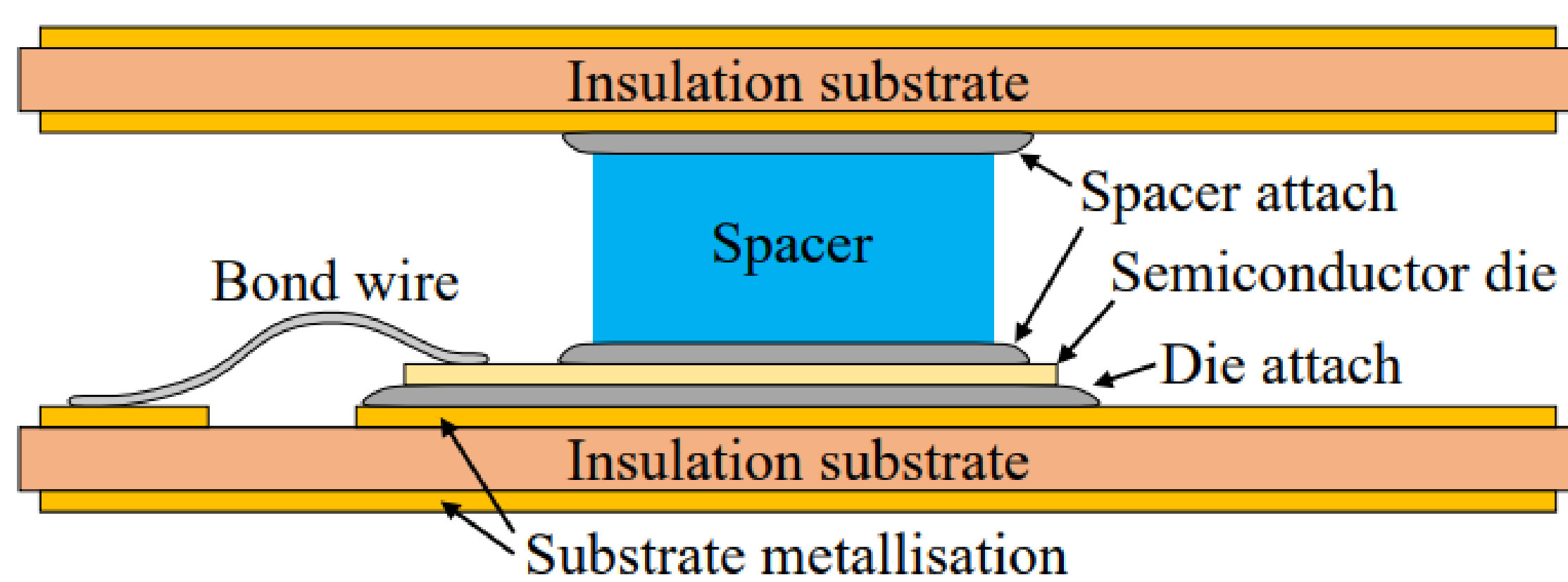
¹⁾Infineon Technologies AG, Germany

Thermal characterisation of DSC power modules

Double Sided Cooled (DSC) power module enables high heat-flux capability and compact inverter design. In DSC packages with spacers: due to additional spacer related thermal resistance, attach layers and reduced chip contact area an heat-flow asymmetry between top and bottom sides of power module expected



→ Package related consequence: top and bottom heat-flows and resulting heat sink temperatures for top and bottom sides can significantly differ. Evaluation of a single heat sink temperature point can bias the extracted junction to heat sink thermal resistance

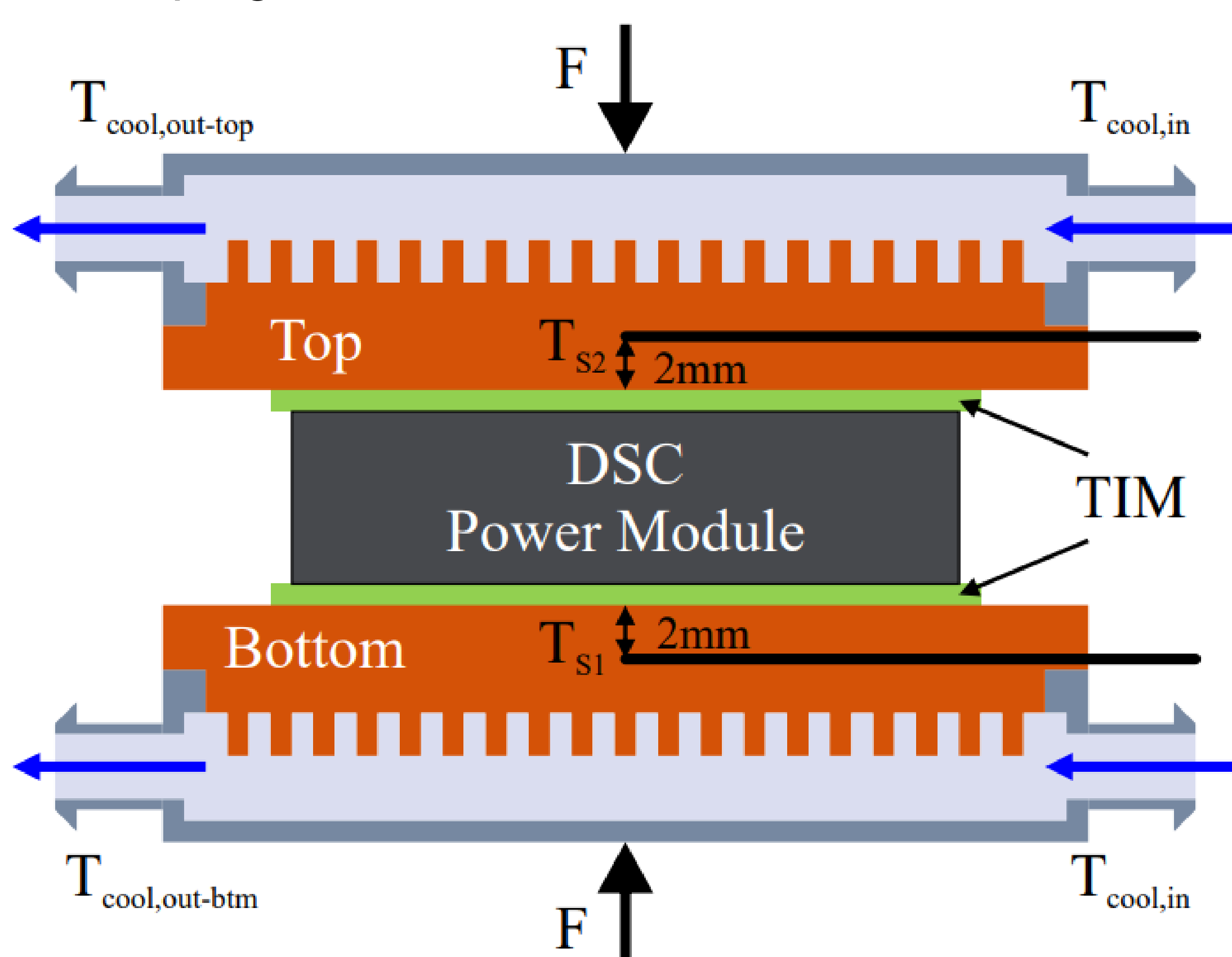


Cross-section of DSC power module housing

AQG324-oriented test arrangement

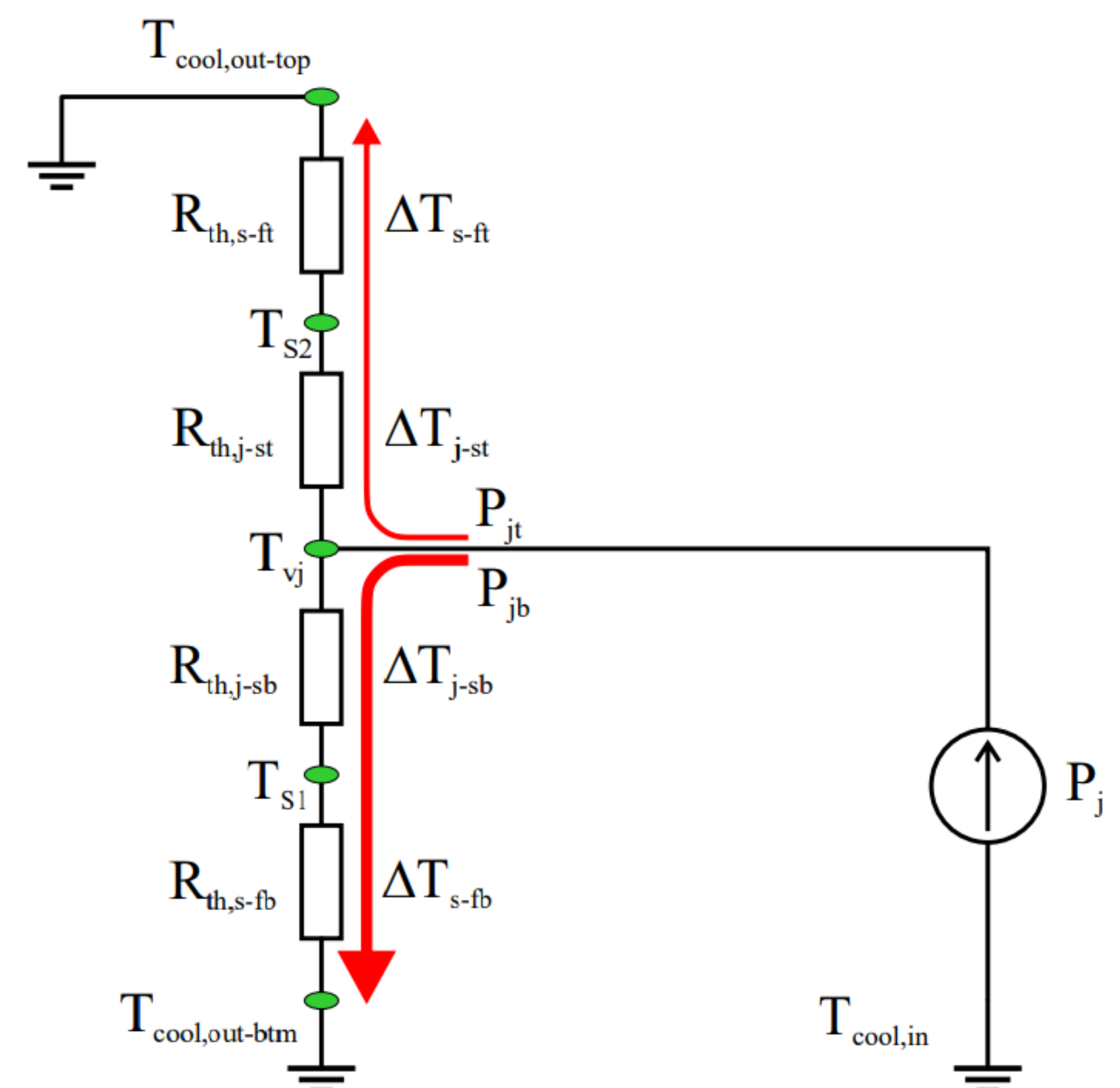
Based on AQG324 guide the cooling/characterisation arrangement is utilized for the R_{th} measurement

- TSEP-based junction-temperature measurement
- Separate top and bottom heat sink thermocouples
- Separate outlet-fluid temperature determination
- Parallel fluid flow cooling arrangement for power module
- 30µm effective TIM thickness
- 800N clamping force F



Measurement overview

Measured quantities based on AQG324 cooling/characterisation arrangement: T_{vj} , T_{S1} , T_{S2} , $T_{cool,in}$, $T_{cool,out-top}$, $T_{cool,out-btm}$



Thermal equivalent circuit for DSC power modules

In case of asymmetric temperature for top-bottom heat paths, different temperatures for top-bottom heat sinks.

$$R_{th,j-s/j-c} = \frac{T_{vj} - \frac{T_{S1} + T_{S2}}{2}}{P_V}$$

Simple arithmetic mean → no good approach (errorous for R_{th} determination).

Due to parallel connection of top and bottom thermal paths:

$$\frac{1}{R_{th,totao}} = \frac{1}{R_{th,top}} + \frac{1}{R_{th,bottom}}$$

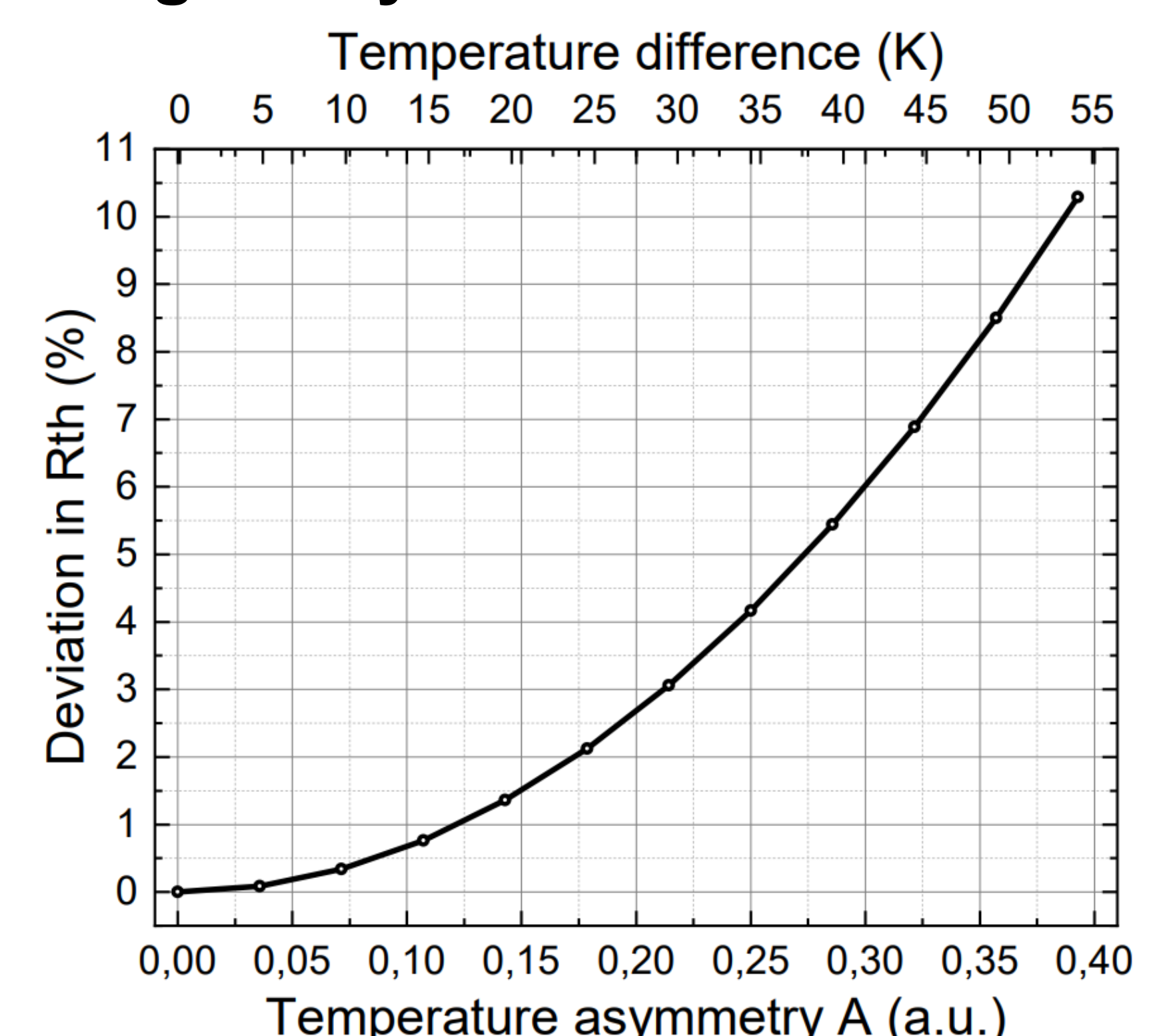
Physically correct approach → **Harmonic mean** $T_{avg} = \frac{n}{\sum \frac{1}{T_i}}$

Arithmetic average: why insufficient?

Deviation for R_{th} shows in percentage range temperature differences between top and bottom thermal paths

Temperature asymmetry:

$$A = \frac{\Delta T_S}{\Delta T_{S1} + \Delta T_{S2}}$$



→ **Arithmetic averaging introduces an error (lower R_{th}) compared to harmonic averaging (physically correct)**

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Thermal shunt-based method

Symmetrically designed cooler provides equal heat sink to fluid thermal restances for both thermal paths.

Thermal shunt technique: unknown thermal flux P_j can be determined using the temperature ΔT and known thermal resistance R_{th} . Analogous approach compared to the electrical shunt method: electrical current is determined based on the voltage drop across a known resistor.

$$P_j = \frac{\Delta T_{s-f}}{R_{th,s-f}}$$

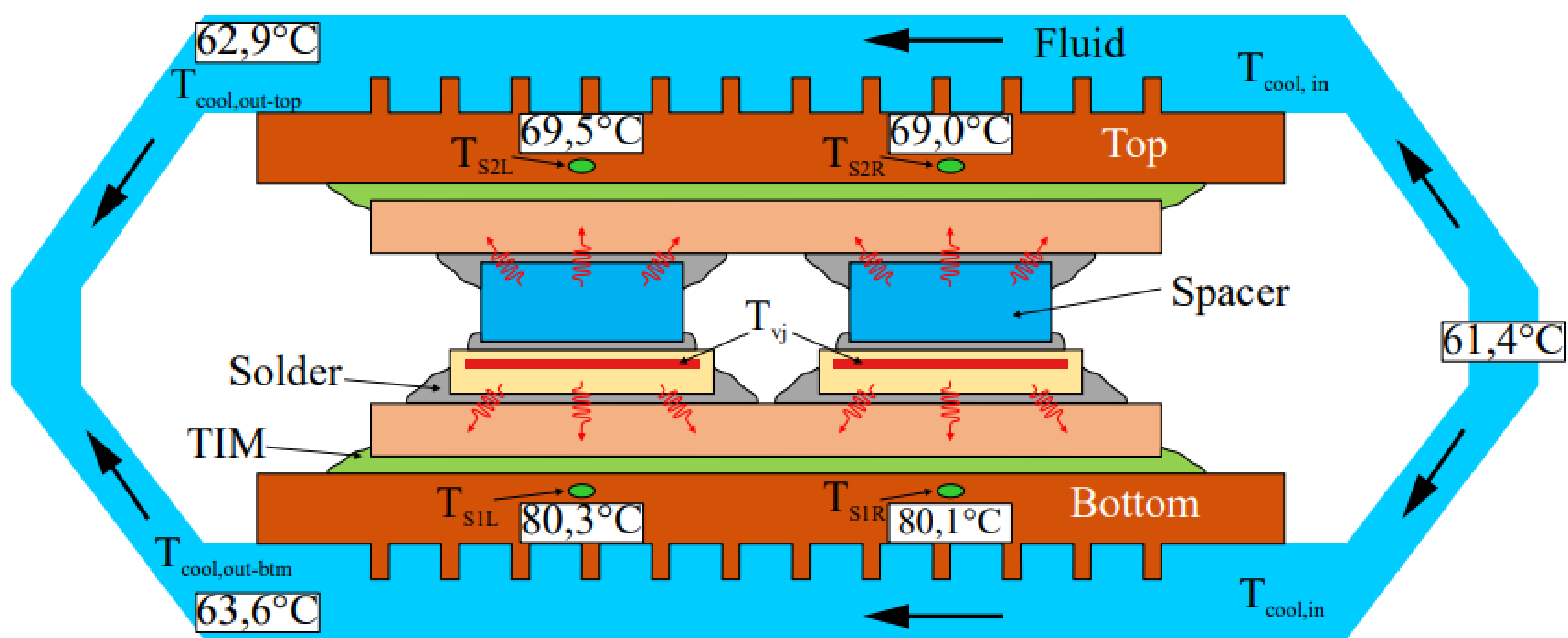
Determination of the separate power module's R_{th} contributions (top/bottom) using following assumptions:

- Thermal heat flux conservation is fulfilled: $P_j = P_{jt} + P_{jb}$
- Measurement configuration allows for separate measurement of temperatures: $T_{cool,in}$, $T_{cool,out-top}$, $T_{cool,out-btm}$ and heat sink temperatures T_{S1} and T_{S2}
- Measurement configuration is completely symmetrical: $R_{th,s-ft} = R_{th,s-fb}$

→ Physically consistent separation of the two package thermal paths under asymmetric temperatures.

Results for FF06MR12A04MA2

Measured quantities based on AQG324 cooling/charaterisation arrangement:



Power module operation conditions:

- Virtual junction $T_{vj} = 175\text{ °C}$, coolant temperature $T_{cool,in} = 60\text{ °C}$
- Fluid flow rate $\Delta V/\Delta t = 10\text{ lpm}$, clamping force $F = 800\text{ N}$

Results overview:

Parameter	Value	Level
$R_{th,j-st}$	1.543 K/W	single die
$R_{th,j-sb}$	0.549 K/W	single die
$R_{th,j-st}/R_{th,j-sb}$	2.81	single die
$R_{th,s-ft}$	0.102 K/W	single die
$R_{th,s-fb}$	0.103 K/W	single die
$R_{th,j-s}$	0.203 K/W	module level
$R_{th,j-f}$	0.233 K/W	module level

- 65% of the generated heat flux is guided through the lower-resistance bottom path
- Higher top path resistance caused by spacer, additional solder layers and reduced contact area

→ Double sided cooling is not thermally symmetric by default. Characterization and optimization must treat both paths separately

Optimization potential for power module

Based on the power module characterisation results:

- Spacer optimization: reduced spacer thickness can improve the top thermal stack but has impact on manufacturability and costs
- Ceramic optimization: Due to increased thermal resistance of the top thermal path, lower heat flow is given. Top ceramic contributes less to the overall module resistance

→ Replacing the upper AlN ceramics with adjusted Al_2O_3 increases the overall module R_{th} by only about 5% based on the paper's first-order estimate.

→ Good cost-performance ratio can be found

Conclusion

- Thermal shunt-based approach separates top and bottom heat flows experimentally
- Investigated DSC power module shows pronounced spacer-driven heat flow asymmetry
- Top thermal path is ~2.8 times more resistive than the bottom thermal path
- Presented approach supports physically consistent characterization and targeted package/cooling optimization

Main Takeaway

→ Measure the heat-flow split first. Then optimize each thermal path accordingly to its real contribution to the module performance and costs.