COOLING:
COLD PLATE

Cooling the 448G Frontier: Thermal Architecture for 500 W-Class HSIO Using Direct-to-Chip Liquid Cooling

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OCP SILVER Member

Agenda

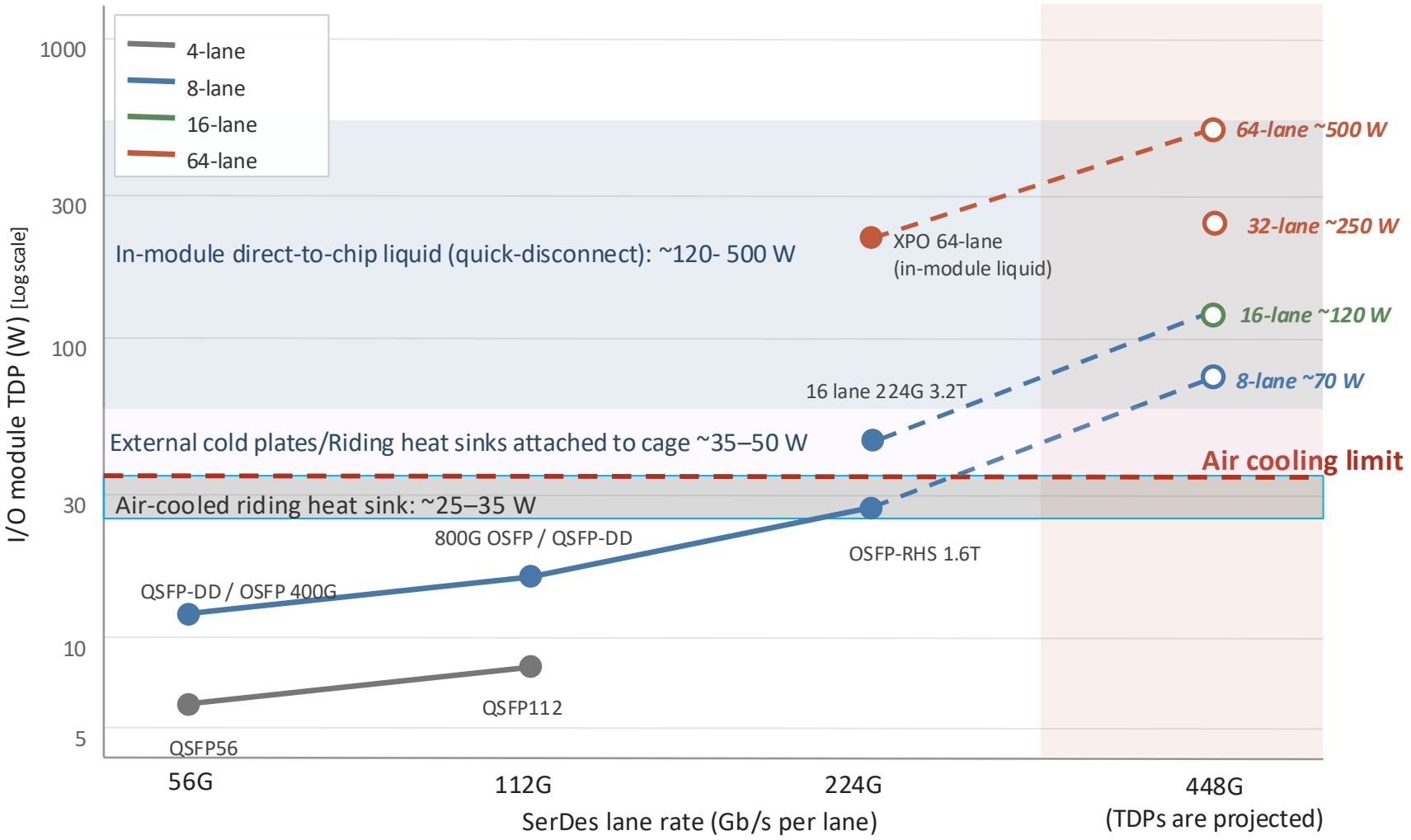
01 **Introduction**
Pluggable I/O module: Thermal Design Power trends

02 **System Architecture**
Direct-to-chip vs. External cold plates

03 **Direct to Chip**
Cold plate designs for 448G IOs

04 **Future Work**
Next steps and call to action

Introduction: Pluggable I/O Thermal Evolution



IN-MARKET TRENDS

- 4-lane: QSFP56 → QSFP112
- 8-lane: OSFP 400G → 1.6T RHS
- 64-lane: XPO for 224G (in-module liquid)

Liquid Cooling beyond > 35w

- Cage cold plate with thermal bridge (dry TIM)→ ~50 W.
- Liquid cooling→ 35-500 W.

Why do I/O Modules need liquid cooling?

Power per lane

Increased 5x for 56G→448G
(1.5 → 7.5 W)

Air- Cooling limitations

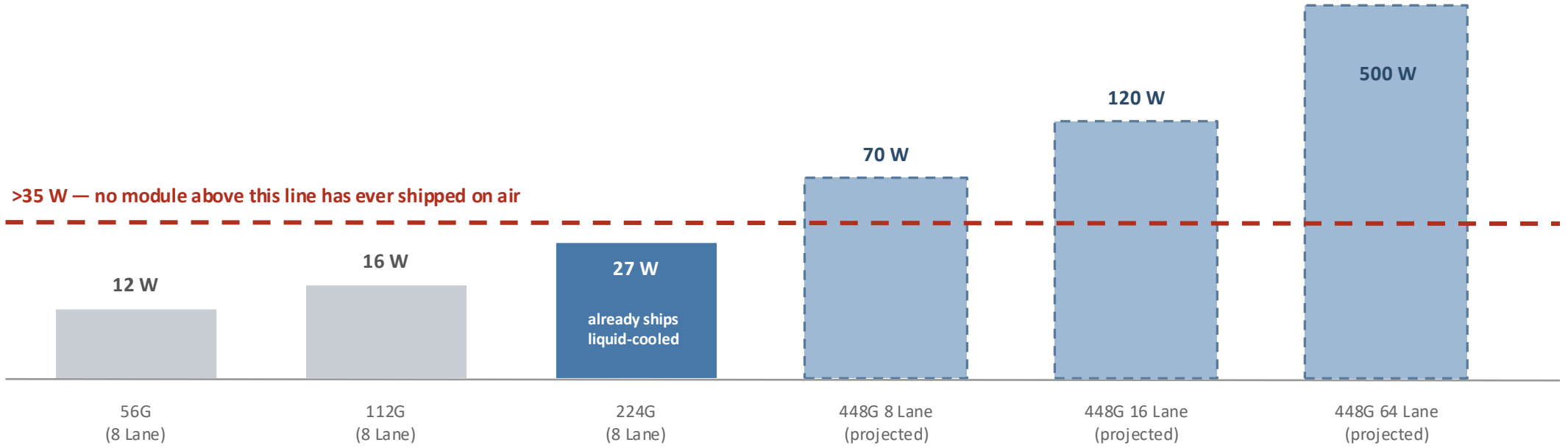
Highest air-cooled module
In market is ~35W

Heat Flux

100+ W/cm² for DSP chips
(> most CPUs)

19" Standard racks

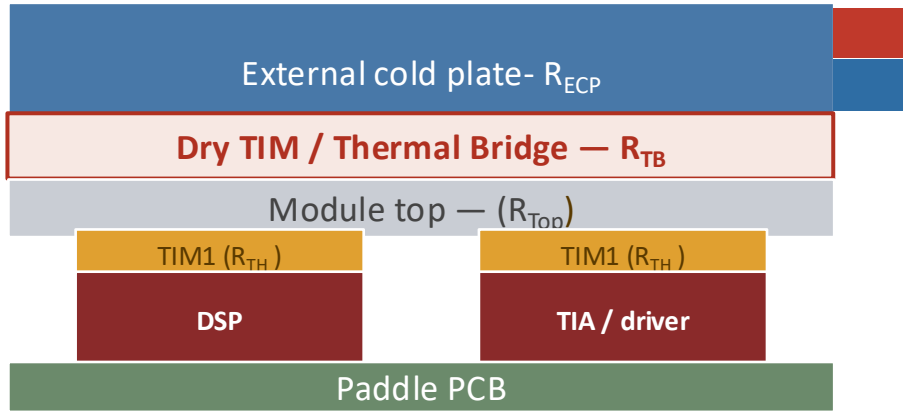
Same rack, same 32 ports for 1RU
0.4 kW @ 56G → 0.9 kW @224G → 1.9 kW per RU for faceplate



Physics of air cooling met its limitation for beyond 1.6T, 224G Modules

Why Direct-to-Chip is the Path for Future I/O

EXTERNAL — COLD PLATE IN CONNECTOR CAGE

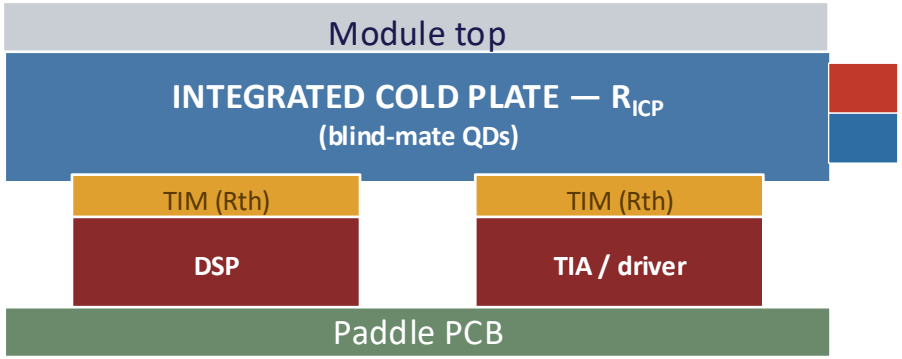


$$\Sigma R = R_{TH} + R_{Top} + R_{TB} + R_{ECP}$$

MOVE THE WATER INSIDE MODULE:

→

DIRECT-TO-CHIP : IN-MODULE



$$\Sigma R = R_{Th} + R_{ICP}$$

Every layer between the die and coolant adds to thermal resistance stack up

Four layers in the stack vs. **Two** → Fewer components, lower ΣR.

External Cold Plate vs In-Module Direct-to-Chip at 448G

EXTERNAL — CAGE COLD PLATE

- ✓ No leakage risks
- ✓ Widely adopted, lower risk of infant failure rate
- ✓ Aids dry hot-swap for pluggable IO
- ✗ Current dry TIMs have high thermal resistances
- ✗ Some dry TIMs age every insertion cycle (max mating 10 cycles).
- ✗ Dry TIM requires very high compressive forces
- ✗ Proven compression hardware to support TIM compression
- ✗ Challenging to cool high-density modules

vs

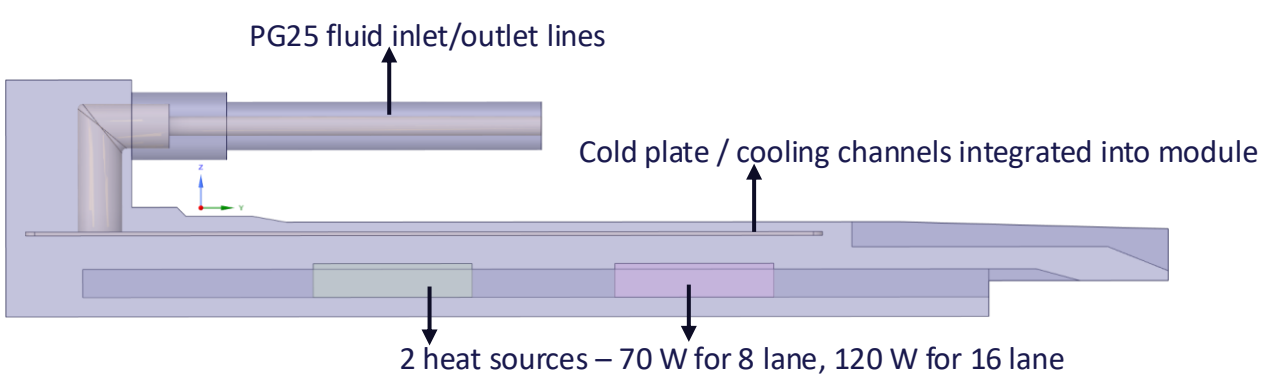
IN-MODULE — DIRECT-TO-CHIP

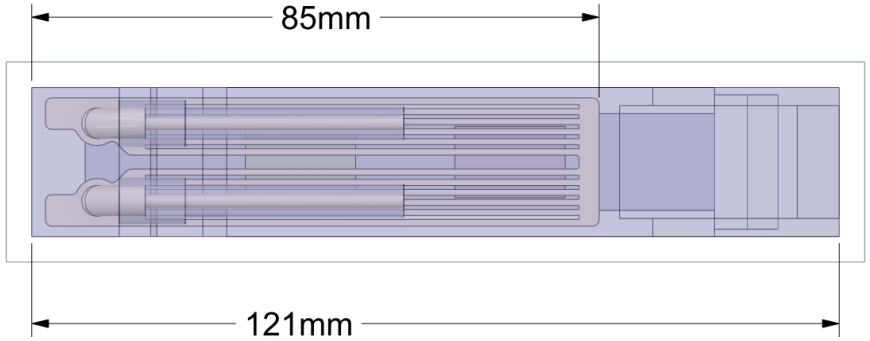
- ✓ Ability to cool with margins at 500W
- ✓ Better thermal performance = higher reliability for module components
- ✓ Can meet 100 insertion cycles
- ✗ Ecosystem is immature, higher chance of infant mortality rate.
- ✗ Leakage risks, interop challenges between QD vendors.
- ✗ High pressure drops with mini QDs.

448G: DTC Cold Plate Designs

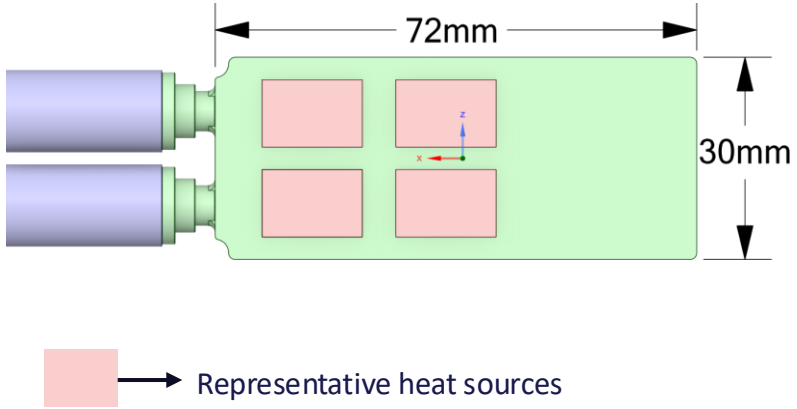
Two cold plate concepts evaluated for thermal and pressure drop performance across 8, 16, 32 and 64 lanes

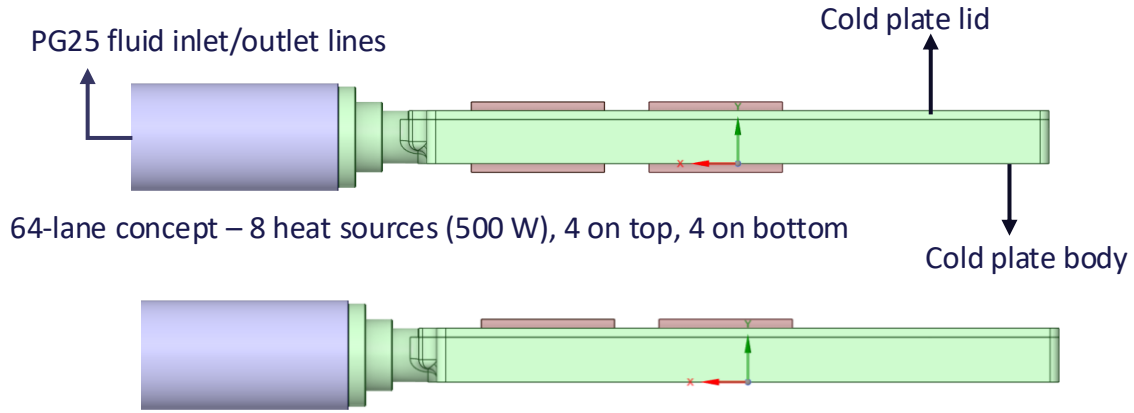
8 & 16 LANES — INTEGRATED COLD PLATE MODULE · 70 / 120 W





32 & 64 LANES — 5 MM MICROCHANNEL COLD PLATE · 250 / 500 W





448G: DTC Cold Plate Design - Assumptions

Two cold plate concepts evaluated for thermal and pressure drop performance across 8, 16, 32 and 64 lanes

POWER PER CONCEPT — DISTRIBUTED EQUALLY ACROSS HEAT SOURCES

x8	x16	x32	x64
70 W	**120 W**	**250 W**	**500 W**
2 heat sources	2 heat sources	4 heat sources	8 sources – 4 top, 4 bottom

MODEL ASSUMPTIONS — THERMAL, FLOW & BOUNDARIES

TIM RESISTANCE
0.05 °C/W – worst case for PTM-type material

INLET TEMPERATURE
System and fluid inlet at 45 °C

FLOW RATES
1.5 lpm per KW –

1. 0.1/ 0.2 / 0.3 lpm for x8 & x16
2. 0.4/ 0.7 / 0.9 lpm for x32 & x64

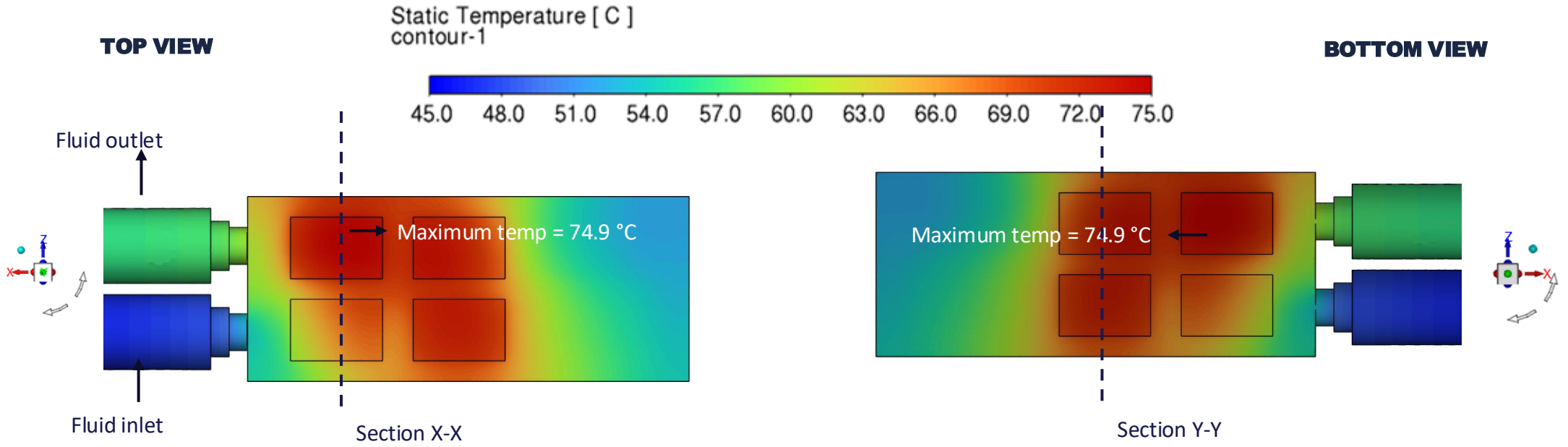
MATERIAL & FLUID
Copper cold plate and lid, PG 25 coolant

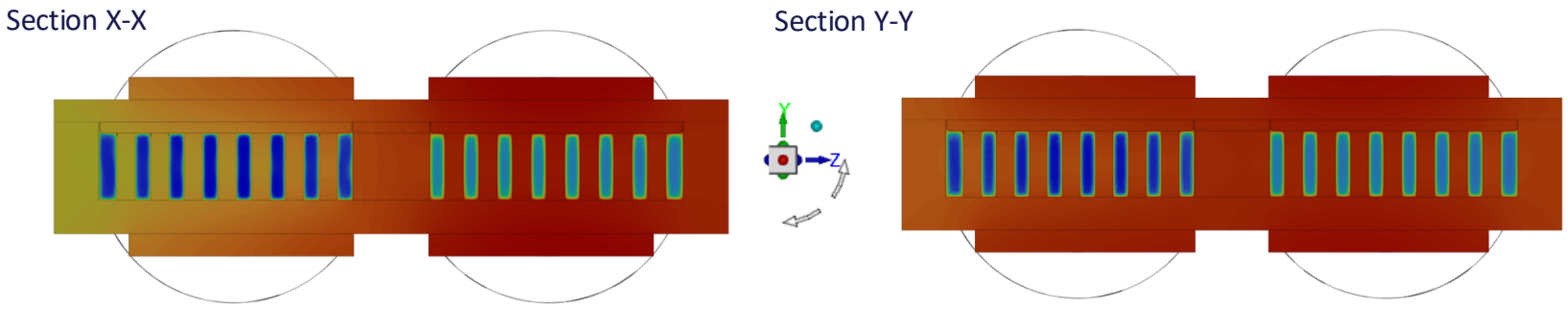
HEAT TRANSFER
All chip heat removed entirely by the coolant

BOUNDARY
All walls adiabatic – no heat loss to surroundings

448G: DTC Cold Plate Simulation Results

64-lane concept at 500 W and 0.7 lpm — steady-state temperature distribution





Section through Sources 1,4,5,8

Section through Sources 2,3,6,7

MAX CHIP TEMP

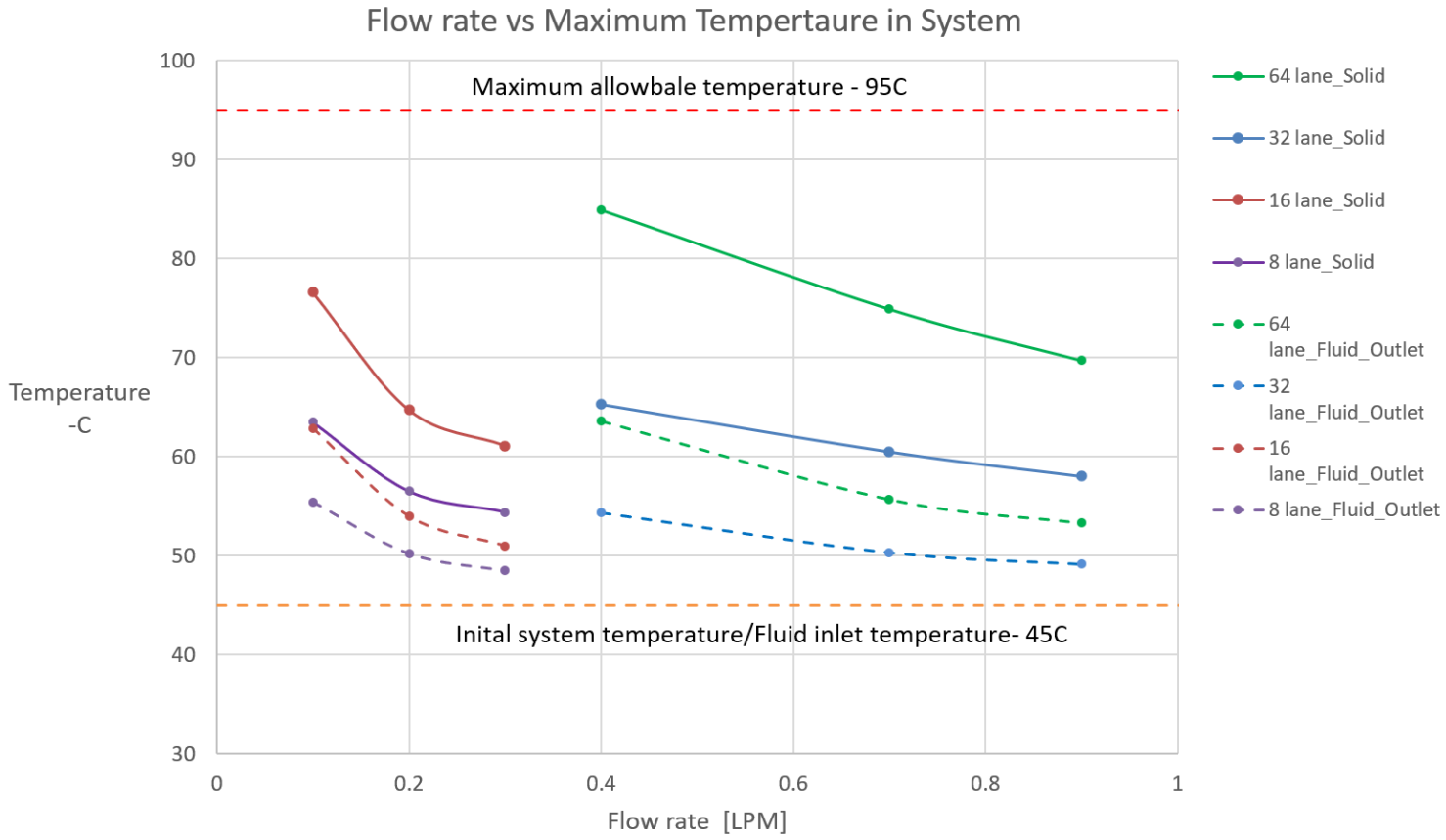
74.9 °C

Target < 95 °C • fluid 45 → 55 °C

448G: DTC Cold Plate Simulation Results

All cold plate scenarios evaluated for thermal and pressure drop performance

THERMAL PERFORMANCE — ALL SCENARIOS MEET THE TARGET



MAX CHIP TEMP

< 85 °C

across every scenario evaluated

ALLOWABLE LIMIT

95 °C

dashed line on chart

INLET TEMPERATURE

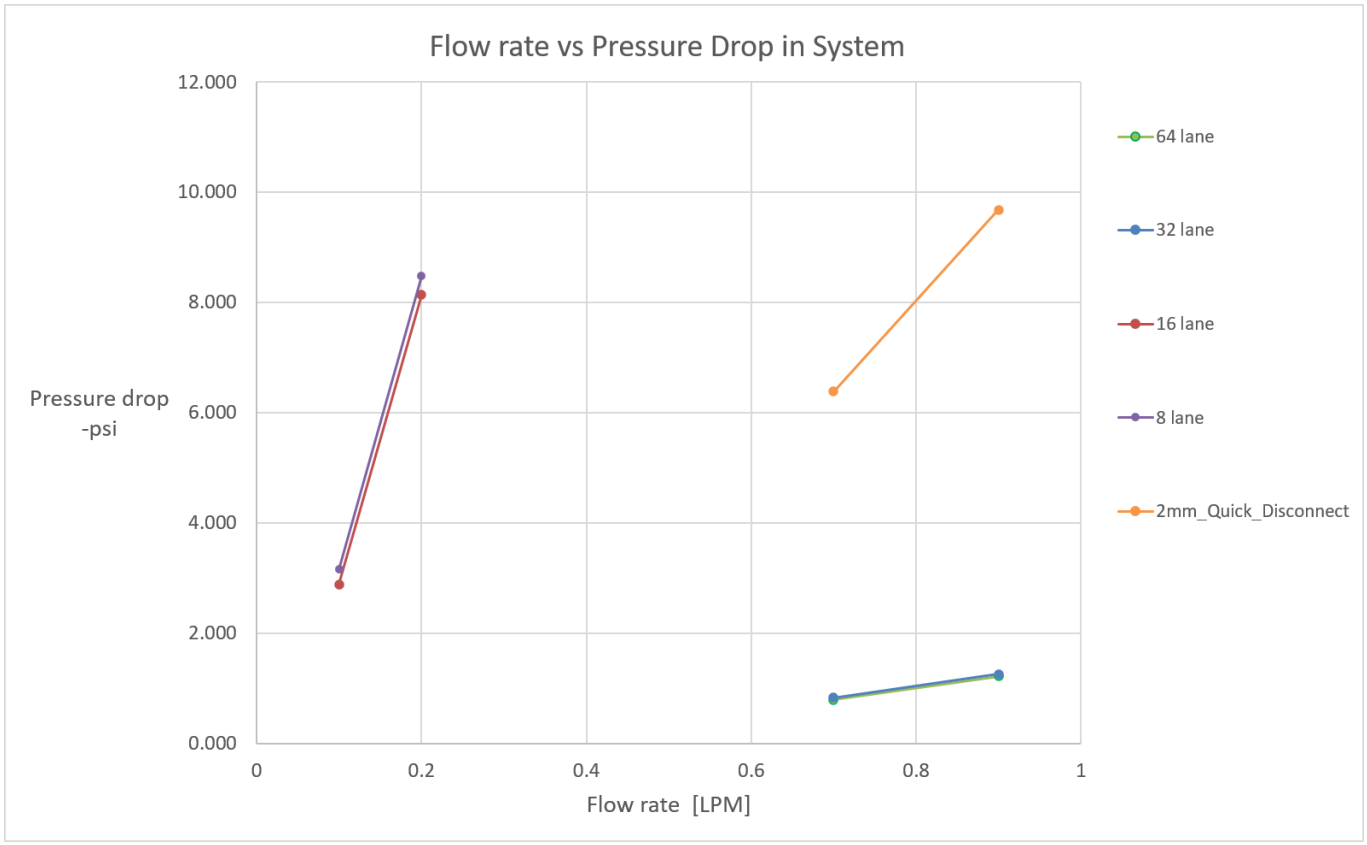
45 °C

system and fluid at start

448G: DTC Cold Plate Simulation Results

All cold plate scenarios evaluated for thermal and pressure drop performance

PRESSURE DROP PERFORMANCE ACROSS FLOW RATES



x32 / x64 COLD PLATE

< 2 psi

at 0.7 – 0.9 lpm

x8 / x16 COLD PLATE

< 9 psi

at 0.1 – 0.2 lpm

MINI QUICK DISCONNECTS

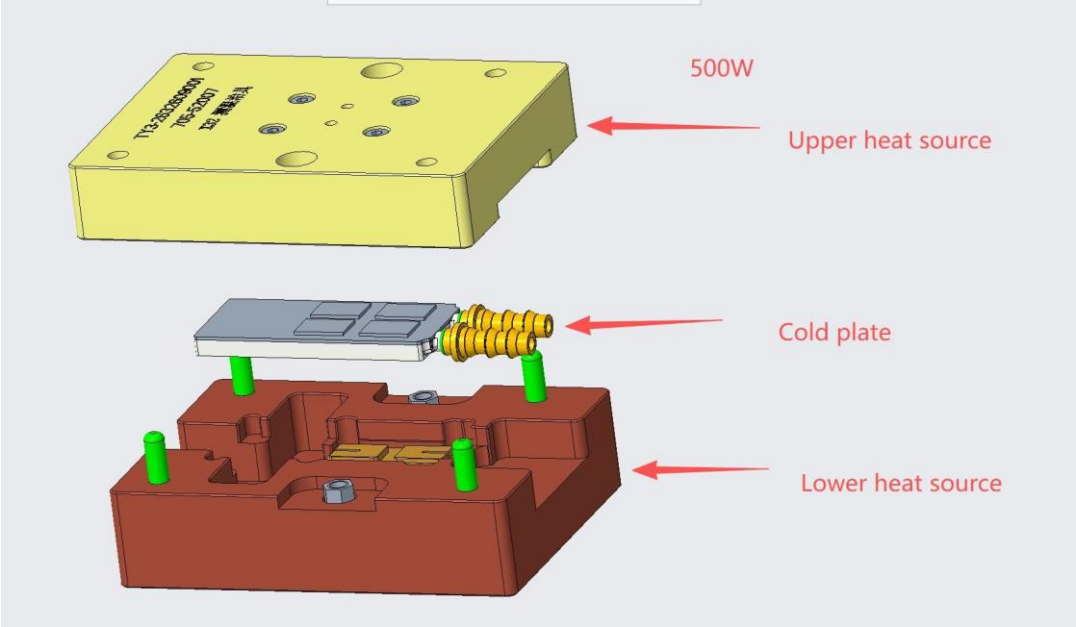
6 – 10 psi

added drop at 0.7 – 0.9 lpm

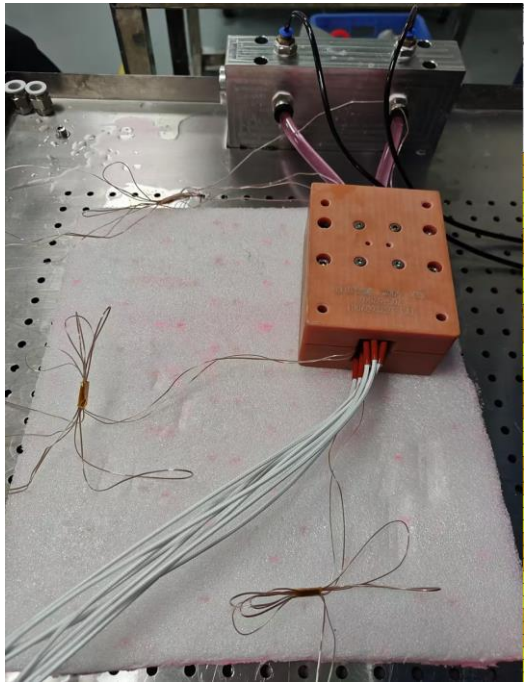
448G: DTC Cold Plate Measured Data

Bench measurements for 500 W and 250 W scenarios validate the simulation model

TEST set up



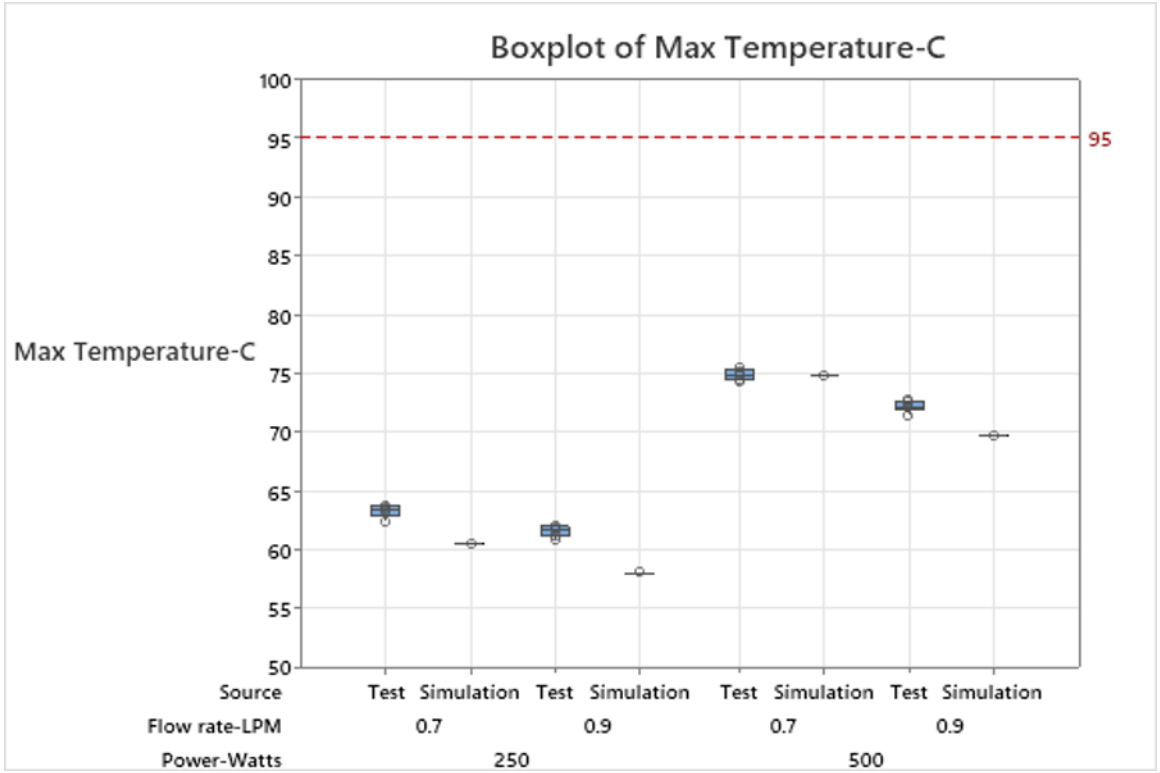




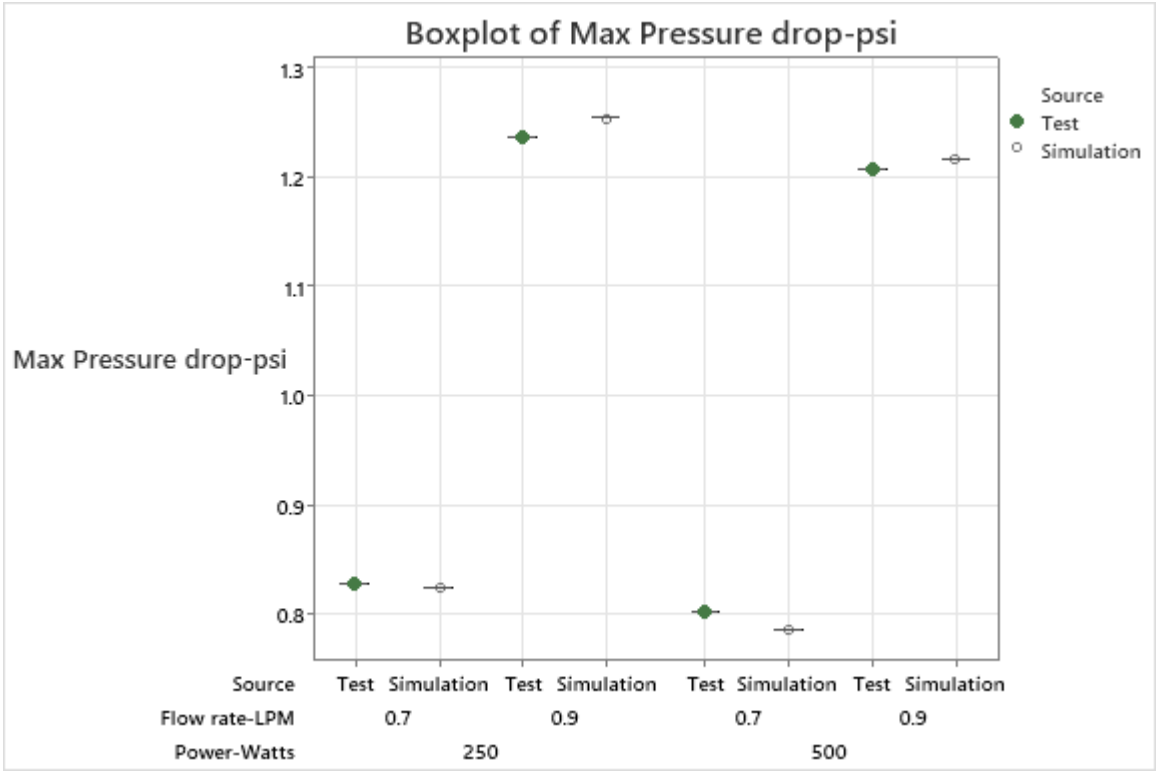
448G: DTC Cold Plate Measured Data

Bench measurements for 500 W and 250 W scenarios validate the simulation model

MEASURED DATA — RESULTS TRACK SIMULATION EXPECTATIONS



MAX CHIP TEMPERATURE — TEST vs SIMULATION



MAX PRESSURE DROP — TEST vs SIMULATION

Call to Action

- Problem to solve:
  - For direct-to-chip, analyze the impact of pressure drop across multiple cold plates.
  - Reliability testing at system level for to meet lifetime warranty.
  - Standardizing the cold plates for pluggable modules and present updates in OCP Cold plate workstream.
- External cold plate:
  - Continue exploring TIMs that require lesser insertion forces, improved durability against shear forces (100 mating cycles) and lower thermal resistance.
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  - sridhar.mukthineni@te.com

Open Discussion

