Load board Cooling Technology to Support Higher Currents on ATE Boards

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Advantest Interconnect Solutions

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- Leading supplier of DUT Board Consumables [Interface Boards, Sockets, Thermal Hardware]
- Largest design engineering and SIPI capacity spanning more than 200+ engineers worldwide
- Largest in-house manufacturing capacity with two FABs (New Jersey, US and Taiwan)
- Most advanced inhouse socket and thermal solution manufacturing (Industry 4.0) in Arizona US

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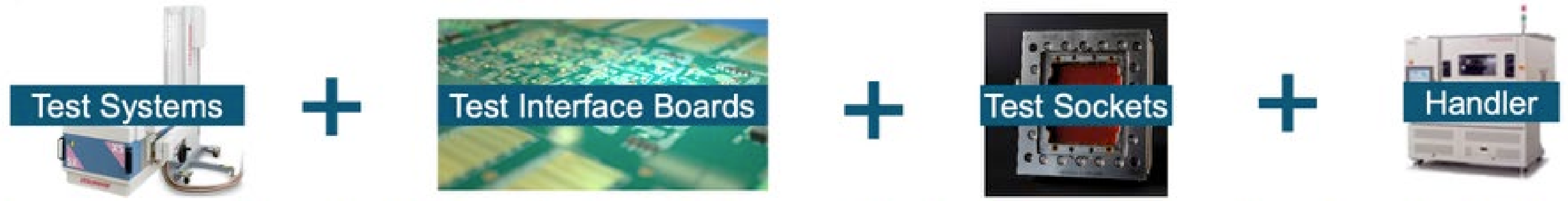

High-quality end-to-end solutions that are indispensable for future high-end semiconductor test

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Agenda

- ATE power requirements rising through the years
- Thermal / Joule's heating and its effect on power delivery
- 6.5kW load board design and study
- Designing for thermal dissipation
- Electrical and thermal results for 6.5kW test vehicle
- Bonus: Impact of using IVRs on packages
- DUT board cooling, setup, thermal simulations
- MLO cooling strategies
- Summary and conclusion
- Acknowledgements

Semiconductor Test Power Requirements

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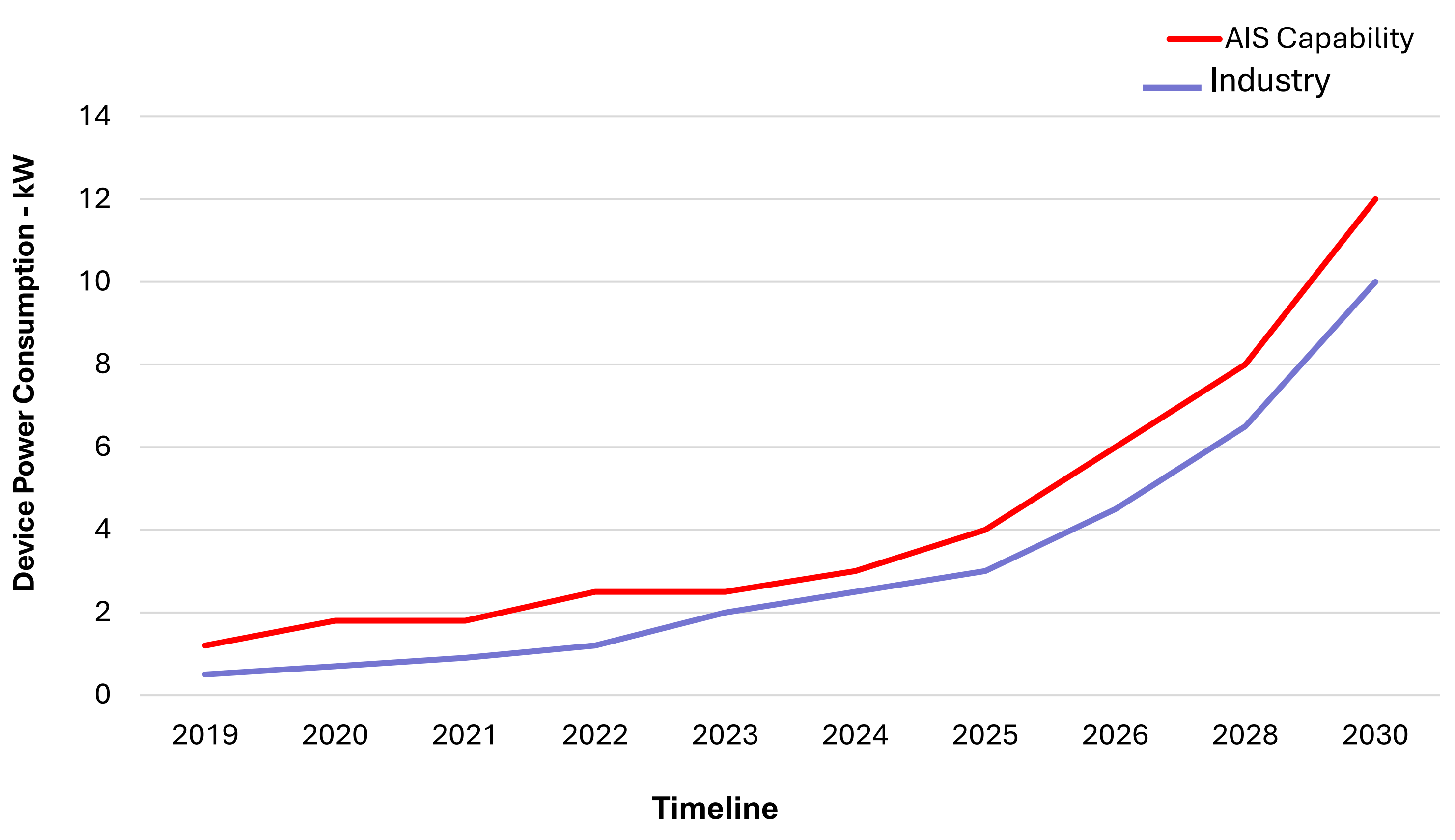
Industry has seen constant rise in power requirement

AIS roadmap is to support a > 5kW device by 2026

- This is a significant power/thermal concern
- Engineering studies and experiments are underway
- Different cooling strategies including liquid cooling, thermal cooling extensions from test systems are being considered

Power Consumption

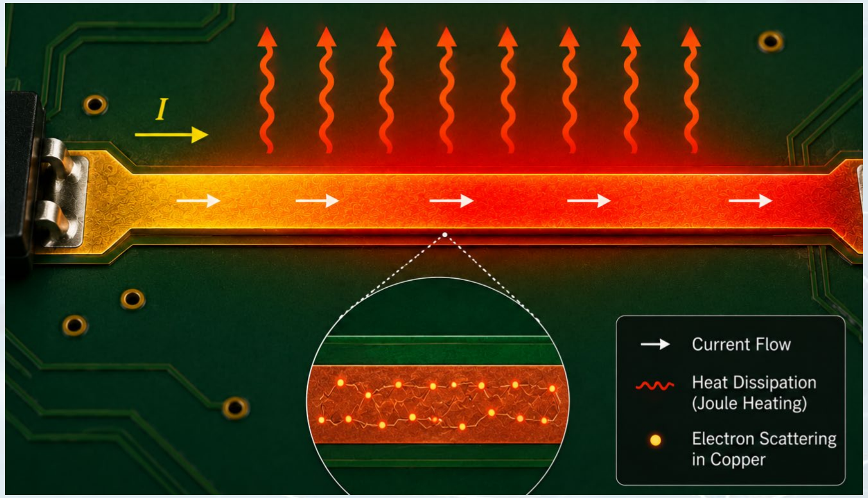


Co PI/Thermal simulations will become key enabler for high power designs!

Joules Heating Through Circuits

Electric current dissipates energy when it meets with resistance as it passes through metal structures as per the power dissipation equation

$$P = I^2 R$$



*Graphics source: GPT

Thermal Equilibrium

Is reached when:

The rate of heat generated = Rate of heat removed

Copper Conductivity

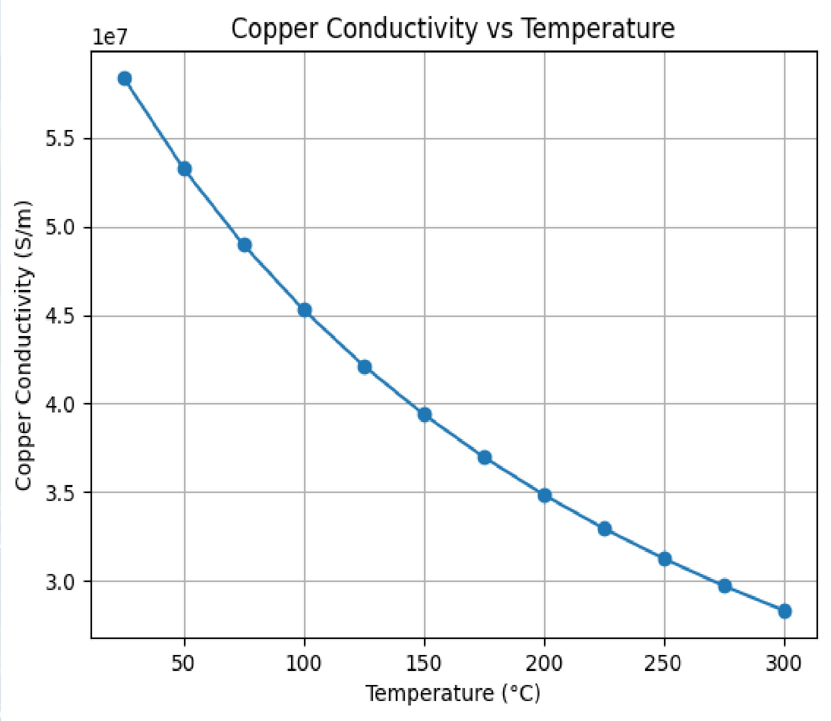
Copper conductivity decreases as the temperature rise

- Electrical current when met with resistive board structures, planes, vias, pin fields etc. results in a drop in voltage commonly referred as “IR-Drop” or “Voltage Drop”

- The higher the IR-Drop, the more power is dissipated

- IR-Drop is typically lowered by increasing metal area for the current to flow – This is limited by board stack-up!

- IR-Drops are typically compensated by sense lines in ATE test systems. However, at high current applications with a lot of heat dissipation, IR drop increase with temperature – voltage compensation sends the board hardware to a thermal loop of increasing temperature causing the equilibrium condition difficult to reach!



IR Drop compensation by test systems should also be limited as compensating voltage eats into the head room of power amplifier !!

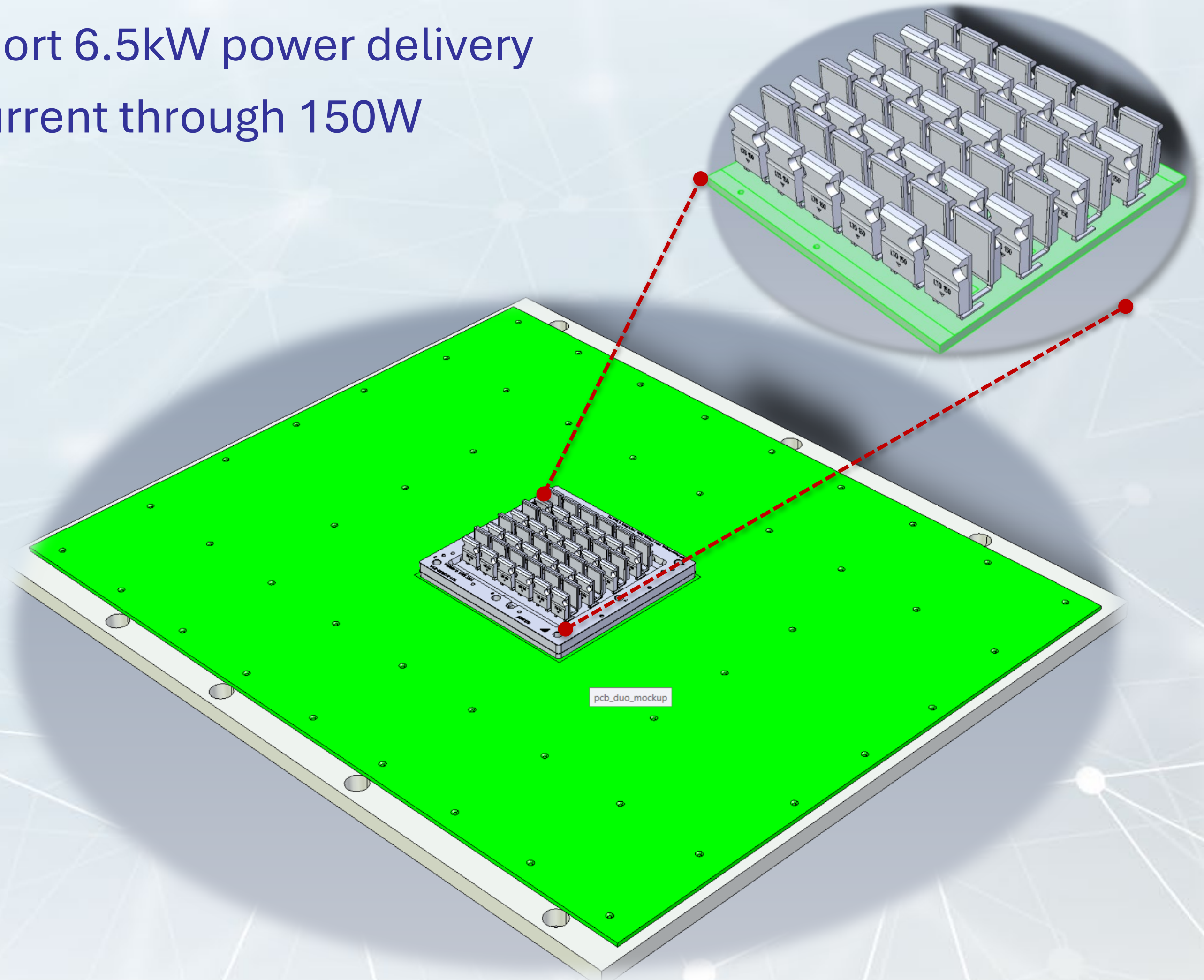
6.5kW Load board Study

Setup

Load board and a surrogate board designs to support 6.5kW power delivery

- Thermal test vehicle board sinks continuous current through 150W ceramic resistors
- V93000 load board, 0.400” thick, 90 Layers
- Optimized design and package ball-map

#	Supplies	Voltage (V)	Current (A)
1	V1	0.8	700
2	V2	0.8	700
3	V3	1.2	312
4	V4	1.2	312
5	V5	1.2	312
6	V6	1.2	312
7	V7	1	460
8	V8	1	480
9	V9	1.2	460
10	V10	1.2	480
11	V11	1.2	346
12	V12	1.2	346
13	V13	1.5	346
14	V14	1.5	346



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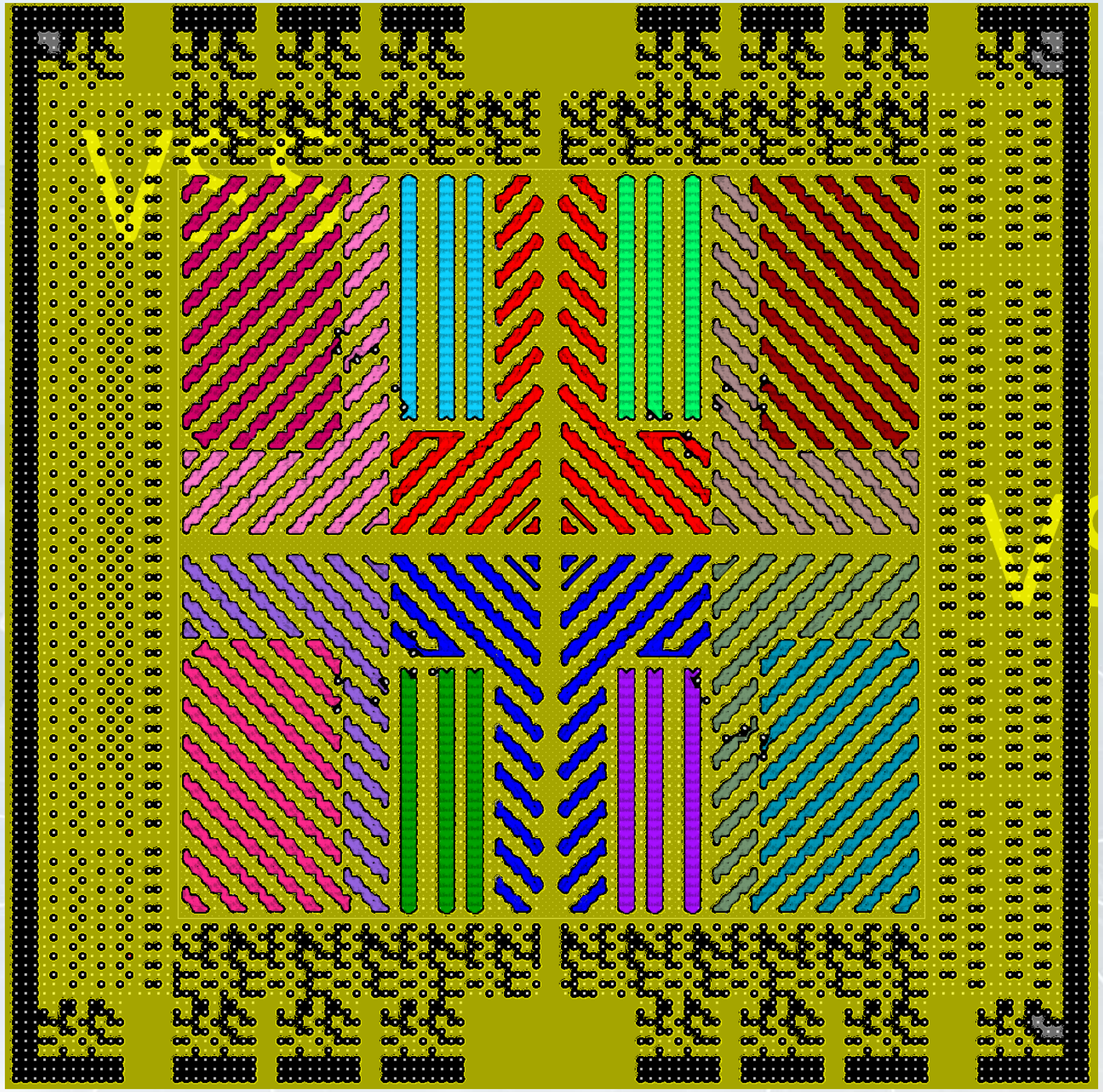
Package Design Considerations

Package designs can have a profound impact power dissipation

- A proper package design can mitigate a lot of power delivery issues
- Good channel design for current to flow into the power core
- Number of power pins to current ratio
- Signal / Power region bifurcation improves ATE board layout



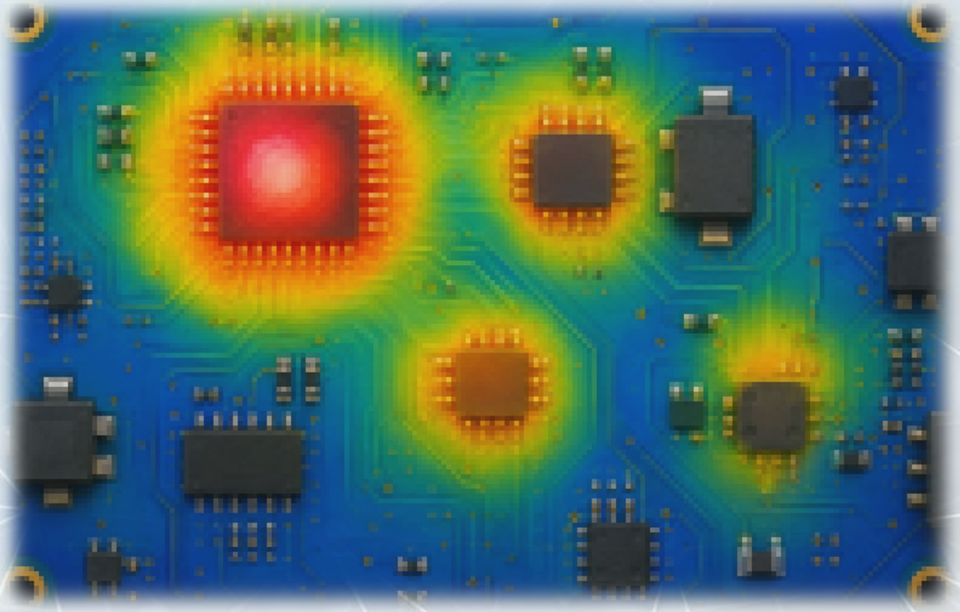
Design For Thermals!

Extraction of dissipated power is critical!

- ATE industry has long used “Design for Manufacturing”, “Assembly” and “Test” rules for ATE hardware
- “Design for Thermal” dissipation is going to be required for high power designs for future power designs

What does that mean?

- As more electrical current passes through resistive board copper structures (vias, planes, traces etc.), more heat is generated
- ATE designs needs optimization to ensure the heat is extracted from the board, proper heat dissipation structures are present to remove the heat from the board on potential outer layers or cooling structures designed to dissipate energy



*Graphics source: GPT

- Efficient design to support thermal ensures better power delivery on ATE boards

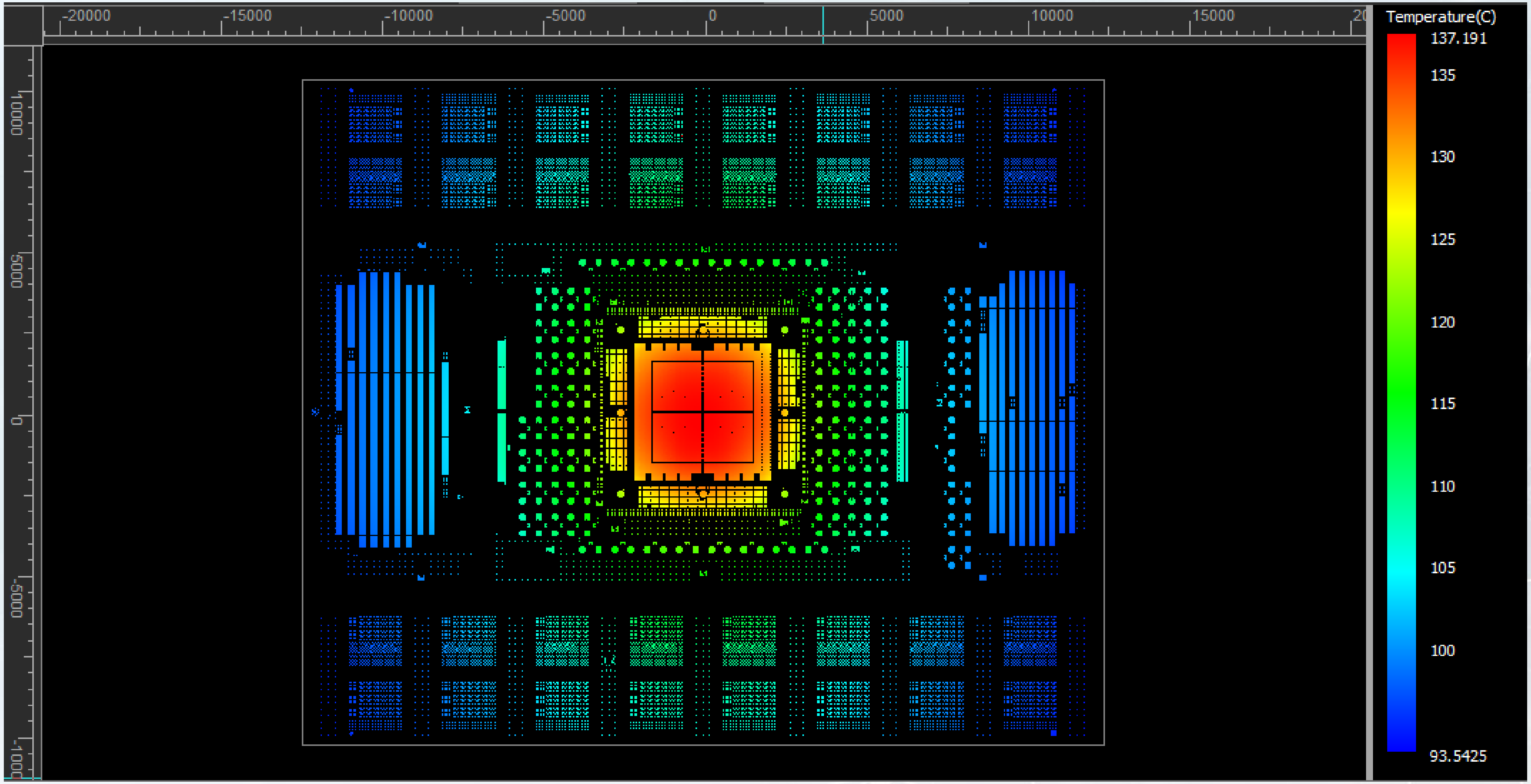
6.5kW Board Design and Simulated IR-Drop

- DUT Board and test vehicle (DUT simulator) pin-outs are optimized for high power delivery
- Design has been optimized to extract dissipated powers to thermal pads
- Multiple thermal and current/power monitoring circuits on place to verify heat map / hot spots
- Total simulated dissipated energy due to power drop only is ~222W
- Total simulated dissipated energy due to total drop (power + GND) is ~394W

#	Supplies	Voltage (V)	Current (A)	Power Drop (mV)	Ground Drop (mV)	Total IR Drop (mV)	% Power Drop	% Total IR Drop
1	V1	0.8	700	24.27	29.89	54.15	3.03%	6.77%
2	V2	0.8	700	24.63	29.38	54.01	3.08%	6.75%
3	V3	1.2	312	57.61	27.33	84.94	5.76%	8.49%
4	V4	1.2	312	37.98	28.16	66.14	3.80%	6.61%
5	V5	1.2	312	38.17	27.61	65.78	3.82%	6.58%
6	V6	1.2	312	54.71	28.48	83.19	5.47%	8.32%
7	V7	1	460	28.89	29.19	58.08	2.89%	5.81%
8	V8	1	480	30.39	30.27	60.66	3.04%	6.07%
9	V9	1.2	460	34.09	29.50	63.60	2.84%	5.30%
10	V10	1.2	480	36.78	30.08	66.86	3.06%	5.57%
11	V11	1.2	346	52.86	29.41	82.28	4.41%	6.86%
12	V12	1.2	346	45.07	28.79	73.85	3.76%	6.15%
13	V13	1.5	346	53.56	28.39	81.96	4.46%	6.83%
14	V14	1.5	346	45.87	27.95	73.82	3.82%	6.15%

6.5kW Board Temperature Simulations

- Co electrical / thermal simulations based on sustained currents
- Does not use any mechanical interface in simulations
- Simulation models temperature change as electrical current passes through board metal structures

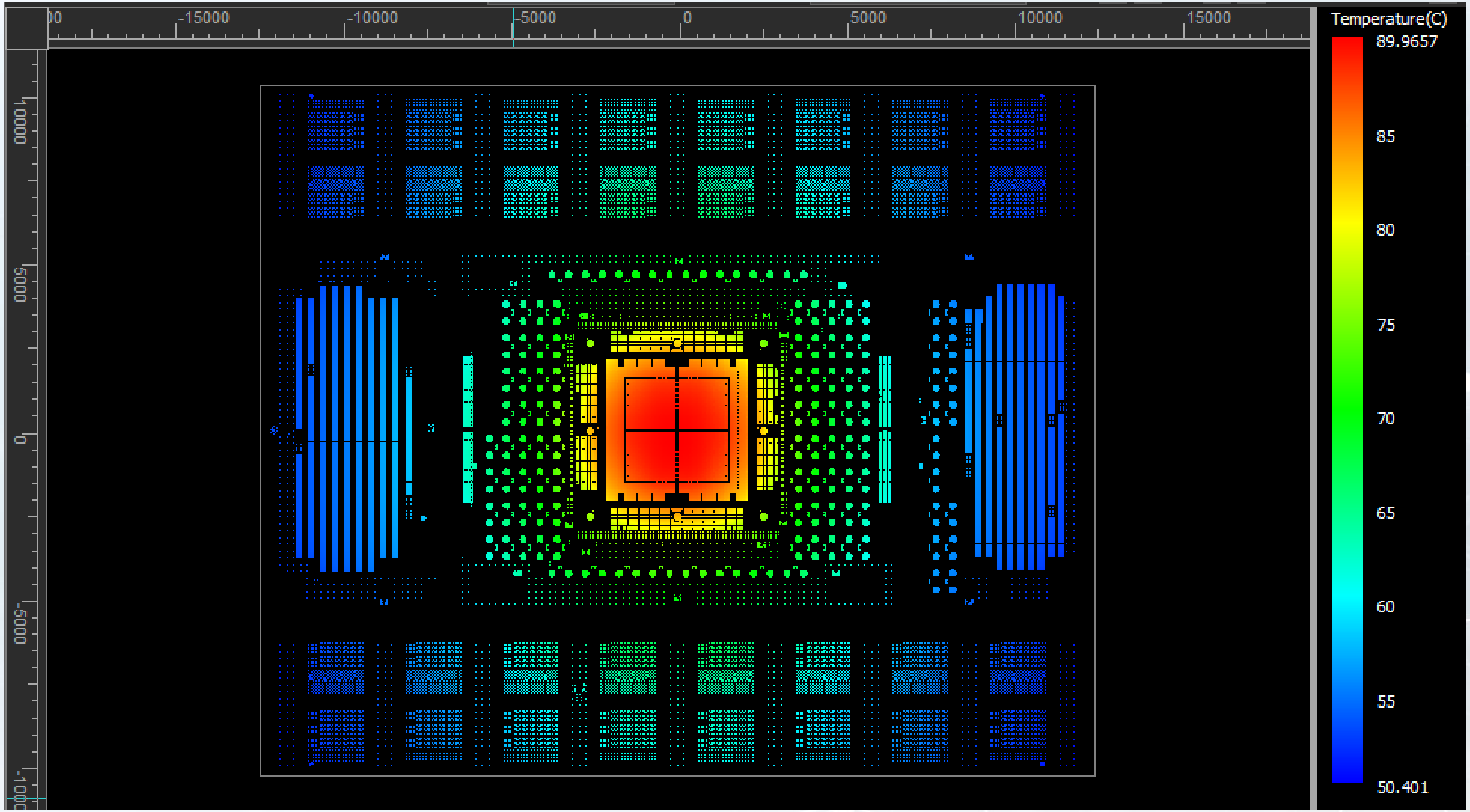


137 Degree C

93.5 Degree C

6.5kW Board Temperature Simulations with Air Flow (3.76 m/s)

~45 Degree improvement in temperature gradient with ambient temperature air flow at 3.76 m/s



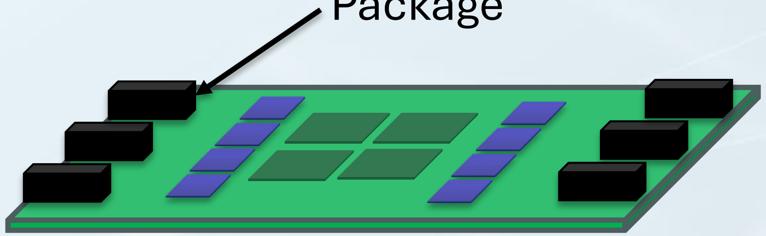
90 Degree C

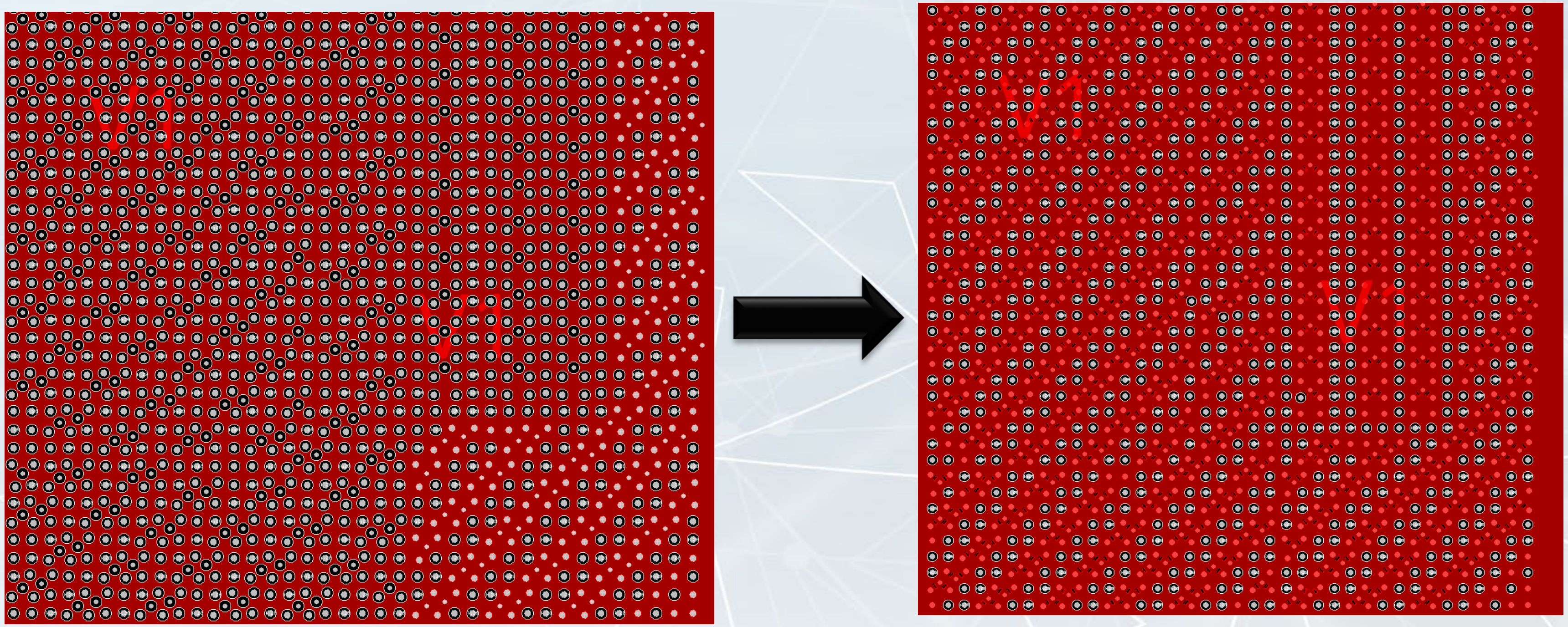
50 Degree C

PI and Thermal Improvements using Integrated Voltage Regulators

- A significant improvement on IR-Drop occurs with merging supplies
- Copper planes are replicated and Swiss-cheese effects of planes reduced
- Since power via anti-pads are on same nets, it creates more channels for current to flow to the core

Integrated Voltage Regulator on Package





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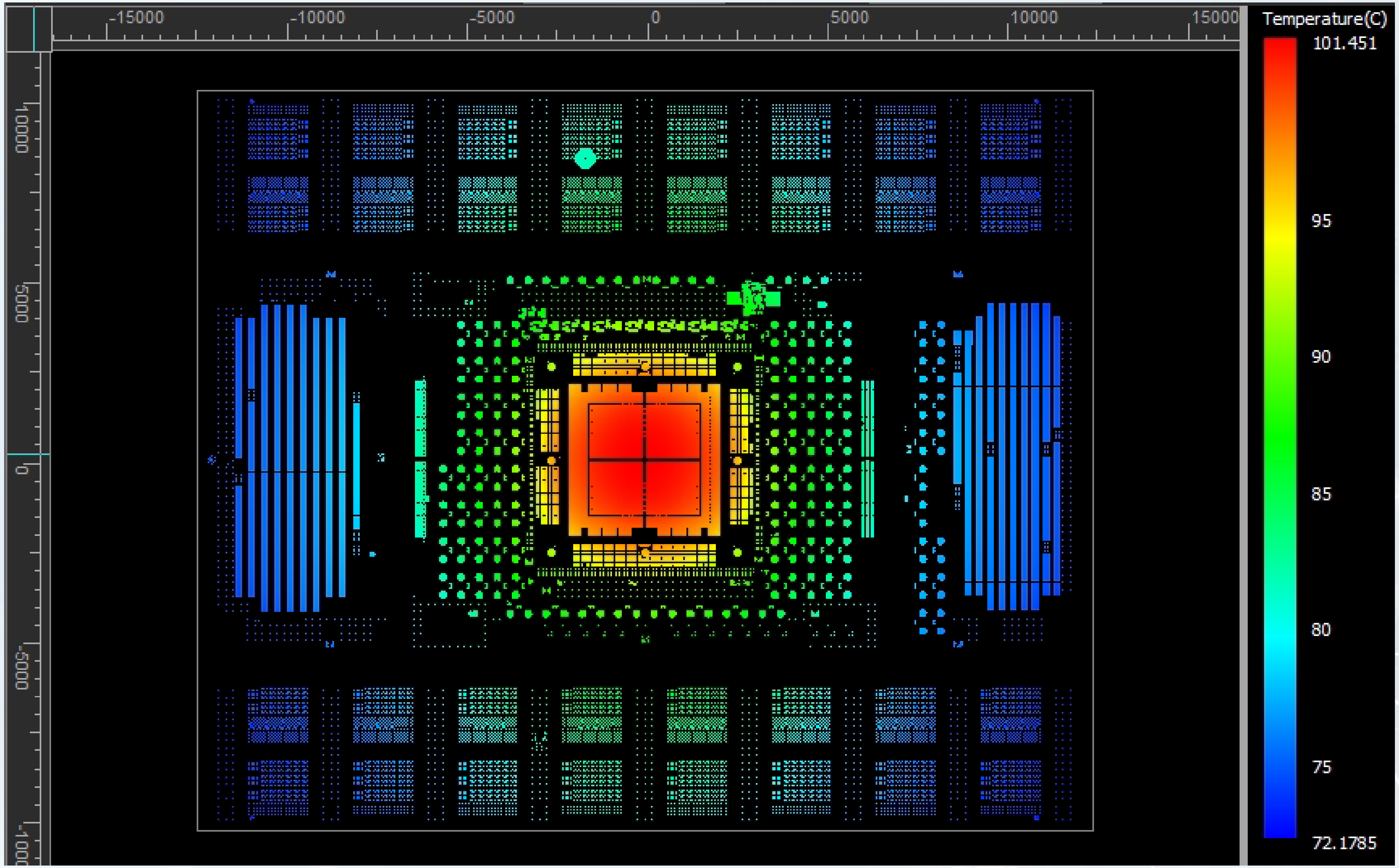
IR Drop and Thermal Simulations with IVR Based Design

#	Supplies	Voltage (V)	Current (A)	Power Drop (mV)	Ground Drop (mV)	Total IR Drop (mV)	% Power Drop	% Total IR Drop
1	V1-14	1.2	5500	24.47	26.47	50.94	2.04%	4.25%



101 Degree C

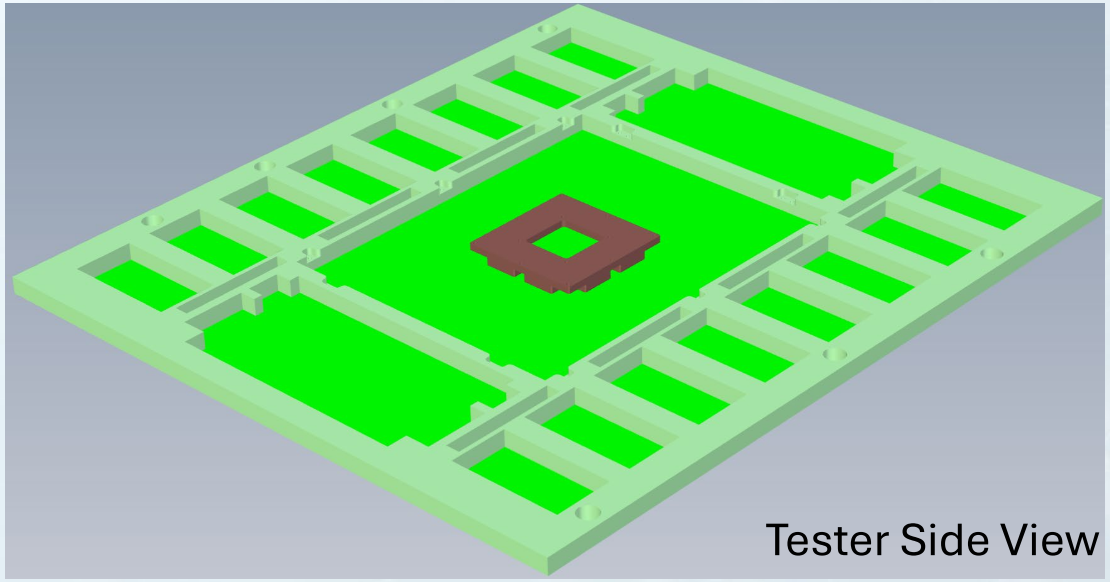
Power Drop = 145.6W
(53% Improvement)

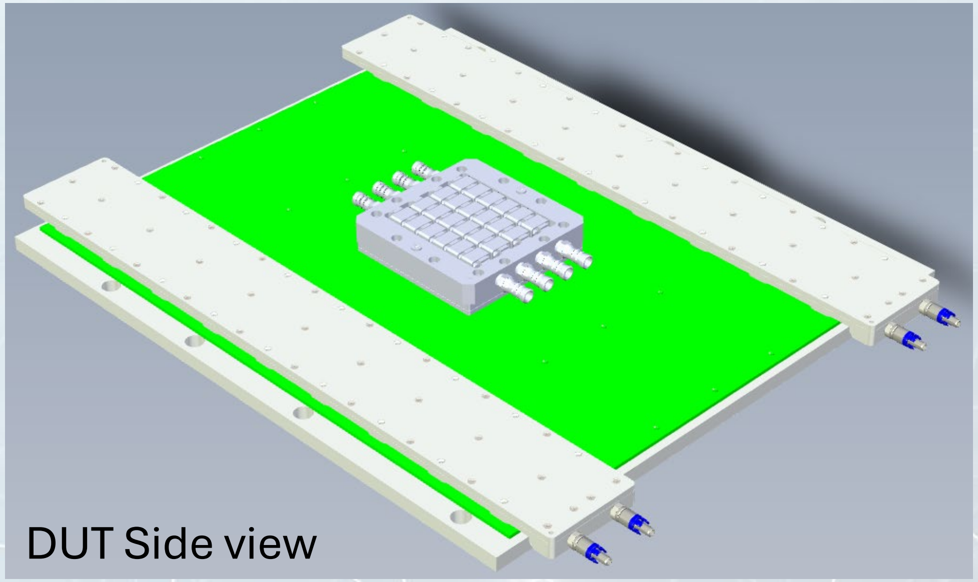
With GND Drop = 280W
(40% Improvement)

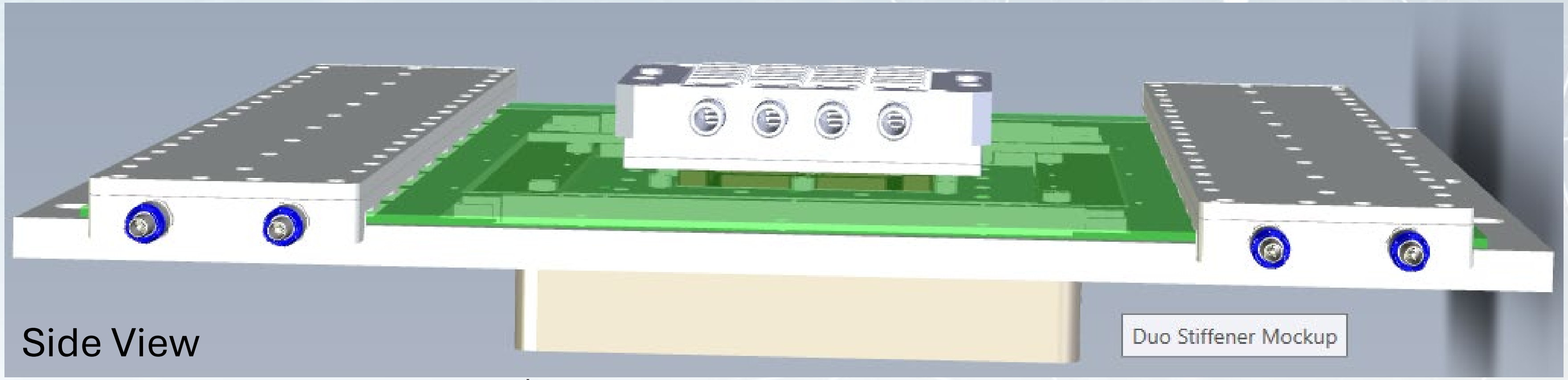
72 Degree C

Thermal Cooling Setup

A cooling setup was designed for load board and surrogate (DUT simulator) to dissipate heat and validate measurements (Patent Pending)







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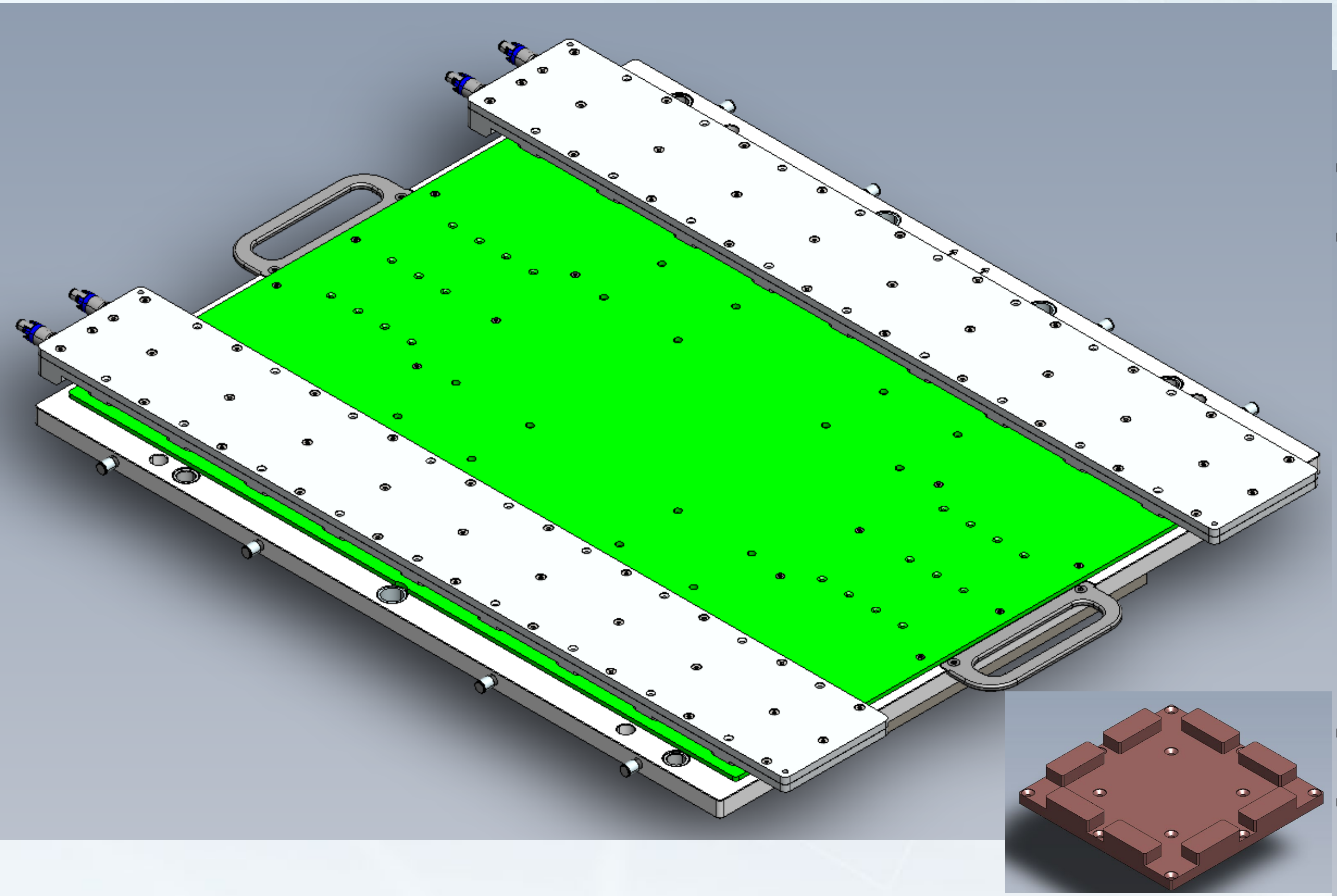
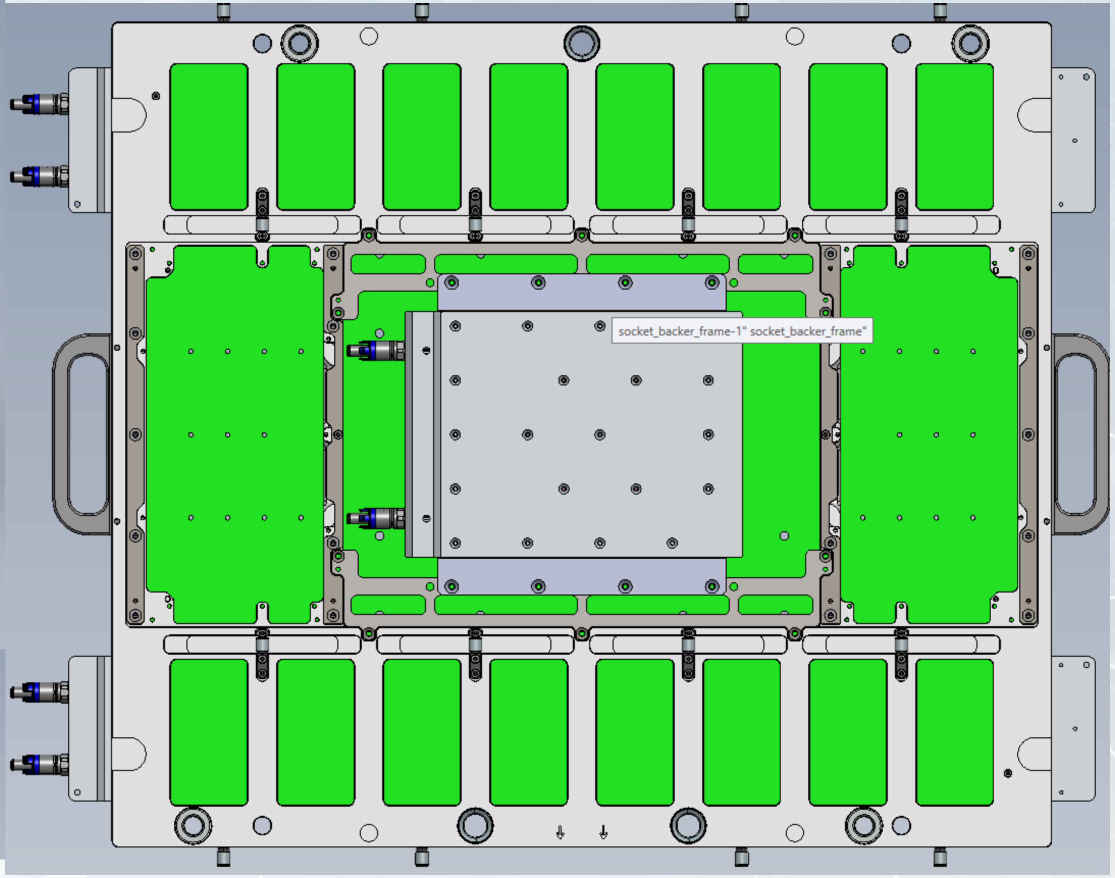
DUT Interface Board Cooling Prototype Hardware (Patent Pending)

- Thermal plates designed to contact top side pogo areas and bottom contact areas near DUT for extracting heat from load board
- 0.4” thick DUT scale duo final test engineering board
- Heat spreader block (Brown block) is custom designed to fit variety of DUT footprints
- Cooling inlets / outlets are connected to external chillers which keeps on rotating coolant for DUT interface board cooling





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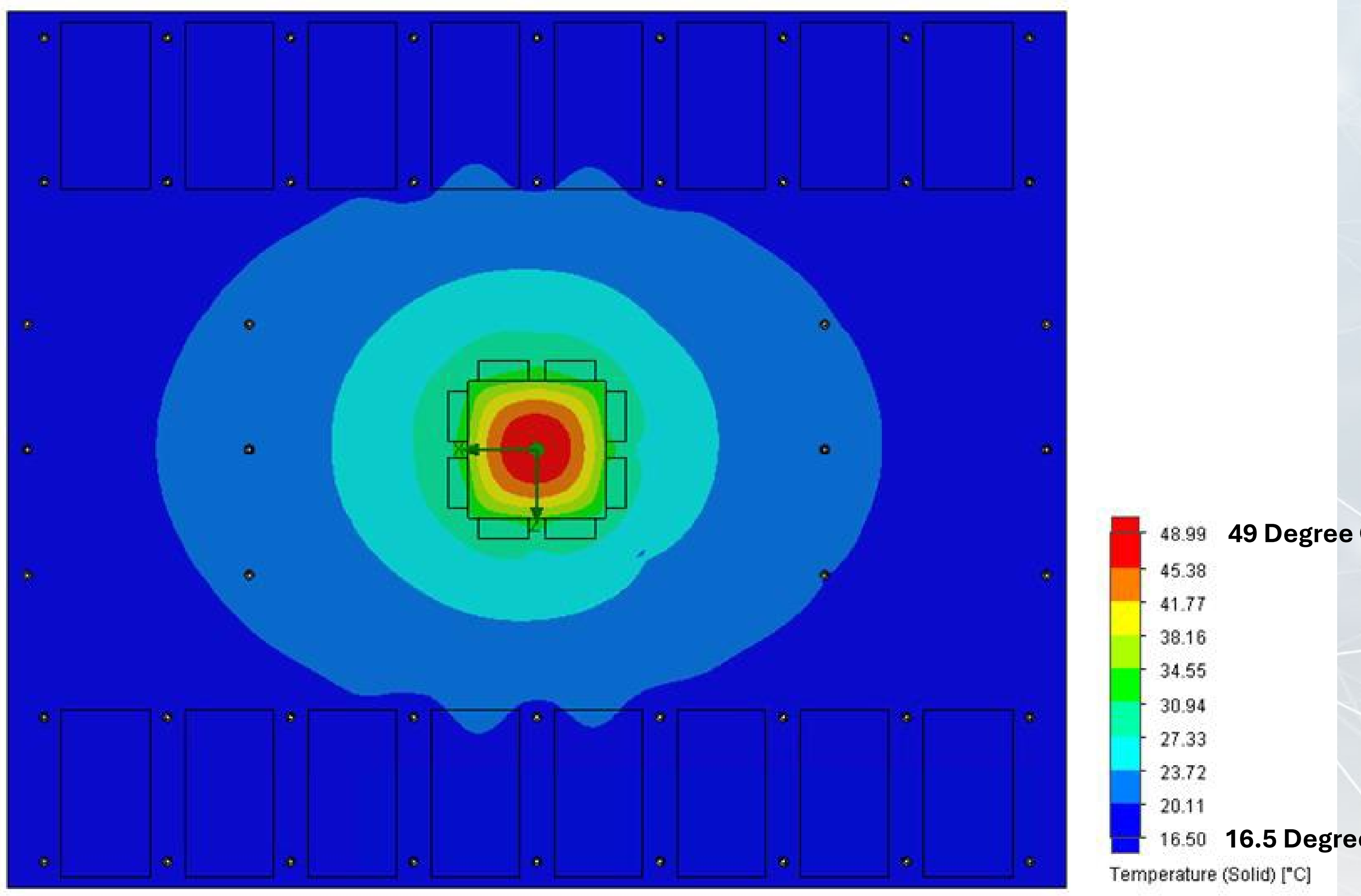
6.5kW Liquid Cooling Simulation Results

~89 Degree C temperature drop vs. original electrical/thermal Sims!

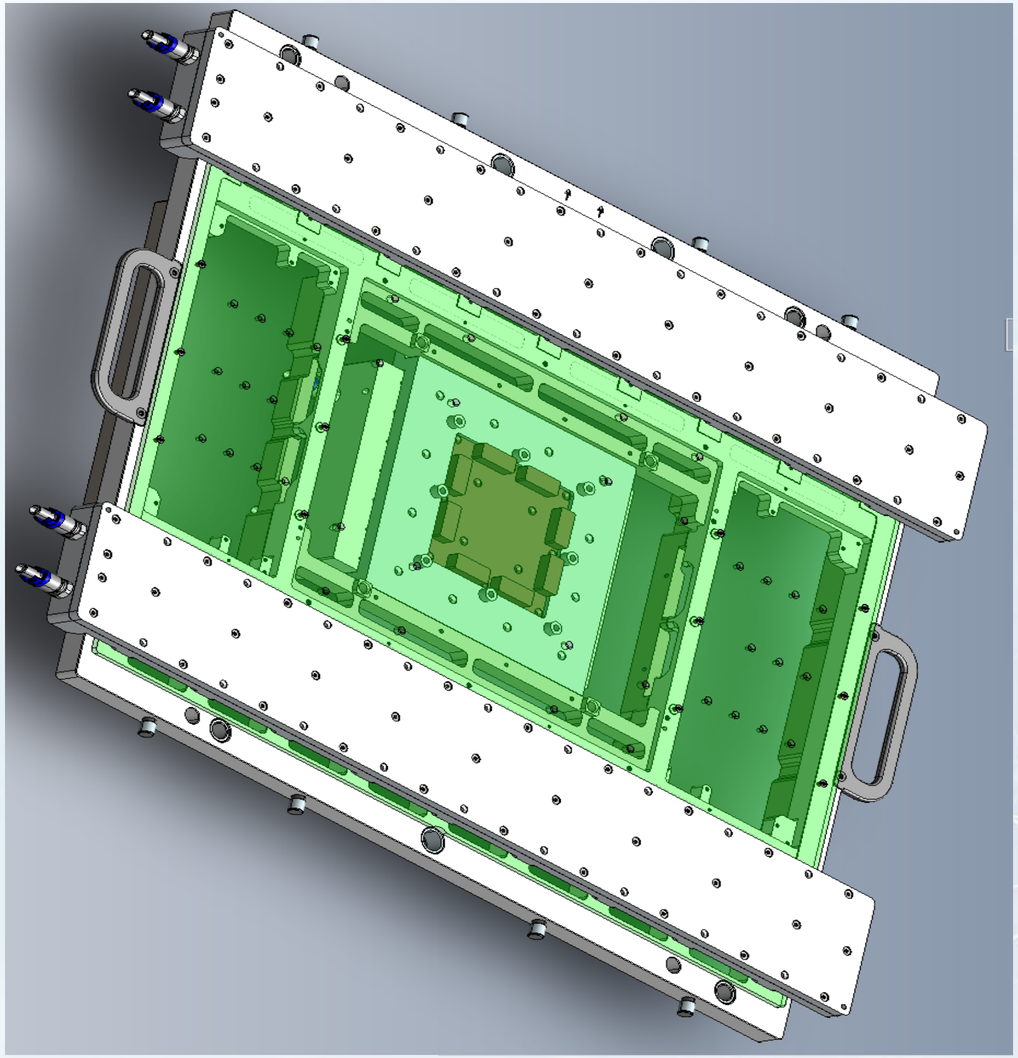
- Significant temperature drop observed with sustainable ~6000A current on the DOE boards
- 15 Degree-C coolant* running on the cooling hardware No purge air system required
- Further customization on hardware can improve temperature gradient further*

*Note: Actual thermal gradient depends on supply switching / duty cycles and maximum current running and sinking through the devices in operations



* [Controlled 21 Deg C, 65% Humidity, 14 Degree C Dewpoint]

6.5kW Power Delivery DIB Prototype – Next Steps



Next Steps

- Prototype board measurements are planned by end of September
- Hardware will be tested on V93000 tester
- Starting from low power, ramping up current clamps and measuring temperatures and power on the board

Validation

- Correlating voltage drops between simulated and measured values as the current clamp is increased
- Verifying thermal simulations with thermal plots obtained from the sensors on board on ATE board and device
- Enable cooling and validate performance improvements due to cooling hardware

HVM Rollout

- Expected measurements completed by Q4' 2026
- Roll out for select engineering designs by Q1' 2027
- Expected roll-out to volume production by Q2' 2027

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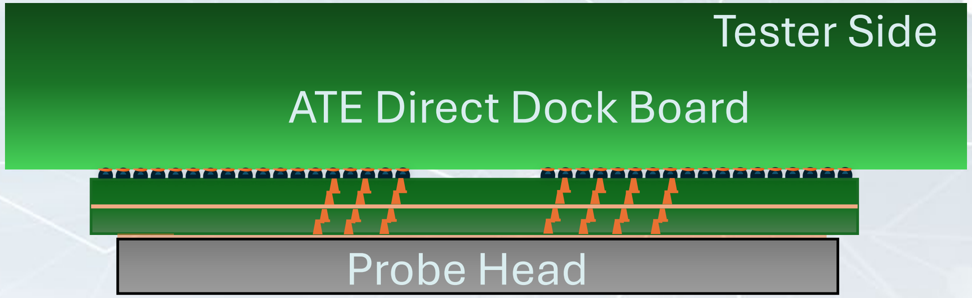
MLO Cooling Topologies

MLO / Probe board cooling can help extract dissipated thermal energy from the MLO using the right thermal design and mechanical cooling interface

- Probe Manufacturers are working on different technologies to help cool the MLOs
- Work with your probe supplier to identify requirements related to probe / MLO / substrate cooling technologies
- Ensuring a good thermal design on MLO will result in better heat extraction and improved power delivery



Summary

Thermal dissipation is essential for systems running higher power

- **As the current rises, specially for devices with higher current transients, electrical conductivity of the copper and metal features in the board decreases with rise in temperature due to thermal dissipation**

- **Thermal dissipation occurs with higher currents. Thermal dissipation on a system running 5000A @1V will have higher dissipation than 4167A @1.2V [both 5kW]**

  - DUT boards with ~0.4” thickness, and ~60 – 80Oz power layers can handle ~4000A of continuous current with standard ATE supply specs without external cooling

  - DUT boards would require some cooling interface (air or liquid) between the range of 4000A – 5500A

  - DUT boards running at >5500A continuous currents would probably require liquid cooling due to higher amount dissipation and board temperatures

  - It is important to understand the supply switching / duty cycles and extract maximum current running and sinking through the devices in operations – **this defines the actual thermal gradient!**

Acknowledgements

Sincere appreciation to Advantest Teams and members for their contribution:

- Cymeyna Mcfarland – Advantest V93000 R&D
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