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Thermal Challenges & Cooling Methods for High Power Electronics

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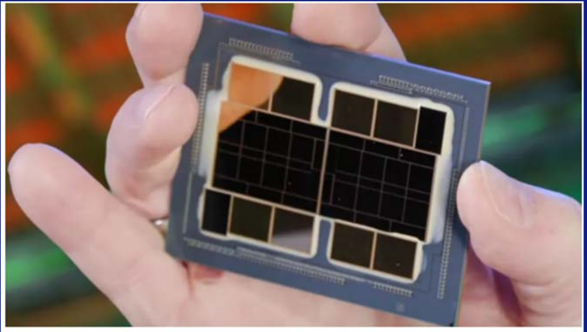
Chip I/O Density & Thermal Design Power

- Data rate, I/O density and heterogeneous integration is forcing chip to dissipate more and more heat, nowadays.
- Thermal design Power (TDP) of high performance CPU and GPU has already reached up to approx. 700 W, which includes AMD's EPYC Turin and Intel's Ponte Vecchio.
- To keep these Chips cool at safe level, there must be need of some enhanced and efficient cooling system.

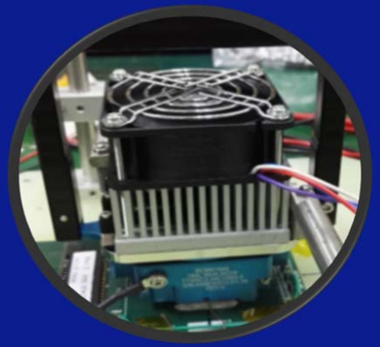


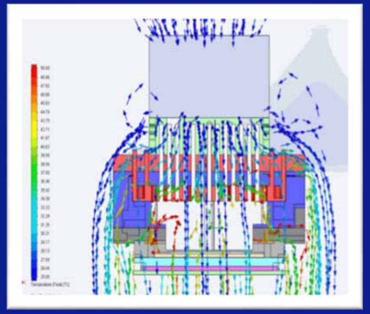
(Image credit: Intel)

Technology		TDP
	Smart Wearables / Smart Phones	10W
	Laptops/automotives	50W
	Desktop CPU's	280W
	GPU / Accelerator (HPC & AI)	500W
	Servers and Data center CPU's	700W

Conventional Cooling Methods

- Heat sink is the most conventional method to cool down the Chip/IC.
- A heatsink with an external size SQ100 mm can dissipate a maximum of 150 W of heat and has a higher thermal resistance.
- To push the heat dissipation envelop of a heat sink, you may require to design a huge size heat sink with noisy fans, which may not be suitable to use with socket lid application.
- Aluminium thermal conductivity is 180 W/mK and Copper is 380 W/mK. We need a much higher thermal conductive material or medium that transfers heat more quickly and efficiently.





Customer Inputs & Challenges

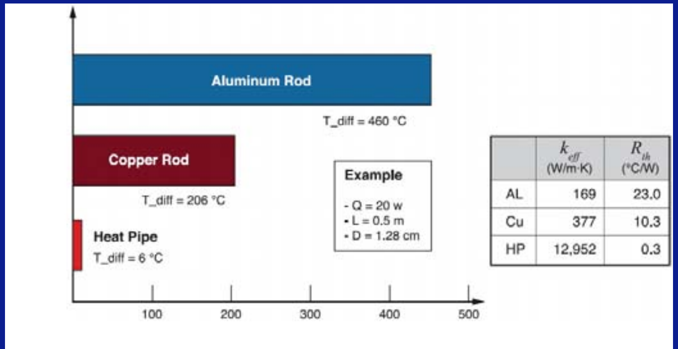
- Customer requested to provide cooling unit for up to 1500 W for Chip qualifications

- Off-the-shelf heat pipes and liquid cooling units are available, but :
  - a) they are not designed for high heat dissipation.
  - b) they can not be integrated on all kind of socket-lid application, due to different package types, sizes, attachment methods and power density.
  - c) they are bulky in size / space issue

- To provide cooling solutions up to 1500 W, we decided to develop custom made heat pipe and Liquid cooling solution and divided high power into two categories:
  - a) 500 W
  - b) 1500 W

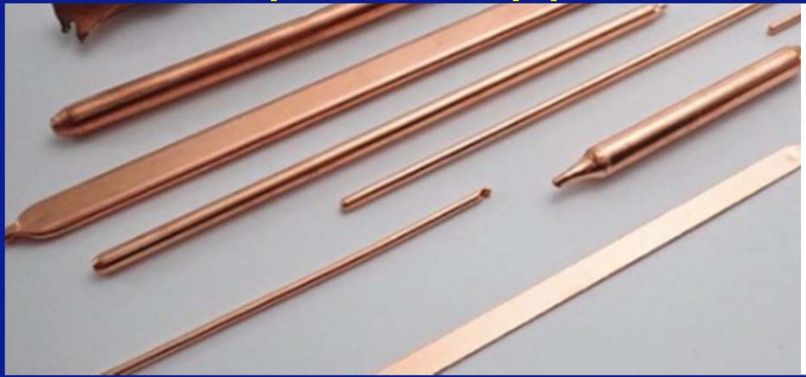
Heat pipes

- Heat pipes are vacuumed sealed enclosure with a wick structure inside walls and having a little amount of liquid (working fluid) inside.
- A heat pipe can transfer up to 1000 times more thermal energy, than copper, the best known conductor. That's why heat pipe are referred as "superconductors"



The superiority of heat pipe over other thermally conducting materials.

Different shapes of Heat pipe

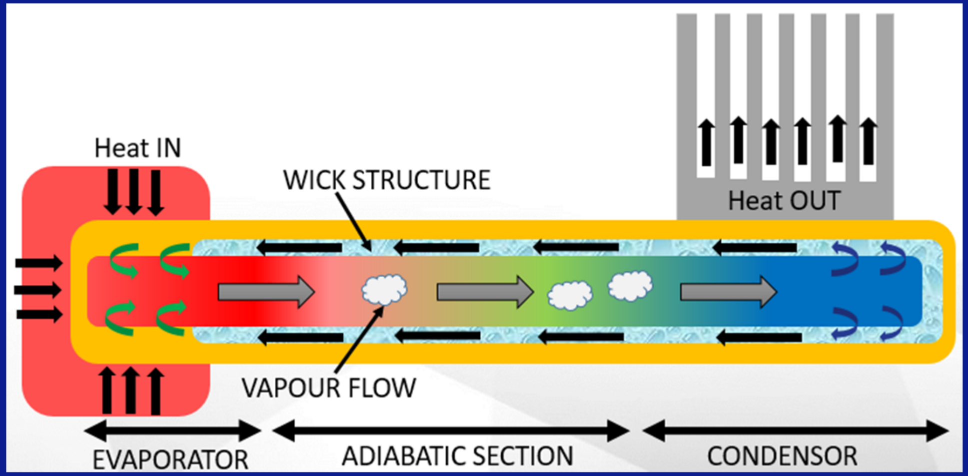


Heat pipe embedded to a heat sink

Working principle and limitation

- Heat is applied (to Evaporator). Working fluid immediately vaporizes and travels to lower pressure area (Condenser) where heatsinks is connected. The condensed fluid is then absorbed by the wick structure, return to liquid form and transported back to the heat source via capillary action.

Heat Pipe working principle



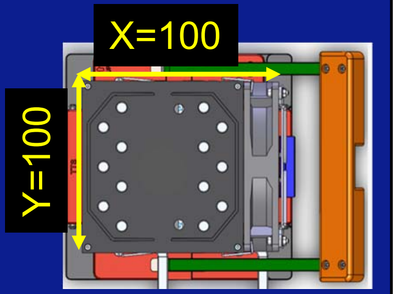
Key factors to heat pipe performance

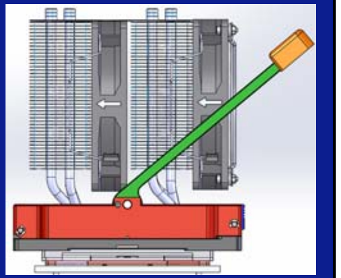
- Heat pipe diameter.
- Choose the best performance wick structure.
- Design heat pipes with minimum bending.
- Tubular heat pipes can carry more heat than flattened one.
- Use high fin density heat sink with high static pressure fan.

Development of Custom heat pipe

- Our Target was to develop custom heat pipe models to dissipate:
  - ➢ Up to 500 W with external size less than 100x100 mm^2

    Market available can only dissipate ~300 W with a footprint of 135x135 mm^2

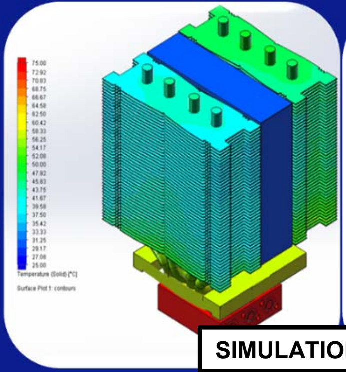


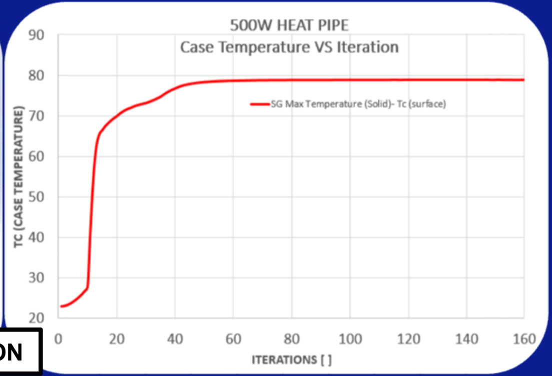


- To qualify heat pipe unit, it must maintain Case Temperature (Tc) 80 ^{o}C or below.
- Initial simulation was done on various designs to optimise for the best outcome.

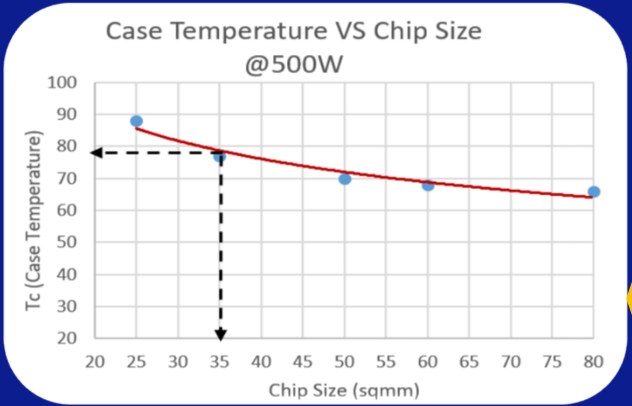
Validation setup

500W Cooling Unit (HP Case Study)





Case Temperature VS Chip Size

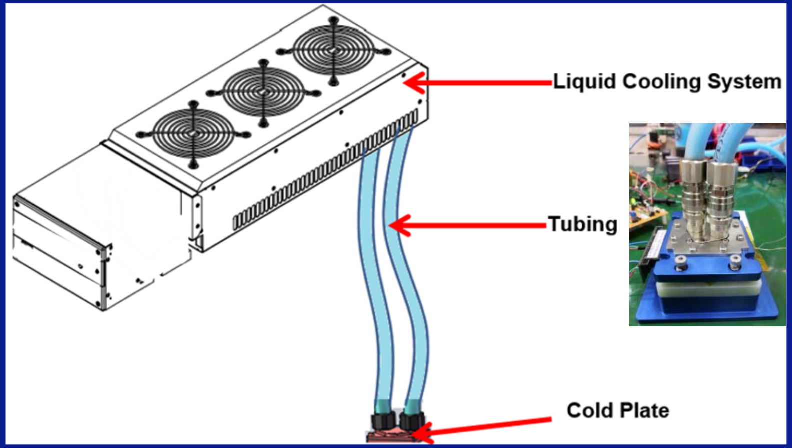


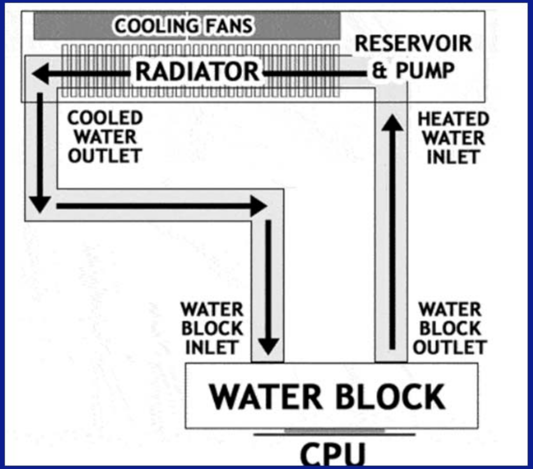
Results:	Power (W)	Ta (C)	Tc (C)	Theta-CA (C/W)	% Offset (Simulation VS Validation)
SIMULATION	500	23	77	0.110	5.19
VALIDATION	500	23	81	0.116	

- ✓ Chip tends to be more cooler when its surface area increases, together with the base of heat pipe.
- ✓ This model is suitable for chip size in the range SQ25 mm to SQ80 mm.

Liquid Cooling Unit

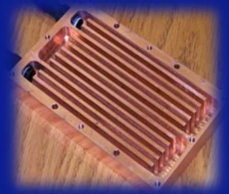
- Liquid cooling system uses a 'water block' where coolant absorb the heat from DUT and carry it to the radiator.
- At radiator, fans are attached which blow the heat away to ambient and the coolant re-enters the water block and cycle repeats.
- Heat Capacity of water is four times higher than copper, which make it an efficient heat carrying medium.





Key factors for Liquid Cooling Design

- Water Block Design – most common are Micro-fins type, maze type and round vertical fins type. Out of these micro-fins are more efficient, since they increase the total surface area to be cooled.

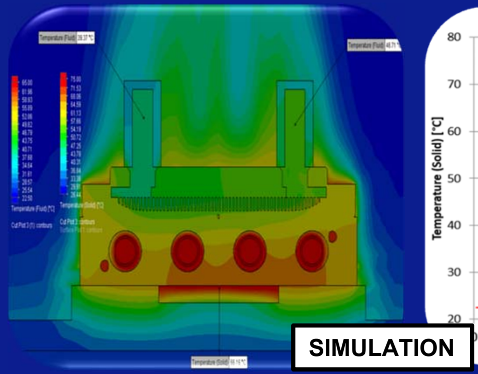



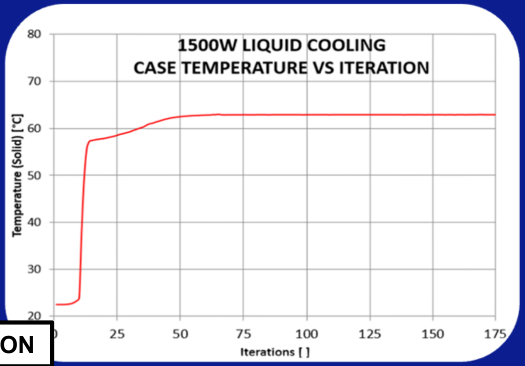
- Pump /Flow rate – appropriate flow rate is required to make sure pump is pushing the liquid throughout the loop.

- Radiator Size – a brass/copper radiator with suitable fan may require for high heat dissipation.

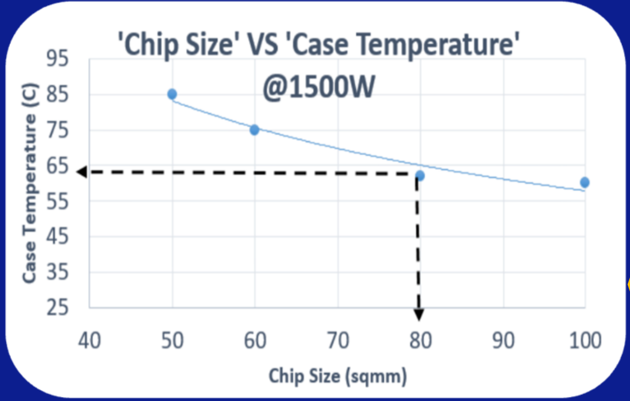
- Coolant –Water could be best coolant to dissipate heat efficiently, but it possibly produce corrosion, contamination and bacterial growth inside radiator and reservoir when using for long term. A mixture of water with propylene glycol is recommended.

1500W Cooling Unit (LC Case Study)





Case Temperature VS Chip Size

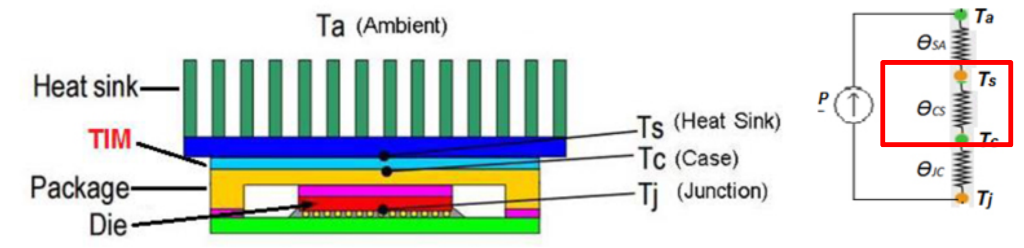


Results:	Power (W)	Ta (C)	Tc (C)	Theta-CA (C/W)	% Offset (Simulation VS Validation)
SIMULATION	1500	25	62	0.024	9.6
VALIDATION	1500	25	68	0.028	

- ✓ Chip tends to be more cooler when its surface area increases, together with the water block size.
- ✓ This model is suitable for chip size in the range SQ60 mm to SQ100 mm.

Importance of Thermal Interface Material in High Power Application

- To minimize overall thermal resistance of system, TIM must be selected with least thermal resistance and high thermal conductive, as it could become a major contributor in high power application.



$$\theta_{JA} = (T_j - T_a)/P = \theta_{JC} + \theta_{CS} + \theta_{SA} = \theta_{JC} + \theta_{CA}$$

Where,

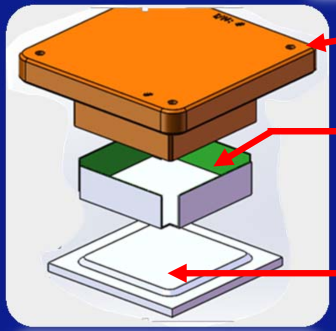
$$\theta_{JC} = (T_j - T_c)/P$$
$$\theta_{CS} = (T_c - T_s)/P$$
$$\theta_{SA} = (T_s - T_a)/P$$
$$\theta_{CA} = (T_c - T_a)/P$$

- θJA = Thermal Resistance of Thermal Design Target
- θJC = Thermal Resistance of Package
- θCS = Thermal Resistance of TIM
- θSA = Thermal Resistance of Heat Sink
- θCA = Thermal Resistance of Cooling Solution Provided
- P = Heat Dissipation Power

Importance of Thermal Interface Material in High Power Application

- Grease TIM has very low thermal resistance, and capable to fill air gap more efficiently. They are off course a good choice, but they could be messy if customer requires to change 100’s of chip samples for qualification purpose.

- Metal TIM (Graphite/Graphene or Heat Spring) might be suitable to use as a removable/ replaceable, without getting messy (for a limited numbers of touchdowns).



- Metal TIM may require high mounting pressure to give optimum performance.

Conclusion

- Each type of cooling method has its own pros and cons.
- If design properly we can develop Air/Liquid cooled solution up to 1500 W heat dissipation
- Our study & test data shows that, out of these cooling techniques, Liquid cooling is more efficient in dissipating heat and less noisy. Below are some pros/cons for both types of cooling methods.

Air Cooled:

Pros:

- One piece part solution / No moving parts
- No maintenance required
- Could support up to 1000 W

Cons:

- Bulky
- Noisy
- Long Lead Time

Liquid Cooled:

Pros:

- Only Water Block is required to attach to DUT
- Least maintenance required
- Less Noisy
- Could support up to 1500 W
- Short Lead Time

Cons:

- Involves some parts
- Leakage, if not proper fitting.

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