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Cooling Solution for IC Device Testing

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Smiths interconnect

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Shanghai ▪ October 29, 2019

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bringing technology to life

Agenda

- Background
- Heat Transfer
- Structure
- Natural Convection
- Force Convection (Fan)
- Force Convection (Liquid Cooling)
- Force Convection (Fan W/heat pipe)
- Conclusion

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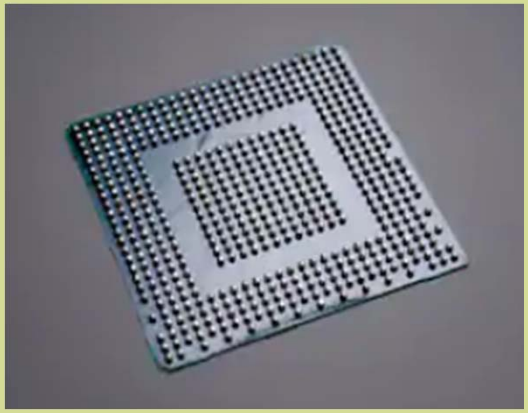
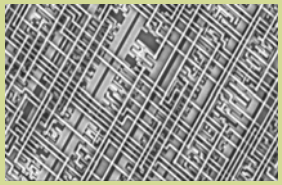
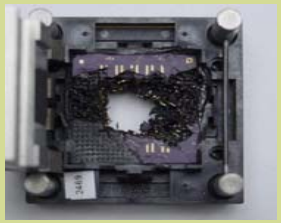
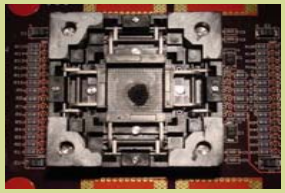
Background

- Billions of transistors.
- Higher Power, Higher Dissipation
  - Test socket probes damage.
  - IC thermal breakdown & thermal runaway.
  - PCB thermal runway.

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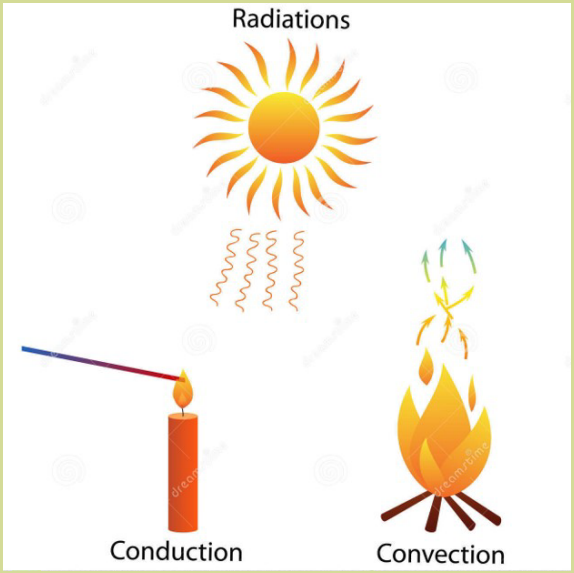
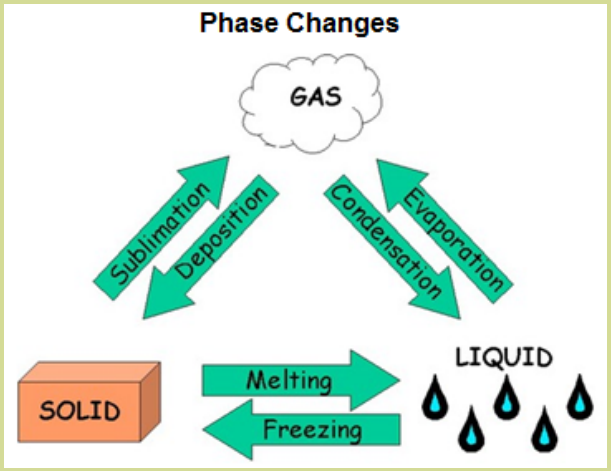
Heat Transfer

Sometime have phase changes while heat is being transferred.





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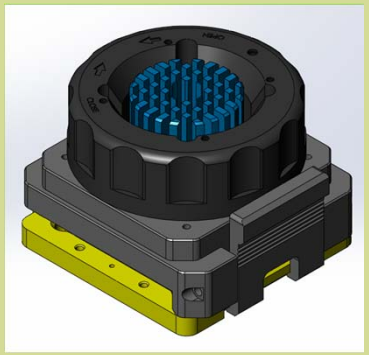
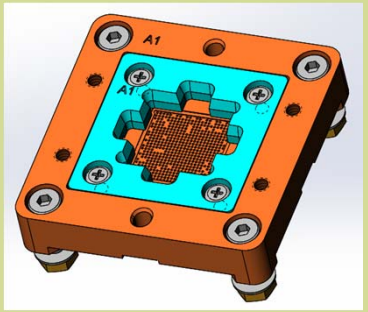
Structure

- Device can be cooled from bottom side by PCB ground layers.
- Also, device can be cooled from top side by Hand Socket Lid (HSL) for Manual test and Work Press for Handler test.
- HSL or Work Press will have heatsink for heat dissipation by natural or force convection.





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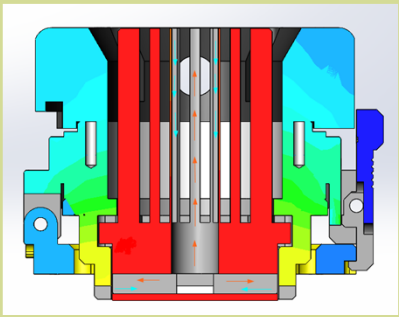
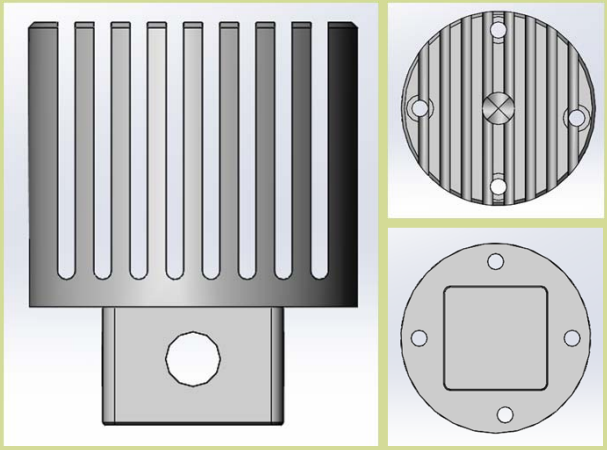
Natural Convection

Power: Low

Heatsink material: Aluminum, Copper





Touching surface: Conduction

Fins Area: Convection

Air flow holes

MTG holes

Natural Convection

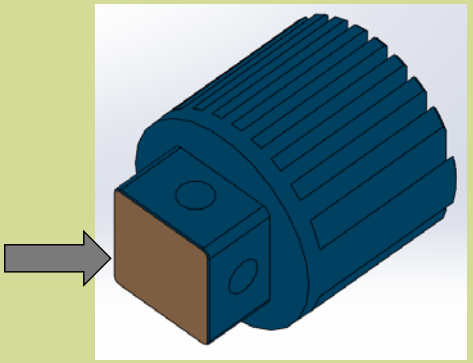
Simulated the two different Contact Area of heatsink & IC top surface.

Definition:

Design A1: Area 16.5 mm X 16.5 mm

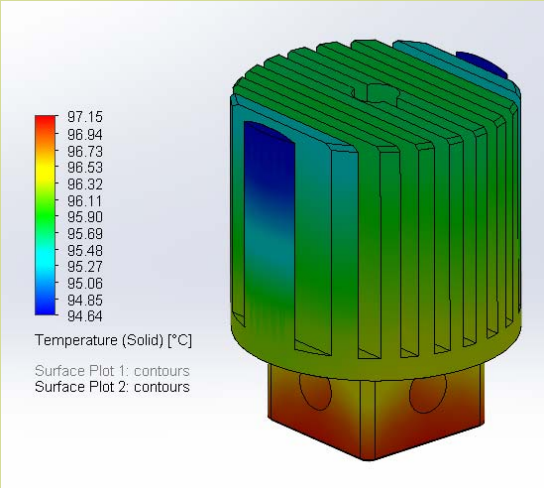
Design A2: Area 10.0 mm X 10.0 mm

Heat resource: 8 W

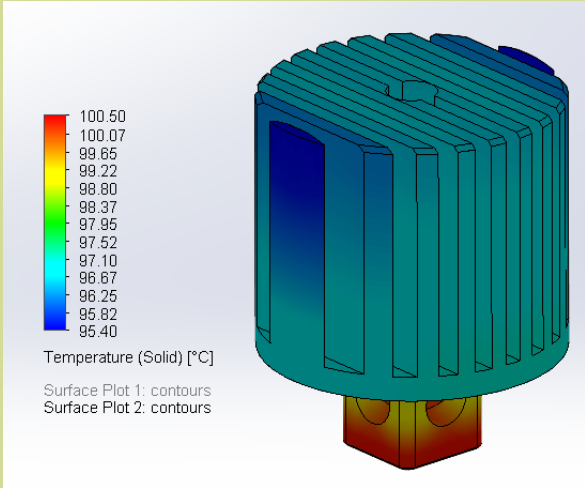


Natural Convection

Design A1



Design A2



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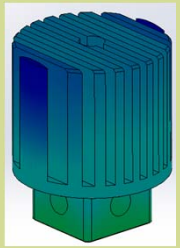
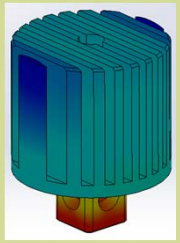
Natural Convection Result (conduction)





Item	Design A1	Design A2
Max Temp.(℃)	97.1	**100.5**

$q = - kA \nabla T$

- q = heat flow vector, (W)
- k = thermal conductivity, a thermodynamic property of the material. (W/m K)
- A = Cross sectional area in direction of heat flow. (m^2)
- ∇ T = Gradient of temperature (K/m)
- $= \partial T/\partial xi + \partial T/\partial yj + \partial T/\partial zk$

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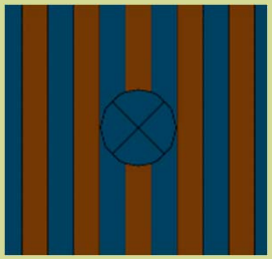
Natural Convection

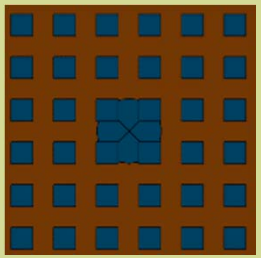
Heatsink can have wall fins, cross-cut fins or cylindrical fins.

Refer to **top views** below for heatsink fins/types:



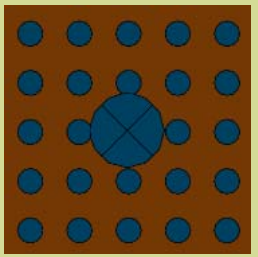
Design B1

Wall fins



Design B2

Cross-cut fins



Design B3

Cylindrical fins

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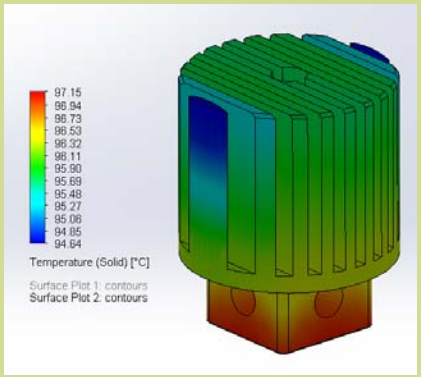
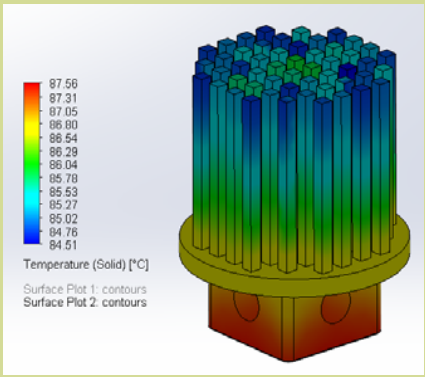
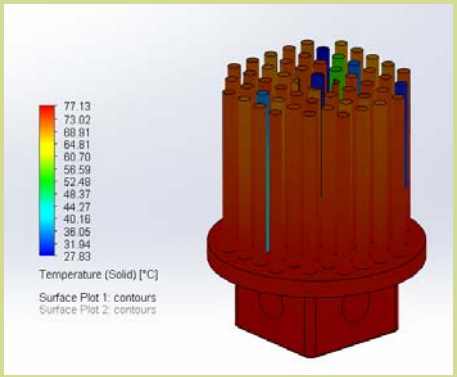
Natural Convection

Design B1	Design B2	Design B3







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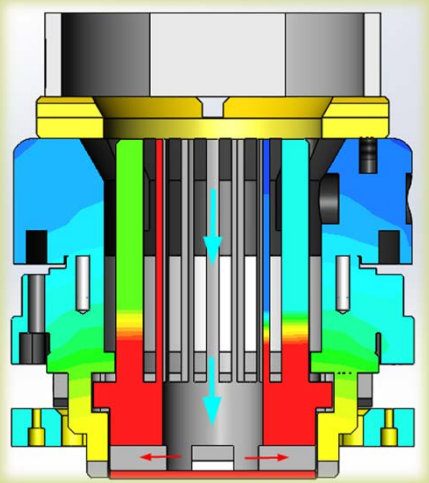
Natural Convection Result (convection)

Item	Design B1	Design B2	Design B3
Max Temp.(℃)	97.1	87.5	77.1

Newton's Law of Cooling: q = h As ΔT

- q = heat flow from surface, a scalar, (W)
- h = heat transfer coefficient (which is not a thermodynamic property of the material, but may depend on geometry of surface, flow characteristics, thermodynamic properties of the fluid, etc. (W/m^2 K)
- As = Surface area from which convection is occurring. (m^2)
- ΔT = $T_S - T_\infty$ = Temperature Difference between surface and coolant. (K)

Force Convection: Fan



IC power: Medium

Component: Fan, Heat sink

Media: Air

Force Convection: Fan

Axial fans are recommended in force convection to cool the device.

Definition:

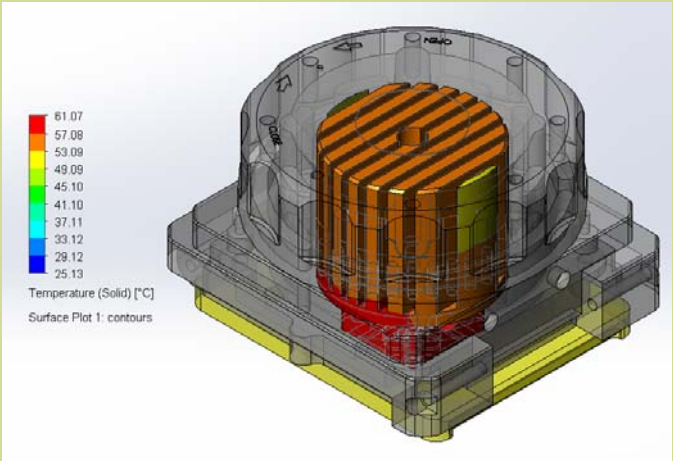
Design C1: Fan 1 Max airflow 10.10 cfm.

Design C2: Fan 2 Max airflow 31.30 cfm.

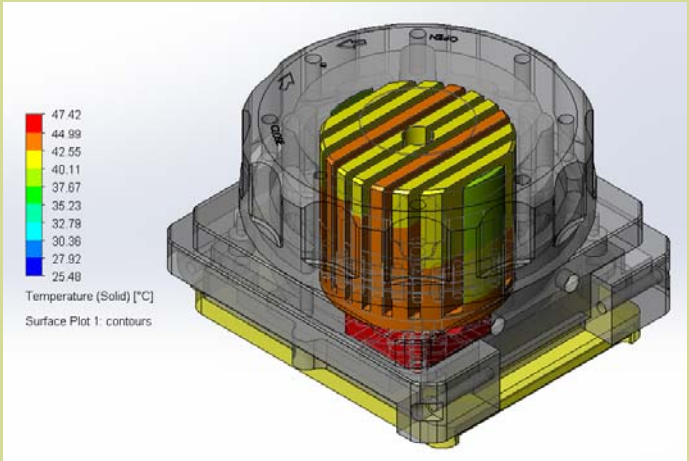
Heat resource 20 W

Force Convection: Fan

Design C1



Design C2



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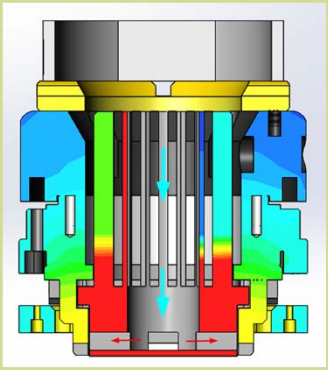
Force Convection: Fan

item	Design C1	Design C2
Max Temp.(℃)	61.0	47.4



Newton's Law of Cooling: $q = h\,A_s\,\Delta T$

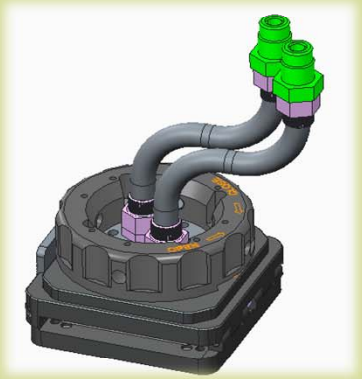
h = heat transfer coefficient (which is not a thermodynamic property of the material, but may depend on geometry of surface, flow characteristics, thermodynamic properties of the fluid, etc. (W/m^2K)

Force Convection: Liquid Cooling

IC power: High

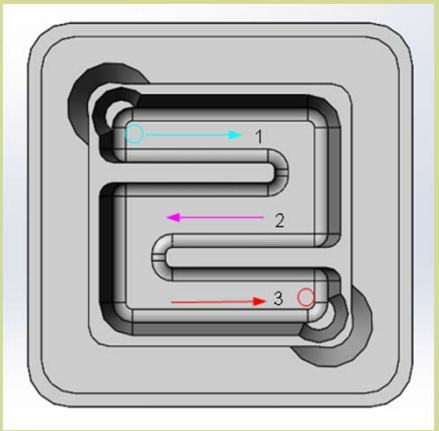
Component: Pump, Heat sink

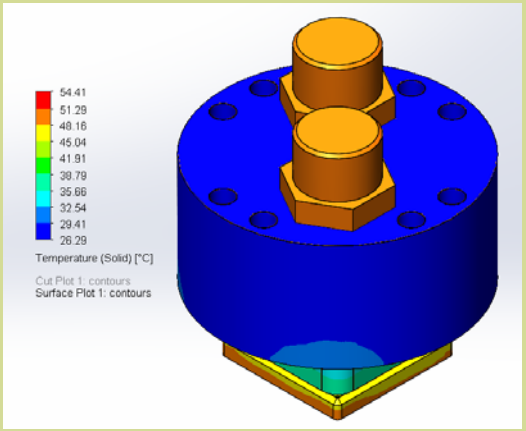
Media: Water



Force Convection: Liquid Cooling

Design D1





Series grooves: The three paths carry water one by one.

Heat resource 300 W, die size 23 X 23 mm^2.

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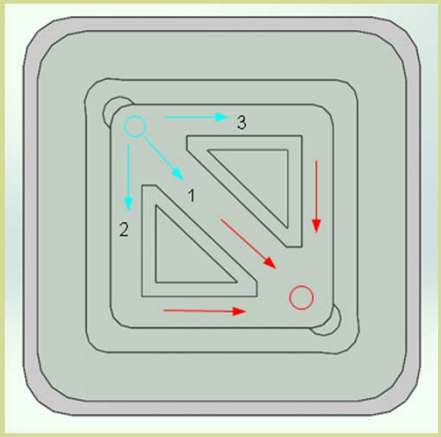
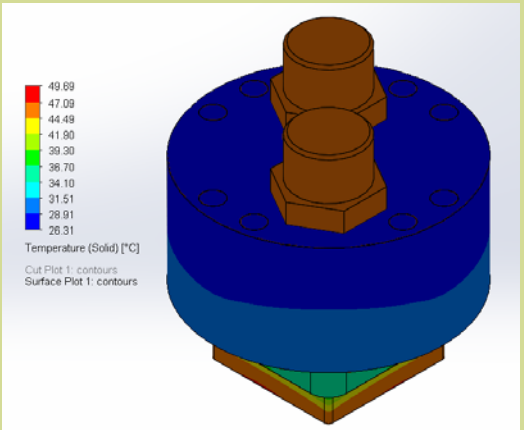
Force Convection: Liquid Cooling

Design D2



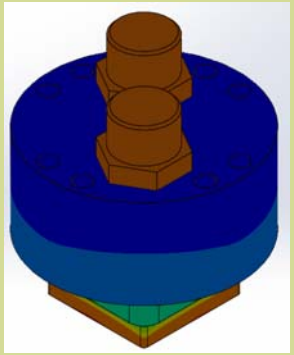


Parallel grooves: 3 paths have a same start point.

Heat resource 300 W die size 23X23 mm^2.

Force Convection: Liquid Cooling

item	Design D1	Design D2
Max Temp.(℃)	54.4	49.6



Newton's Law of Cooling: $q = h\,As\,\Delta T$

h = heat transfer coefficient (which is not a thermodynamic property of the material, but may depend on geometry of surface, flow characteristics, thermodynamic properties of the fluid (like as specific heat, thermal conductivity), etc. (W/m^2K)

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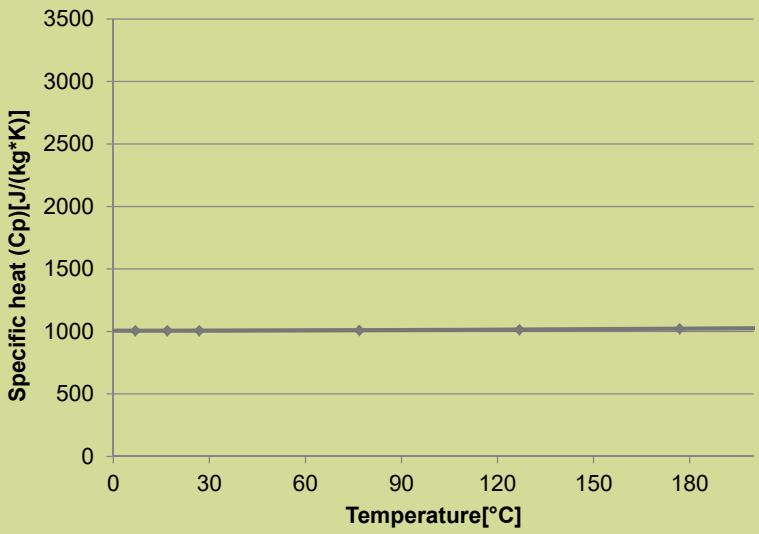
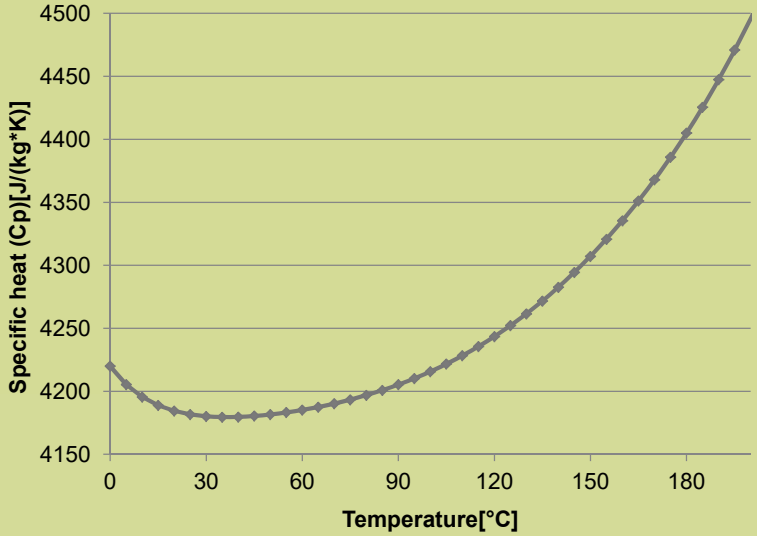
Force Convection: Comparison

Air



Water



Cp-water ≈ 4.2X Cp-air

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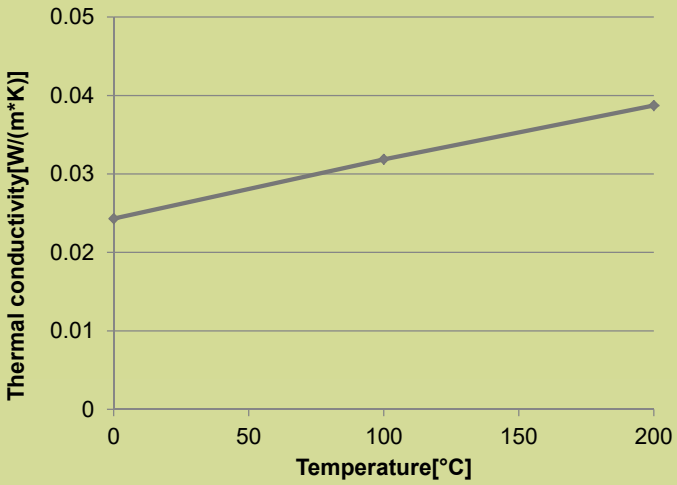
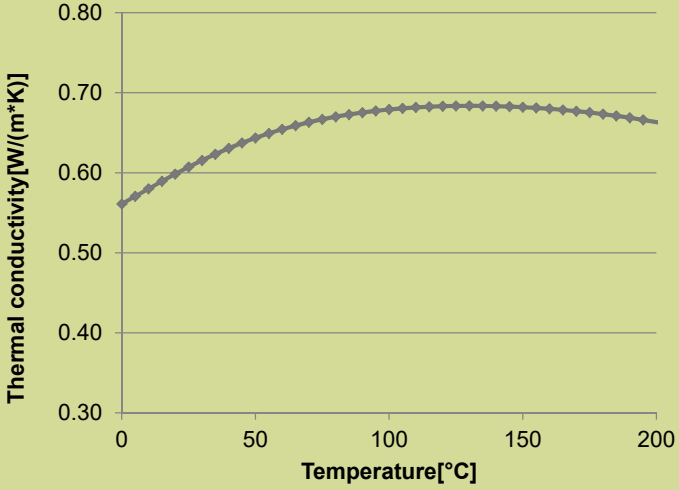
Force Convection: Comparison

Air



Water



K-water ≈ 30X K-air

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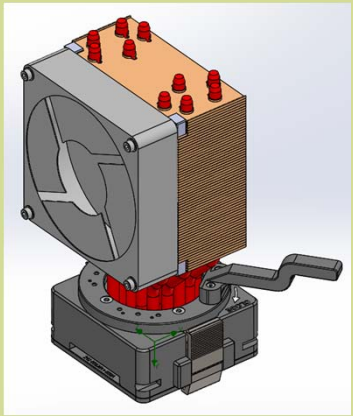
Force Convection: Fan W/Heat pipe

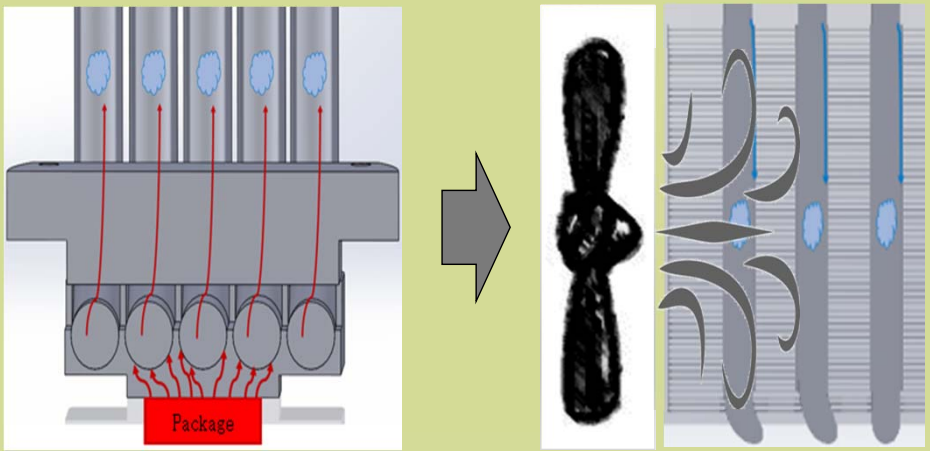
IC power: high

Component:
Fan, HS(heat pipe)+ Fins

Media: Air



Force Convection: Fan W/Heat pipe



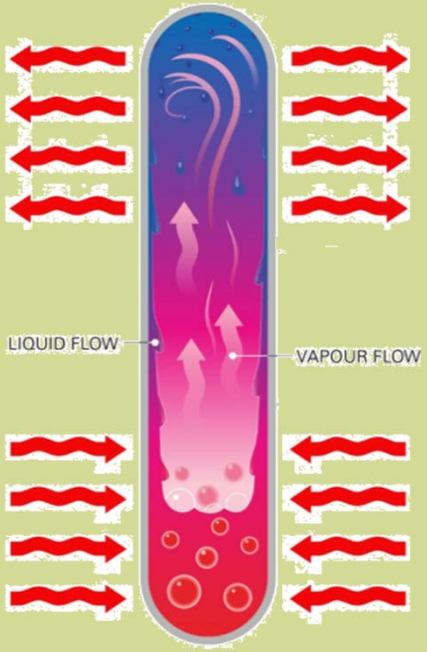
Several heat pipes

Fins

Fan

others

Heat Pipe



- Enclosed tube (Copper)
- liquids
- **Phases change**
- Evaporation-Condensation cycle
- Low heat loss

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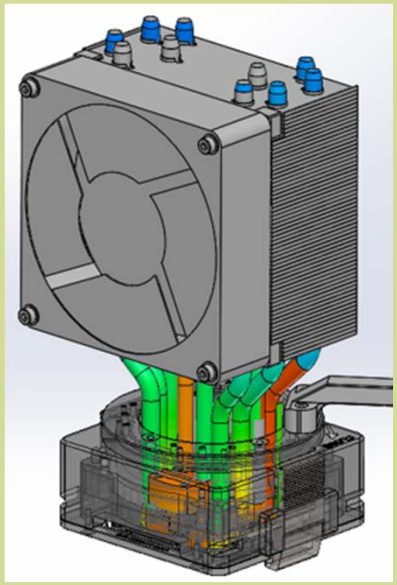
Force Convection: Fan W/Heat pipe

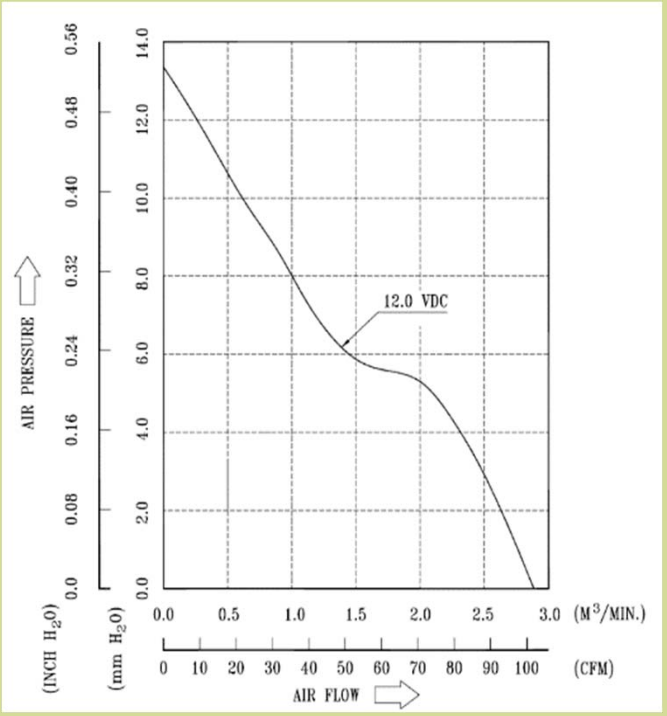


IC heat resource: 100 W

Die size 19X18 mm^2

Design E1: Heat Pipes

Design E2: Copper Rods



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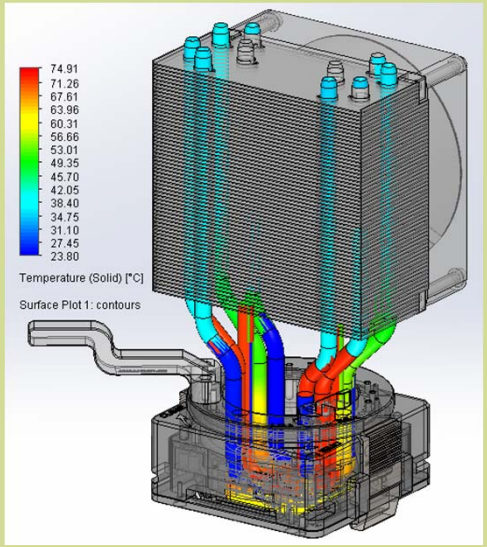
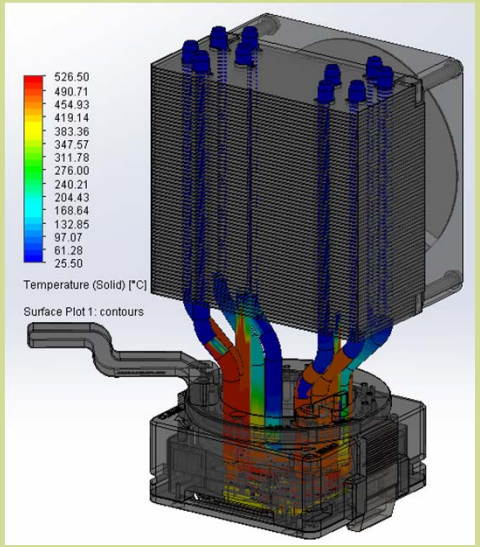
Force Convection: Fan W/Heat pipe

Design E1

74.9 ºC



Design E2



526.5 ºC

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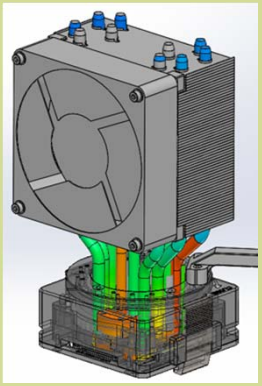
Force Convection: Fan W/Heat pipe

item	Design E1	Design E2
Max Temp.(℃)	74.9	526.5 FAIL



Material: E2 is using Copper rods. Copper thermal conductivity is 398 W/(m·K), while heat pipe thermal conductivity is over 10000 W/(m·K).

Structure: E1 heat pipes internal liquids change phases while transferring heat but copper pipes not.

Since heat pipes utilize phase changes process and benefit from very high heat transfer coefficients during boiling and condensation stages. therefore, heat pipes thermal conductivity is 10x greater than copper. Hence, heat pipes are highly effective thermal conductors.

Conclusion

- Fan cooling is using force air convection to improve performance.
- Water cooling is using water special specific heat property to get high performance.
- Heat pipes can transfer amount of heat from one end to another by internal liquids phase change.

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