Liquid Cooling: An Update

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Content

1. **Main Trends in meeting challenges of thermal management within computer industry and power electronics**
2. **Liquid Cooling – niche for these applications**
3. **Current Conditions of the liquid cooling market - main applications, standard and new technologies**
4. **New Direction in liquid cooling – Submerged Jets**
5. **Different Technologies within Submerged Jets and main results of their implementations**
6. **Conclusions**

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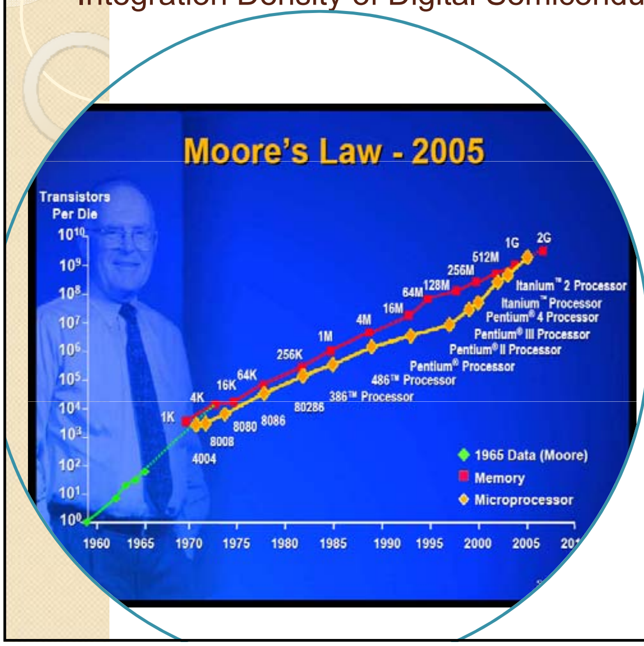
Integration Density of Digital Semiconductors



1. More transistors require more power
2. More power produces more heat to be dissipated
3. Faster microprocessor more frequency - more heat to be dissipated
4. Next step – Multi-core architecture
5. More cores – higher heat flux – more challenges for heat dissipation

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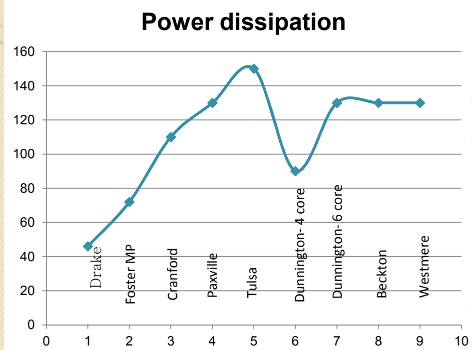
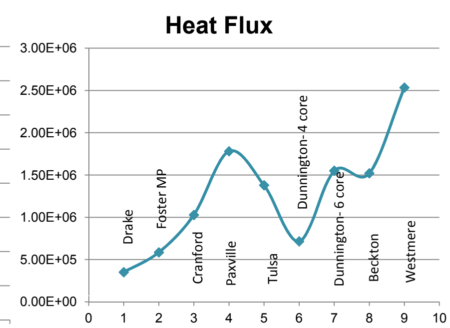
Heat Density Challenge

Intel Xeon processor family– **Servers, 7000 series**





Years of the 21-st century

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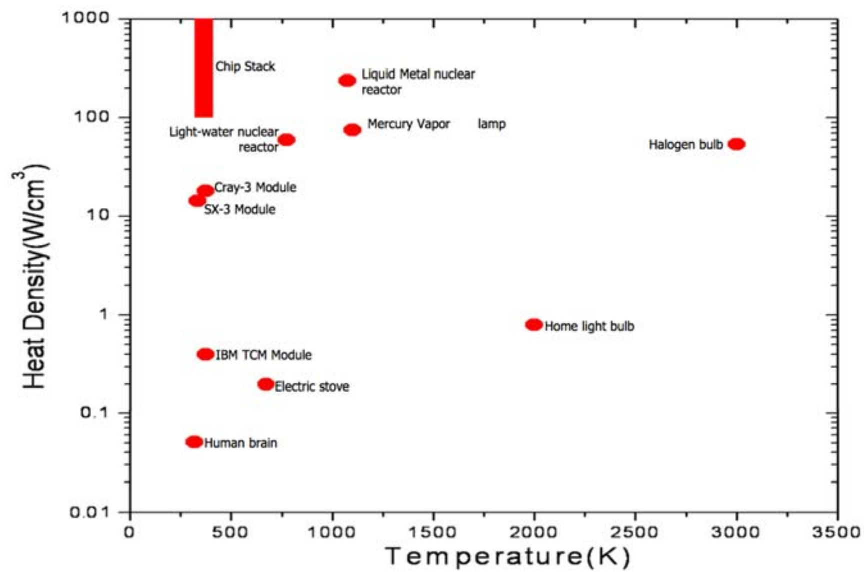
Heat Density Challenge



* Prof. A. Bar-Cohen, IMAPS, AWT, 2011

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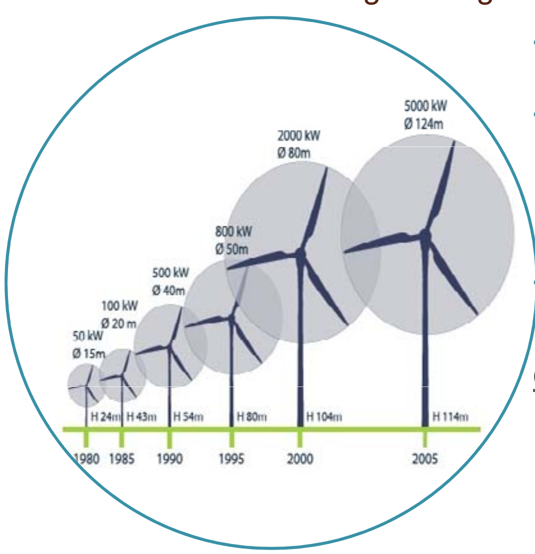
Power Electronics: Evolution in Wind-Energy Engineering



- Increase of peak power up to 7 MW per unit
- High power IGBT-modules and inverters are needed for high efficiency energy conversion
- 1% loss of efficiency at 7 MW = 70 kW heat

Consequences:
Increase of system power = larger power dissipation

→ MORE HEAT

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In Power Electronics More HEAT is generated due to:
- General increase of power capacity of semiconducting devices
- Even the most efficient circuitry design cannot negate negative effects of the absolute increase in power dissipated by a device

In Digital Computational Devices More HEAT is generated due to:
- Increase of computational power due to higher clock rates
- Higher performance by multi-core design architecture

Solution:
- Efficient Thermal design
- Implementation of appropriate cooling method
- Selection of high-efficiency cooling systems and components

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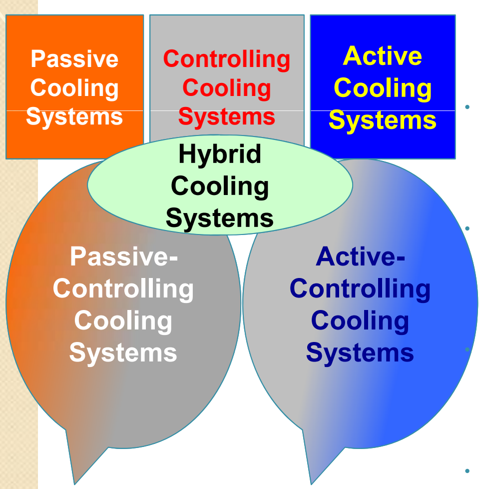
Cooling Systems. Classification



- Passive Cooling System – dissipates heat at the level at or above ambient temperature without possibility of Tj control – Constant current and voltage fans, radiators, cold plates.
- Passive Controlling Cooling System – dissipates heat at the level at or above ambient temperature with a possibility of Tj control – Variable speed and voltage control fans, cold plates with variable flow pumps.
- Active Cooling System – dissipates heat at the level below ambient temperature without possibility of Tj control – Constant voltage thermoelectric devices, Stirling micro refrigerator, closed loop chillers.
- Active Controlling Cooling System – dissipates heat at the level below ambient temperature with possibility of Tj control – Constant voltage thermoelectric devices, Stirling micro refrigerator, closed loop chillers
- Hybrid Cooling System – dissipates heat at any desired level. At the level at or above ambient temperature – Passive Cooling is employed, while at the level below ambient temperature Active Cooling kicks in.

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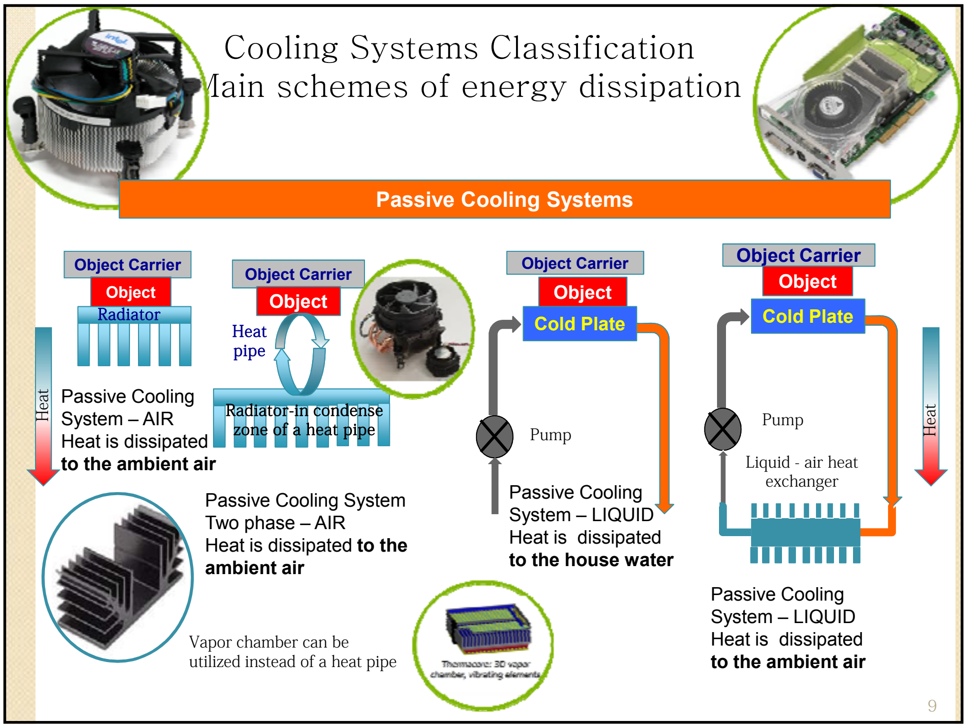
Cooling Systems Classification
Main schemes of energy dissipation
Passive Cooling Systems
Object Carrier
Object
Radiator
Heat
Passive Cooling System – AIR Heat is dissipated to the ambient air
Object Carrier
Object
Heat pipe
Radiator-in condense zone of a heat pipe
Passive Cooling System Two phase – AIR Heat is dissipated to the ambient air
Vapor chamber can be utilized instead of a heat pipe
Object Carrier
Object
Cold Plate
Pump
Passive Cooling System – LIQUID Heat is dissipated to the house water
Object Carrier
Object
Cold Plate
Pump
Liquid - air heat exchanger
Heat
Passive Cooling System – LIQUID Heat is dissipated to the ambient air
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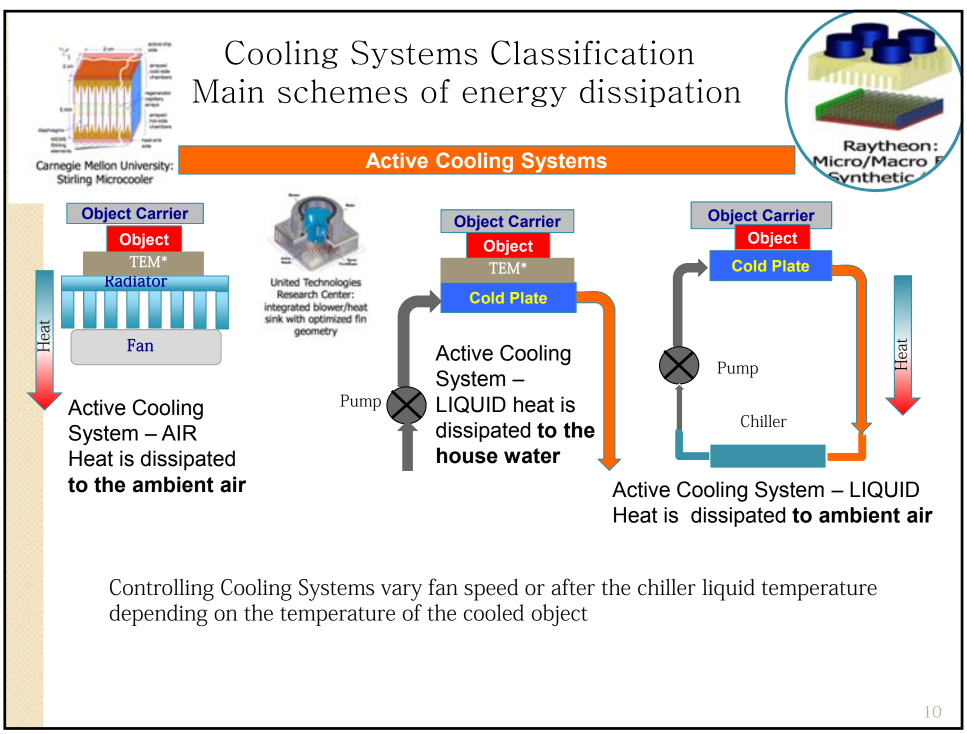
Cooling Systems Classification
Main schemes of energy dissipation
Carnegie Mellon University: Stirling Microcooler
Active Cooling Systems
Raytheon:
Object Carrier
Object
TEM*
Radiator
Fan
Heat
Active Cooling System – AIR Heat is dissipated to the ambient air
United Technologies Research Center: integrated blower/heat sink with optimized fin geometry
Object Carrier
Object
TEM*
Cold Plate
Pump
Active Cooling System – LIQUID heat is dissipated to the house water
Object Carrier
Object
Cold Plate
Pump
Chiller
Heat
Active Cooling System – LIQUID Heat is dissipated to ambient air
Controlling Cooling Systems vary fan speed or after the chiller liquid temperature depending on the temperature of the cooled object
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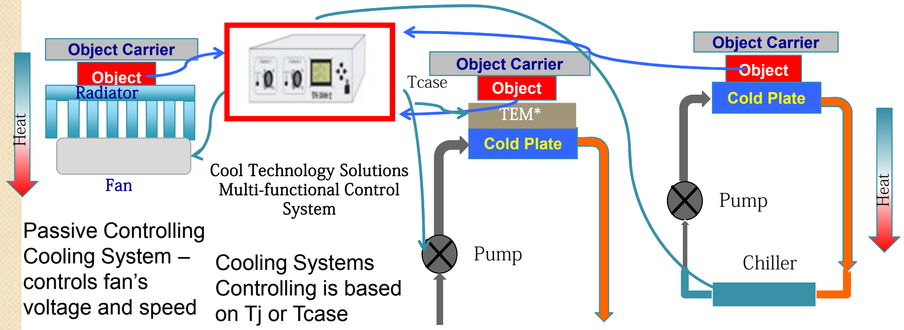
Cooling Systems Classification
Main schemes of energy dissipation

Controlling and Hybrid Cooling Systems



Passive Controlling Cooling System – controls fan's voltage and speed

Cooling Systems Controlling is based on Tj or Tcase temperature of the object being cooled

Active Controlling Cooling System – controls TEM's voltage and/or pump's voltage and speed

Active Controlling Cooling System – controls chiller's temperature set point

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The heat convection is ALWAYS part of heat dissipation because heat from OBJECT may dissipate outside only to air or to Liquid (house water, river, sea)

Type of convection	Heat Transfer Coefficient "h", W/m²K	Advantage	Disadvantage
Natural air convection	From 5 to 10	Cost: zero, very compact	Dissipated heat is limited to no more than 2 W
Forced air convection	From 10 to 200	Very efficient and practical.	Dissipates heat in applications up to 300 W Acoustic noise from fans Requires highly developed dissipating surface
Laminar liquid convection	From 5 to 10^3	Capable of dissipating up to 800 W of heat Utilizes low pressure, therefore low acoustic noise pump	Expensive. Requires cold plates with micro structures to significantly increase contact area
Turbulent liquid convection	From 10^3 to 5*10^5	Capable of dissipating up to 30 kW	Requires usage of high pressure powerful pumps
Two phase : water boiling, vapor chamber..	Two phase water boiling 10^6	Can dissipate almost any amount of heat	Next to impossible to create compact solutions. Require special device for vapor condensation

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Heat Transfer / Convection

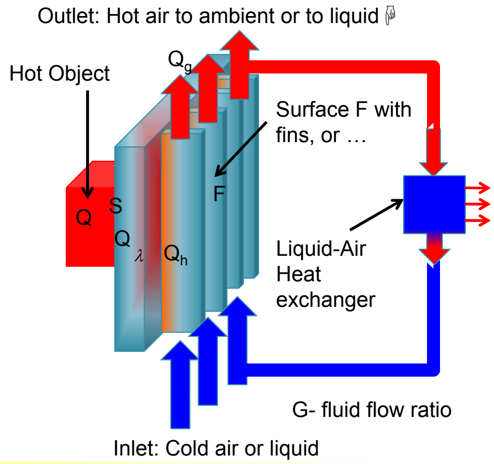
Mechanism:

- Entrainment of thermal energy in a flowing liquid or gas.

$Q_h = h*F * (T_f - T_{avr.env})$
$Q_g = G*c*(T_{out} - T_{in})$
$Q_h = Q_g$;

S- contact surface area, F- surface area of radiator or cold plate; F/S- coefficient of finned surfaces

Utilization of lower $T_{avr.env}$ (cryogenic liquids) to increase dissipated heat is impossible in semiconductors industry as many semiconducting devices (example: transistors in microprocessors' technology with less than 60 nm) are freezing at temperatures below minus 30° C



Main scientific and engineering direction of Cool Technology Solutions, Inc.: development of devices where turbulent convection is achieved artificially at low media velocities (at velocities 8 to 10 times lower than where usual laminar-to-turbulent transfer happens)

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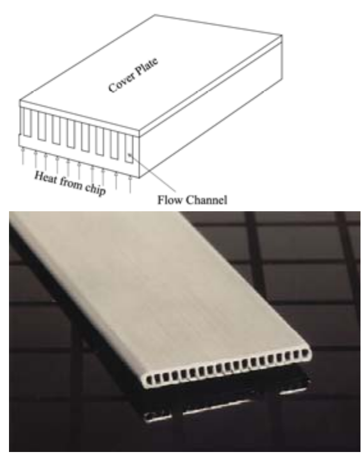
Main Liquid Cooling Technologies on a Market

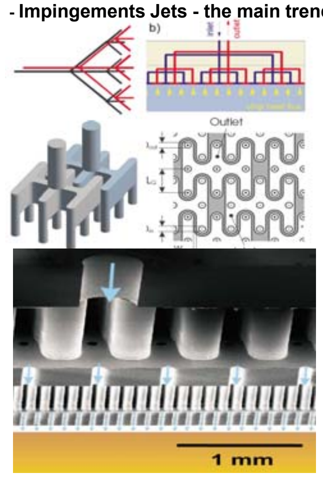
WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...

Contact surface is comprised of:
- pins, plates, pin-fins with some increasing properties using diamond pins, pimples, dimples and etc
- **Micro-channels as the main trend**



Highest results of thermal performances
Micro-channels

Most modern heat transfer devices implement:
- Synthetic Jets
- **Impingements Jets - the main trend**



Highest results of hydraulic performances
Impingements Jets

Industry/University Cooperative Research Centers Program - http://www.nsf.gov/pubs/2002/nsf01168/nsf01168ff_photo_02.htm
Single-phase, miniaturized convective cooling- http://www.zurich.ibm.com/st/cooling/convective.html

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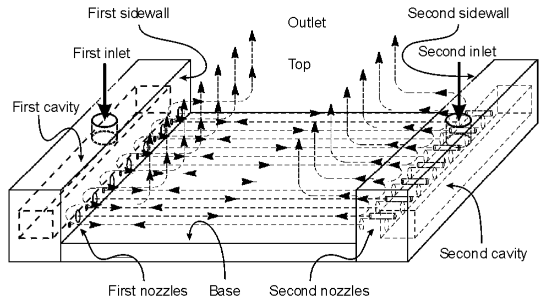
WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...

SUBMERGED JETS
New Generation of Cooling Technologies
CONCEPT AND BRIEF SUMMARY

The first implementation of Submerged Jets Cooling Technologies family, new single-phase liquid cooling system* - **Collider Jet™** Cooling Technology - was unveiled in September of 2010 at Intel Development Forum.

This cooling system for processors had utilized sets of jets directed towards each other with relative micro shift on the central axes snuffed to achieve sharp artificial turbulization of streams. Although not the best in the "family", it is representative of physical processes that take place inside, and therefore deserves detailed description.



Concept of Jet Cooling Technology

*Volodymyr Zrodnikov, Mikhail Spokoyny, "Interlocked jets cooling method and apparatus", Patent Appl No.: US 2011/0042041 A1, Date of Patent: Aug.18, 2010.

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WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...

JET COOLING SYSTEM FOR MICROPROCESSORS
DESIGN REALIZATION, CFD and Experimental Data

Heat sinks were made of copper and aluminum and had the following basic geometrical characteristics:

Overall dimensions	Array of Jets dimensions
20 x 26 x 14 mm	from 0.05 x 0.05 mm
30 x 46 x 26 mm	to 0.9 x 0.9 mm
55.6 x 55.6 x 23 mm	and Diameter
88 x 93 x 26 mm	from 0.1 mm
140 x 180 x 26 mm	to 0.9 mm

Pin dimensions	Gap between pins
from 0.5 x 0.5 x 3.8 mm	from 0.25mm
to 1.2 x 1.1 x 6.8 mm	to 1.2 mm

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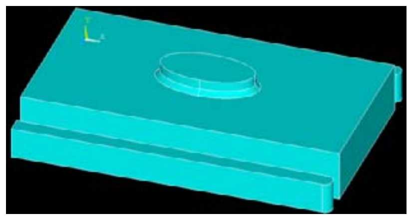
WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...

DIRECT NUMERICAL SIMULATION OF OPPOSING JETS FLOW STRUCTURE

Navier-Stokes equations along with a system of non-stationary, three-dimensional continuity expressions constituted system's mathematical model. These were resolved using icoFoam and turbFoam solvers from the hydrodynamic modeling system OpenFOAM along with pre and post-processor data preparation systems Salom and Paraview.

Direct numerical simulation Computational domain is presented on pictures. As seen from these images, the computational domain represents the flow volume of filling the manifold.



Computational domain. General view.

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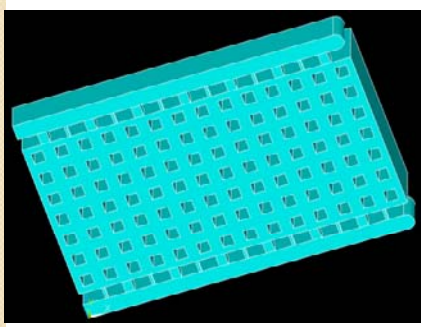
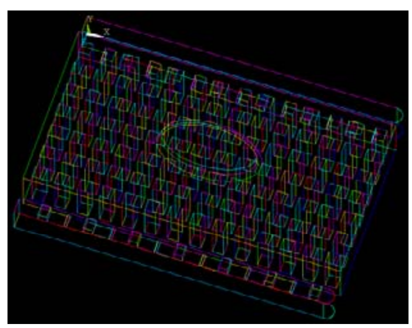
WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...





Computational domain. Bottom view. Computational domain. Frame.

Time-dependent hydrodynamic interaction of opposing jets and coolant flow animation were obtained from simulations.

As an example, on these pictures show typical images of the velocity distribution U and flow structure in the characteristic section of the computational domain during developed steady flow.

The presented results allow to understand the nature of coolant flow inside the heat sink, making it possible to tailor geometrical parameters for prototyping and fabrication of experimental samples.

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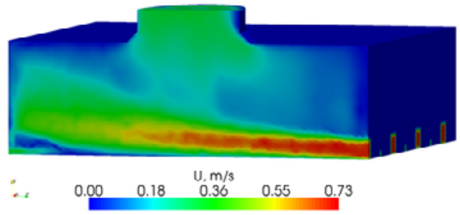
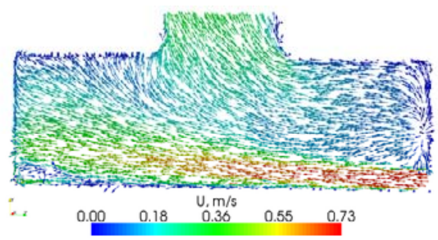
WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...



Typical distribution of flow velocity U in the gap between the pins located in the plane of symmetry of computational domain. Main nozzles 0.7 x 0.7 mm, support nozzles 0.12 x 0.12 mm.



Typical flow structure in the gap between the pins located in the plane of symmetry of computational domain. Main nozzles 0.7 x 0.7 mm, support nozzles 0.12 x 0.12 mm.

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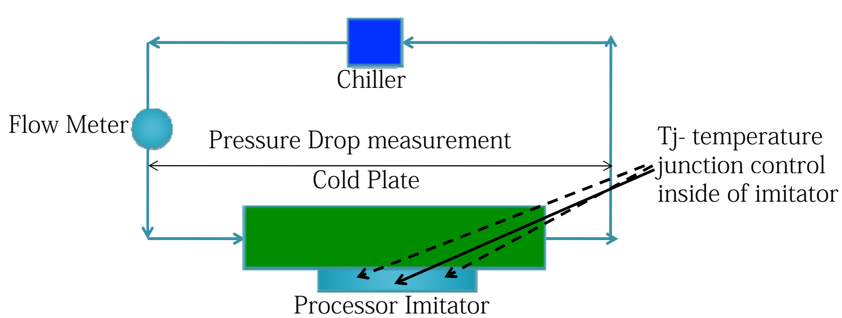
WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...

EXPERIMENTAL RESULTS

The section presents experimental results of the thermal resistance as a function of the flow rate in aforementioned cold plates. Experimental setup's schematic drawing is shown on the picture. The temperature of the Processor Imitator was measured by a thermocouple, embedded in the center (and ¼, and ¾ of size) of Imitator and connected to a data acquisition system. Coolant's flow rate varied between 0.1 GPM and 4 GPM. Corresponding pressure drops varied between 2 psi and 35 psi. Footprint cold plate 3"x 3" (77mm x 77mm)



Experimental setup's schematic drawing

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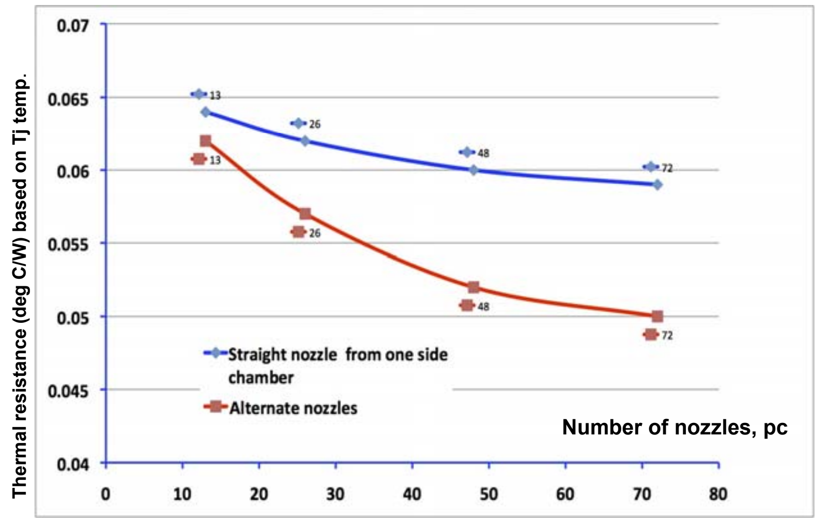
WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...

Comparison results between straight and alternate jets with the same total cross section area



Cold Plate's thermal resistance as a function of the method and number of nozzles

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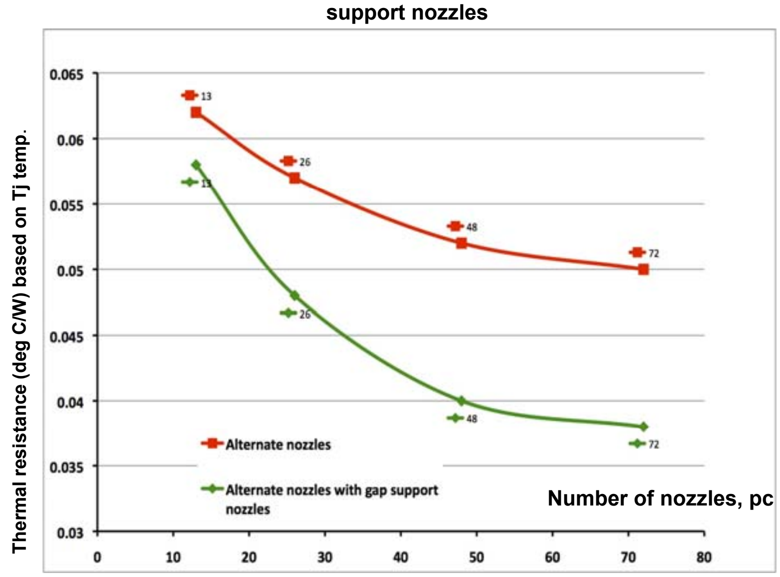
WHAT KIND of TECHNOLOGY SHOULD BE NEXT?...

Comparison results between alternate jets and alternate jets with gap support nozzles



Cold Plate's thermal resistance as a function of the method and number of nozzles

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WHAT KIND of TECHNOLOGY SHOULD BE NEXT?....

CONCLUSION - 1

Thermal Performances (based on Thermal resistance)	Hydraulic Performances (based on pressure drop)
Best	Best
Micro channels	Impingement Jets
Collider Jets™ – Alternate horizontal jets with gap support jets	Straight horizontal jets
Impingement Jets	Collider Jets™ – Alternate horizontal jets with gap support jets
Alternate horizontal jets	Alternate horizontal jets
Straight horizontal jets	Micro channels
Worse	Worse

Collider Jets™ Cooling Technology main advantage –
Highly efficient thermal performance (although not as high as for Micro channels)

Collider Jets™ Cooling Technology main disadvantages –
High pressure drop (poor hydraulic performances)
Inability to dissipate heat from local hot spots

SOLUTION?
Next generation of SUBMERGED JETS Cooling Technologies: Vortex Alternate™, Swirling Jets-Stream ™, and Wave Jets™

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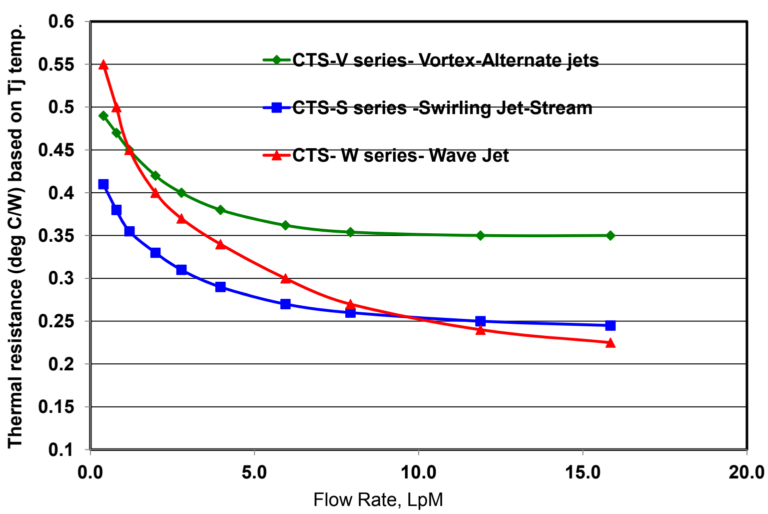
The NEXT COOLING TECHNOLOGY

Next Generation of SUBMERGED JETS Cooling Technologies – Vortex Alternate™, Swirling Jets-Stream ™, and Wave Jets™
Comparison of preliminary results

Thermal Performances vs. Flow Rate



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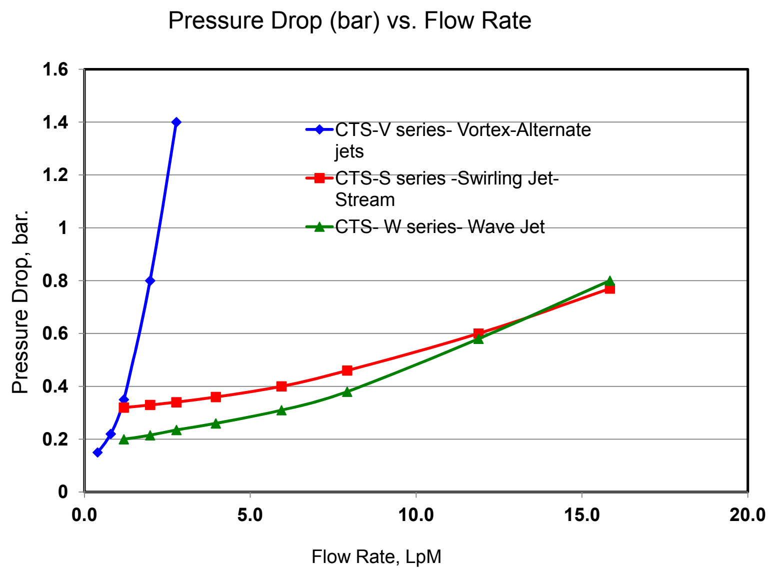
The NEXT COOLING TECHNOLOGY

Next Generation of SUBMERGED JETS Cooling Technologies – Vortex Alternate™, Swirling Jets-Stream ™, and Wave Jets™
Comparison of preliminary results



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The NEXT COOLING TECHNOLOGY

Preliminary CONCLUSION - 2

Thermal Performances
(based on Thermal resistance)

Best

- **Swirling Jets-Stream™** | **Micro channels** low Re numbers
- Wave Jets™
- Collider Jets™ - Alternate horizontal jets with gap support jets
- Impingement Jets
- Vortex-Alternate Jets™
- Alternate horizontal jets
- Straight horizontal jets

Worse

Hydraulic Performances
(based on pressure drop)

Best

- **Wave Jets™** | **Impingement Jets** low Re numbers
- Swirling Jets-Stream™
- Straight horizontal jets
- Vortex-Alternate Jets™
- Collider Jets™ – Alternate horizontal jets with gap support jets
- Alternate horizontal jets
- Micro channels

Worse

New Parameter – Technology's Ability to dissipate heat from a local hot spot

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The NEXT COOLING TECHNOLOGY

Preliminary CONCLUSION - 3

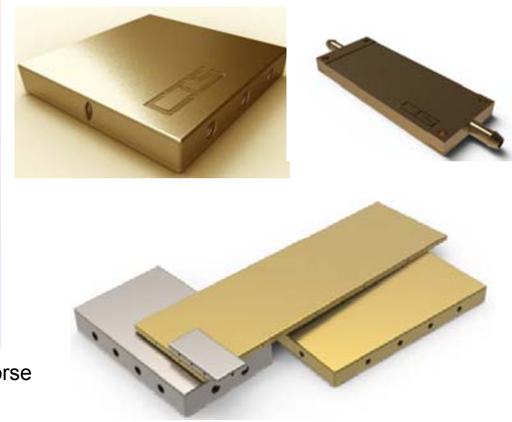
Ability to dissipate heat from local hot spot
(max Thermal Performance for max Heat Flux based on Local Thermal Resistance)

Best

- **Swirling Jets-Stream™**
- Impingement Jets
- Wave Jets™
- Micro channels
- Vortex-Alternate Jets™
- Alternate horizontal jets
- Collider Jets™ -Alternate horizontal jets with gap support jets
- Straight horizontal jets

Worse

Samples of manufactured cold plates and heat exchangers implementing Submerged Jets Cooling Technologies developed by Cool Technology Solutions, Inc.



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The NEXT COOLING TECHNOLOGY - SUBMERGED JETS

Preliminary CONCLUSION - 4

So far, among all existing on the market thermal management technologies ideal can not be found, each one has its disadvantages and limitations.

Usually better thermal performance (efficiency of heat transfer) is accompanied by either worse hydraulic properties, or limited, if any, capability of handling of (to dissipate heat from) a local hot spot.

New **SUBMERGED JETS Cooling Technologies – Vortex Alternate™, Swirling Jets-Stream ™, and Wave Jets™ (US Patent Pending Applications)** are not ideal either, but have already shown unique capabilities and extremely impressive performance.

We are very optimistic about New **SUBMERGED JETS Cooling Technologies** and it capabilities and prospects, and are pretty sure that for each specific request for any specific application we will be able to find the best applicable technology and solution capable of meeting requested set of parameters.

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THANK YOU!
ANY QUESTIONS ?

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