Technology for Increasing the Density of Air Cooled Power Supplies

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Charlotte, NC

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Outline

- Introduction
- Trends in Industry
- Innovative Thermal Management Solutions
- Questions and Answers

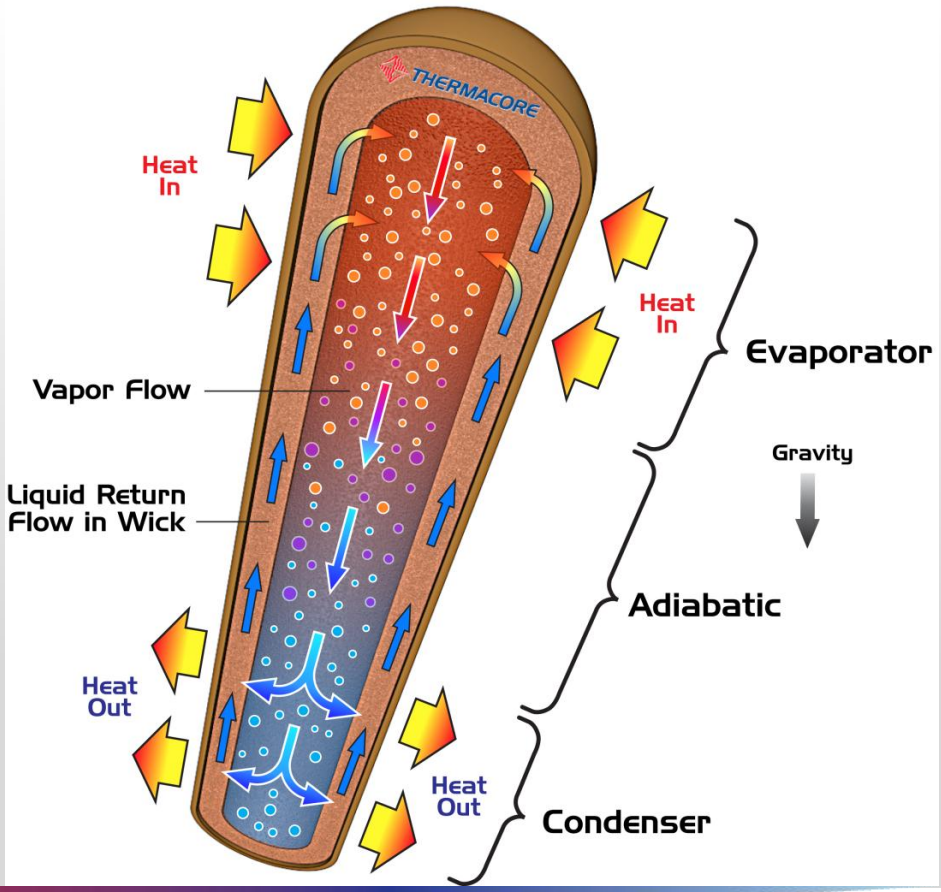
Trends & Challenges in Power Supply Cooling

- Trends
  - Increasing Power
  - Faster Digital Signal Processing
  - New Semiconductor Materials
    - Gallium Arsenide (GaAs)
    - Gallium Nitride (GaN)
    - Silicon Carbide (SiC)
- Challenges
  - Reduction in SWaP-C Requirement
    - Size, Weight, Power and Cost (SWaP-C)
  - Need for Innovative, High Performance Cooling
    - To drive power and improve efficiency

Heat Pipe Technology…a method to hold off transitioning to liquid cooling.

Heat pipes move or spread heat from a concentrated heat source to a heat sink for dissipation to a coolant through forced or natural convection.

- **Evacuated, Sealed,** Vacuum **vessel with liquid**
- **Evaporation and condensation**
- **Silent and Passive**
- **Very low temperature drop or DT**
- **Can operate against gravity**
- **Various geometries**
- **> 20 years of operation with Cu/Water**
- **Reliability:**
  - **Calculated MTTF >125,000 hours**



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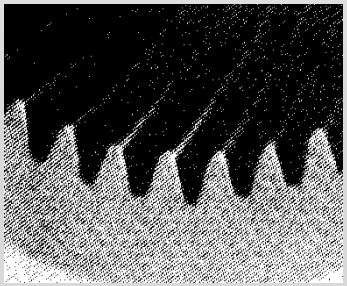
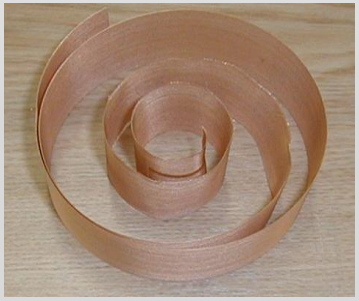
Common Heat Pipe Wick Structures

Wick Structure	Operational Orientation Relative to Gravity	Power Density / Heat Flux Capabilities	Freeze Tolerance (Water)
Wickless (i.e. Thermosyphon)	+90° to +5° "Orientation Sensitive"	Up to 5 W/cm^2 "Very Low Density"	No
Grooves	+90° to +0° "Orientation Sensitive"	Up to 10 W/cm^2 "Low Density"	No
Screen/Wire	+90° to -5° "Orientation Sensitive"	Up to 15 W/cm^2 "Medium Density"	No
Sintered Powder	+90° to -90° "Orientation Insensitive"	> 15 W/cm^2 (350 W/cm^2 achievable) "High Density"	Yes

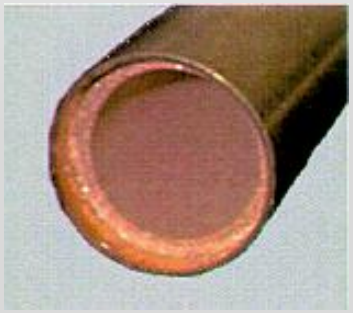
Groove Wick



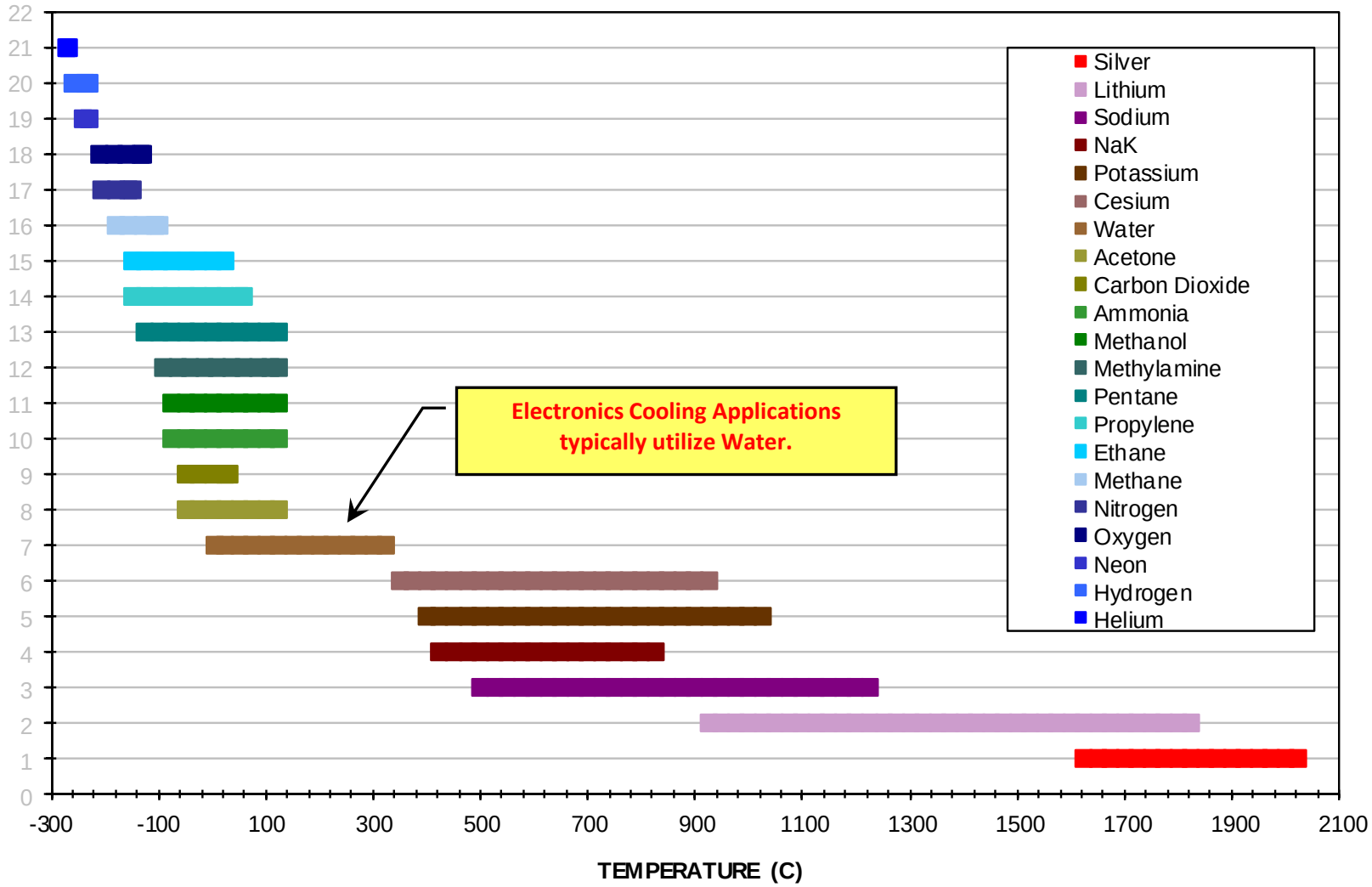
Screen/Woven Wick



Sintered Powder Wick



Heat Pipe Working Fluids



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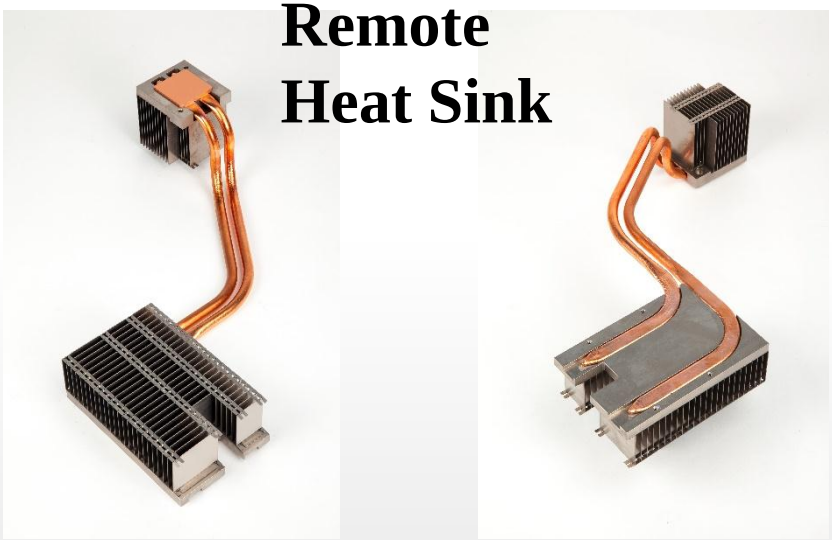
Heat Pipe Assembly Examples

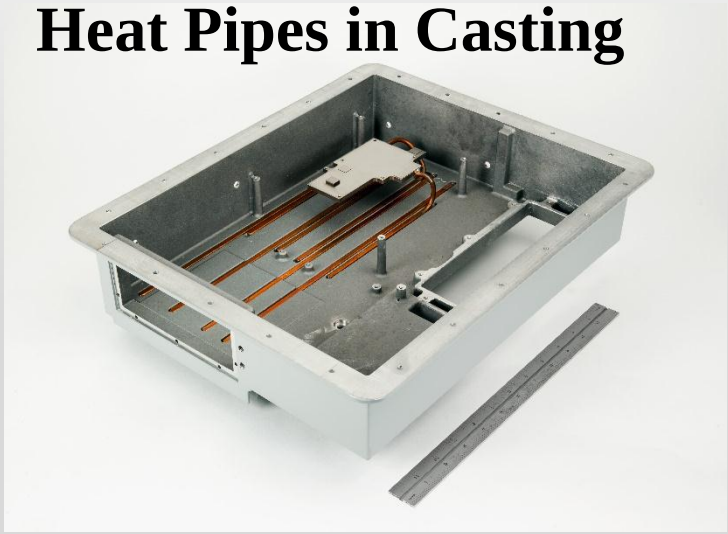
Remote Heat Sink



Embedded Heat Pipe Heat Sink

Flat Vapor Chamber Heat Sink

Heat Pipes in Casting



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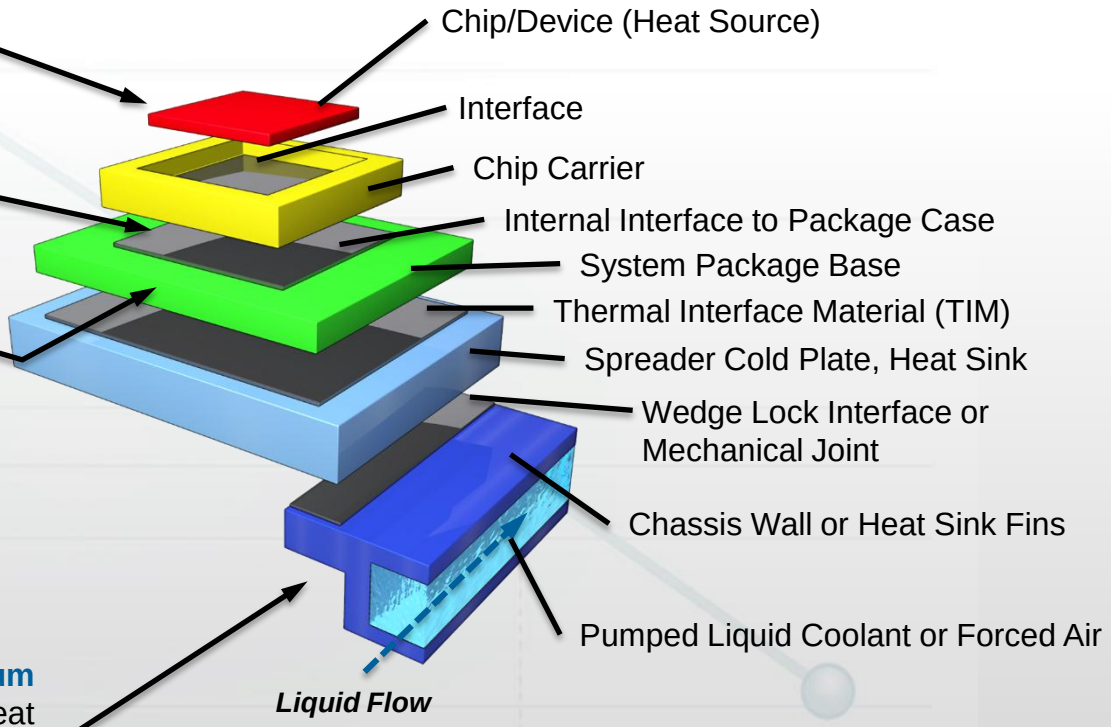
New Technology…Reduce the Internal Packaging Thermal Resistance

Chip-scale Thermal Management
Objective: Reduce Intra-device Temperature Rises

Thermal Interfaces (Multiple)
Objective: Reduce Thermal Interface Resistance (i.e. Temperature Rise)

Heat Spreading
Objective: Low Temperature Rise Spreading with Minimal Thickness using a **Heat Pipe Thermal Ground Plane (TGP) - DARPA Funded**

Heat Transport to Ultimate Heat Sink Medium
Objective: Low Thermal Resistance Heat Rejection in Limited Volume and Minimal Power Input with **MACE Technology**



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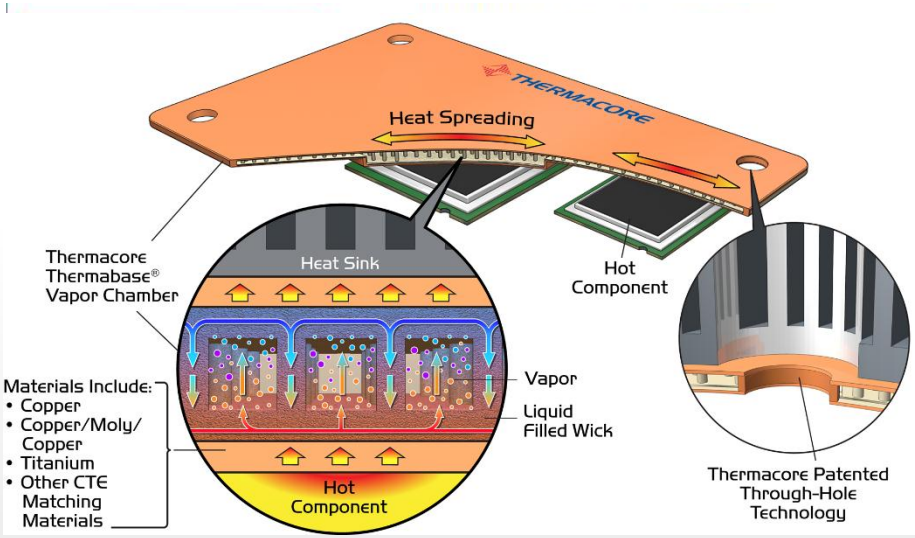
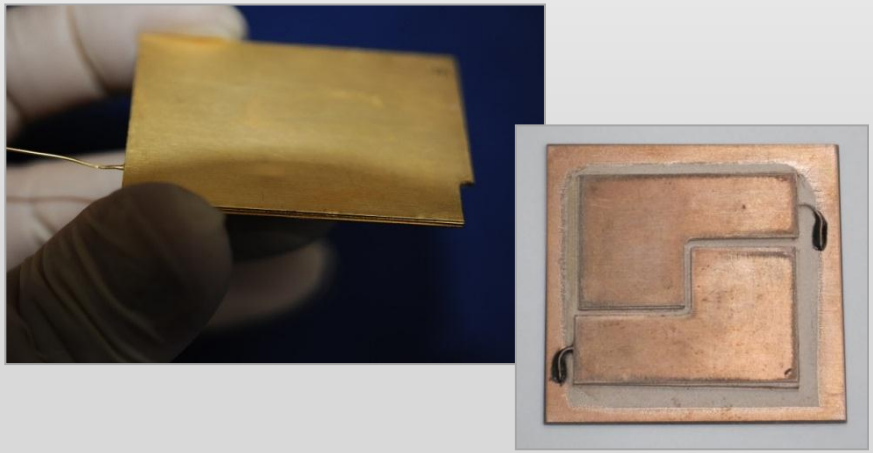
CTE Matching - Thermal Ground Plane (TGP)

- **Challenge**
  - **High-Thermal Conductivity Substrates for Multi-Chip Modules (MCM)**
  - **Large Increases in Power Density Transport over current MCM substrates (ex. CuMo)**
- **Cooling Approach**
  - **Heat Pipe Two-Phase Cooling**
    - **Very High Thermal Conductivity (>600 W/m·K)**
    - **Extreme reliability**
    - **Passive: No moving parts or need for external power**
  - **CTE Matching Materials**



- **Benefits to Systems**
  - Large increases in power density heat transport over current MCM substrates;
  - Ability to operate under 20 g acceleration
  - Thin, planar geometries
  - Low Density
  - Thermal Expansion Coefficients matched to within 1% of a chosen semiconductor material (e.g. Si, GaAs, GaN, SiC)
  - Extreme Reliability: Indefinite operation with no degradation in thermal performance.

Thermal Ground Plane Product Examples



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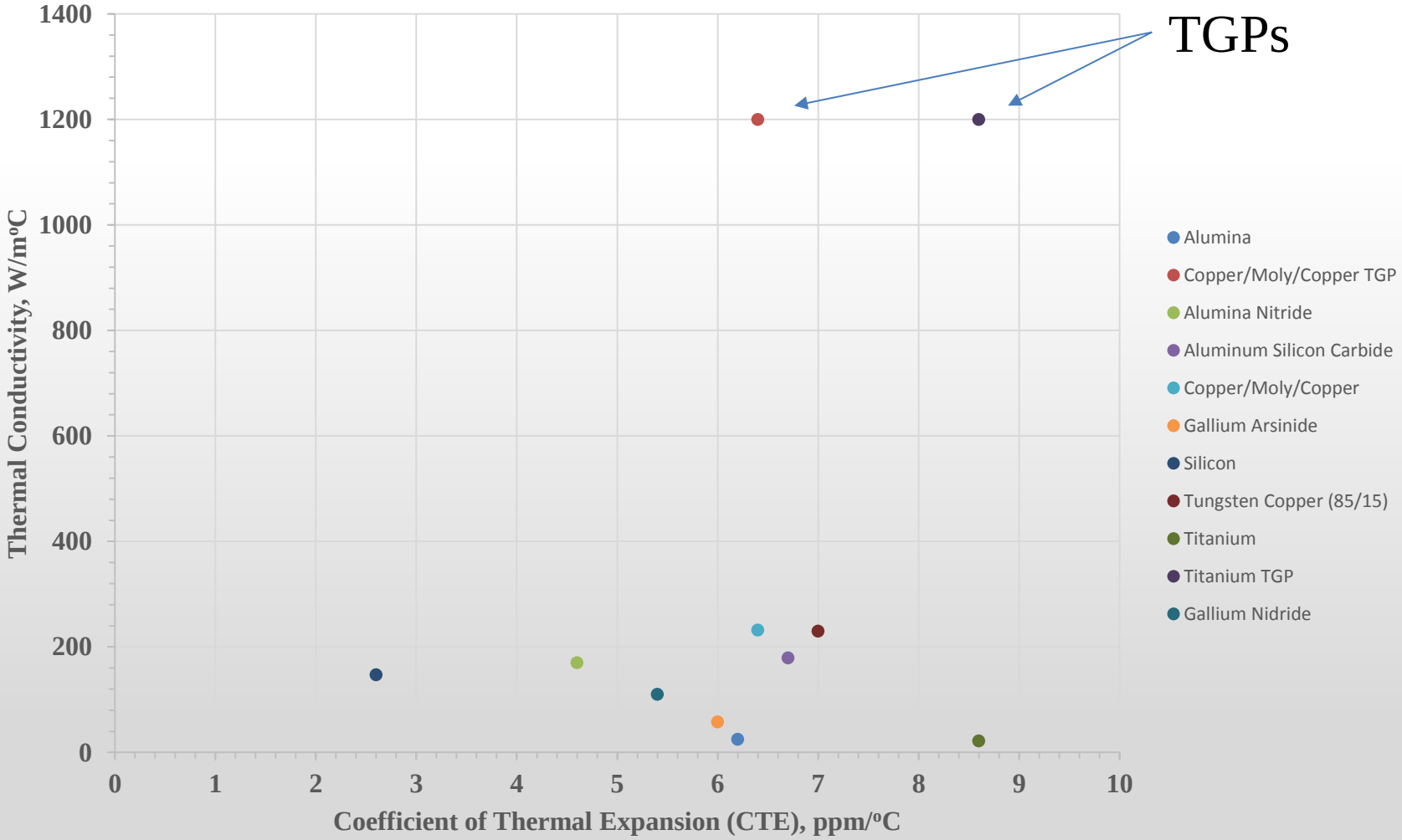
CTE Comparison of Electronic Materials to CTE matching TGPs



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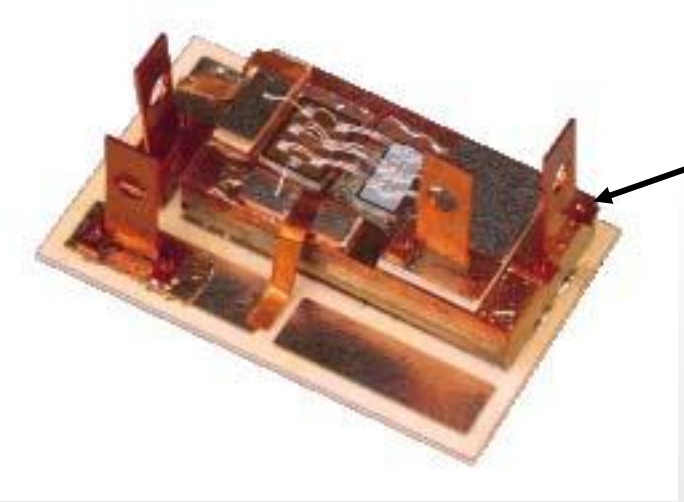
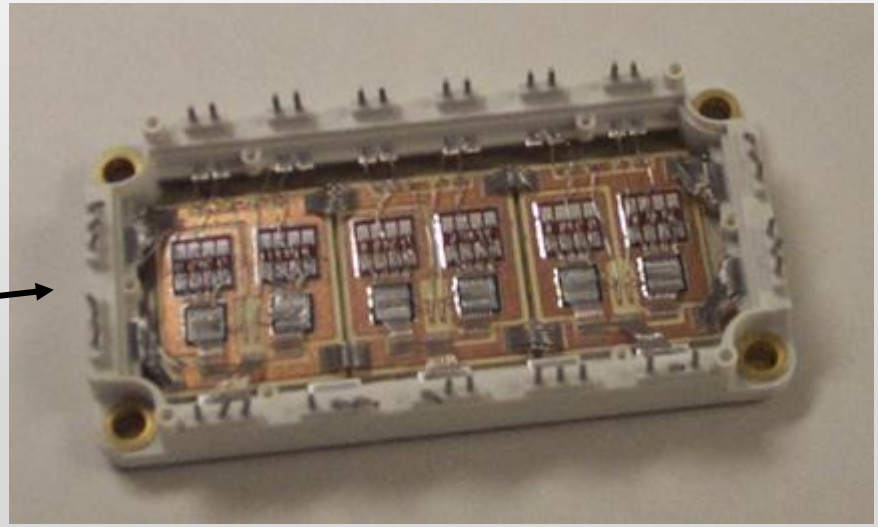
Reducing the Internal Packaging Thermal Resistance



Heat Pipe TGP to spread heat from die.

Example: Internal view of an IGBT module

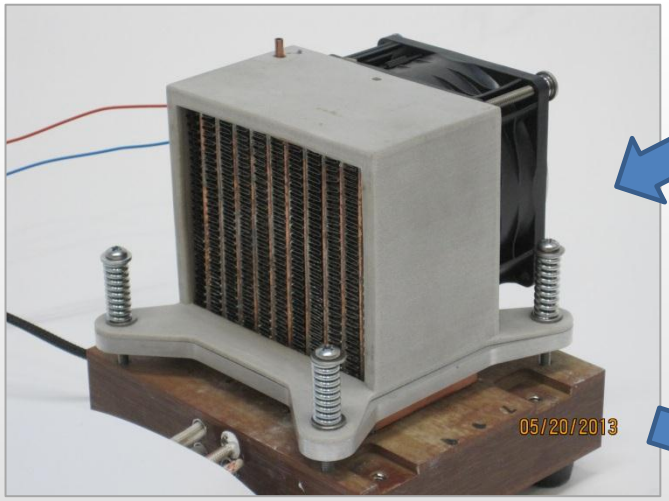


Power Electronics Device Level Cooling
Internal Cooling of an IGBT

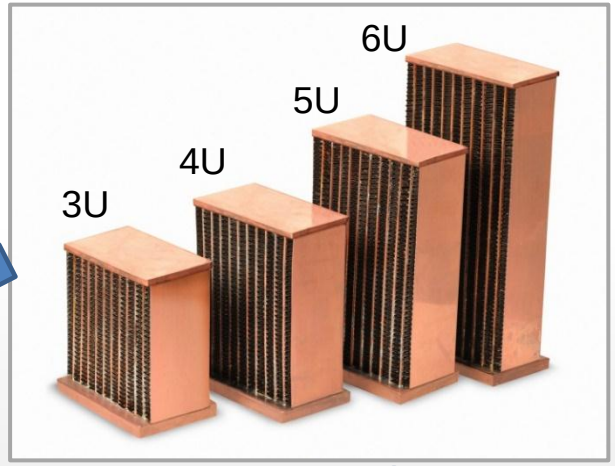
Replace the Solid Copper Base of the IGBT with a Heat Pipe Plate to obtain better heat spreading into the heat sink.

Next Step: Micro-technologies for Air Cooled Exchangers (MACE)

3-dimensional spreader



MACE Compact Heat Exchanger Assembly with Fan, Shroud, and Mounting Hardware



MACE Compact Heat Exchanger Core

MACE Compact Heat Exchanger Assembly installed within an Application

Take Away: This technology postpones the need to transition to liquid cooling.

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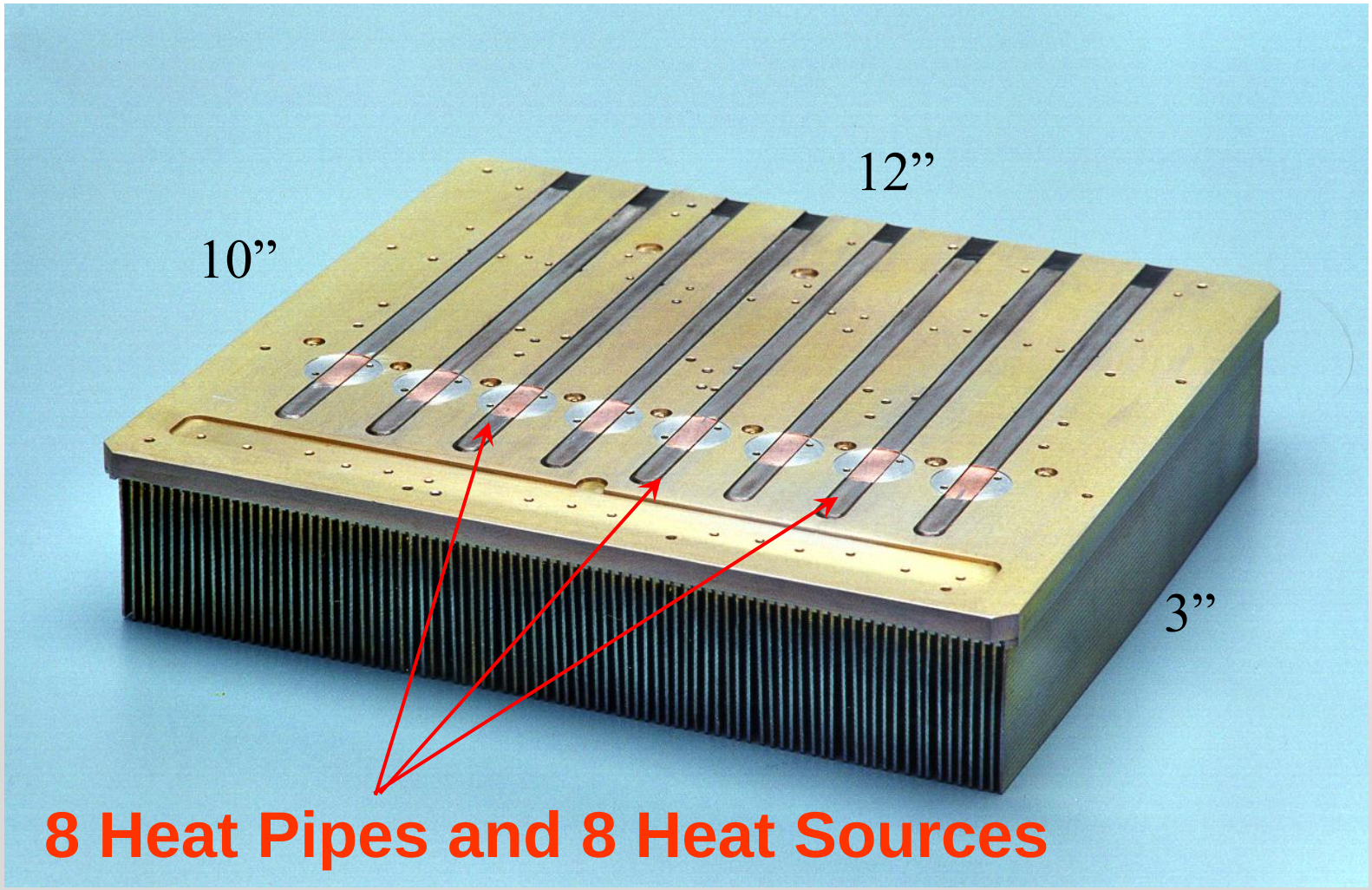
Industry Application Examples

Improved Air Side Cooling of Power Electronics with Heat Pipe Augmented Bonded Fin Heat Sink



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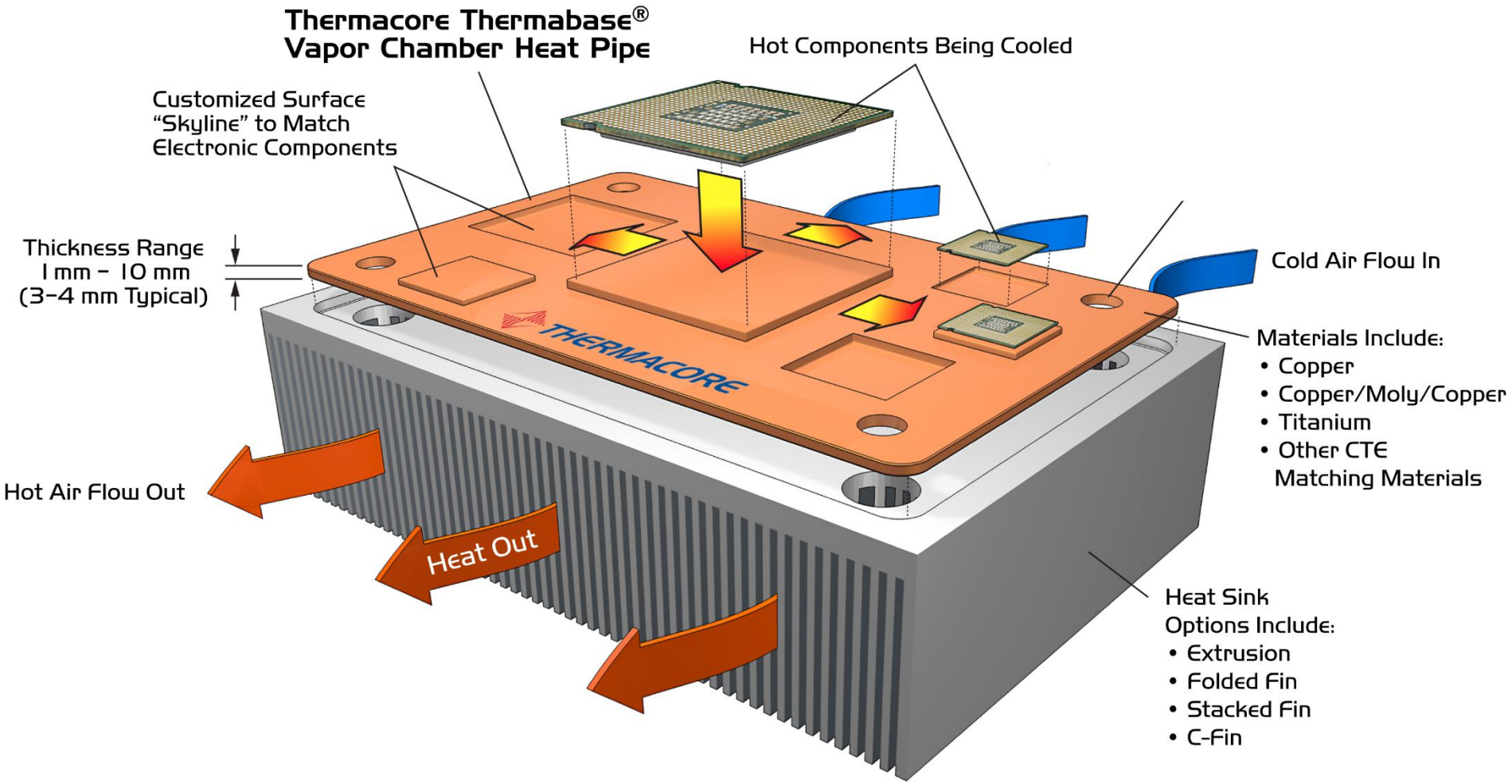
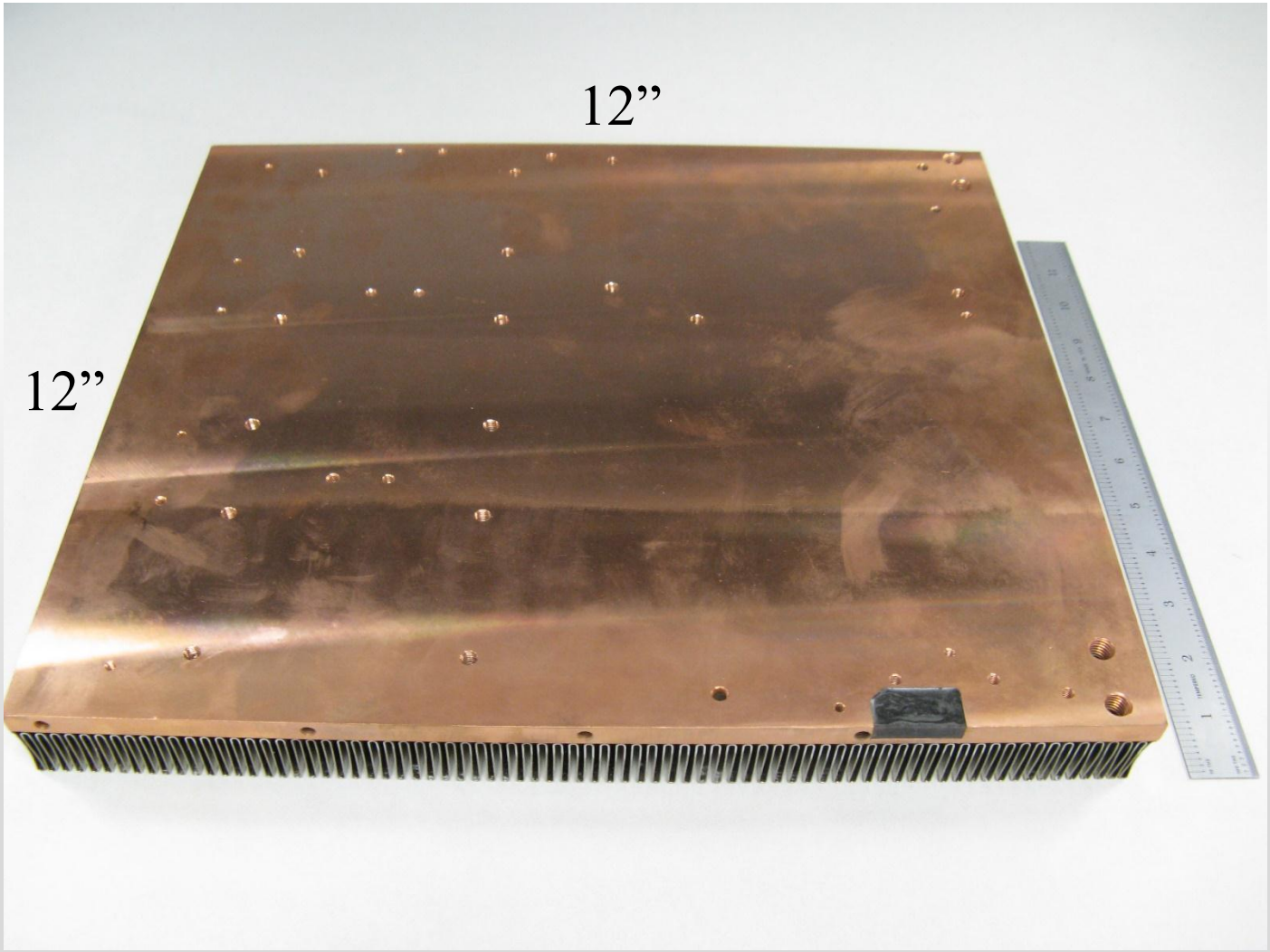
Flat Plate Heat Pipe Geometry in Heat Sink



Example: Improved Air Side Cooling of Power Electronics with Heat Pipe Augmented Heat Pipe Vapor Chamber



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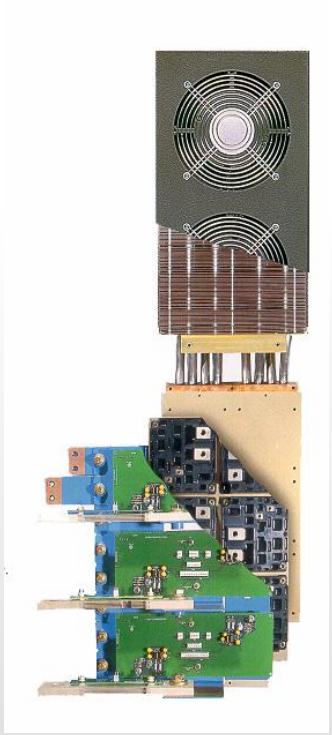
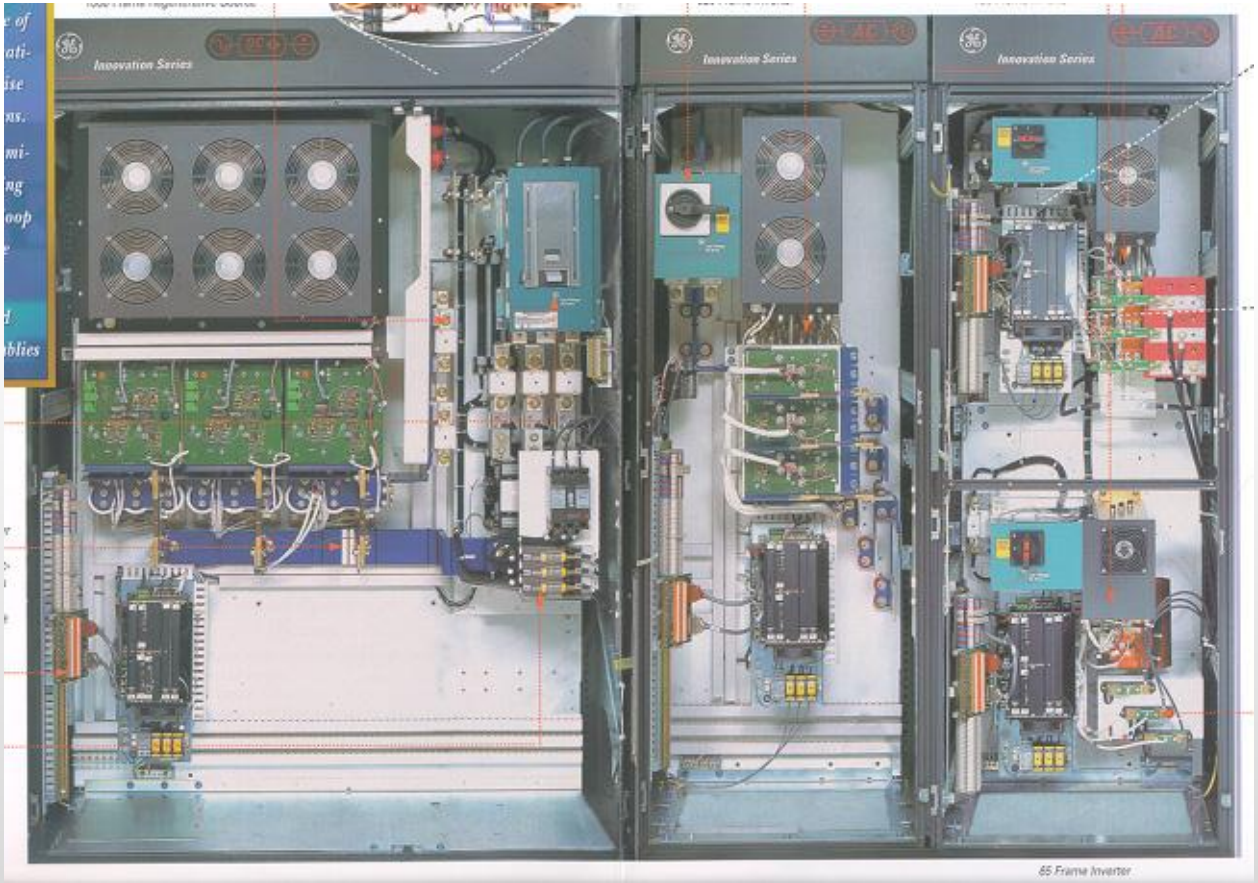
Multi-Kilowatt Heat Pipe Heat Sink Installations





Air Cooled Systems

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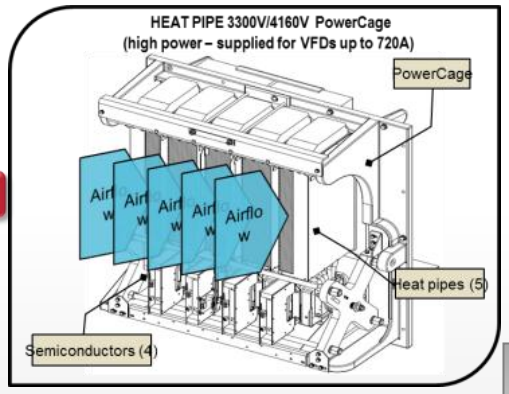
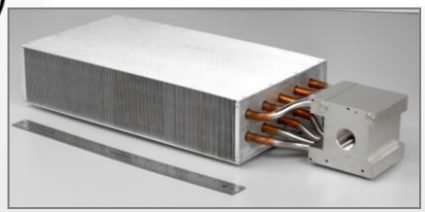
Motor Drive Electronics Cooling - Remote Heat Pipe Heat Sink





20” x 9” x 4”

Custom SGCT Passive Heat Pipe Heat Sink

- **Power Rating:** 2400 Watts each
- **Nom. Air Flow:** 300 CFM
- **Heat Pipes:** Ten ½” Dia. Cu/Water
- **Operating Range:** 5°C - 125°C
- **Storage Temp. Range:** - 40°C to 150°C
- **Fin Material / Pitch:** Aluminum / 12 fins/inch

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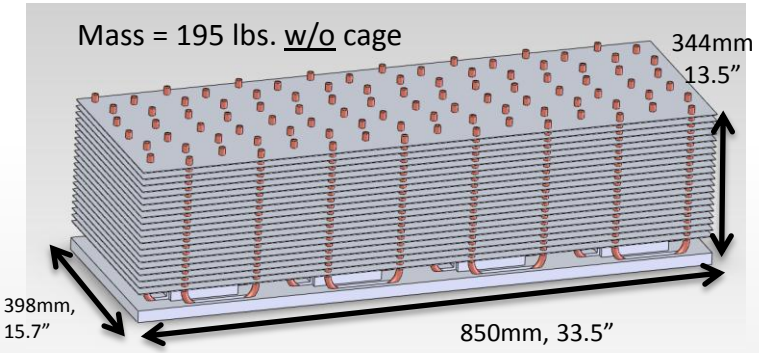
Power Electronics

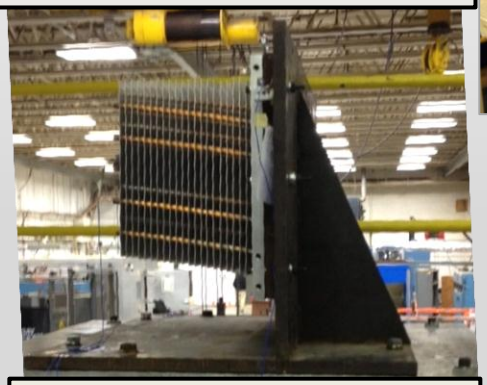
Transportation – Light Rail IGBT Cooling

- **Application:**
  - Light Rail Propulsion System Inverter Power Electronics Cooling
- **Product:**
  - Heat Pipe Heat Sink Assembly
  - Application: Inverter Electronics Cooling



- **Technical**
  - Power Rating: 2.8kW Avg., 9.6 kW peak
  - Nom. Air Flow: varies with train motion
  - Number of Pipes: 32
  - Diameter of Pipe: 12.7mm
  - Working Fluid: Water

19” wide x 41” long x 18” tall



Weight = 195 lbs. w/o Cage

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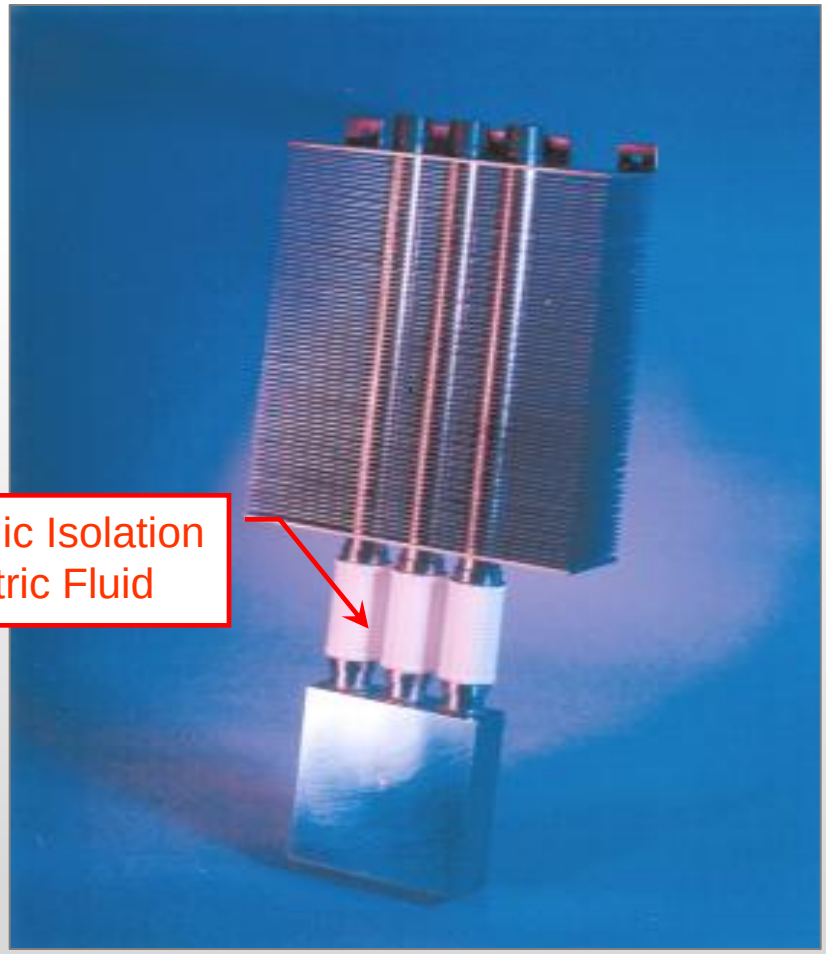
High Speed Train – Electronically Isolated Electronics Cooling



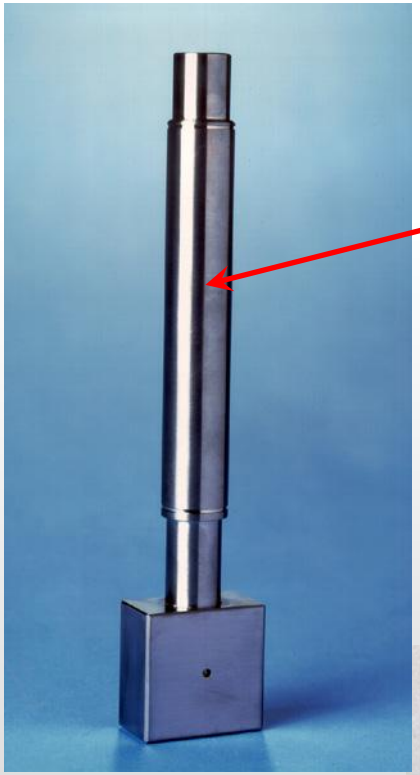
- Application: Thyrister Cooling
- Power: 350 Watts
- Voltage Potential: 5kV
- Fluid: FC-72 Dielectric
- Ceramically Isolated

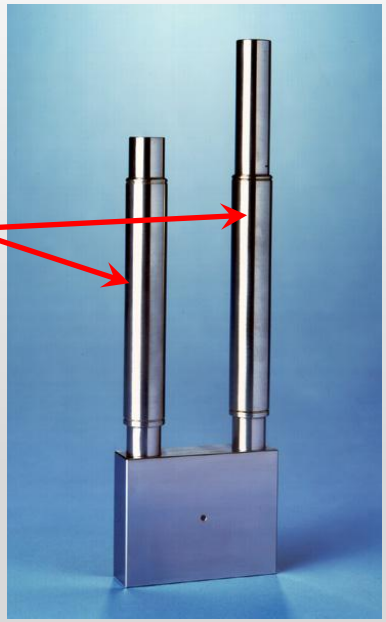
Power Electronics
Transportation

- Application: IGBT Cooling in Locomotive
- Production: >200 Units
- Thermacore P/N: 1300
- Power Rating: 1800 watts
- Nom. Air Flow: 600 CFM
- Number of Pipes: 12
- Diameter of Pipe: 0.75 in.
- Working Fluid: Water

Ferrite Core Cooling
Locomotive Inverter

- Application: Ferrite Core Cooling for Locomotive Inverter
- Heat Load: 150 W
- Thermal Resistance: 0.2 °C/W
- Heat Pipe: Copper with Methanol
- Production: >70,000 Units Supplied





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Heat Pipes for Traction

- Application: Traction
- Production: 5000 Units since 1996
- Power Rating: 700 watts
- Application: Embedded in Extrusion under IGBT in an APU Unit
- Diameter of Pipe: 0.625 in.
- Working Fluid: Water

Electrolytic Capacitor Cooling

Heat Pipe

Bring the heat to the base.

Questions and Answers

Thank You!