Technology for Increasing the Density of Air Cooled Power Supplies

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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
## Common Heat Pipe Wick Structures

<table>
<thead>
<tr>
<th>Wick Structure</th>
<th>Operational Orientation Relative to Gravity</th>
<th>Power Density / Heat Flux Capabilities</th>
<th>Freeze Tolerance (Water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wickless (i.e. Thermosyphon)</td>
<td>+90° to +5° “Orientation Sensitive”</td>
<td>Up to 5 W/cm² “Very Low Density”</td>
<td>No</td>
</tr>
<tr>
<td>Grooves</td>
<td>+90° to +0° “Orientation Sensitive”</td>
<td>Up to 10 W/cm² “Low Density”</td>
<td>No</td>
</tr>
<tr>
<td>Screen/Wire</td>
<td>+90° to -5° “Orientation Sensitive”</td>
<td>Up to 15 W/cm² “Medium Density”</td>
<td>No</td>
</tr>
<tr>
<td>Sintered Powder</td>
<td>+90° to -90° “Orientation Insensitive”</td>
<td>&gt; 15 W/cm² (350 W/cm² achievable) “High Density”</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Common Heat Pipe Wick Structures**

- **Groove Wick**
- **Screen/Woven Wick**
- **Sintered Powder Wick**
Electronics Cooling Applications typically utilize Water.
Heat Pipe Assembly Examples

Remote Heat Sink

Embedded Heat Pipe Heat Sink

Flat Vapor Chamber Heat Sink

Heat Pipes in Casting

5 Heat Input Locations
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
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.
CTE Comparison of Electronic Materials to CTE matching TGPs

![Graph showing comparison of thermal conductivity and coefficient of thermal expansion for various materials.]

- Alumina
- Copper/Moly/Copper TGP
- Alumina Nitride
- Aluminum Silicon Carbide
- Copper/Moly/Copper
- Gallium Arsinide
- Silicon
- Tungsten Copper (85/15)
- Titanium
- Titanium TGP
- Gallium Nitride
Reducing the Internal Packaging Thermal Resistance

Heat Pipe TGP to spread heat from die.

Example: Internal view of an IGBT module
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

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

MACE Compact Heat Exchanger Assembly installed within an Application
Industry Application Examples
Improved Air Side Cooling of Power Electronics with Heat Pipe Augmented Bonded Fin Heat Sink

8 Heat Pipes and 8 Heat Sources
Flat Plate Heat Pipe Geometry in Heat Sink

**Thermacore Thermabase® Vapor Chamber Heat Pipe**

- Customized Surface “Skyline” to Match Electronic Components
- Hot Components Being Cooled

**Thermacore**

**Heat Sink Options Include:**
- Extrusion
- Folded Fin
- Stacked Fin
- C-Fin

**Materials Include:**
- Copper
- Copper/Moly/Copper
- Titanium
- Other CTE Matching Materials

**Thickness Range**
1 mm - 10 mm
(3-4 mm Typical)

**Cold Air Flow In**

**Hot Air Flow Out**
Example: Improved Air Side Cooling of Power Electronics with Heat Pipe Augmented Heat Pipe Vapor Chamber
Multi-Kilowatt Heat Pipe Heat Sink Installations

Air Cooled Systems
Power Electronics
Motor Drive Electronics Cooling - Remote Heat Pipe Heat Sink

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

20” x 9” x 4”
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

Mass = 195 lbs. w/o cage

19” wide x 41” long x 18” tall

Weight = 195 lbs. w/o Cage
Power Electronics
High Speed Train – Electronically Isolated Electronics Cooling

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

- Ceramic Isolation
- Dielectric Fluid
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
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.
Thank You!