

Air Cooling Technology for Advanced Power Electronics and Electric Machines



*U.S. Department of Energy
Annual Merit Review*

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Overview

Timeline

- Project start date: FY06
- Project end date: FY12
- Percent complete: 40%

Barriers

- 15 year life requirement
- High parasitic power
- ***Larger volume***

Budget

- Total project funding
 - DOE share: \$1350k
 - Contractor share: \$0.00
- FY08 Funding: \$350k
- FY09 Funding: \$350k

Partners

- Interactions
 - FreedomCAR Electrical & Electronics Technical Team
 - Delphi, PowerEx, Semikron
- Project lead: NREL

Project Objectives

- Develop air cooling technology that will enable overall system cost reductions to meet the FreedomCAR technical targets (\$8/kW by 2020).
- Eliminate liquid coolant loops.
- Enable heat rejection directly to the sink, namely, ambient air. Simplify the system.
- Maintain die temperature below specified operating limits to assure long-term reliability.

Project Milestones

FY2008

- **Milestone:** Conduct tests with prototype test articles and validate CFD models – Submit a report on findings

FY2009

- **Milestone:** Incorporate air cooling in power electronic modules and test and validate models – Report due September 2009.

**AN ASSESSMENT OF AIR COOLING
FOR USE WITH
AUTOMOTIVE POWER ELECTRONICS**
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Challenges and Barriers

Advantages

Air is the ultimate sink.

Rejecting heat to air can eliminate intermediate fluid loops.

Air is benign and need not be carried.

Air is a dielectric, and can contact the chip directly.

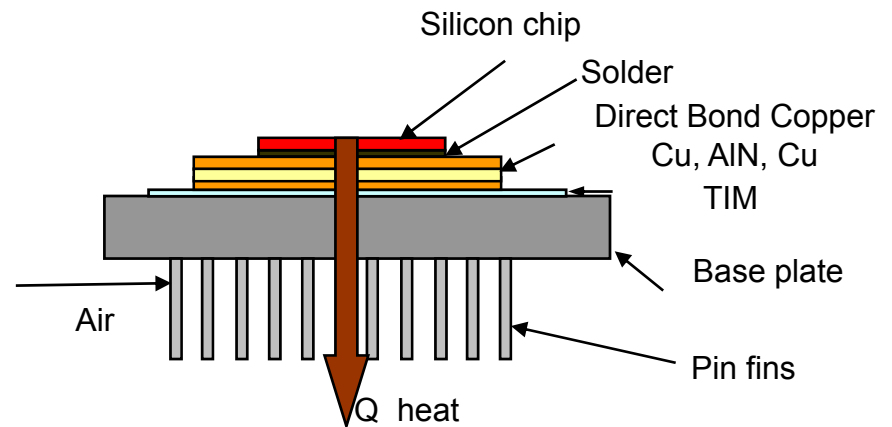
Drawbacks

Air has a low specific heat.

Air is a poor heat-transfer fluid.

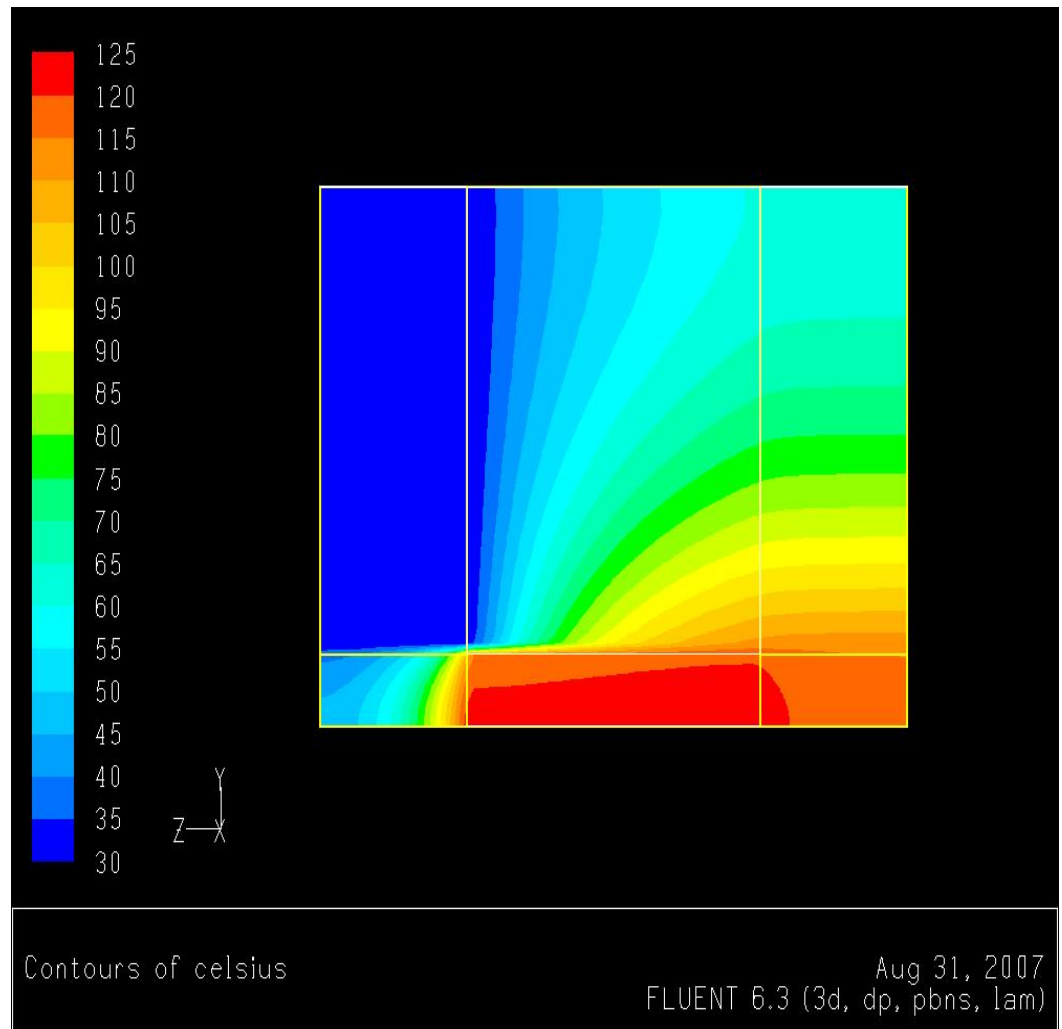
Air density is low.

Cross flow of air complicates heat transfer.



Project Objective for FY09

- Implement air cooling
 - demonstrate technology on a working inverter
- Validate models and design approach.
- Contribute to advanced PE development cooling options
 - meet programmatic goals.



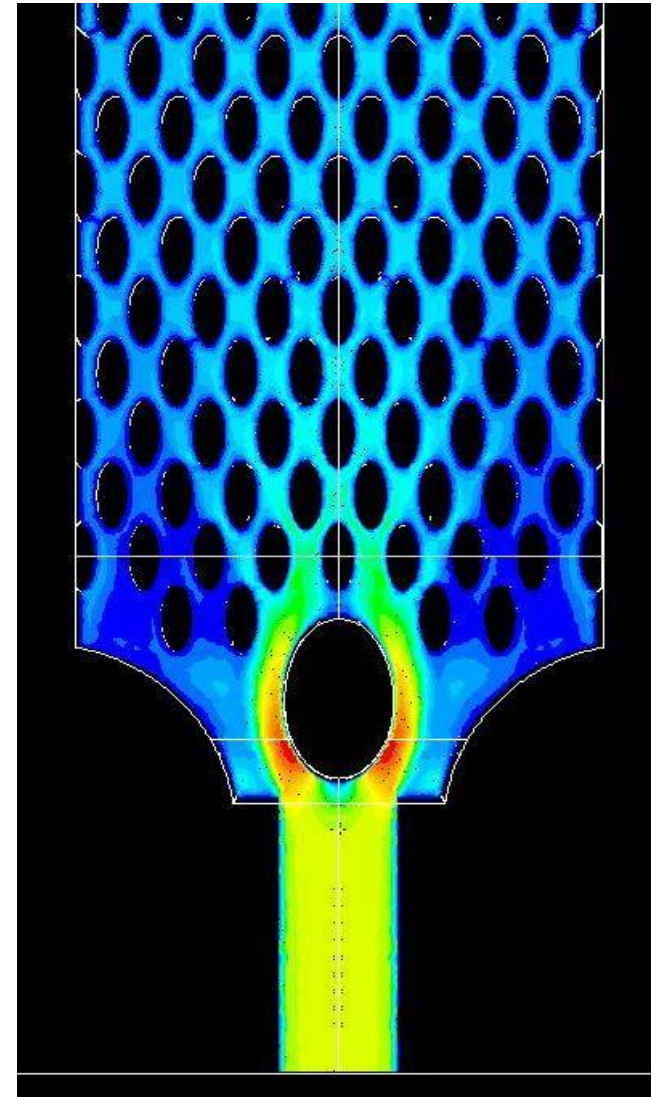
The Problem

- Reduce cost and complexity of cooling system for power electronics by using ambient air
- Air is the ultimate cooling medium.
- Prior work has resulted:
 - in demonstrating high performance for air cooling and
 - in establishing cost reduction potential for air cooling
- Air cooling is essential for long-term cost reduction

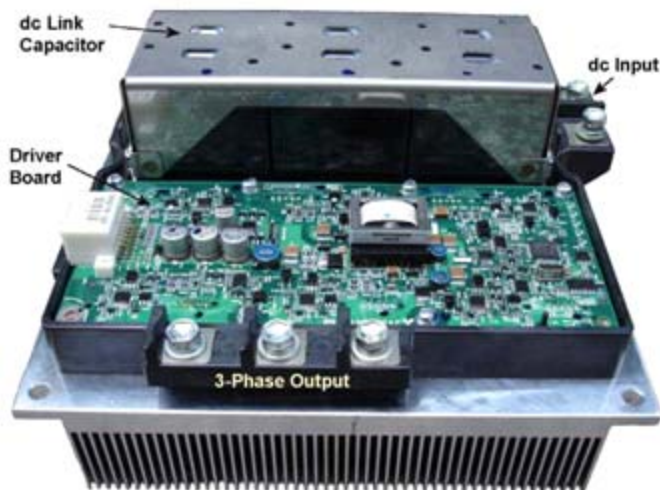
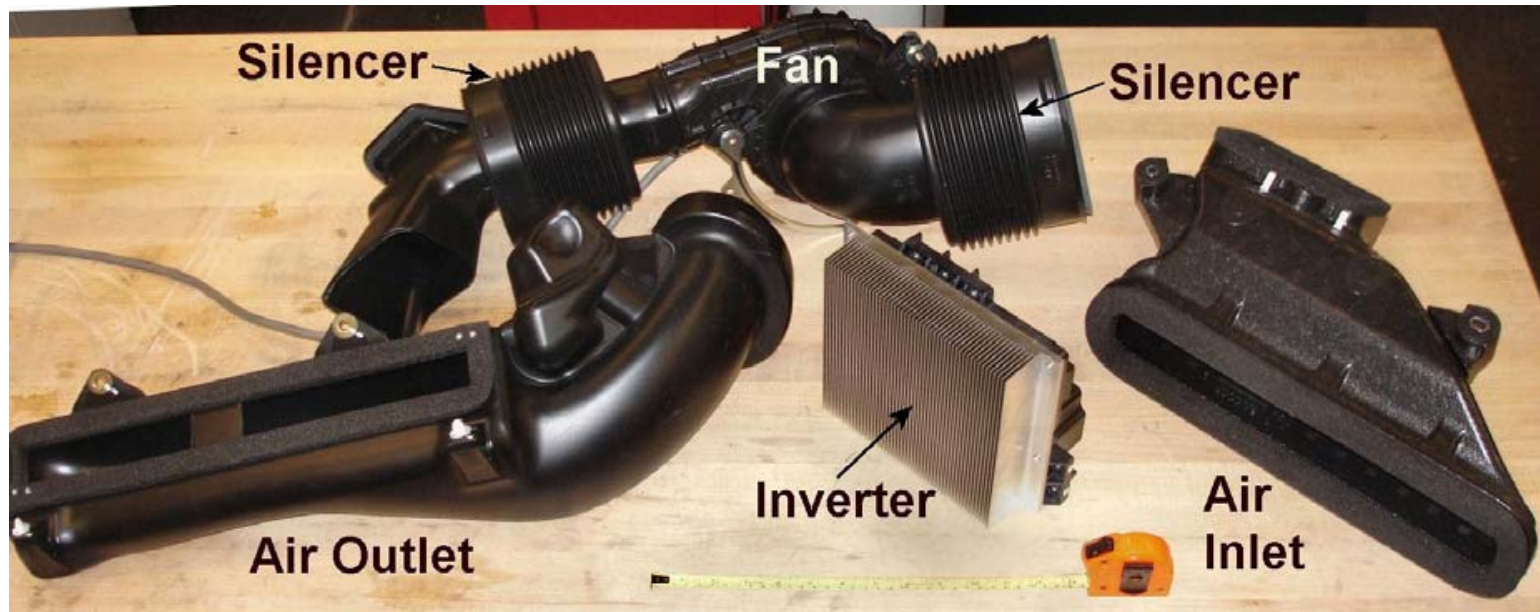


Technical Approach

1. Complete evaluation of alternative heat exchanger designs and system trade-off study
2. Design an air cooled micro-channel fin heat exchanger for an inverter module
 - In close collaboration with industrial manufacturer
 - Meet performance, cost, volume, and manufacturing constraints
3. Incorporate air cooling device in an actual inverter
4. Test performance of the module
5. Validate design with test data
6. Develop guidelines for performance estimation, cost, volume, weight, and other measures for industry.
7. Develop second iteration design and demonstrate air-cooling



Honda – Air-cooled Inverter Package



Power Rating 12 to 14 kW

Active air cooling

Electric blower ~ 120 W

Heat load ~ 700 W

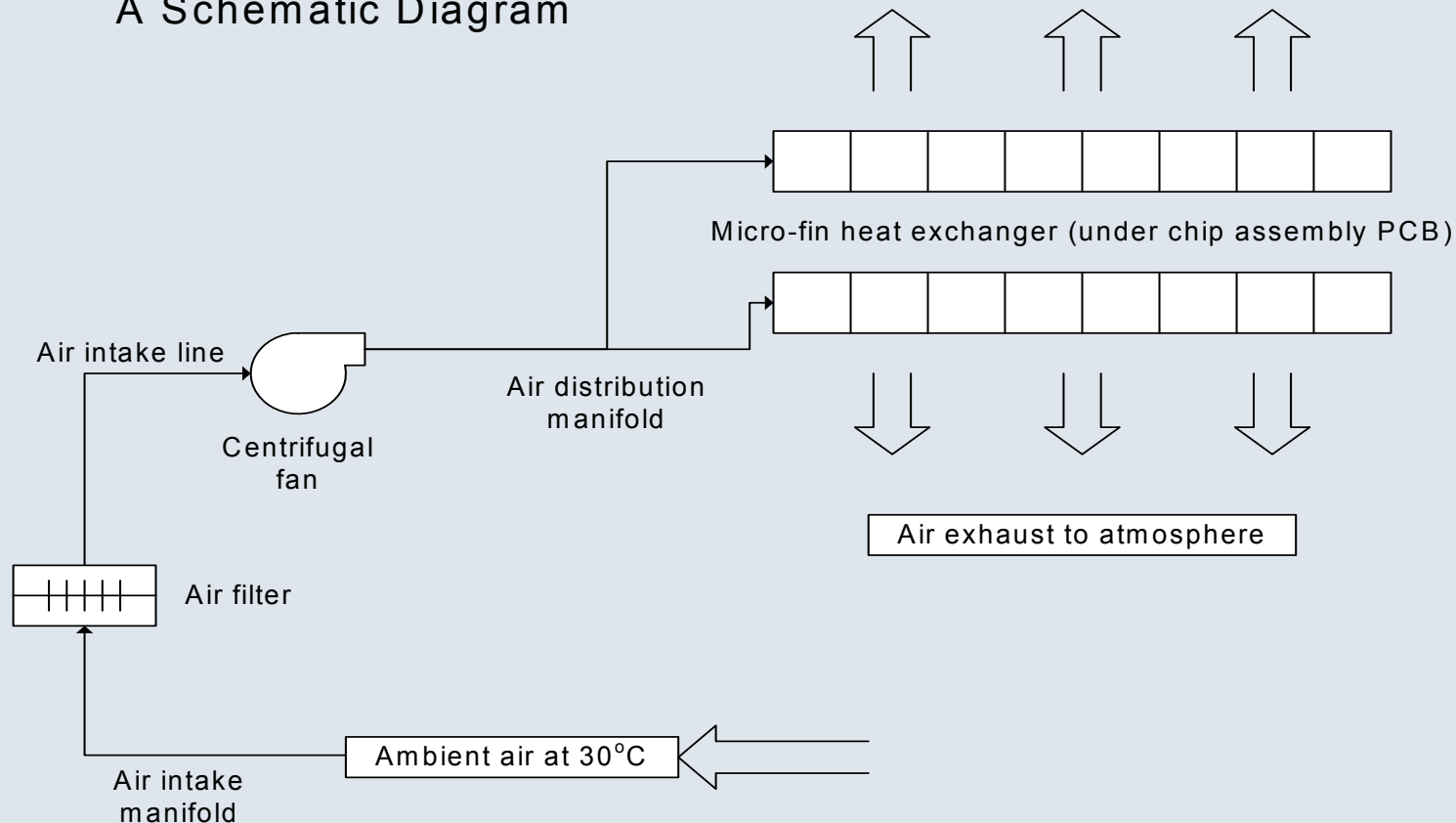
Uniqueness and Impacts

- Our approach aims for simple thermal solutions.
- We offer viable heat rejection fluxes directly to the sink.
- We aim to minimize pressure drop and parasitic power.
- Air cooling offers least number of components and lower cost.
- Air cooling offers high degree of reliability.
- Potential for flow modulation exists.

Accomplishments

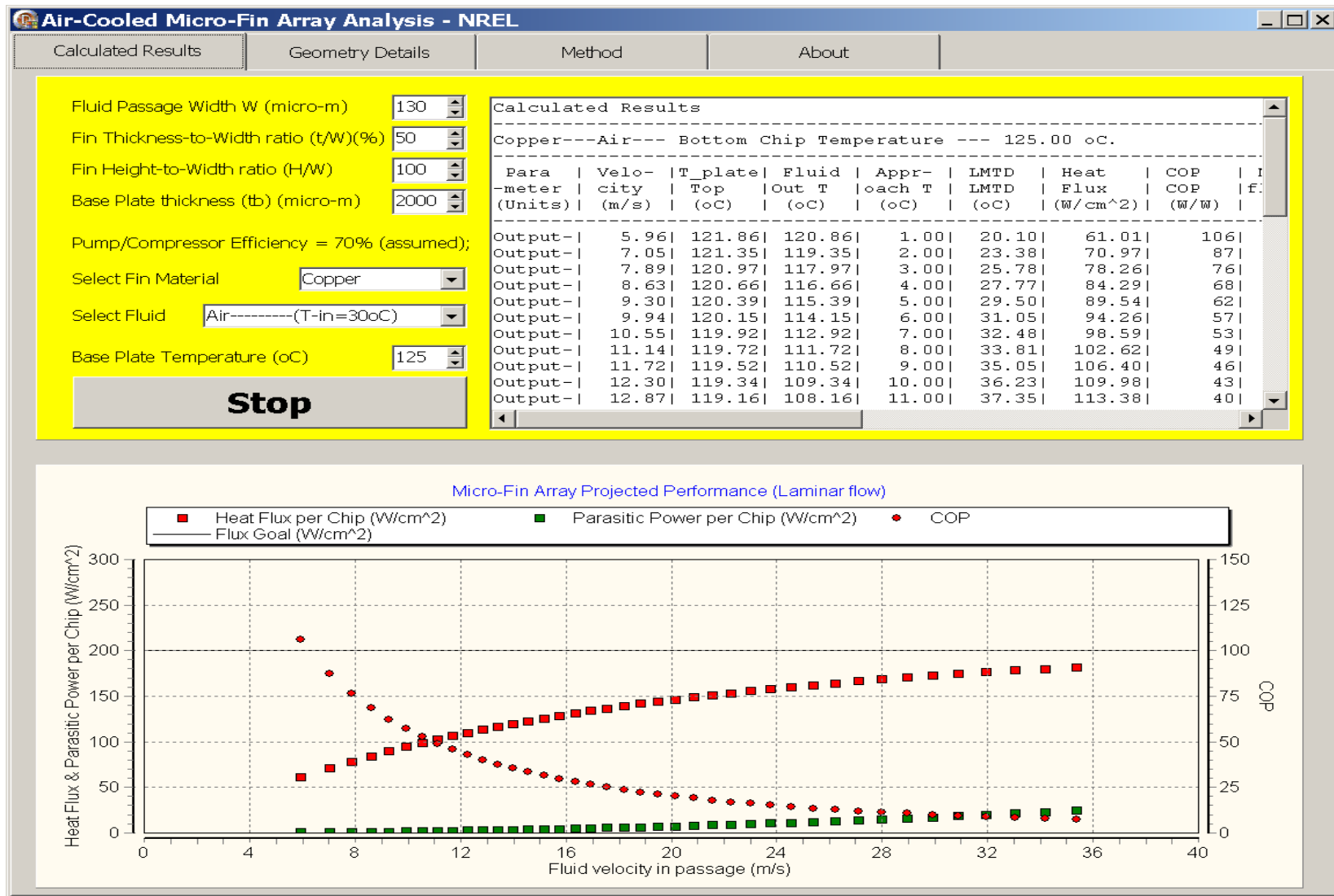
Air-Cooling System for Power Electronics

A Schematic Diagram

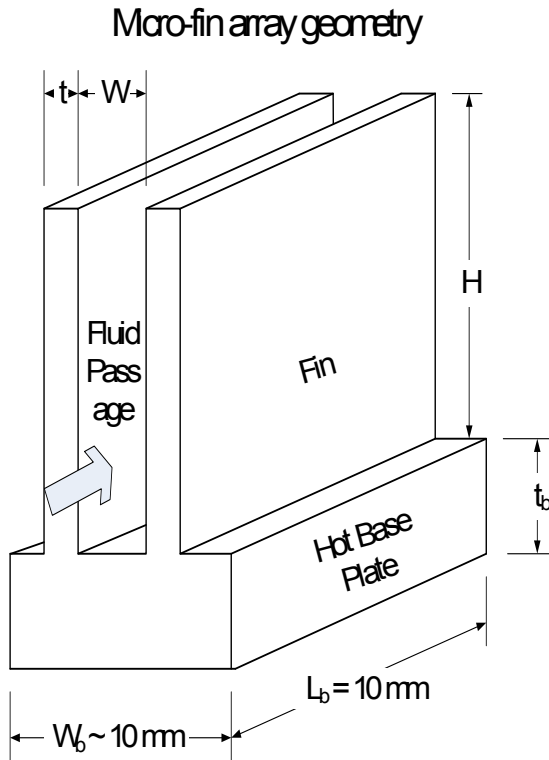


ASPEN model for system trade-offs

Accomplishments



Accomplishments



Typical values are:

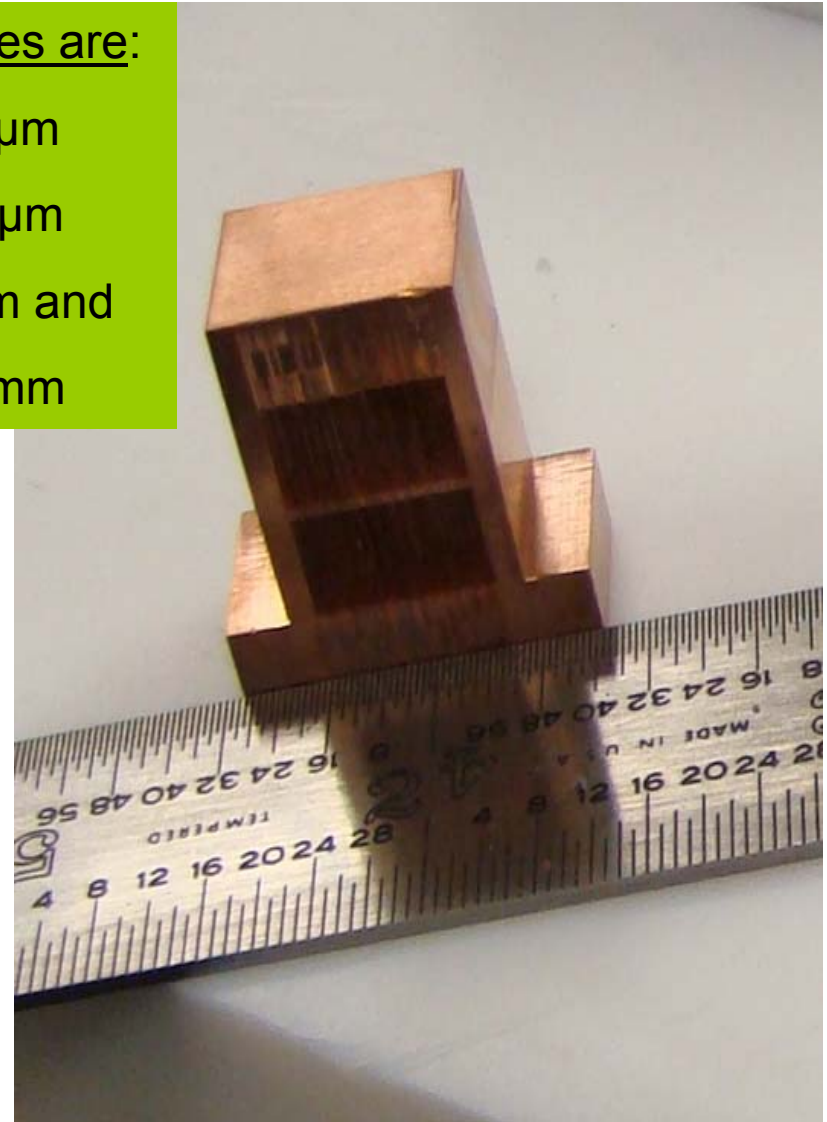
$$W = 130\text{ }\mu\text{m}$$

$$t = 65\text{ }\mu\text{m}$$

$$H = 13\text{ mm and}$$

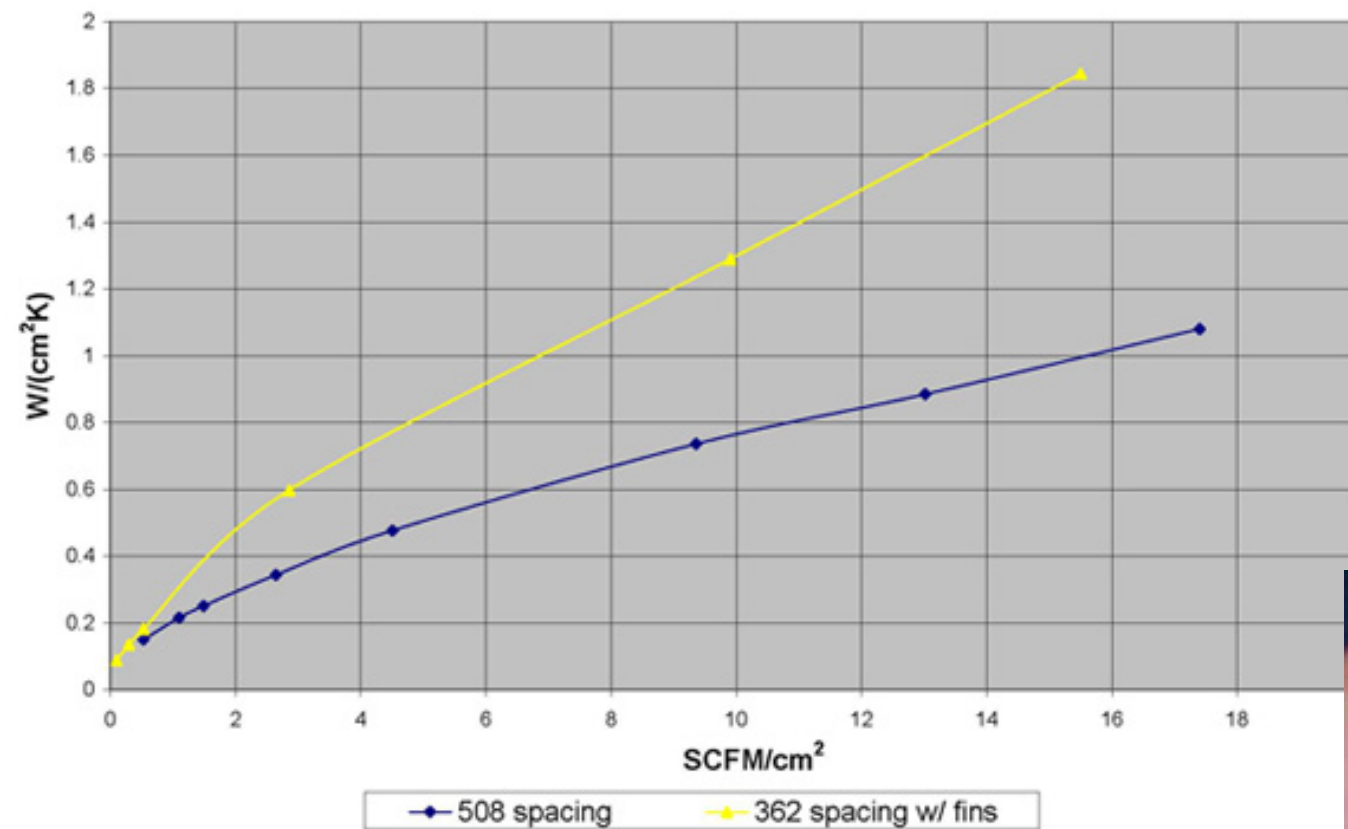
$$t_b = 1\text{ mm}$$

Prototype fabrication, testing, and validation



Accomplishments

AIR BASED MicoJet



Accomplishments

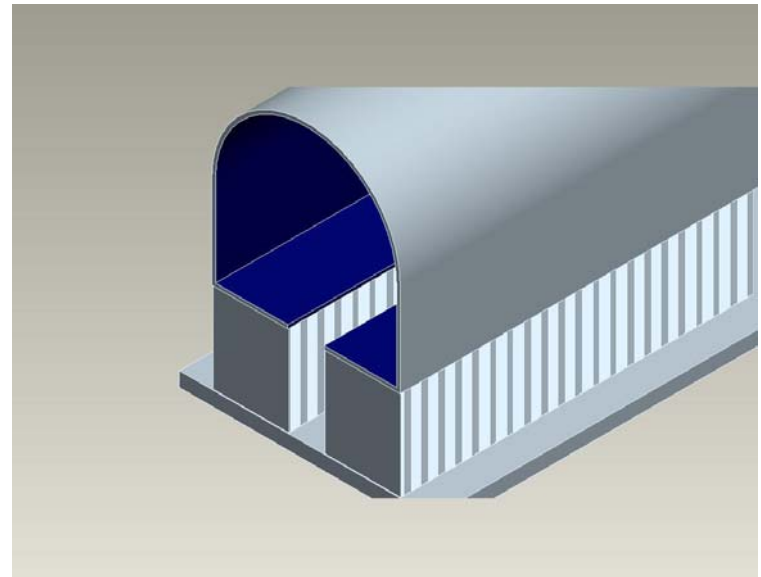
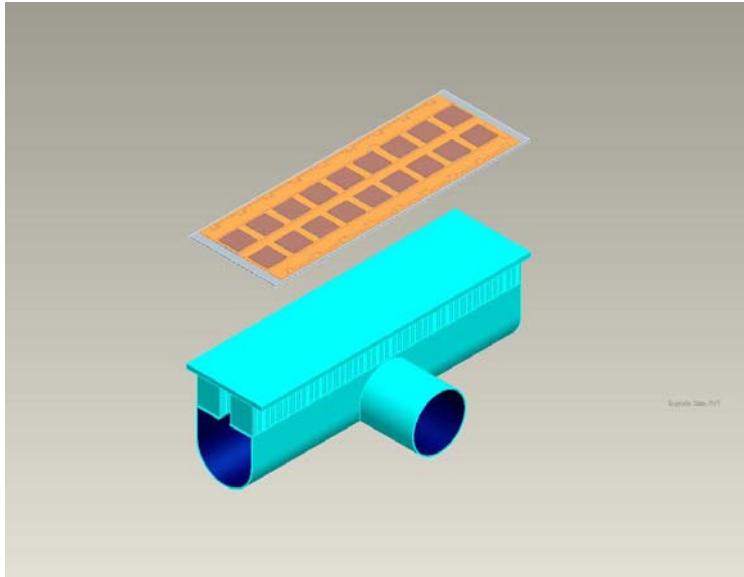
Models show that:

- Air cooling can remove fluxes up to 150 W/cm^2 for Silicon-based devices.
- Higher chip operating temperatures will increase the flux close to programmatic goal of 200 W/cm^2 .

Comparison with the use of an intermediate liquid cooling loop indicate that:

- Air cooling is simple, less costly, and reliable.

Accomplishments

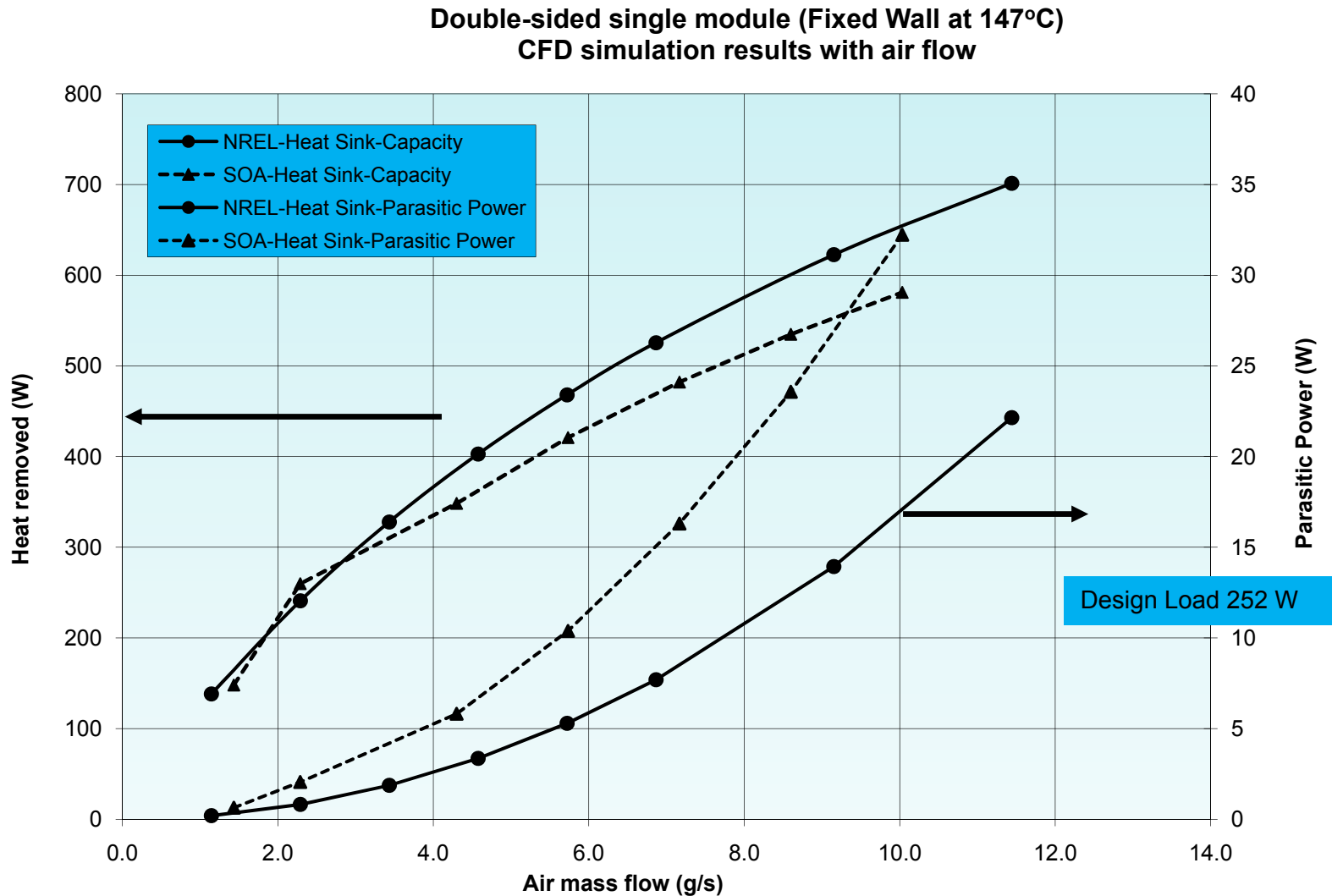


Innovative designs developed for PE packages

Accomplishments

- NREL has developed innovative air-cooled heat sink geometry that improves the SOA:
 - 1) Heat transfer surface available is doubled.
 - 2) Flow pressure drop is reduced by 50%.
 - 3) Colder air is directed toward the hot areas near the source.
 - 4) Air flow over the geometry is streamlined.
 - 5) CFD models indicate substantial increase in performance.

Projected performance Comparisons



Other system related issues – NREL addresses

- Flow configuration
- Fin material and geometry
- Fan configuration and efficiency
- Filtering requirements
- Aerodynamic passages for ducting
- Cooling capacitors
- Extension of novel concepts to motor cooling

Future Work: FY2009 & FY2010

- The cost related to air supply and exhaust system may be comparable to the inverter.
- Manufacturers would rather sell more inverter than an option for air cooling.
- Examples: Due to the high risk nature of this research, industry has been reluctant to embrace the approach.

Summary

DOE
Mission
Support

- Overcome barriers to adoption of low-cost air-cooled heat sinks for power electronics and motors; air remains the ultimate sink.

Approach

- Create and validate models of air-cooled heat sinks; generate prototype designs for sinks and overall system; demonstrate viability on performance, long-term reliability and competitive costs.

Summary

Technical Accomplishments

- Created prototype designs
 - CFD performance estimation
 - Experimental validation of performance
 - Innovative designs to improve performance
 - Addressing system issues regarding flow, filter, ducting, air distribution

Collaborations

- Collaborating with industry & partners
 - interacting with Auto OEMs and suppliers for test data, review, and validation activities
 - interacting with ORNL, ONR, and NASA.
 - conferring with Jason Lai of VPI.