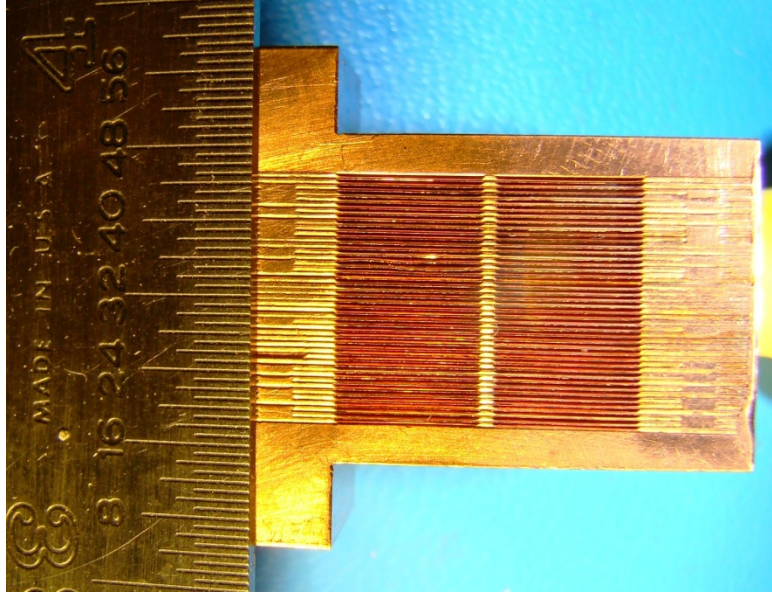


Air Cooling Technology for Power Electronics Thermal Control



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Project Duration: FY06 to FY09

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Advanced Power Electronics and
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FY08 Kickoff Meeting

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*This presentation does not contain any
proprietary or confidential information*

The Problem

- **Eliminate liquid coolant loops.**
- **Enable heat rejection directly to the sink, namely, ambient air. Simplify.**
- **Maintain die temperature below specified operating limits for long-term reliability.**
- **Reduce cost and meet other FreedomCAR goals for year 2020 (\$8/kW for a 55 kW traction system).**

Description of Technology

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

Silicon chip

Solder

Direct Bond Copper
Cu, AlN, Cu

TIM

Drawbacks

Air has a low specific heat

Base plate

Air

Air is a poor heat-transfer fluid

Pin fins

Air density is low

Q heat

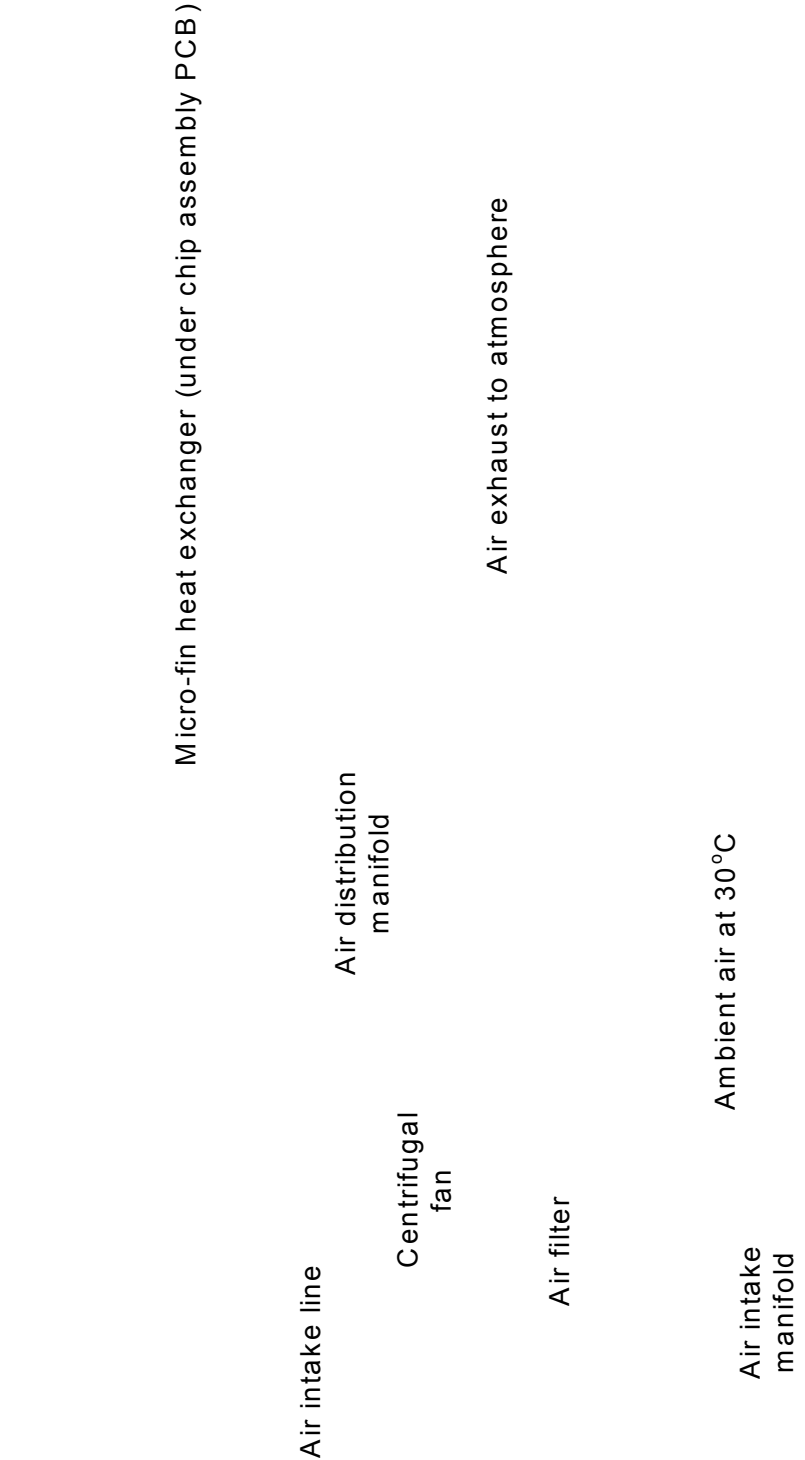
Uniqueness of Project and Impacts

- **Approach looks at simple thermal solutions.**
- **Offers viable heat rejection directly to the sink.**
- **Air cooling offers simplicity and least number of components.**
- **Air cooling offers high degree of reliability.**

Accomplishments to Date

Air-Cooling System for
Power Electronics

A Schematic Diagram



Accomplishments to Date

Micro-fin array geometry

t W

Fluid
Pass
age

Fin

Hot Base
Plate

$L_b = 10 \text{ mm}$

$W_b \sim 10 \text{ mm}$

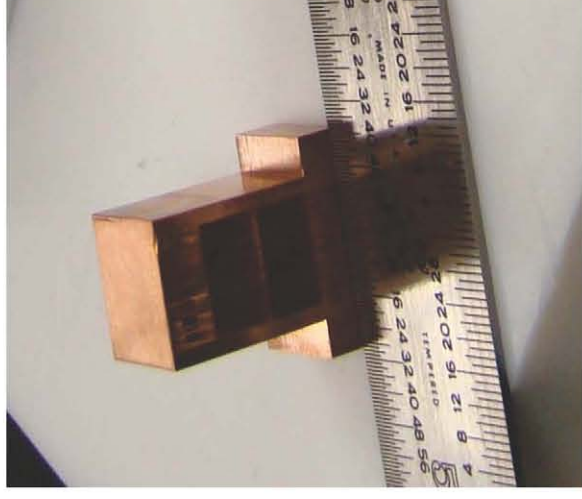
Typical values are:

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

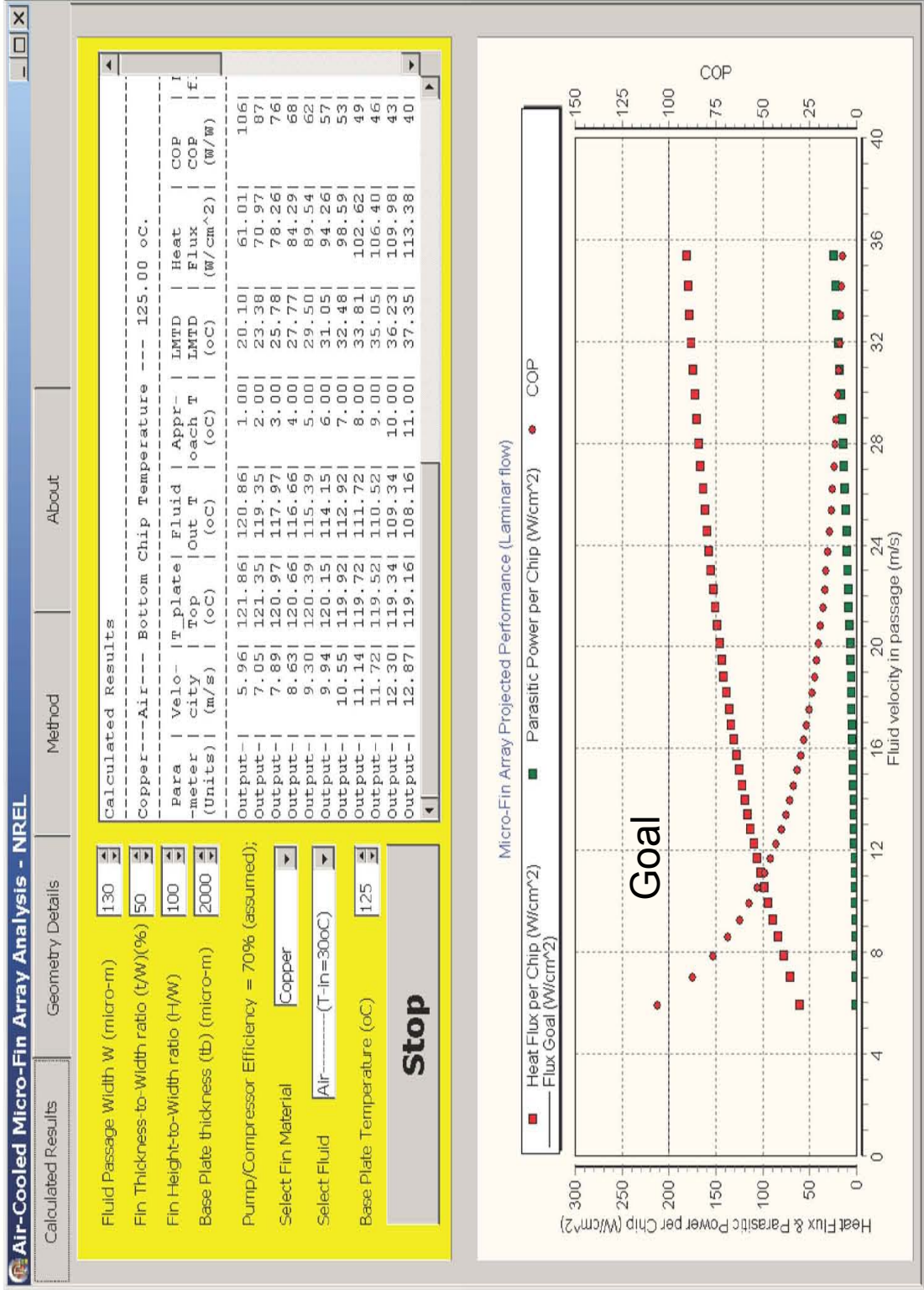
$t = 65 \text{ } \mu\text{m}$

$H = 13 \text{ mm}$ and

$t_b = 1 \text{ mm}$



Accomplishments to Date



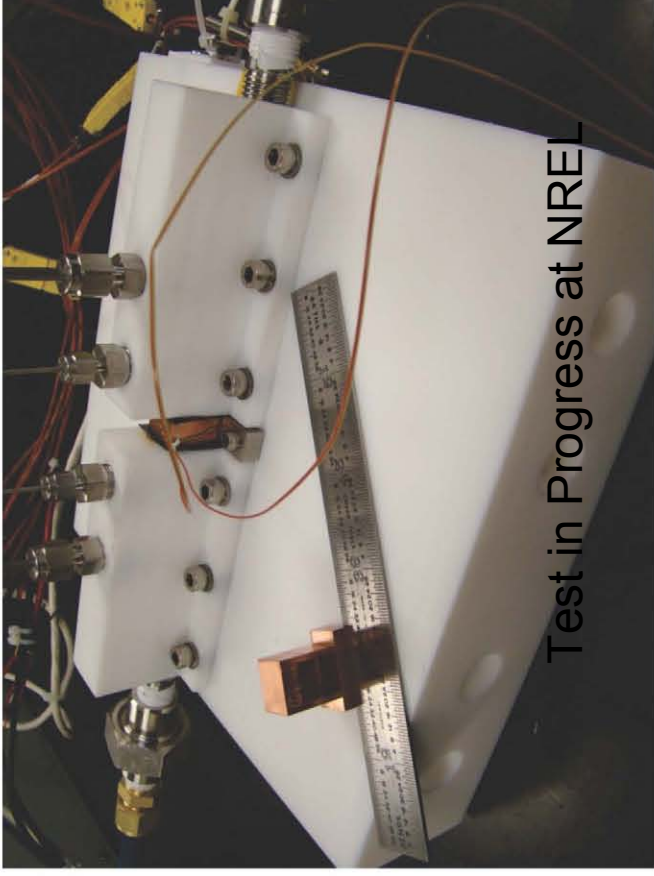
Accomplishments to Date

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 .

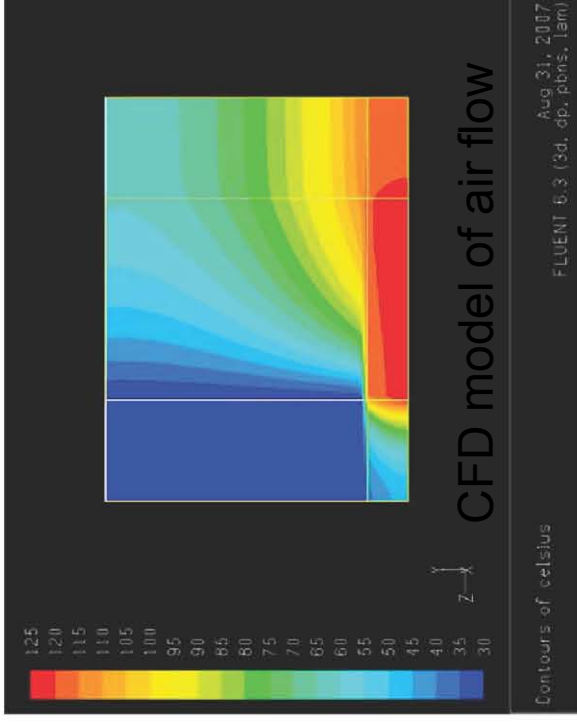
Comparison with the use of an intermediate liquid cooling loop indicate that:

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

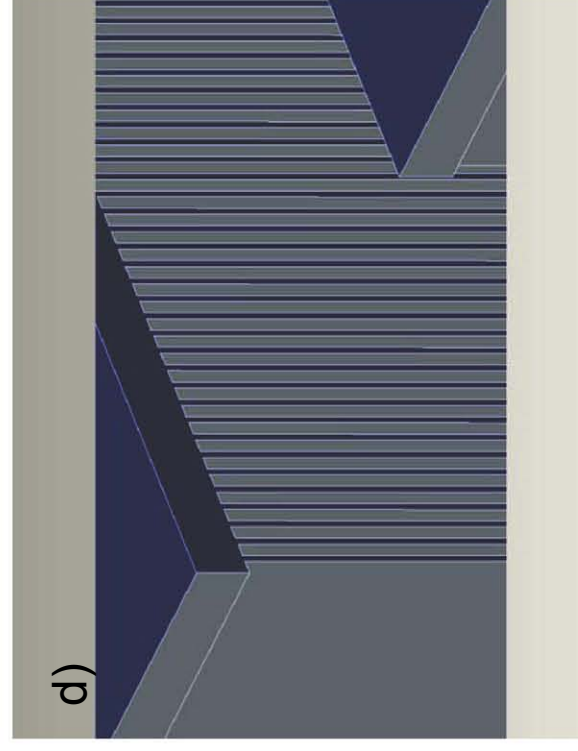
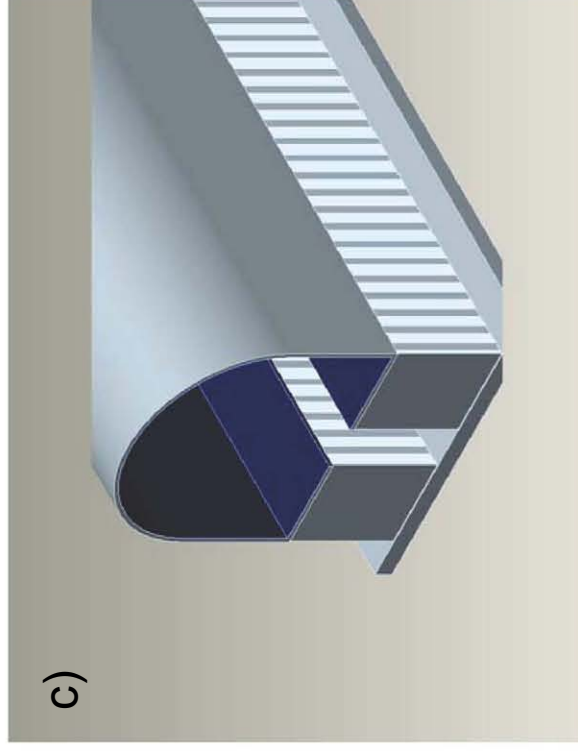
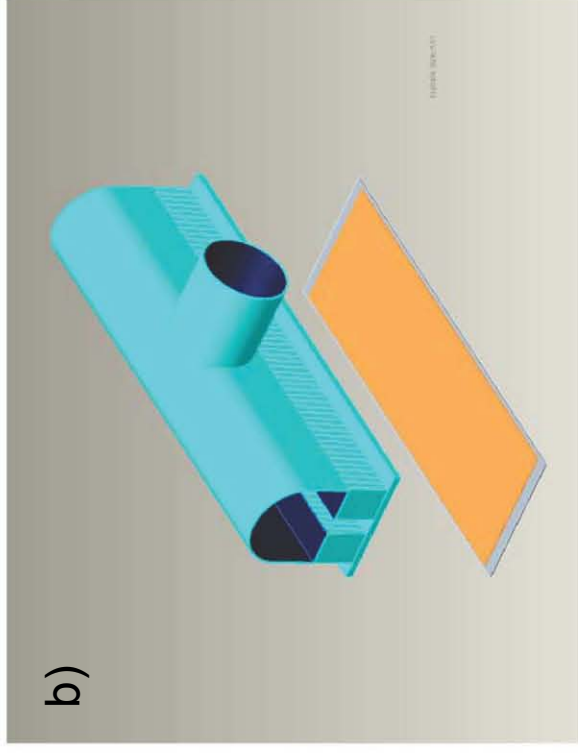
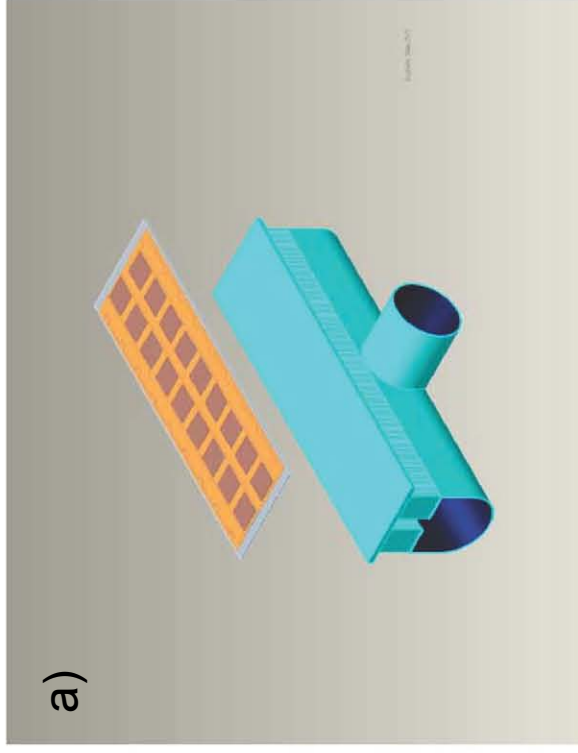


Project Objectives for FY08

- Implement air cooling
 - Work with an industrial partner to accommodate technology on a working inverter module to meet FreedomCAR goals.
- Validate models and design approach.
- Contribute to advanced PE development cooling options
 - Work closely with ORNL in development efforts to meet programmatic goals.

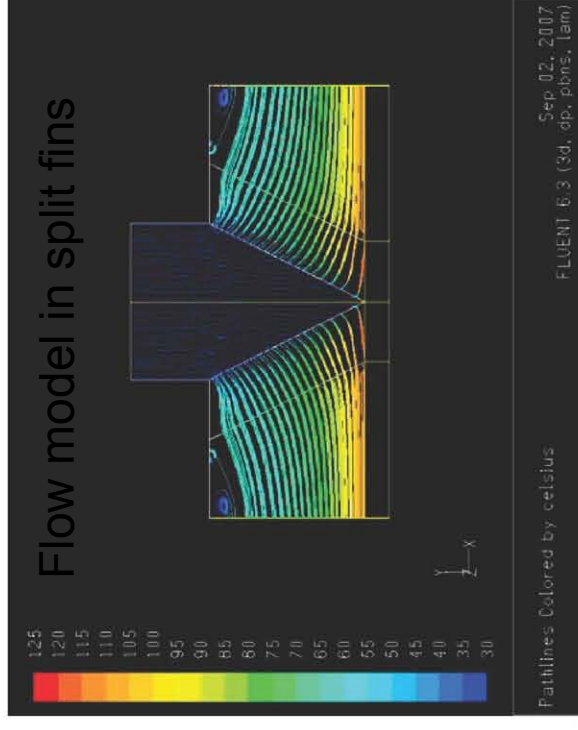


Technical Approach for FY08



Technical Approach for FY08

1. Design an air cooled micro-channel fin heat exchanger for an inverter module
 - in close collaboration with a chosen industrial manufacturer that meets the performance goals and other manufacturing constraints.
2. Incorporate air cooling device in a production model as a prototype.
3. Test performance of the module under realistic working conditions.
4. Validate design with test data.
5. Develop guidelines for performance estimation, cost, volume, weight and other measures for air cooling for use by the industry.
6. Develop second iteration design and demonstrate air-cooling as a viable option.



Timeline

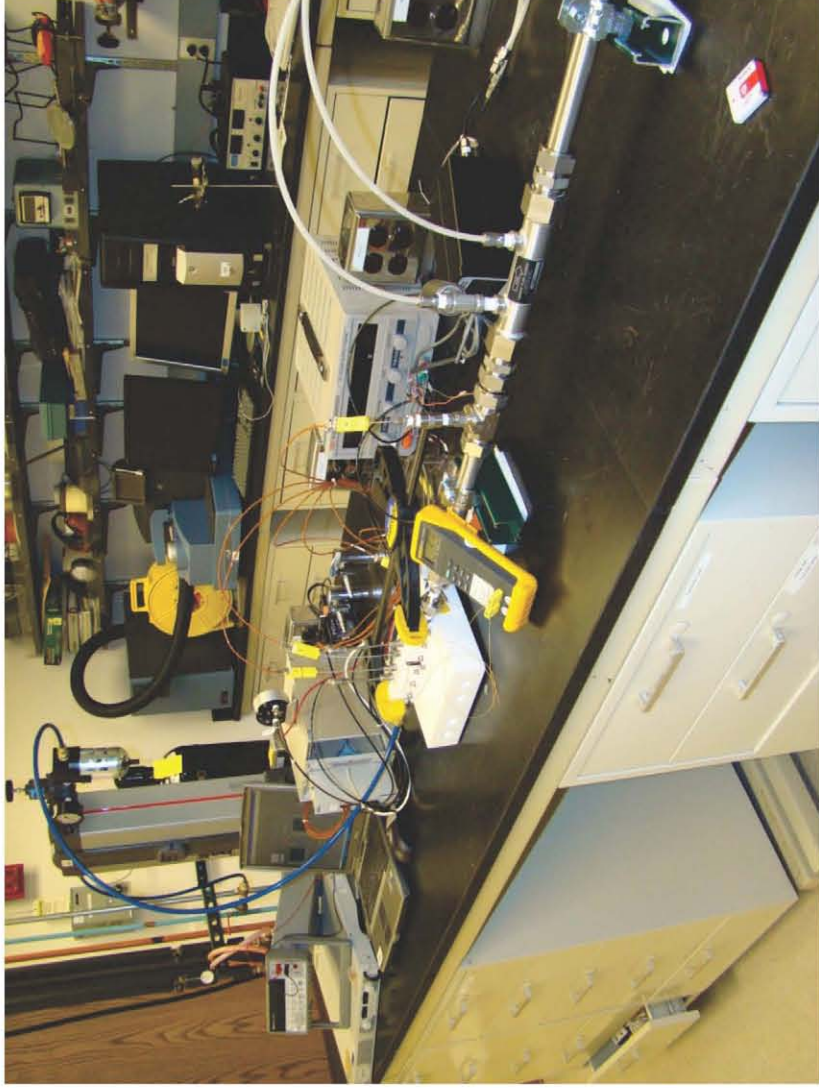
2007	Oct	Nov	Dec	2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Consult with manufacturers for incorporating air cooling option													
Initiate and fine tune design with constraints													
Incorporate air cooling in a prototype													
Flow and thermal testing													
Develop design guidelines for the industry													
Develop next generation design													
Thermal testing/validation for micro-fin channel geometry at lab scale													

The Challenges/Barriers

To be addressed:

- Erosion concerns -- due to coolant impingement and long term effects of jet impingement on copper fins.
- Potentially low blower efficiency.
- Potential noise generation due to air flow on fins.
- Difficulties with differential thermal expansions and resulting stresses.
- Convince industry this is a viable technology with advantages, while long-term reliability issues are addressed.

Beyond FY08 -- Integrate the developed thermal control technology with reliability tasks based on a systems level approach

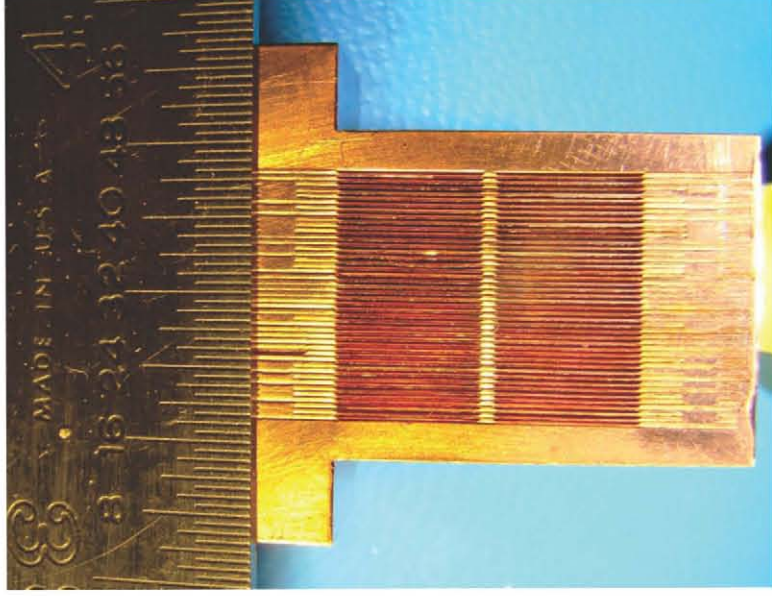


- Analyze pulsed systems to power
- Generate a design tool for air cooling
 - Provide industry with an easy-to-use tool to evaluate all aspects of performance and specifications.

Base plate

Copper micro-fins

Bottom enclosure



Channel
enclosure