Designing & Testing Thermal Management System for SiC PV Converter

Team 13

<u>Electrical Engineering</u>
Melanie Gonzalez
Tianna Lentino

<u>Mechanical Engineering</u>
Leslie Dunn
James Hutchinson
Colleen Kidder

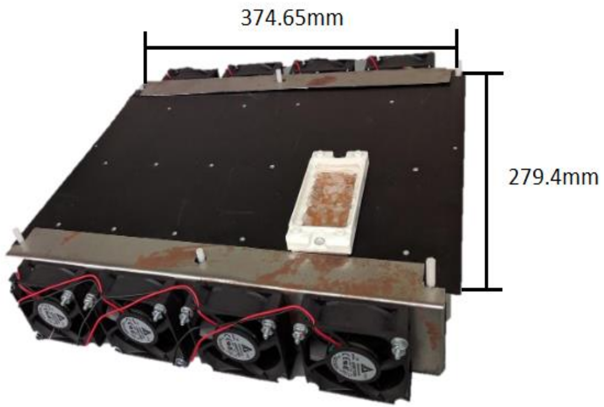
Power Electronic Devices

- PV Converters made with PE devices
  - Transform energy from solar array to usable
  - Generate heat
  - Cooled by heatsink/fans
- Typically made with Silicon
  - Cheap & abundant
  - Dominate the market
- SiC Power Electronic Module
  - Pro: Efficient
  - Con: Expensive
  - PowerAmerica goal: make SiC cost competitive

SiC Power Module

Project Overview

- **Background:** CAPS Next Generation PV Converter has one of the highest power densities (Power/weight)
  - Further increase power density
- **Problem:** Heatsink used for this PV Converter was overdesigned
  - Remains cool during operation
  - Too heavy
- **Solution**: Provide an optimal heatsink design
  - Decrease weight of system, increase power density
- **Approach:** 3 methods to verify design
  - Simulation, Calculations, & Experimentation



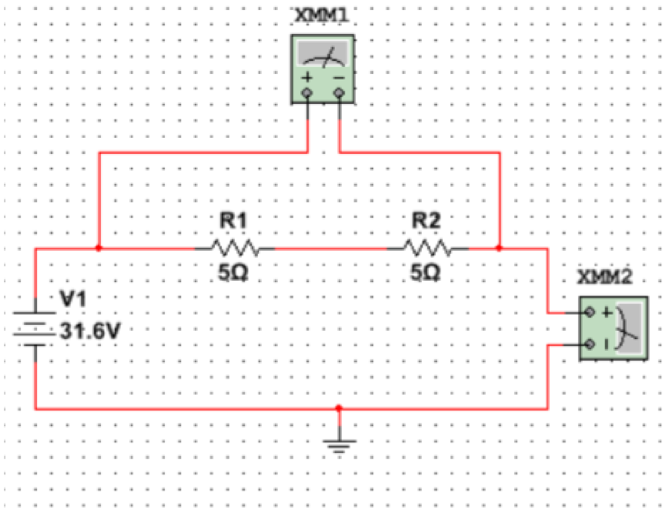
Next Gen PV Converter

- Plate Fin Heatsink
- 8 Power Modules & Fans
- 375 mm x 280 mm x 80 mm
- 6.5 kg

Bi-Modular Design for Heatsink

Heatsink Design	Plate Fin	Pin Fin
Size	127mm x 127mm x 69.2mm	113.7mm x 113.7mm x 17.8mm
Weight (including fans)	0.954 kg	0.553 kg
Fan Orientation	Lateral	Axial

Heat Source Emulator



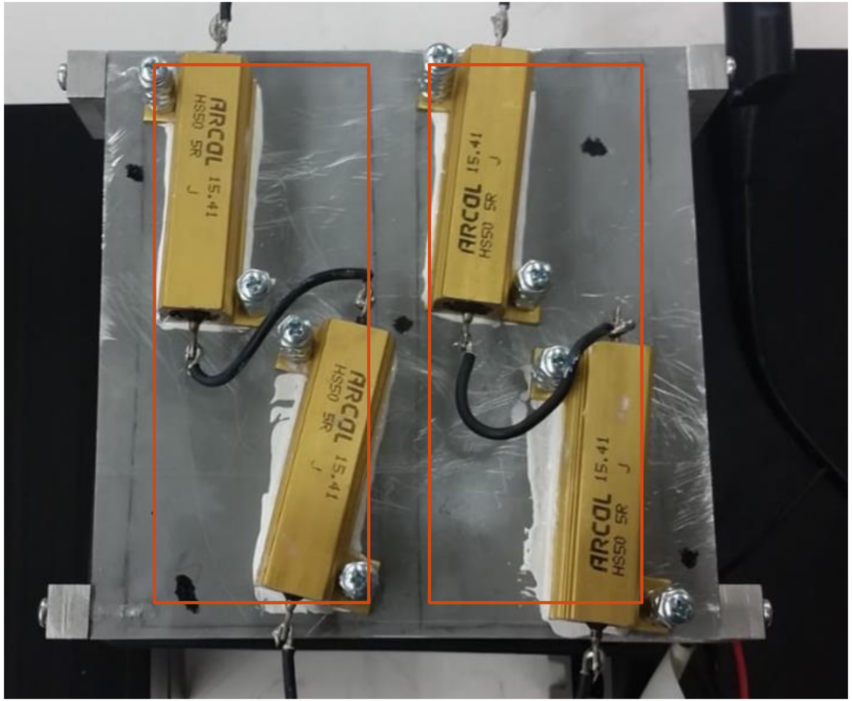


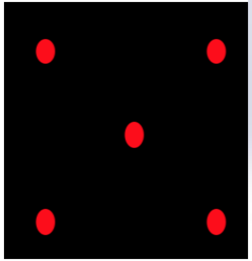
Plate Fin Testing

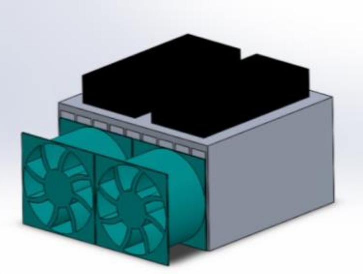
- With copper plate

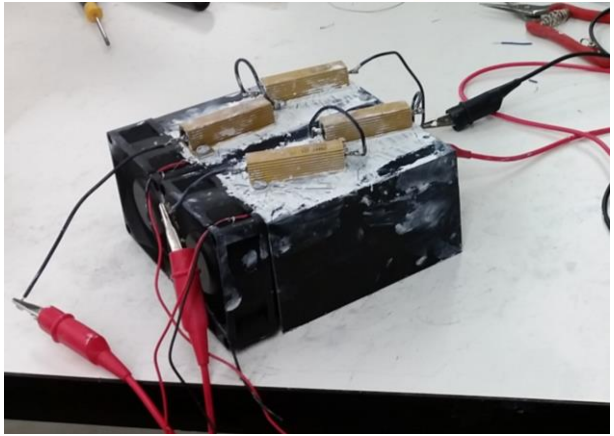
Power Diss. /Emulator (W)	Total Power Diss. (W)	Average Temp. (°C)
0	0	23.36
15	30	28.04
30	60	30.36
45	90	33.22
60	120	36.4
75	150	42.08
90	180	42.5

- Without copper plate

Power Diss. /Emulator (W)	Total Power Diss. (W)	Average Temp. (°C)
0	0	23.9
15	30	28.16
30	60	29.22
45	90	34.6
60	120	37.2
75	150	39.6
90	180	41.4

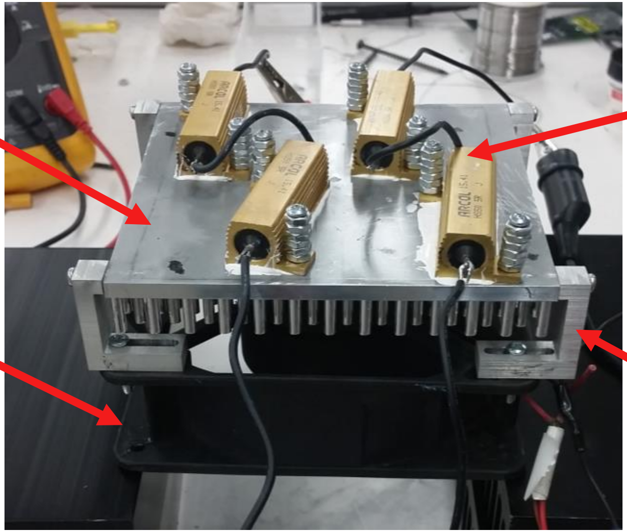




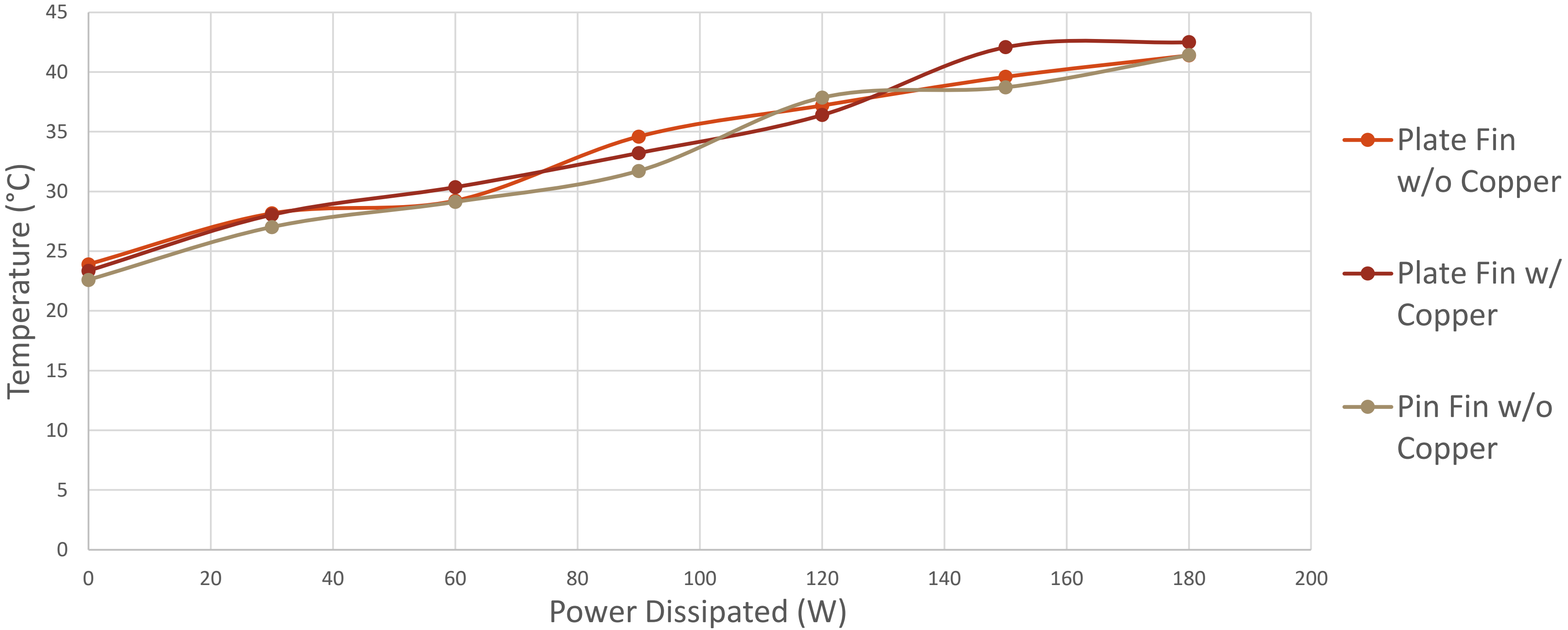


Pin Fin Testing

Power Dissipated per Emulator (W)	Total Power Dissipated (W)	Average Temperature (°C)
0	0	22.6
15	30	27.02
30	60	29.12
45	90	31.72
60	120	37.86
75	150	38.72
90	180	41.42



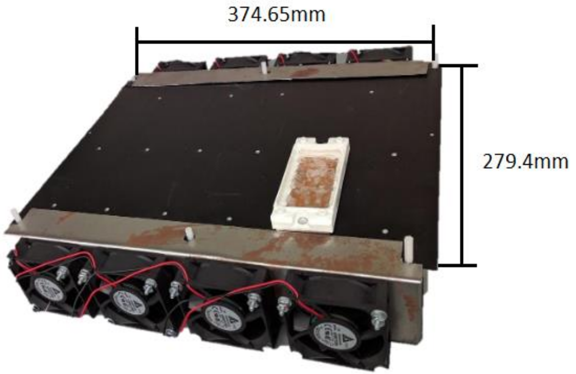
Experimentation Results



Project Approach

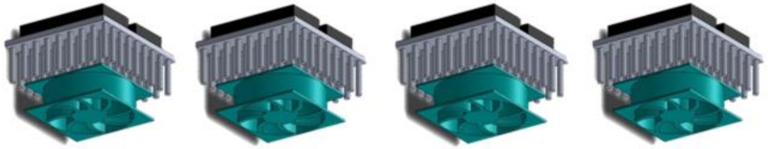
Original CAPS Heatsink

- Plate Fin Heatsink
- 8 Power Modules & Fans
- 375 mm x 280 mm x 80 mm
- 6.5 kg



Solution: 4 Pin Fin Heatsinks

- Pin Fin Heatsink
- 2 Power Modules / Heatsink
- 1 Fan / Heatsink
- 115 mm x 115 mm x 14.7 mm
- $\leq$ 0.56 kg per heatsink (2.2 kg total)

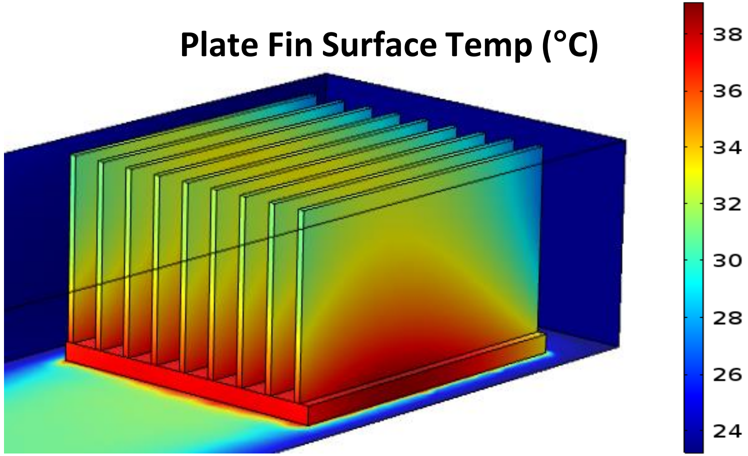


Comparison of Plate vs Pin

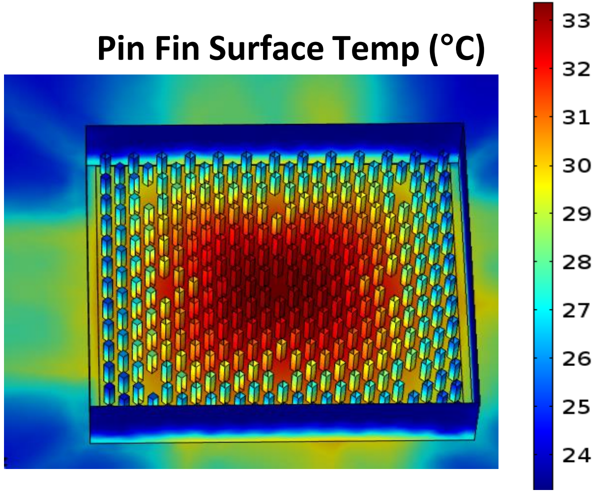
Pin fin heatsink design has been chosen for optimization over the plate fin heatsink

- Weight reduction is more significant for pin fin
- Thermal performance of pin fin virtually equal to that of plate fin
- Pin fin equations provide less error than plate fin equations

Plate Fin Surface Temp (°C)

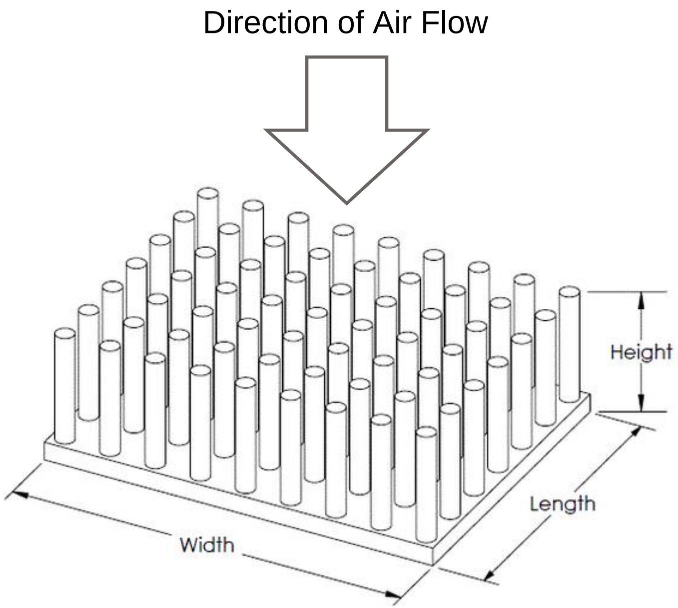


Pin Fin Surface Temp (°C)



Theoretical Analysis

- Convective Thermal Resistance
  - Reynolds Number
  - Nusselt Number
  - Fin Efficiency
- Conductive Thermal Resistance
  - Geometry
  - Thermal conductivity
- Weight



Heatsink Optimization

Optimizing by varying heatsink geometry and fan speed.

Input Values	Output Values	Constant Values
• Length of pins (5mm-40mm) • Diameter of pins (2mm-5mm) • Pin Spacing • Number of Pins • Fan Speed	• Total Weight • Thermal Resistance	• Base Size • Base Thickness

Heatsink Optimization

Goals

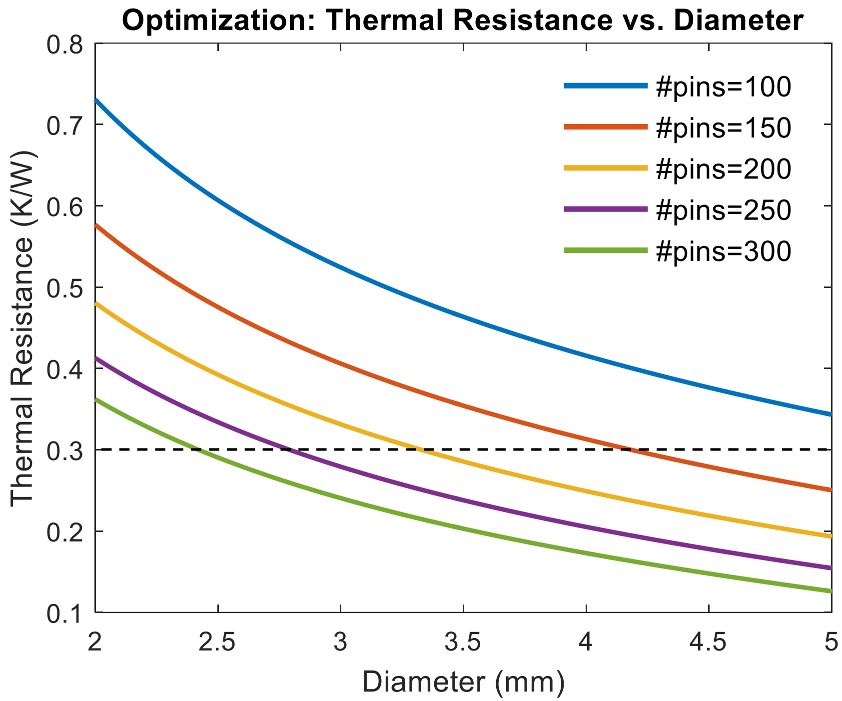
- Minimize heatsink weight (< 0.254 kg)
- Obtain thermal resistance of 0.3 K/W or less
- Baseplate temperature should be in the range 30-60°C

Assumptions

- Constant baseplate size: 115 mm x 115 mm x 4.7 mm
- Power loss/Heat source: 105.2 W

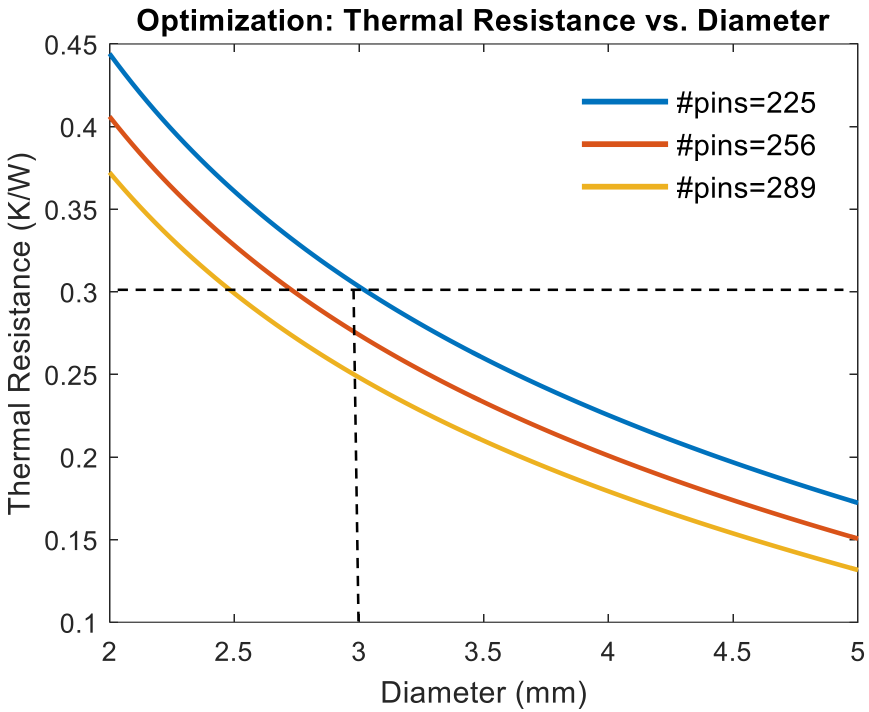
Optimization: Diameter

- Varying diameter size: 2-5 mm
- Each line represents different number of pins from 100-300
- To obtain necessary thermal resistance, #pins > 200
- Minimum diameter **3.0 mm** based on results



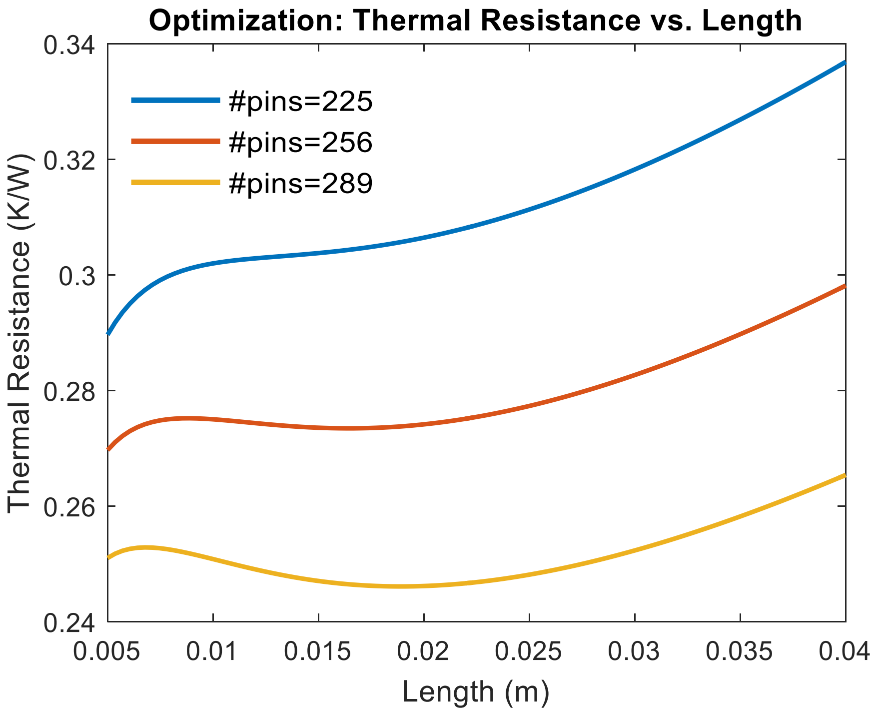
Optimization: # of Pins

- A uniform number of pins in each direction is needed to obtain even spacing
- Looking in the range of 200-300 total pins:
  - **15x15 = 225 pins**
  - **16x16 = 256 pins**
  - **17x17 = 289 pins**
- Acceptable thermal resistance is obtained at D=3.0 mm for each pin variation



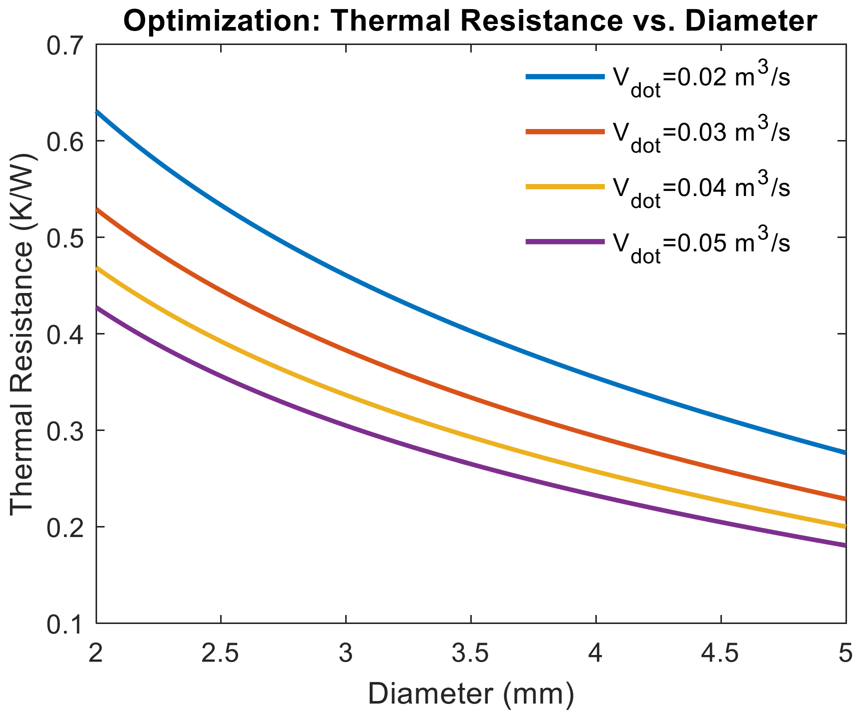
Optimization: Length

- Varying pin length: 5-40 mm
- Change in length affects thermal resistance far less than change in diameter
- To minimize weight and have dependable thermal resistance, **10 mm** length was chosen



Optimization: Fan Speed

- Varying fan flow rate: 0.02-0.05 m^3/s
- Increasing the speed, lowers thermal resistance
- Fan must operate at least at **0.04 m^3/s** to obtain desired thermal resistance



Fan Selection

- Searched for lowest weight fan that met sizing, flow rate, and voltage requirements
- New fan nearly **half the weight** of old fan

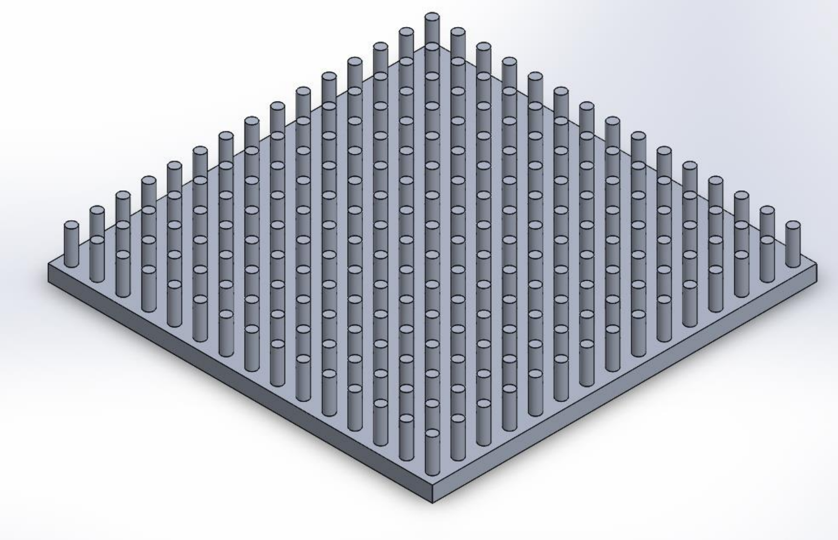
	Old Fan	**New Fan**
Weight (g)	300	157
Size (mm^3)	120 x 120 x 38	120 x 120 x 25
Flow Rate (m^3/s)	0.0505	0.051
Voltage (VDC)	12	12

Optimized Design

- 15 x 15 array of evenly spaced pins (225 total)
- Diameter = 3.0 mm
- Length = 10.0 mm
- **Weight = 211 g**

Weight reduction including fans:

- 34% < Manufacturer pin fin
- 77% < CAPS original heatsink

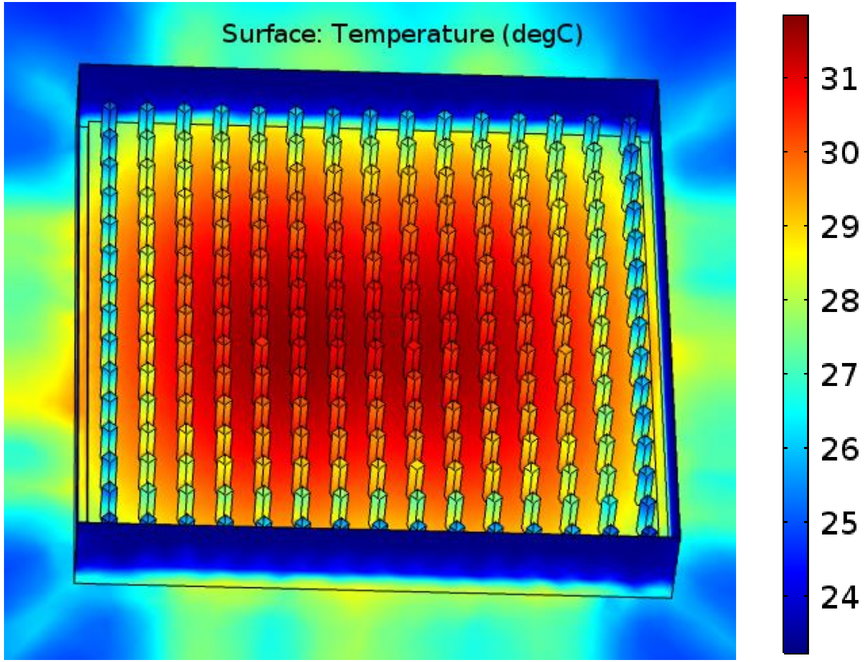


Optimized Pin Fin

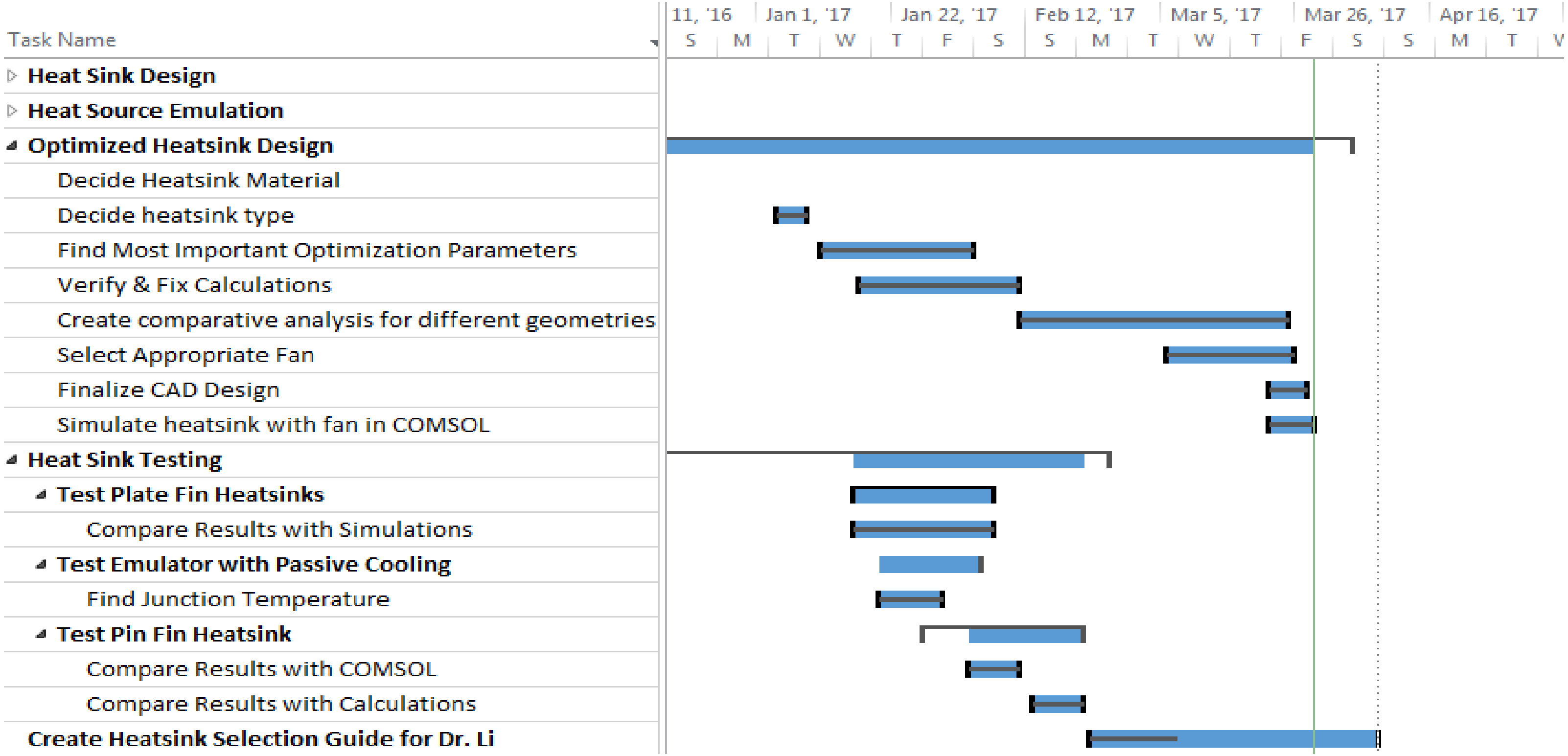
COMSOL Verification

- Max Surface Temperature = 31.6°C
- Yields thermal resistance ≈ 0.3004 K/W

$$R_{total} = \frac{\Delta T}{\dot{Q}}$$



Gantt Chart



11, '16
Jan 1, '17
Jan 22, '17
Feb 12, '17
Mar 5, '17
Mar 26, '17
Apr 16, '17
S M T W T F S S M T W T F S S M T V
Task Name
Heat Sink Design
Heat Source Emulation
Optimized Heatsink Design
Decide Heatsink Material
Decide heatsink type
Find Most Important Optimization Parameters
Verify & Fix Calculations
Create comparative analysis for different geometries
Select Appropriate Fan
Finalize CAD Design
Simulate heatsink with fan in COMSOL
Heat Sink Testing
Test Plate Fin Heatsinks
Compare Results with Simulations
Test Emulator with Passive Cooling
Find Junction Temperature
Test Pin Fin Heatsink
Compare Results with COMSOL
Compare Results with Calculations
Create Heatsink Selection Guide for Dr. Li

Summary

Accomplishments

- Experimentally tested both pin fin and plate fin designs
- Conducted finite element analysis of pin & plate fin with COMSOL
- Developed analytical equations for pin fin heatsink
- Optimized the pin fin heatsink design

Future Plans

- Provide Dr. Li with a Heatsink Selection Guide

References

Cl̀engel, Yunus A., Mehmet Kanoglu, John M. Cimbala, and Robert H. Turner. *Fundamentals of Thermal-fluid Sciences*. Singapore: McGraw-Hill Education, 2017. Print.

"Cold Forging Technology and Pin Fin Heat Sinks." *My Heat Sinks*. Web. 23 Feb. 2017.

"Top 3 Mistakes Made When Selecting a Heat Sink." *Heat Sink Calculator*. 25 May 2016. Web. 26 Mar. 2017.

Questions?