Designing & Testing Thermal Management System for SiC PV Converter

Team 13

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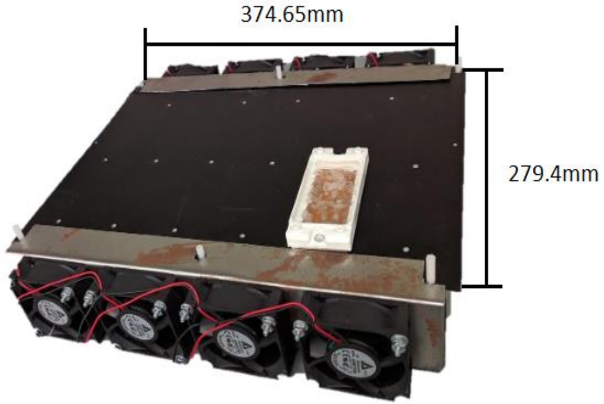
Background Information

- PV Converters made with PE devices
  - Transforms electrical energy (DC/AC)
  - Generate heat
  - Cooled by heatsink/fans
- Typically made with Silicon
  - Cheap & abundant
  - Dominate the market
- SiC: Newer Material
  - 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

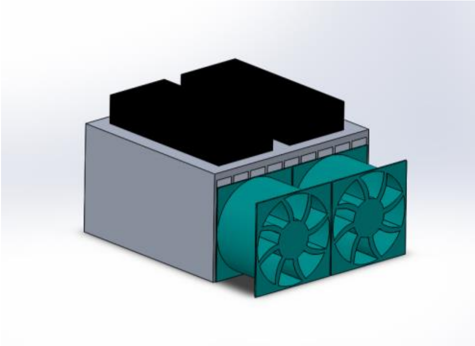


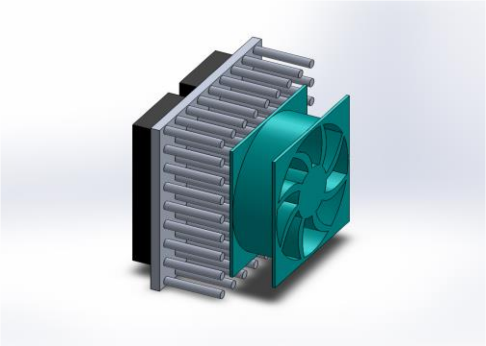
Next Gen PV Converter

- 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

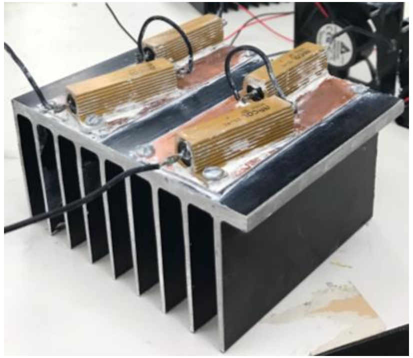


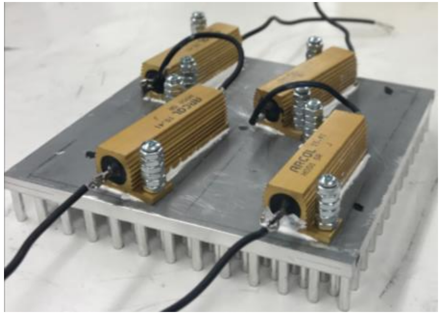


Experimental Testing Procedure

- Two series of tests
  - Natural convection and forced convection
- Measured temperature with infrared gun
  - Took measurements at 5 points and averaged them
- Used power supply for fans
  - Plate Fin: 7.5V, 0.95A, Power = 7.2 W
  - Pin Fin: 11.52V, 0.57A, Power = 6.6 W

- Plate Fin & Pin Fin Natural Convection Tests
  - Supplied a total power of 120 W to the system
  - Temperature exceeded the maximum wanted temperature of 120° C





- No fan tests confirmed the decision to use fans

Plate Fin Testing, Forced Convection

- With copper plates

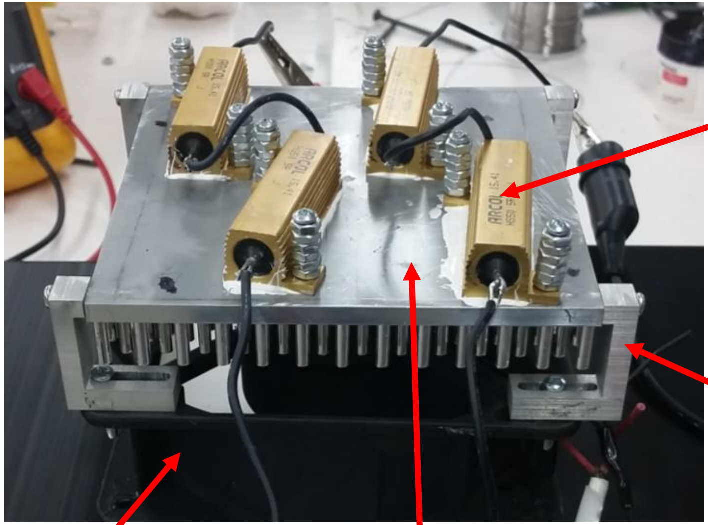
Total Power Diss. (W)	Average Temp. (°C)
0	23.36
30	28.04
60	30.36
90	33.22
120	36.4
150	42.08
180	42.5

- Without copper plates

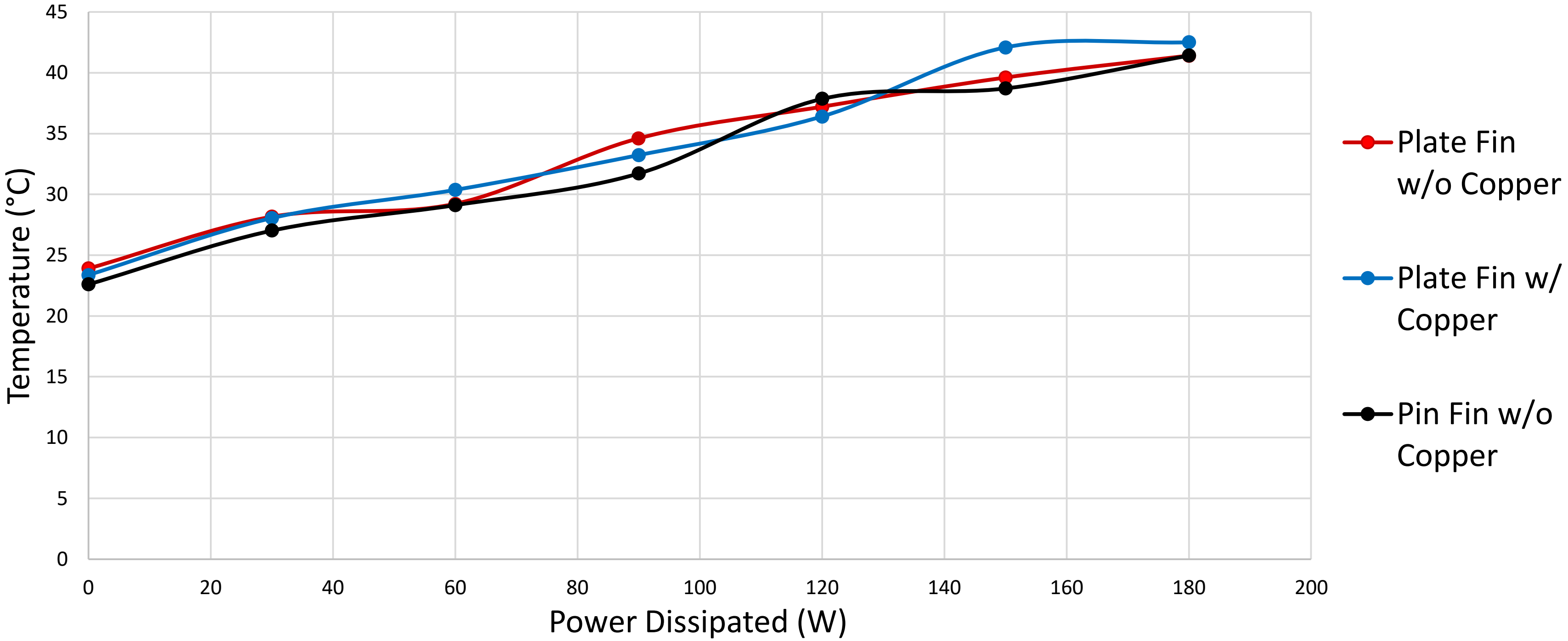
Total Power Diss. (W)	Average Temp. (°C)
0	23.9
30	28.16
60	29.22
90	34.6
120	37.2
150	39.6
180	41.4

Pin Fin Testing, Forced Convection

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



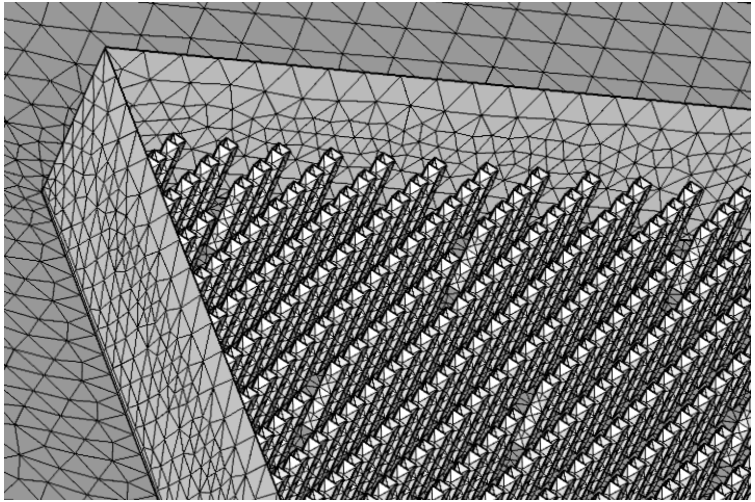
Testing Comparisons



Simulation Procedure

Software: COMSOL Multiphysics

- Constructed geometry and added material properties
- Applied initial/boundary conditions for heat transfer & laminar flow
- Built/refined mesh
- Ran simulation and analyzed results

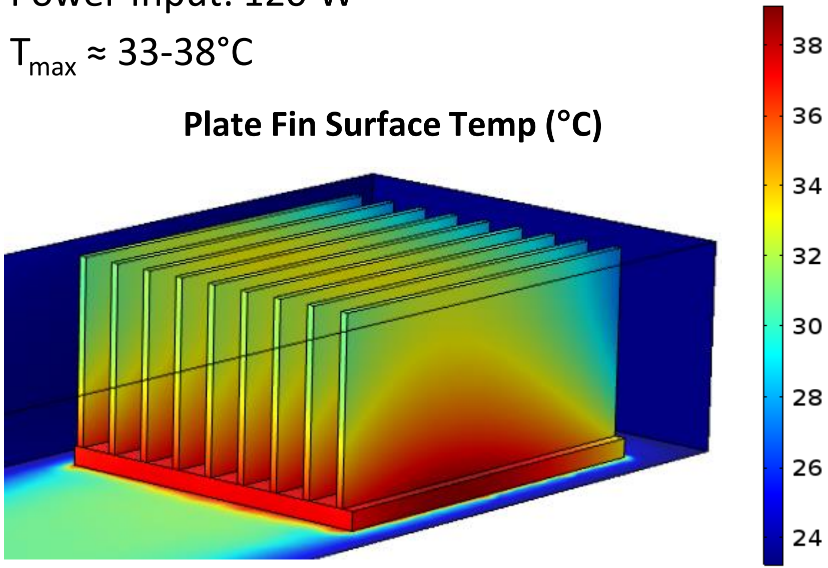


Pin Fin "Coarser" Mesh

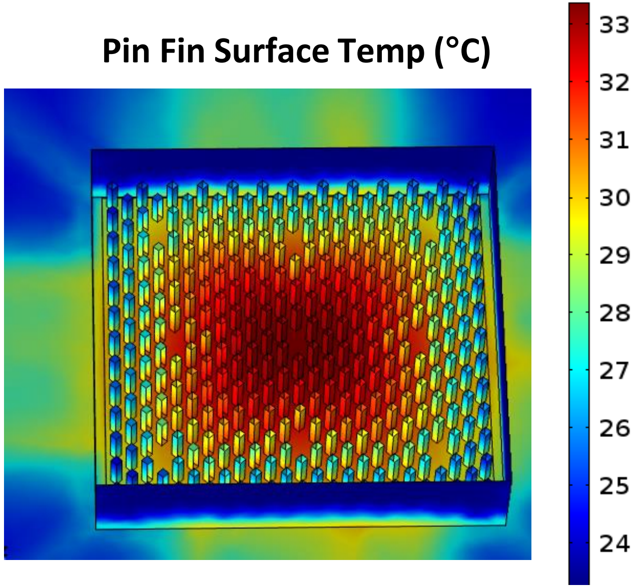
Simulation Results

- Ambient Temperature: 23.25°C
- Power Input: 120 W
- T_{max} ≈ 33-38°C

Plate Fin Surface Temp (°C)



Pin Fin Surface Temp (°C)



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

Theoretical Analysis

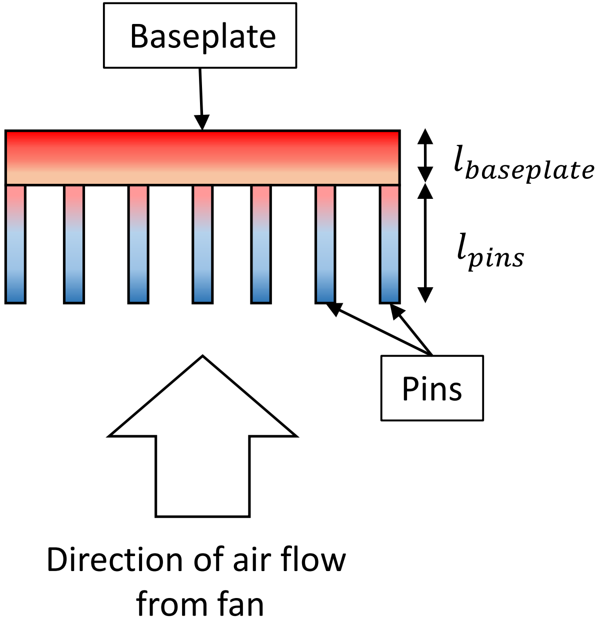
Total thermal resistance of heatsink:

$$R_{total} = R_{conductive} + R_{convective}$$

- Conduction
  - Movement of heat between solids due to a temperature gradient. Conduction requires physical contact.
  - Occurs in Heatsink Baseplate & Pins

$$R_{conductive} = \frac{l_{solid}}{k_{Aluminum} \times A_{cross\ section}}$$

- Convection
  - The transfer of heat from one place to another by the movement of fluids (e.g. air from fan)
  - Most influential convection occurs across fins & at bottom of baseplate

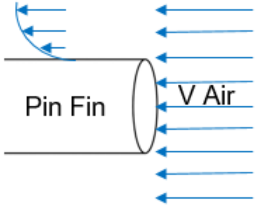


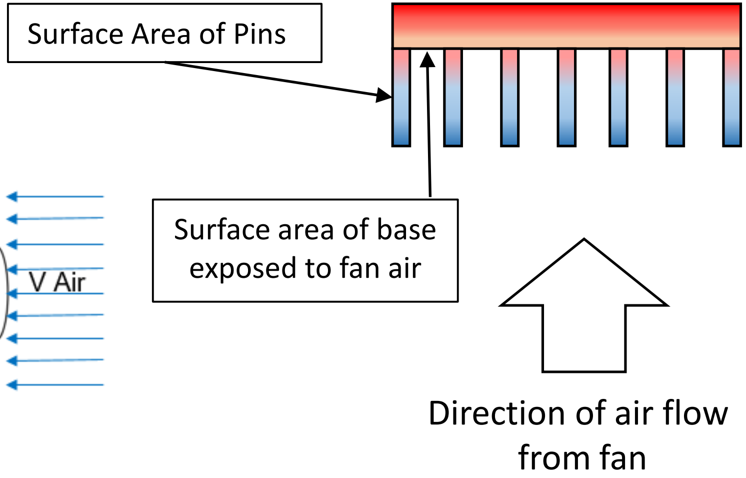
Theoretical Analysis

Convection is more complex

$$R_{convective} = \frac{1}{(N_{fins} \times \eta_{fins} \times h \times A_{fin\_surface}) + (h \times A_{unfin})}$$

- Convective heat transfer coefficient (h)
  - Velocity of air entering array of fins
  - Reynolds Number
  - Prandtl Number
  - Nusselt Number assuming flow over a flat plate
- Fin efficiency (η)
  - Geometry factor for cylindrical fins
  - Corrected fin length
- Correction factor to account for hindrance of air flow from pin array





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
- Uniform pin distribution
- Power loss/Heat source: 105.2 W

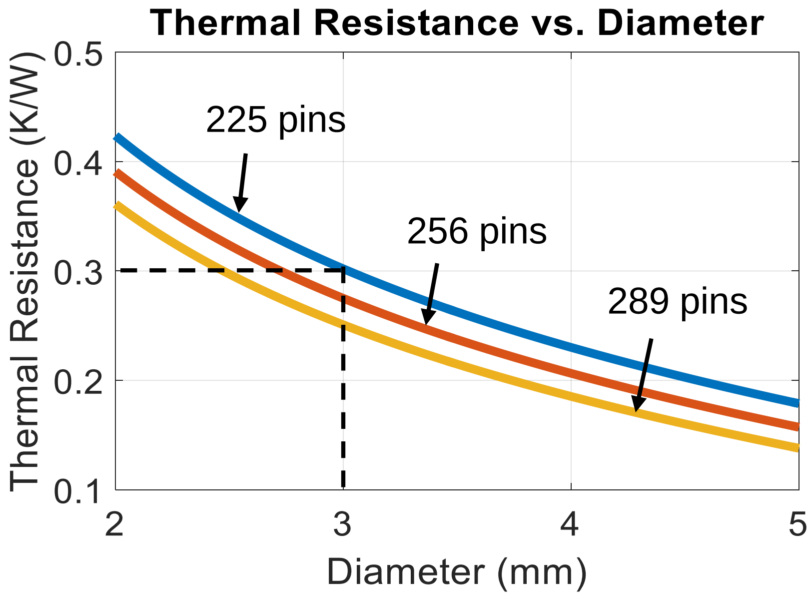
Optimization Relationships

- Cost of decreased weight is increased thermal resistance
- Change in length has least effect on output

Decreasing Parameter	Thermal Resistance	Weight
Pin Diameter	↑	↓
Pin Length	↓	↓
# of Pins	↑	↓
Fan Speed	↑	---

Optimization Results

- Varying diameter size: 2-5 mm
- To obtain necessary thermal resistance:
  - # Pins > 200
  - Diameter >= 3.0 mm
  - Fan speed >= 0.04 m^3/s
- To obtain even pin spacing, a uniform number of pins in each direction is needed



Fan Selection

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

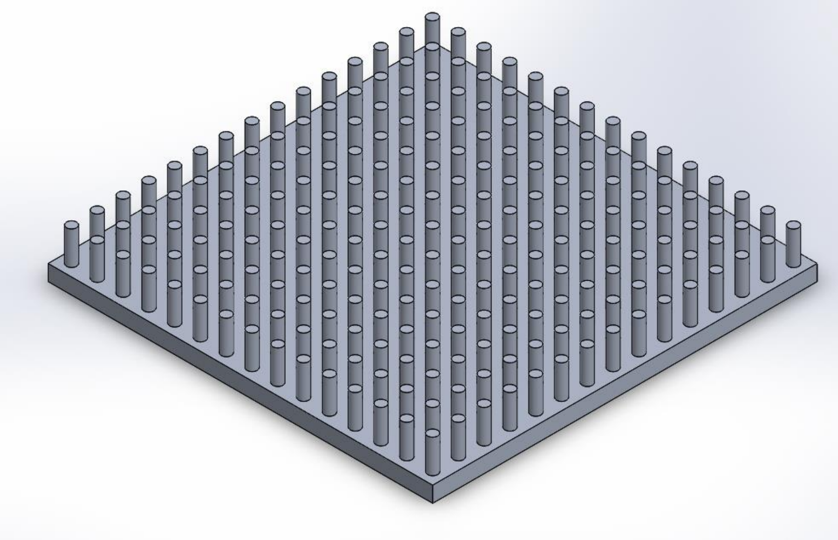
	Old Fan	New Fan
Weight (g)	300	157
Size (mm³)	120 x 120 x 38	120 x 120 x 25
Flow Rate (m³/s)	0.0505	0.051
Voltage (VDC)	12	12

Optimized Design

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

<u>Weight reduction including fans:</u>

- 34% < Manufacturer pin fin
- 71% < CAPS original heatsink

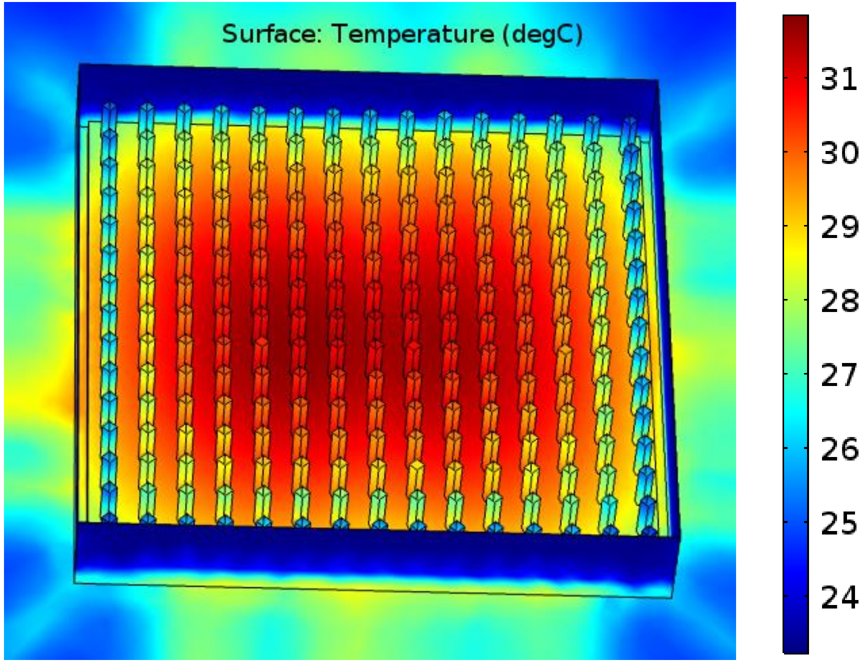


Optimized Pin Fin

COMSOL Verification

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

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



Design Overview

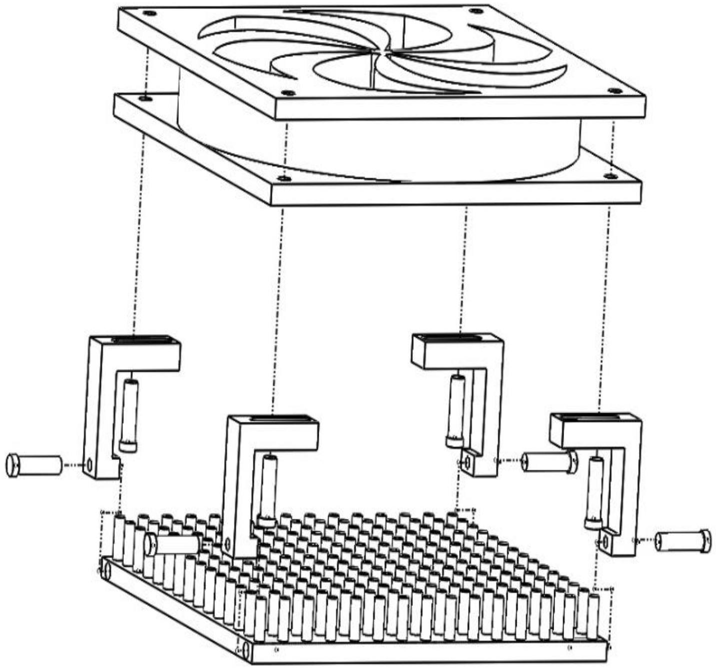
Thermal System

<u>Components x4</u>

- One 115m x 115mm Pin fin heat sink
- Four connector pieces
- Eight screws
- One 120mm x 120mm Cooling fan

<u>Assembly & Placement</u>

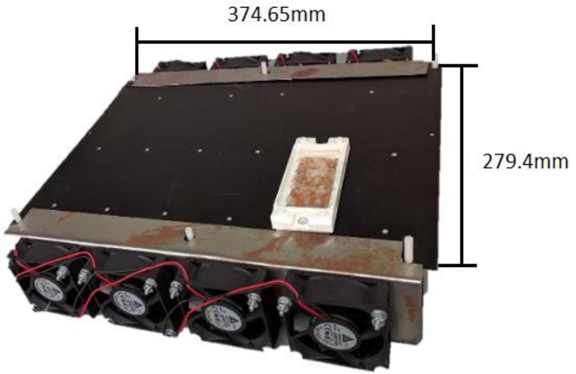
- Assembly will take an estimated 15 minutes
- Each thermal system will be placed 1in apart each other



Final Solution

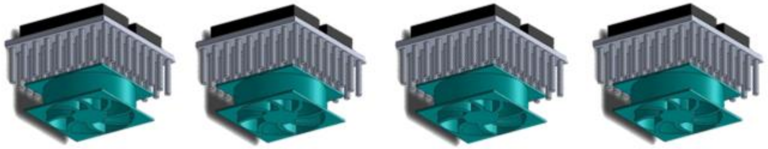
Original CAPS Heatsink

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



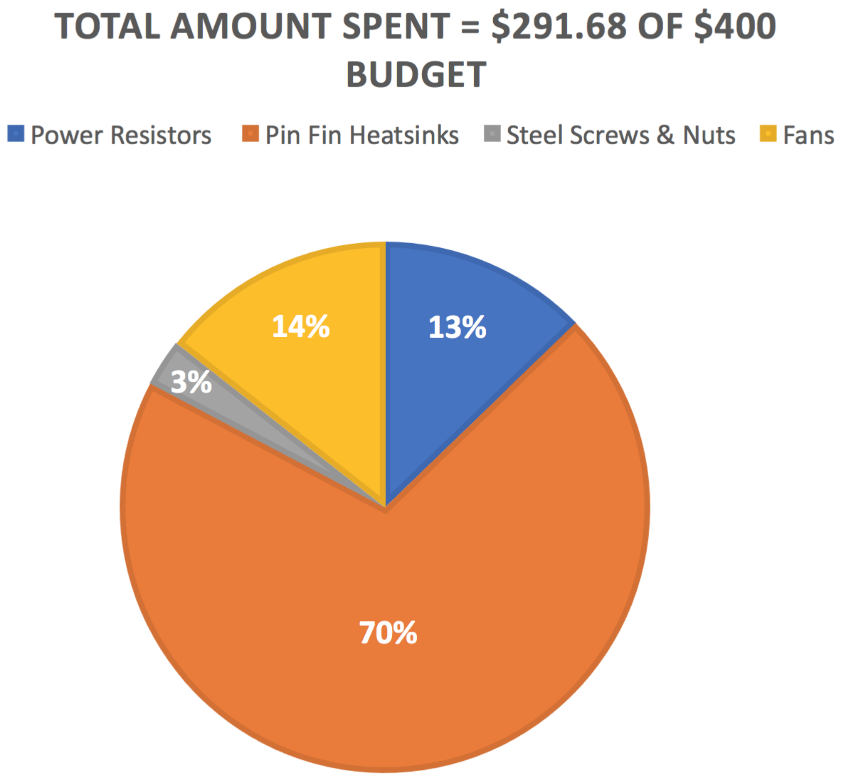
Solution: 4 Pin Fin Heatsinks

- Pin Fin Heatsink
- 2 Power Modules / Heatsink
- 1 Fan / Heatsink
- 115 mm x 115 mm x 14.7 mm
- 0.429kg per heatsink (**1.716** kg total)



Budget Overview

- The total amount spent for this project was kept under the $400 limit
- Total expenditures accounted for $291.68
- A large amount of lab equipment was available in CAPS to offset the price for the project



Accomplishments

Goal statement: Create a lightweight thermal structure for future applications

- Analyzed plate & pin fin designs through calculations, simulations, and experimentation
- Selected and optimized pin fin heatsink design
- Increased power density from 2.5 kW/kg to 6.54 kW/kg
- Reduced the weight of the total thermal system by 71%
- Developed heatsink selection guide

Acknowledgement

- Dr. Li
- Dr. Juan Ordonez
- Dr. Kumar
- Dr. Guo
- Thierry Kayiranga
- Sandro Martin
- Dr. Shih
- PowerAmerica
- CAPS
- AME
- COE Machine Shop

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Questions?