Designing & Testing Lightweight Heatsink for SiC PV Converter

Team 13

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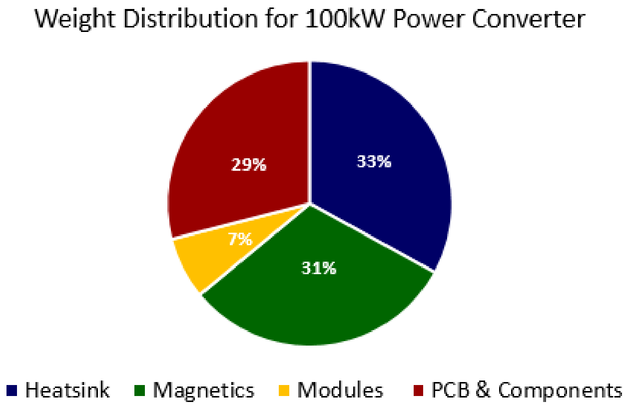
Project Overview

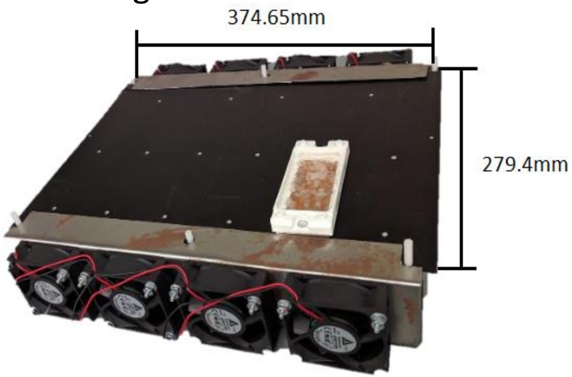
- **Background:** CAPS Next Generation PV Inverter has one of the highest power densities (Power out / weight)
- **Problem:** Heatsink used for this PV Converter was overdesigned
  - Too heavy & cold to the touch at maximum power output
- **Solution**: Provide a heatsink design & test method that will allow for optimal system performance.
  - By decreasing the weight of the heatsink, the power density of the converter can be increased.
- **Approach:** Utilize 3 methods for verification
  - COMSOL, Calculations, & Testing with Heat Source Emulator



Project Approach

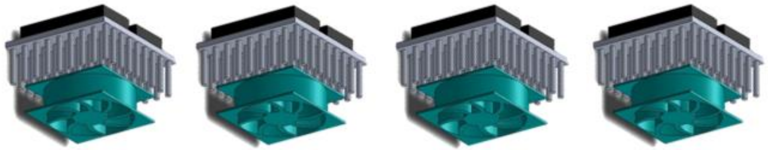
Original CAPS Heatsink

- Plate Fin Heatsink
- 8 Power Modules
- 8 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 X mm
- $\leq$ 0.56 kg per heatsink (2.2 kg total)



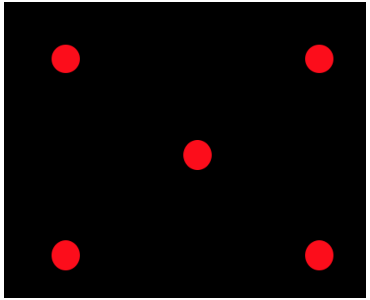
Heatsink Characteristics

- Plate fin and pin fin heatsink designs were analyzed using calculations, simulations and testing

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

Plate Fin Testing Procedure

- Used power supply for fans at 7.5V, 0.95A
  - Power = 7.2W
- Measured temperature with infrared gun
  - Took measurements at 5 points and averaged



Approximate measuring points

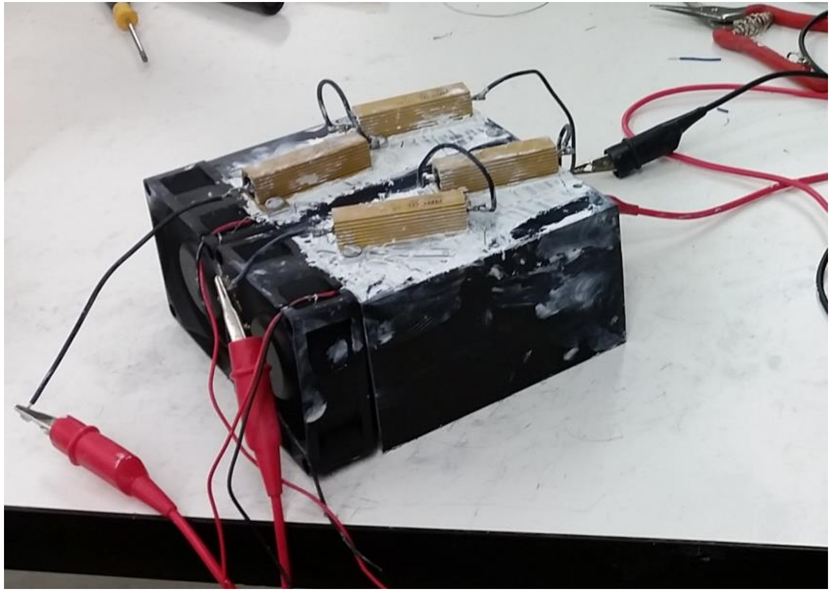


Plate Fin Testing

- With copper plate under emulators

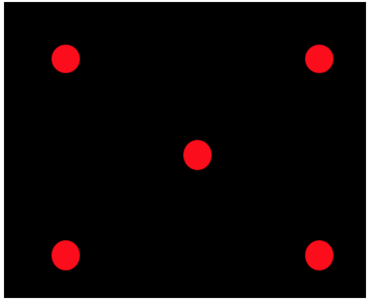
Power Dissipated per Emulator (W)	Total Power Dissipated (W)	Average Temperature (°C)
0	0	23.36
15	30	28.04
30	60	30.36
45	90	33.22
60	120	36.4
75	150	42.08
90	180	42.5

- Without copper plate under emulators

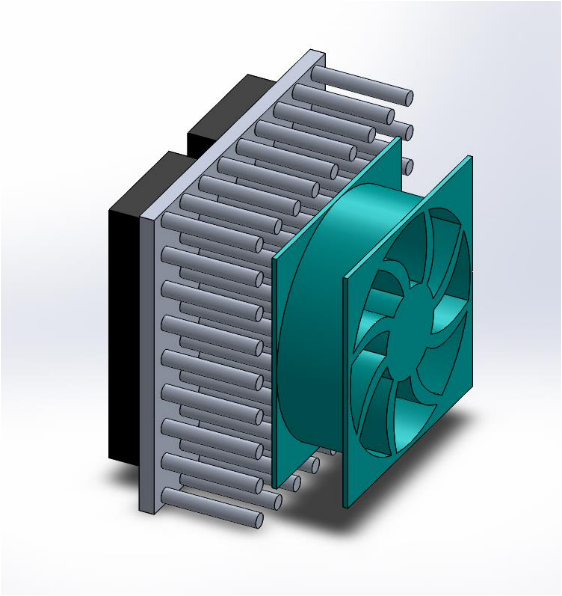
Power Dissipated per Emulator (W)	Total Power Dissipated (W)	Average Temperature (°C)
0	0	23.9
15	30	28.16
30	60	29.22
45	90	34.6
60	120	37.2
75	150	39.6
90	180	41.4

Pin Fin Testing Procedure

- Used power supply for fans at 11.52V, 0.57A
  - Power = 6.6W
- Measured temperature with infrared gun
  - Took measurements at 5 points and averaged



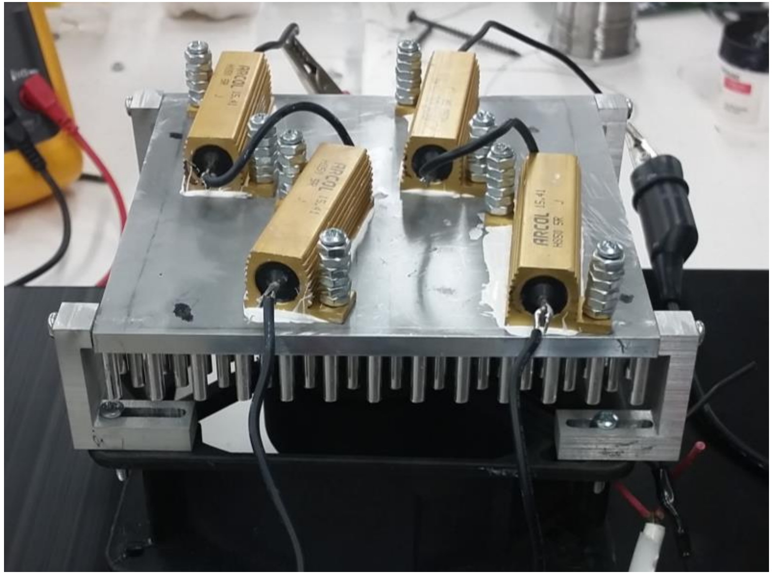
Approximate measuring points



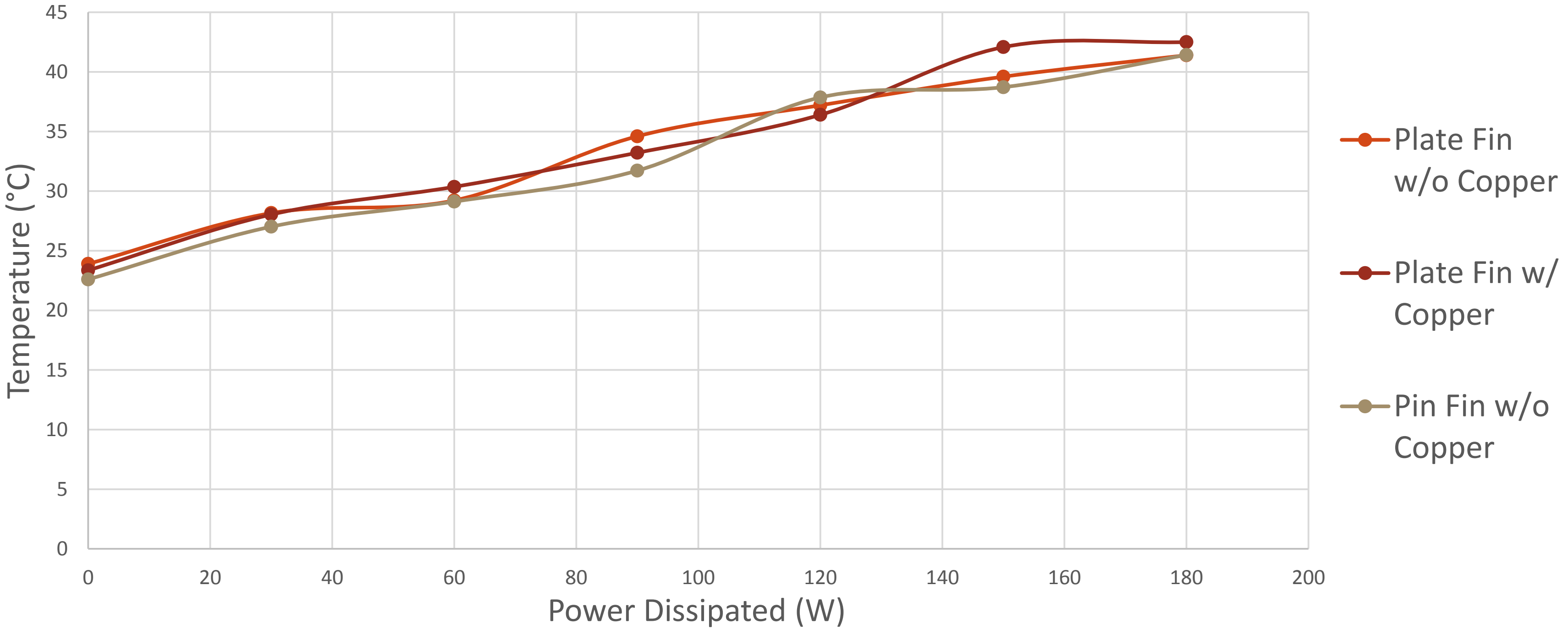
Pin Fin Testing

- Without copper plate under emulators

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

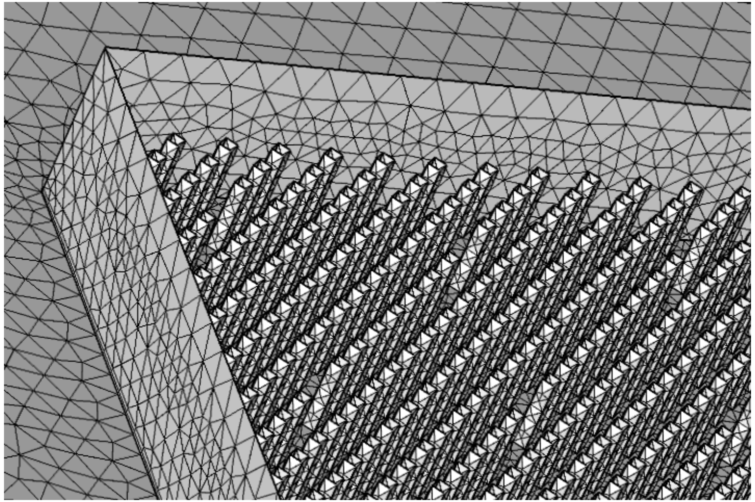


Testing Comparisons



COMSOL Procedure

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

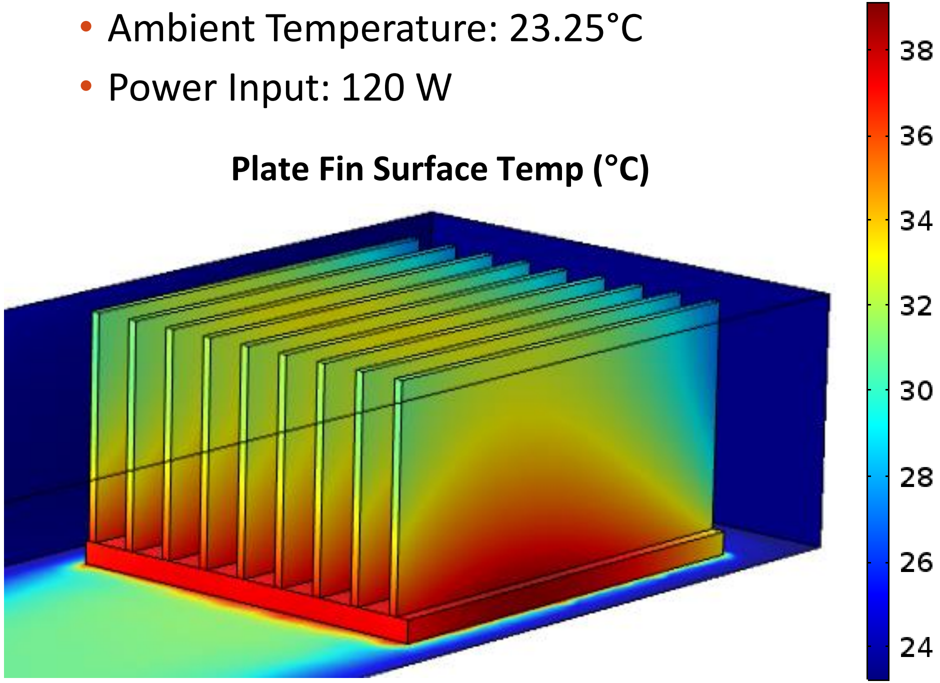


Pin Fin "Coarser" Mesh

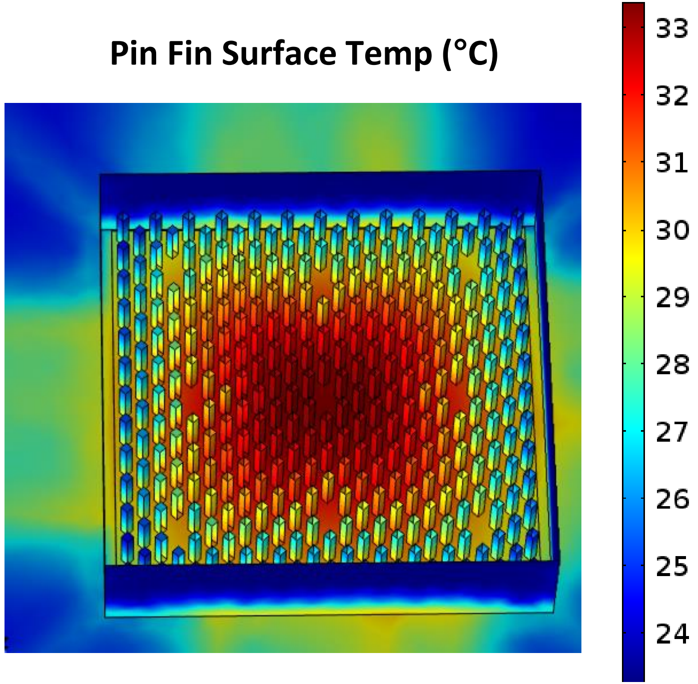
COMSOL Results

- Ambient Temperature: 23.25°C
- Power Input: 120 W

Plate Fin Surface Temp (°C)



Pin Fin Surface Temp (°C)



Procedure for Calculation

- **Thermal Resistance found from COMSOL & Test results**

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

- **Heatsink Mass (comparable to weight)**

$$Mass_{heatsink} = \rho_{Al} \times Vol_{heatsink}$$

- **Thermal Resistance Computed Analytically**

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

$$R_{conductive} = R_{cond\_base} + R_{cond\_fins}$$

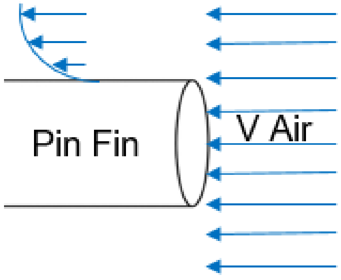
$$R_{cond\_base} = \frac{L_{base}}{k_{Al} \times A_{base\_cross}}$$

$$R_{cond\_fins} = \frac{L_{fin}}{k_{Al} \times A_{fin\_cross} \times N_{fins}}$$

$$R_{convective}$$

Convective Thermal Resistance for 1 Fin

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



Fin efficiency for a cylinder

$$\eta_{fins} = \frac{\tanh\left(m \times L_{corrected}\right)}{m \times L_{corrected}}$$

$$m = \sqrt{\frac{4 \times h}{k_{Aluminum} \times D_{fin}}}$$

$$L_{corrected} = L_{fin} + \frac{D_{fin}}{4}$$

Flow over a flat plate

$$V_{avg} = \frac{\dot{V}_{fan}}{A_{unfin}}$$

$$Re = \frac{L_{fin} \times V_{avg}}{\nu_{kinetic\_air}}$$

$$Nu = 0.664 \times Re^{0.5} \times \Pr_{air}{}^{1/3} \quad for\ (Re < 5 \times 10^5)$$

$$Nu = (0.037 \times Re^{0.8} - 871) \times \Pr_{air}{}^{1/3} \quad for\ (5 \times 10^5 \leq Re \leq 10^7)$$

$$h = \frac{Nu \times k_{air}}{L_{fin}}$$

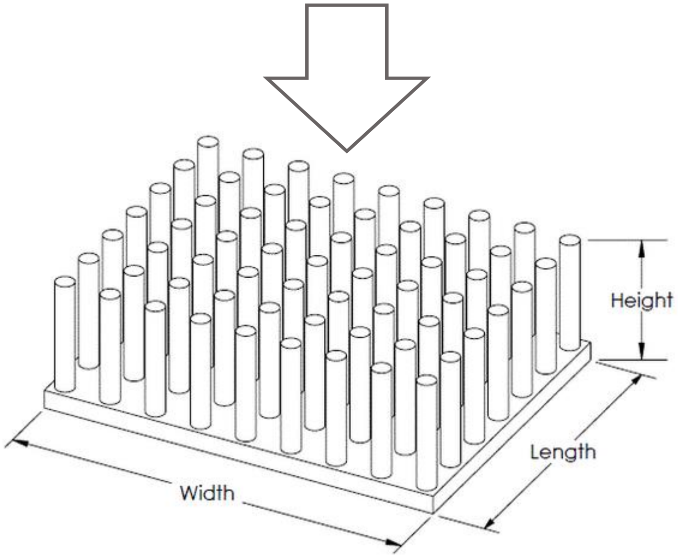
Accounting for an Array of Pins

- Convective thermal resistance was taken considering flow around 1 fin
- The addition of other pins accounts for an estimated 20-30% error in the Convective thermal resistance
- To account for this, a variable $C_{correction}$ is included in the calculations. It's currently considered to be 0.25.

$$R_{convective} = R_{convective} \times (1 - C_{correction})$$

- Percent error in the pin fin calculations has been reduced from roughly 400% to less than 60%.

Direction of Air Flow



Comparison of Thermal Resistances

- **Pin Fin**

	Power Output (W)	Junction Temp. (°C)	Thermal Resistance (°C/W)	Thermal Resistance % Error
Test Results	120	37.86	0.127	---
COMSOL		33.38	0.084	33.9%
Analytical		43.55	0.196	54 %
Total Weight	2.212 kg (65.7 % weight reduction)			

- **Plate Fin**

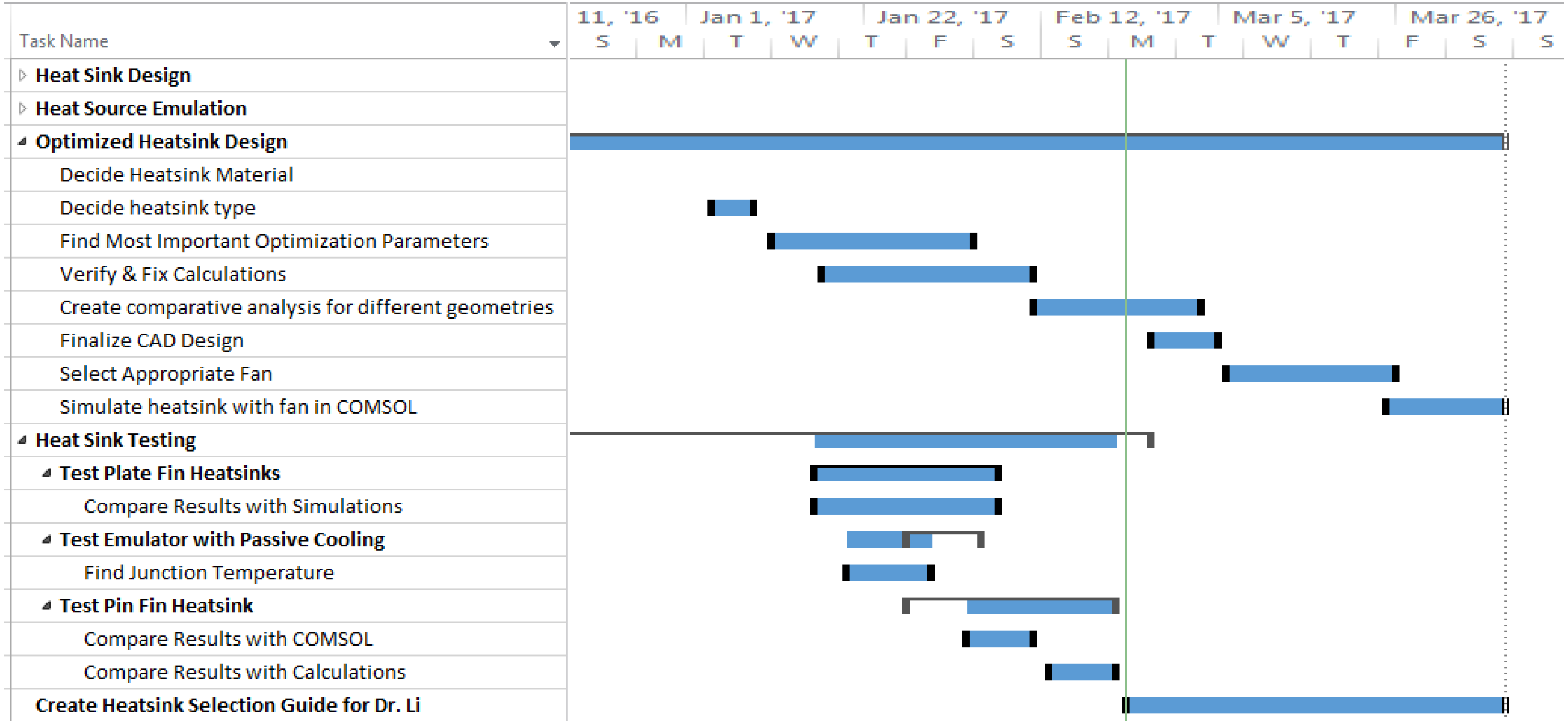
	Power Output (W)	Junction Temp. (°C)	Thermal Resistance (°C/W)	Thermal Resistance % Error
Test Results	120	37.2	0.111	---
COMSOL		39.145	0.132	18.9 %
Analytical		65.6	0.38	242 %
Total Weight	3.816 kg (40.8 % weight reduction)			

Optimization

Optimizing by varying the heatsink's 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

Gantt Chart



Task Name
11, '16
Jan 1, '17
Jan 22, '17
Feb 12, '17
Mar 5, '17
Mar 26, '17
S M T W T F S S M T W T F S S
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
Finalize CAD Design
Select Appropriate Fan
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

- Created analytical equations for pin fin heatsink
- Experimentally tested both pin fin and plate fin designs
- Selected a design

Future Plans

- Optimize the Pin Fin Heatsink design
- 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*. N.p., n.d. Web. 23 Feb. 2017.

Questions?