

Waste Heat Management

HEAT WASTE MANAGEMENT

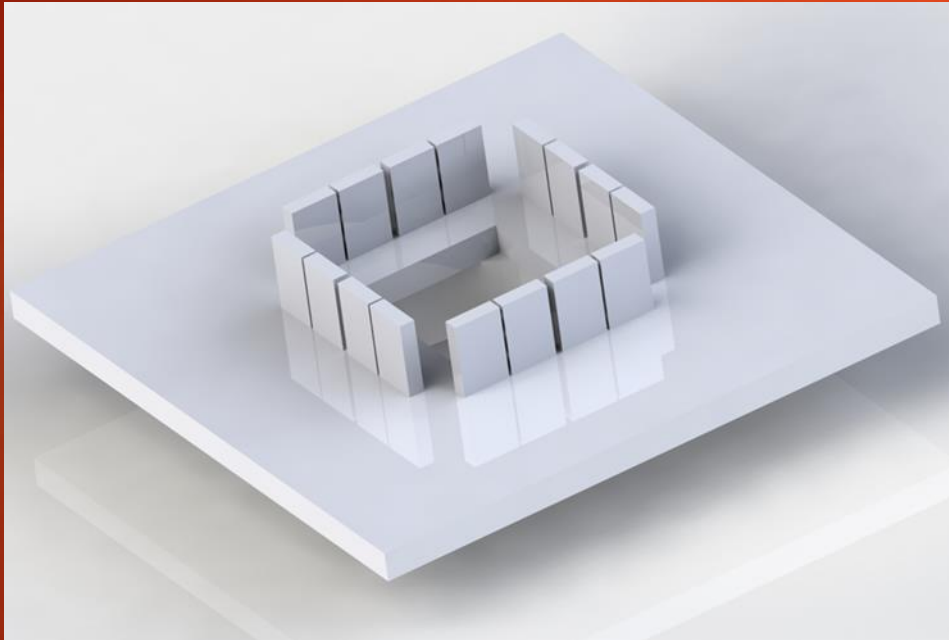
FRIGUS TEAM MEMBERS: JT SUTTON, CALEB JO, AND CONNOR TRULOCK

INSTRUCTORS: HERB HESS, TAO XING, MARK ROLL, RACHEL PETERSON

SPONSOR: US NAVY

Problem Definition and design goals

2



The objective was to design a thermal management system for a multi-kilowatt, multi-phase, power converter based around a unified thermal core with liquid or air cooling.

This project consists of 2 main phases

Phase 1- designing a heat sink to fit within the constraints for the thermal and physical properties defined by board configuration and MOSFET placement.

Phase 2- focused around testing for the purpose of refining heat dissipation, functionality, and efficiency.

Specifications and constraints

3

Variable	Maximum	Operating	Notes
Mechanical Spec's			
Efficiency	94%-97%	94%	
Weight (total)	6 lb	-	Needs to be 2 man portable
Volume	1/32 m ³ or 8.255 gal	-	
Electrical Spec's			
Ambient temperature	-55 C to 70 C	Parametric study	
Number of MOSFETs	16	16	
Temperature range for MOSFETs	-40 C to 150 C	100 C (desired)	Lower end problem
Power	125 W	125 W	this is based off of $P=i^2*r$
Thermal paste (Tpcm 580 series)		$1.6*10^{(-5)}$ [[C*m ²)/W]@ 10 Psi	
Thermal paste Thickness	.00406 M	.000406 M	

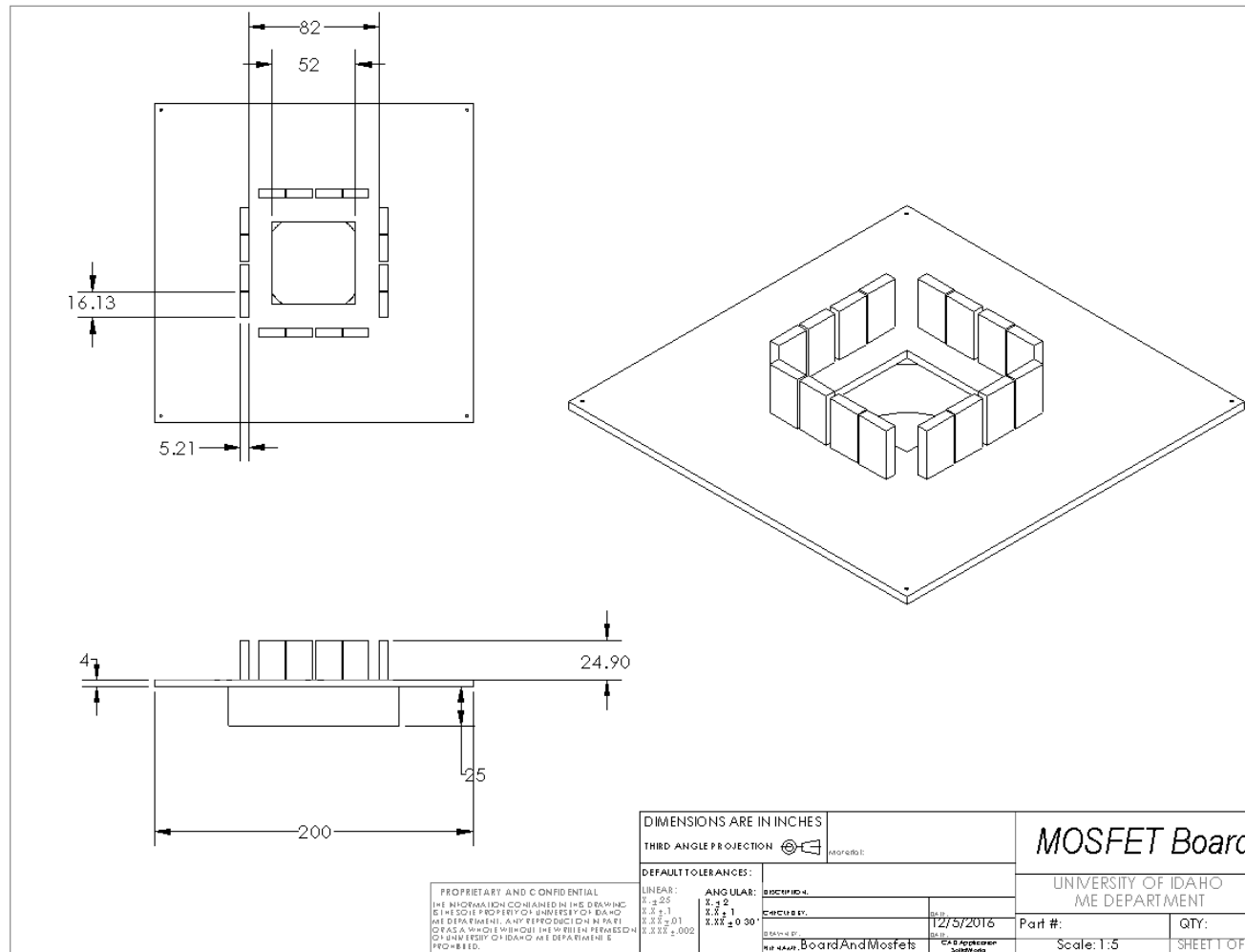
- ▶ The main constraints:
 - ▶ The amount of heat we need to remove
 - ▶ The layout of the circuit board
 - ▶ The weight
 - ▶ The volume

Deliverables



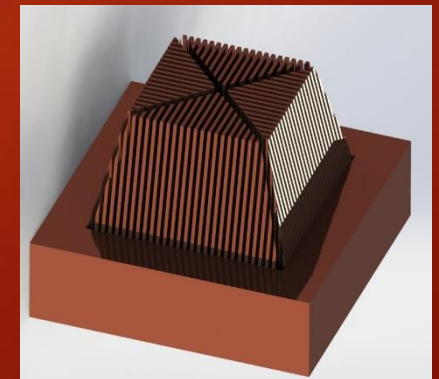
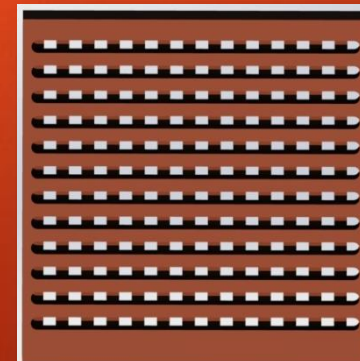
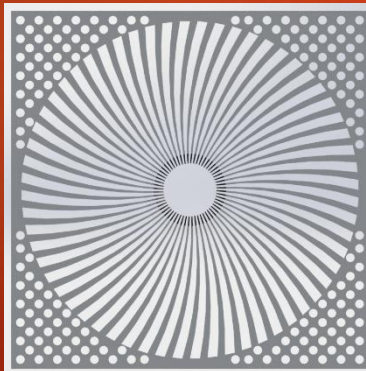
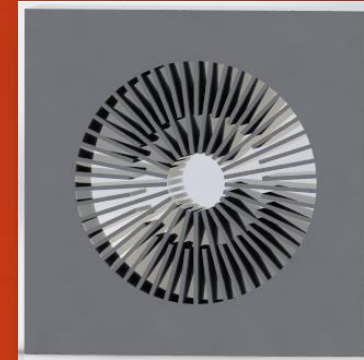
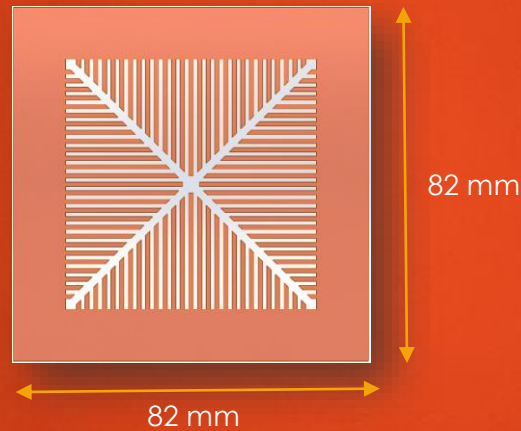
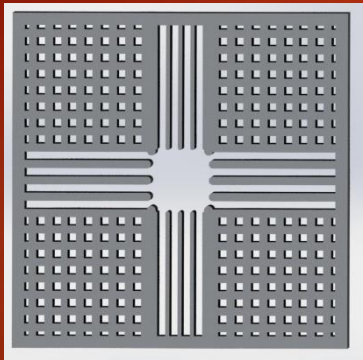
- ▶ One fully designed and tested heat sink proven to be the best of all of our designs at of removing the heat from the MOSFETs as well as meeting all of our other specifications.

Board set up



Design Concepts for the heat sink

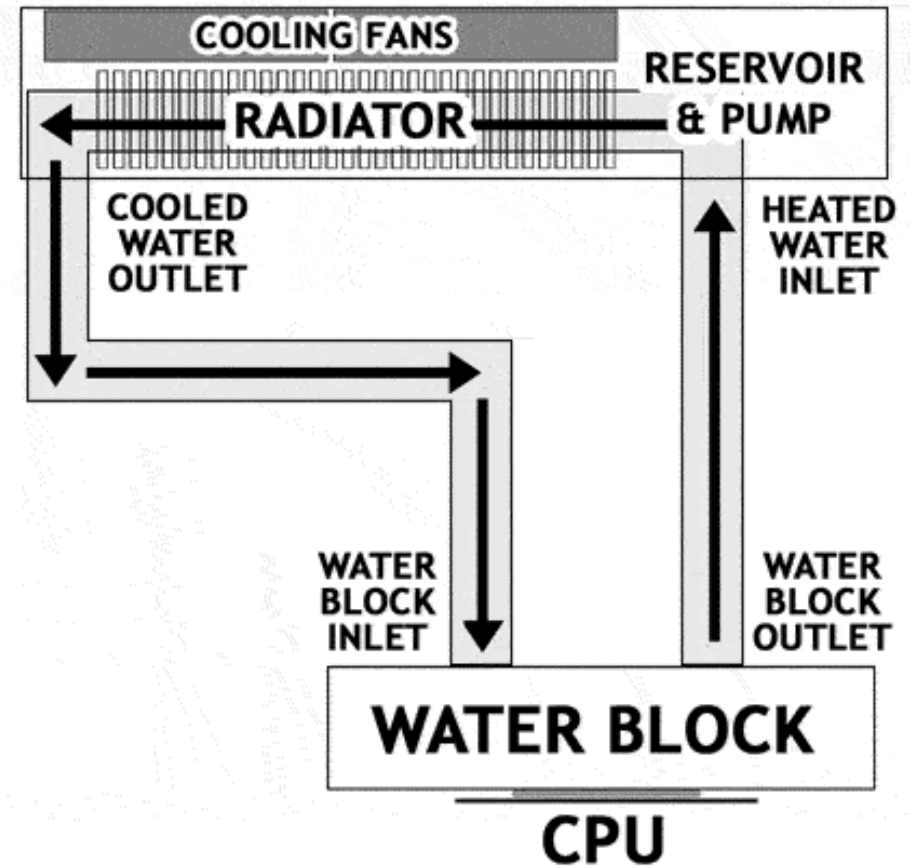
- ▶ We started out with the following preliminary designs aiming to increase manufacturability, maximize surface area, minimize weight, and optimize fin spacing.



Water System



TYPICAL LIQUID COOLED CPU



Simulations & Math Modeling

- ▶ Rachel Peterson was able to run simulations and Math Models for us to verify that that our air cooling system should work
- ▶ This allows us to continue on with the Air cooled system, giving us three different system to work with

Junction Temperature of Each MOSFET	Heat Output per MOSFET obtained with 50% duty cycle	Required Heat Sink Thermal Resistance for sixteen MOSFETs at ambient Temperature of 20°C
150°C	16.6W	0.47°C/W
125°C	14.5W	0.43°C/W
100°C	12.3W	0.39°C/W

Final choice

Cross Hatched Sink



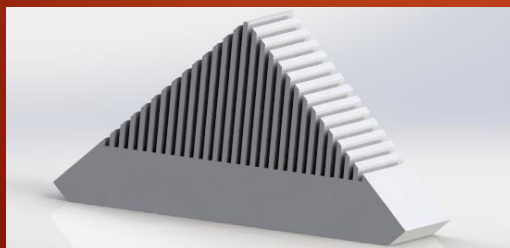
Water Cooled Sink



Cross Hatched Sink Redesign



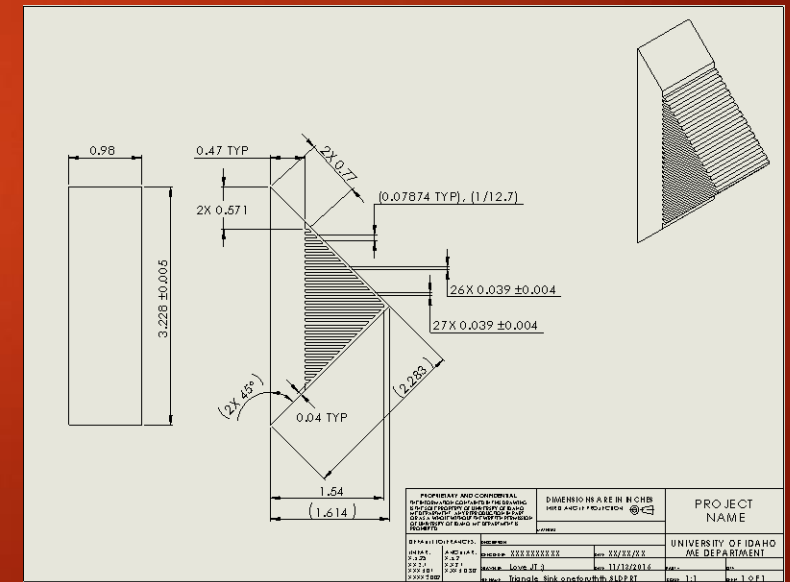
Triangular Sink



- ❑ **Final designs include:**
 - ❑ Water Cooled Heat Sink
 - ❑ Triangular Air Cooled Sink
 - ❑ Crossed Hatched Air Cooled Sink
 - ❑ Redesigned Crossed Hatched Air Cooled Sink
- ❑ **Determined aluminum would work best over copper as it has a higher thermal resistance but much less mass (3x lighter).**

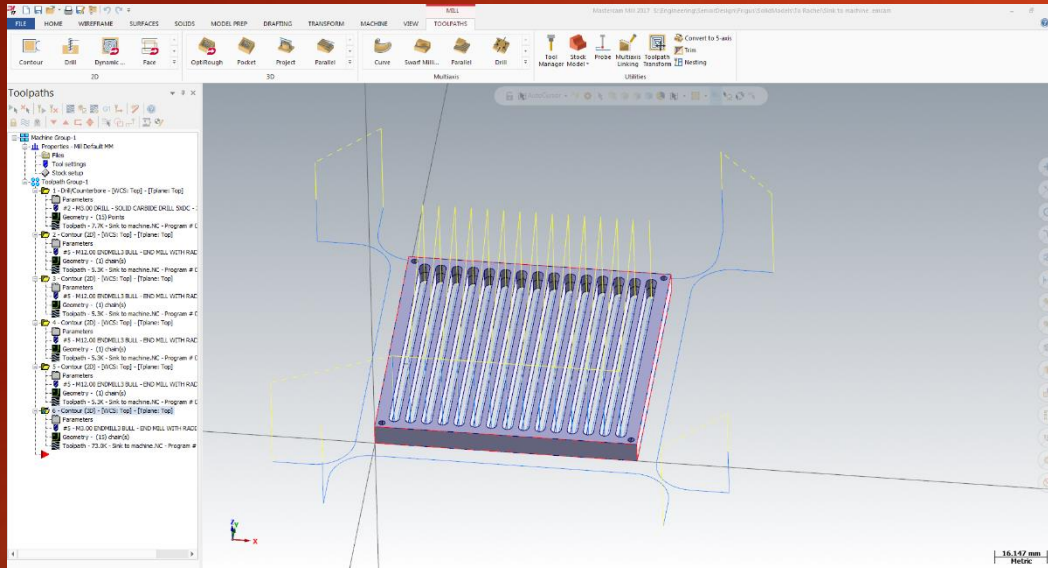
Triangular Heat Sink

- ▶ First heat sink we made. Learned about shop and manufacturing.
- ▶ After researching how to manufacture our heat sinks we found that we could construct this sink using a slitting saw. Using aluminum from the shop we created 4 identical triangular pieces, cut relief spacers between the segments, and finally used a slitting saw to cut the fins.



Cross Hatched Heat Sink

11



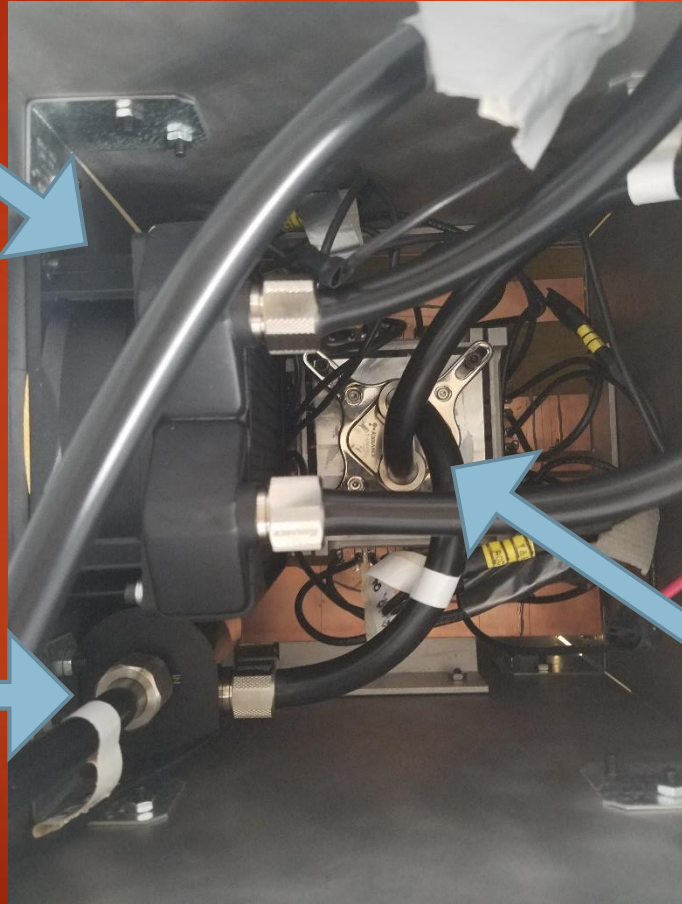
- ▶ After a few modifications we came up with our final crosshatched heat sink design, based around the shops capability.
- ▶ We were able to create a Mastercam code for the sink and then manufacture 4 of them side by side on the shops Hass Mill.



Water cooling system

13

Radiator / Fan



Pump

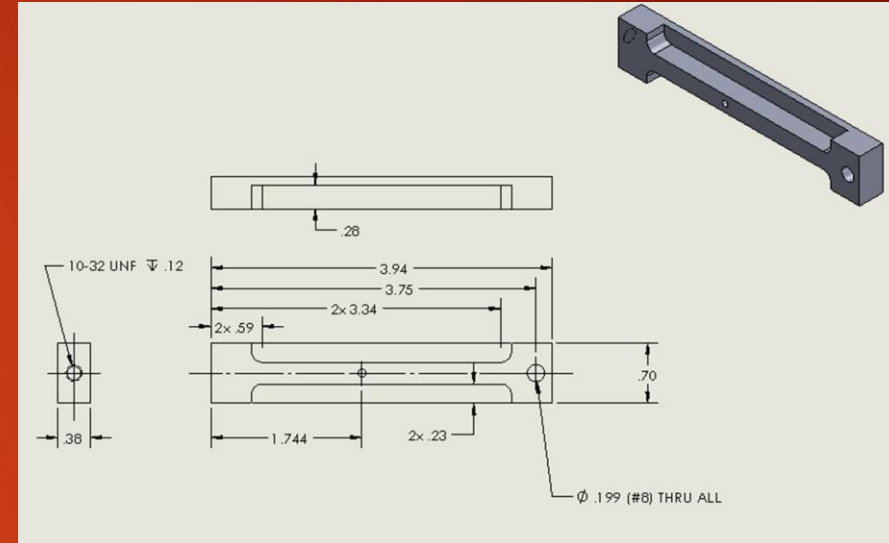
Water Block

- ▶ We originally decided to implement a water cooling system in addition to the air cooled system, on the off chance that the air cooled failed to meet the required cooling capacity
- ▶ We were able to buy the cooling system as a complete package and then manufacture a rectangular aluminum cooling block with taped holes for attaching a cooling plate.

MOSFET Brackets

14

- ▶ Ran into issues with attaching the MOSFET brackets. Holes in the block for attaching cold plate interfered with placement.
- ▶ Came up with a new design to replace the old design.
- ▶ Came up with design that interconnected the ends of each of the bracket sides.
- ▶ Drafted brackets in solid works then machined
- ▶ Work well to secure MOSFET's to the heat sink



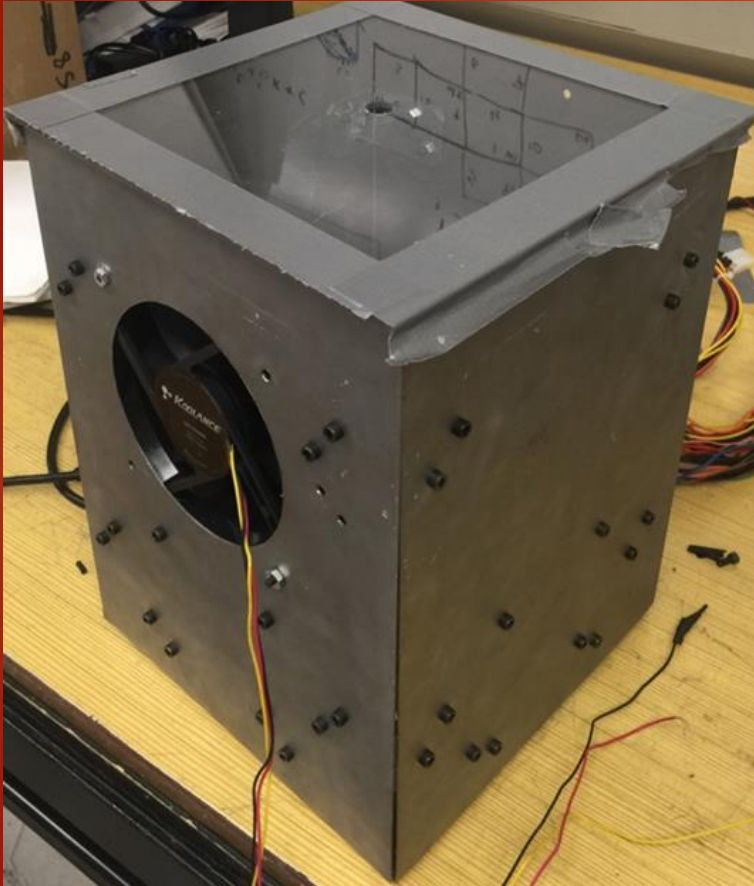
Case Design

- ▶ Designed using Solidworks
- ▶ Cut 20 gauge sheet metal to 8 x 12 in sheets for the sides and 8 x 8 for the top and bottom.
- ▶ Brackets connect the sides together as well as the bottom
- ▶ Brackets were machined to mount and secure the board and the MOSFETS to the case
- ▶ Designed to use 1 fan configuration for ventilating case and a 2 fan configuration where another fan is attached directly over the heat sink to remove heat.



Testing set up

16

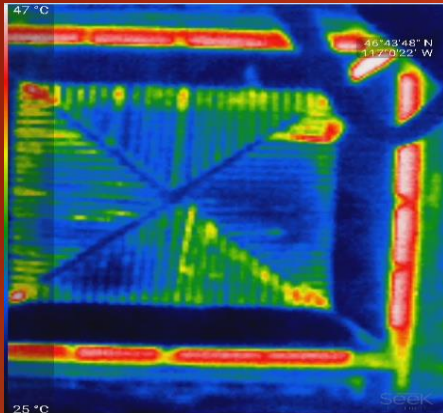


- ▶ We began our testing process by defining our testing variables and creating a rubric for data recording and processing.
- ▶ We then used a watt meter with a variac power supply to power the board at approximately 125 W, as well as a power supply to run the fans and pump. We then recorded 30 minute test segments using our thermal camera

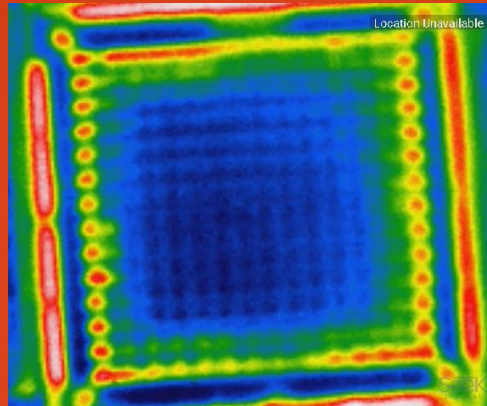


Testing

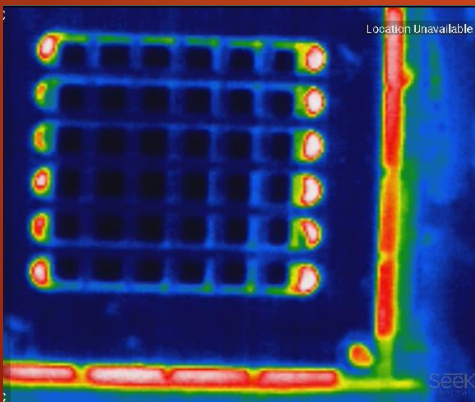
Triangular Sink



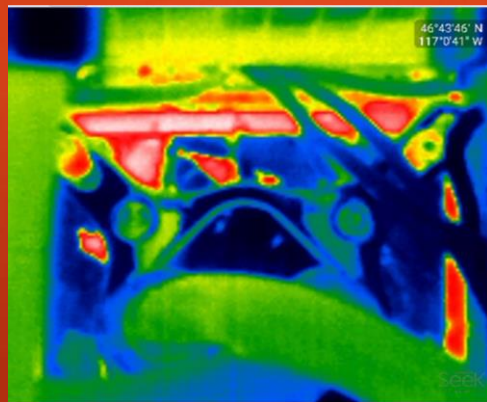
Cross Hatched Sink



Cross Hatched Sink Redesign



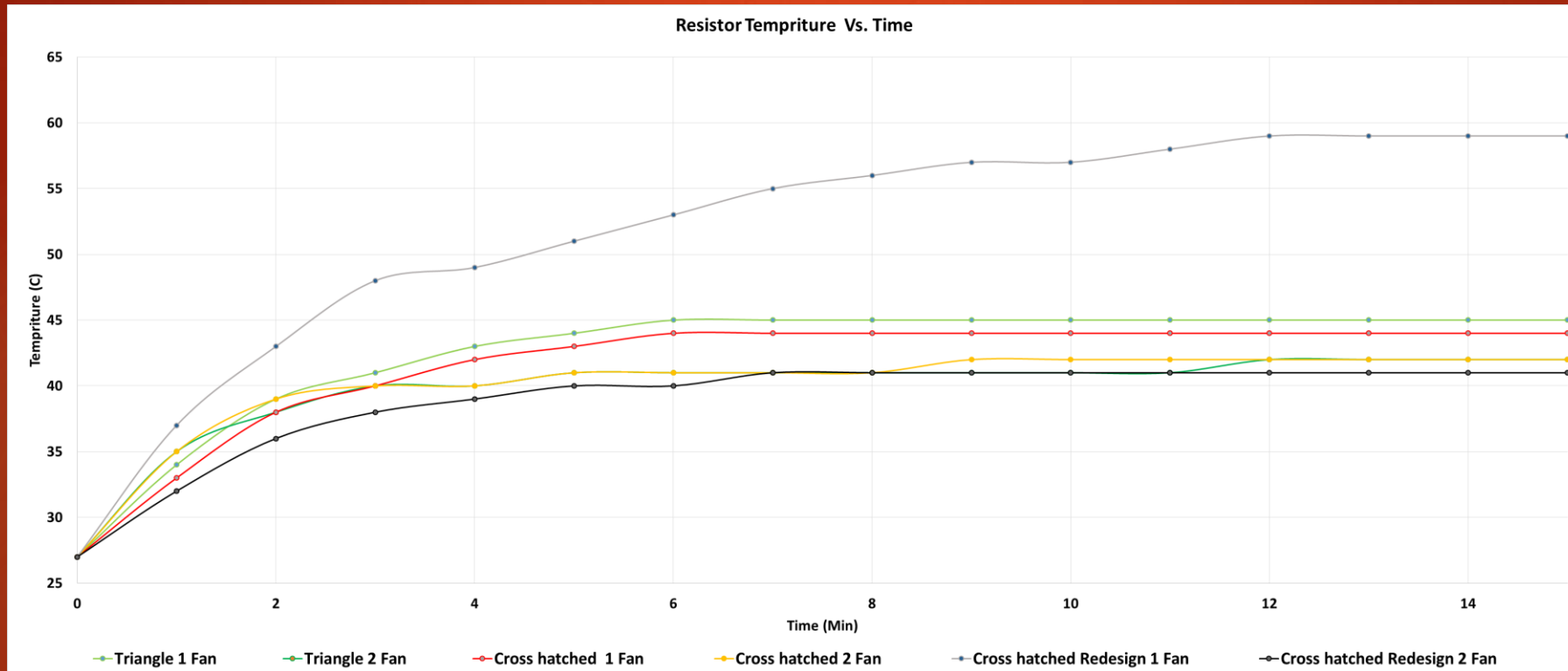
Water Cooled Sink



- ▶ We ran all tests for 30 min intervals
- ▶ Ran at 125 Watts
- ▶ We ran test on the air sinks using 1 and 2 fan configurations.



Results



Testing variable	Water cooling	Triangle 1 fan	Triangle 2 fan	Cross hatched 1 fan	Cross hatched 2 fan	Cross hatched redesign 1 fan	Cross hatched redesign 2 fan
Thermal Resistivity (C/W)	0.09	0.1925	0.1674	0.1912	0.1663	0.3058	0.12479

Results

Testing variable	Energy (watts)	weight (grams)	Manufacturing
Water cooling	33	1891	1
Triangle 1 fan	9	432	6
Triangle 2 fan	27	560	7
Cross hatched 1 fan	9	442	4
Cross hatched 2 fan	27	570	5
Cross hatched redesign 1 fan	9	526	2
Cross hatched redesign 2 fan	27	534	3



- ❑ Compiled all test data
- ❑ Calculated thermal resistivity of each sink
- ❑ Applied weights to test and system variables
- ❑ Characterized heat sink by:
 - ❑ Thermal Resistivity
 - ❑ Power Draw
 - ❑ Weight
 - ❑ Manufacturability
- ❑ Determined that the Crosshatched Heat sink with 1 fans attached, was the most viable solution

Questions ?