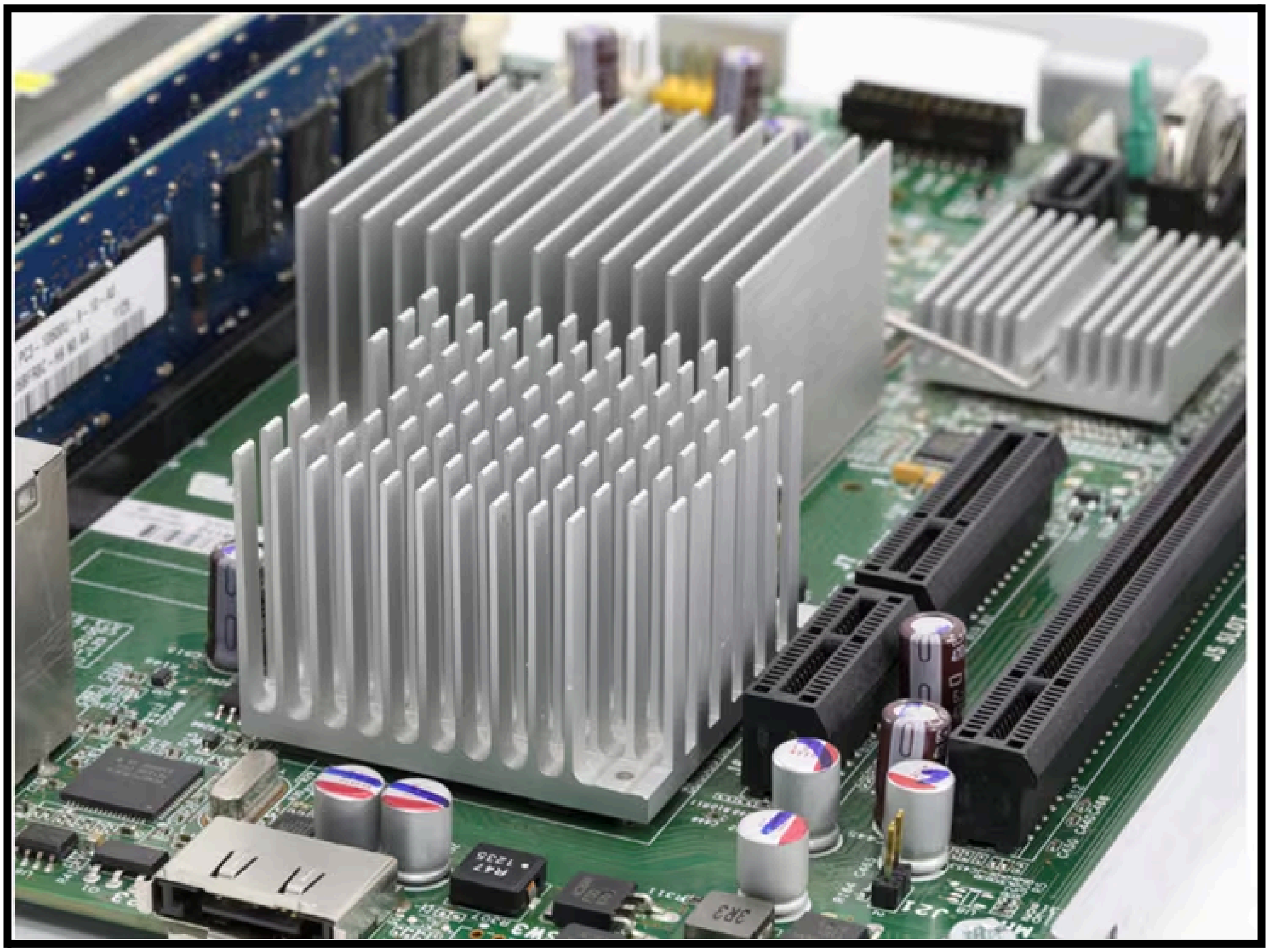
ME4429 Project #3 - Heat Sink Design



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Report Submitted to:

Professor Selcuk Guceri

Simulation of Chips Without the Heat Sink (Part 1)

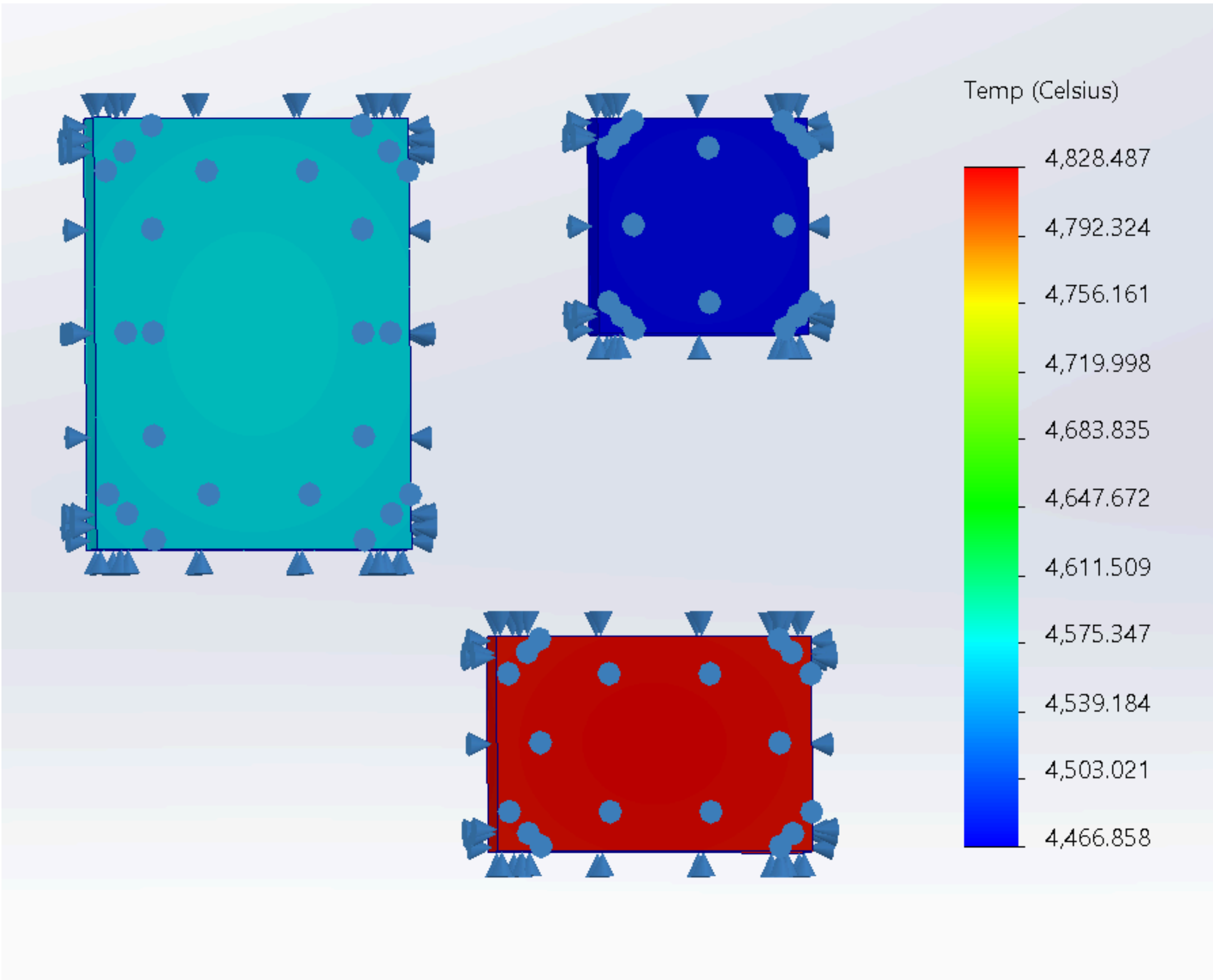


Figure 1: Solidworks Simulation with just silicon chips and no heat sink. Chip 1 (Cyan) is ~4540°C. Chip 2 (Red) is ~4828°C. Chip 3 (Dark Blue) is ~4466°C.

Our original simulation was of the chips with no heat sink attached, as shown in figure 1. We used an h = 10 W/m^2K. For the material of the chips, we chose silicon. The maximum temperatures for each chip, as time approaches infinity, reached absurdly high numbers, ranging from 4466° to 4828°. These numbers are not realistic, as the silicon (melting point of 1414°C) in the chips would melt by this point, but our simulation does not take this into account.

Simulation of Chips With the Heat Sink (Part 2)

For our three trials, we designed a simple heat sink with horizontal dimensions 40 mm x 40 mm with a 3 mm thick base and rods with a height of 20 mm. The rods are 1 mm x 1 mm on and spaced 0.5 mm apart, resulting in square shaped metal rods. We chose 6063-O aluminum as the material for the heat sink as it has very high thermal conductivity (237 W m^−1 K^−1), it is very cheap, and is one of the most common heat sink materials.

Case 1 - h = 10 W/m^2K

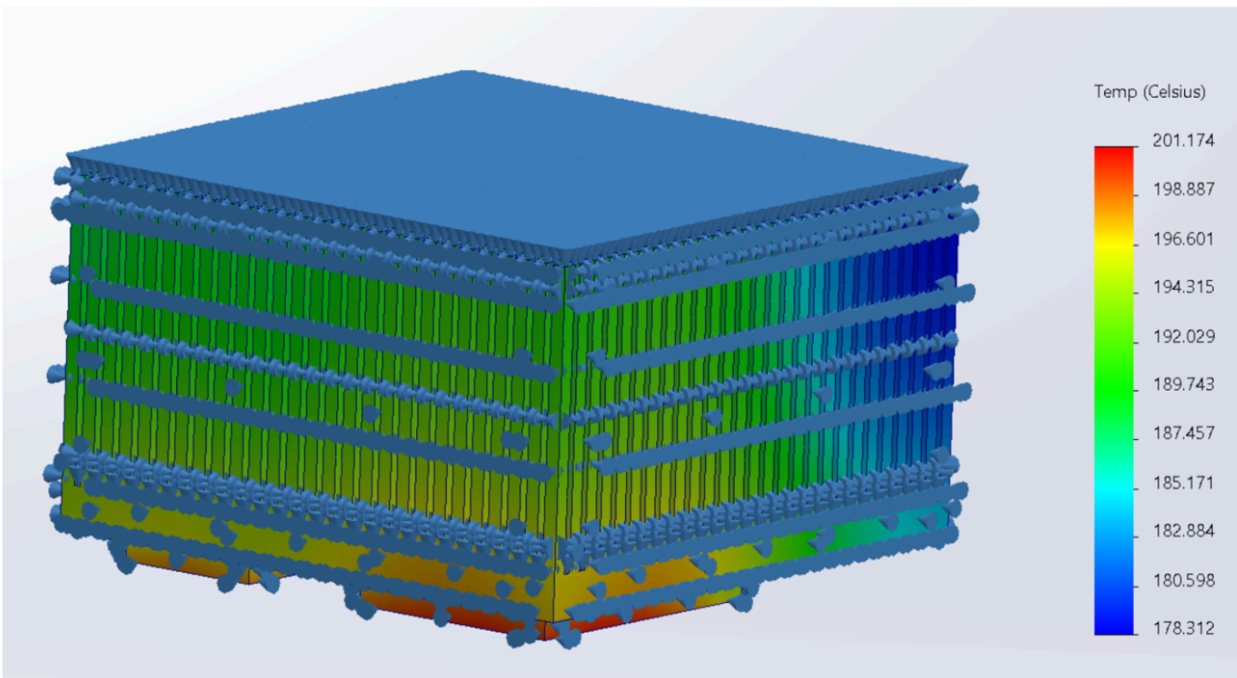


Figure 2: Solidworks Simulation with silicon chips, aluminum heat sink, and h=10 W/m^2K. Heat of the system ranges from 178.312°C at the edges of the heat sink to 201°C at the base of the chips.

For our first trial, we chose a reasonable natural convection of h = 10 W/m^2K. As shown in figure 2, the maximum temperature of the chips as time approaches infinity is recorded at 201.174°C. This means that our convection coefficient of h=10 W/m^2K was not enough to disperse the heat of the chips to 85°C. This led us to raise out h for the subsequent cases.

Case 2 - h = 20 W/m^2K

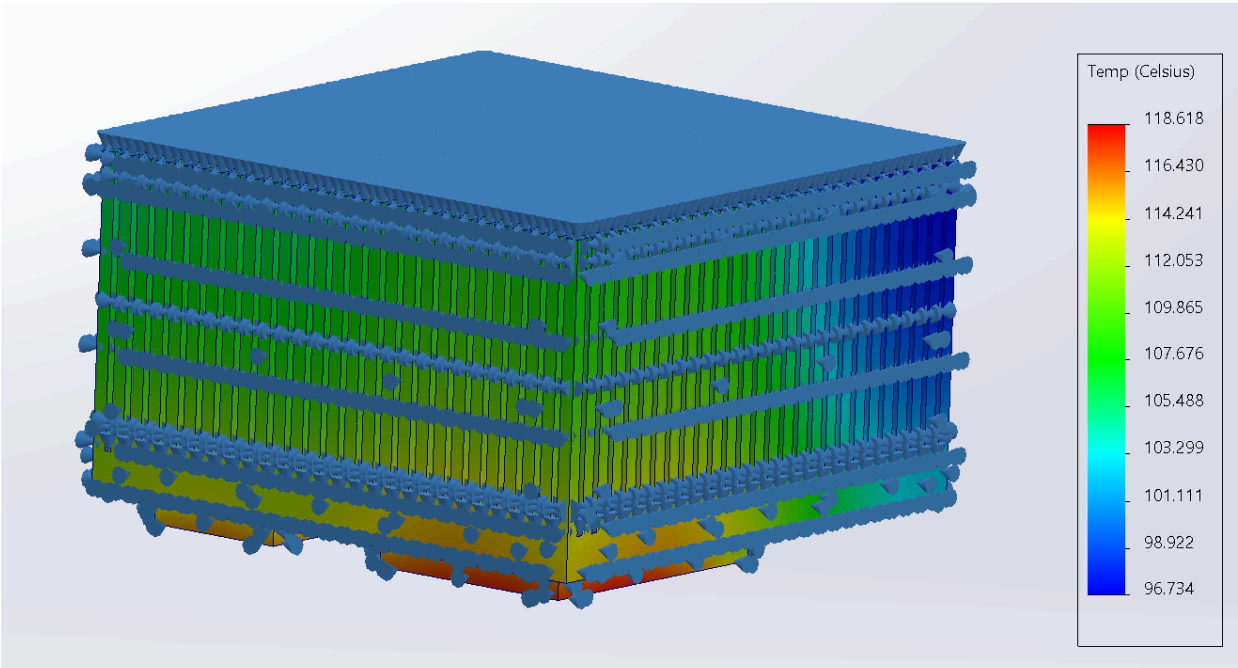
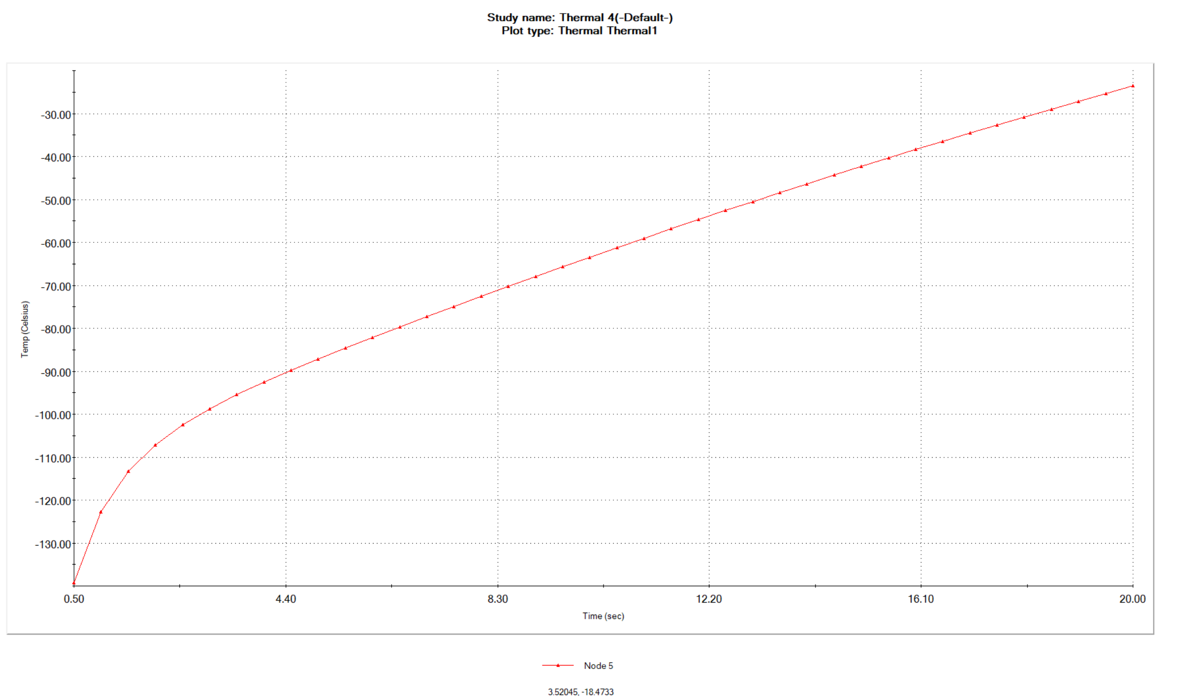


Figure 2: Solidworks Simulation with silicon chips, aluminum heat sink, and h=20 W/m^2K. Heat of the system ranges from 96.734°C at the edges of the heat sink to 118.618°C at the base of the chips.

For our second trial, we chose to double our convection coefficient to h = 20 W/m^2K. As seen in figure 2, The maximum temperature of the chips as time approaches infinity is recorded at 118.618°C. Although this is closer, it is still a far way off from 85°C. This means that our convection coefficient of h=20 W/m^2K was not enough to disperse the heat of the chips to reach 85°C. This led us to raise our h again for the third case.



Case 3 - h = 75 W/m^2K

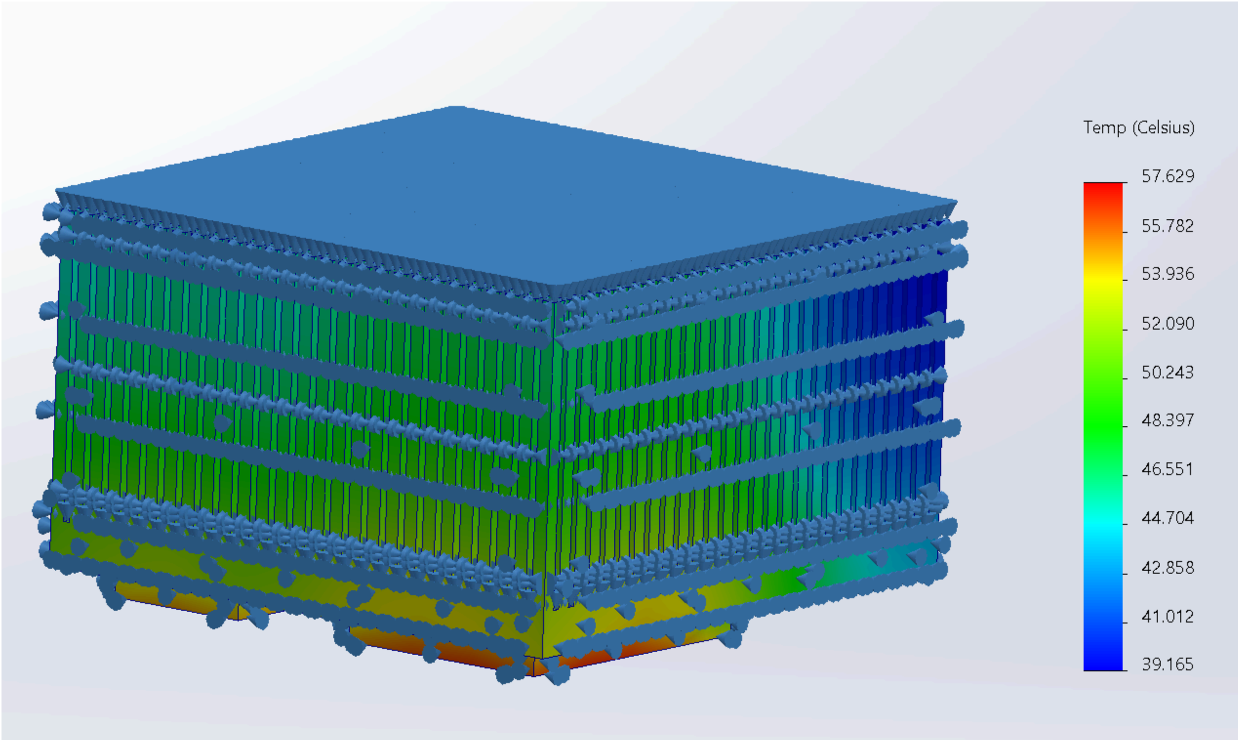


Figure 3: Solidworks Simulation with silicon chips, aluminum heat sink, and h=75 W/m^2K. Heat of the system ranges from 39.165°C at the edges of the heat sink to 57.629°C at the base of the chips.

For our third trial, we chose to jump our convection coefficient to h = 75 W/m^2K. As shown in figure 3, the maximum temperature of the chips as time approaches infinity is recorded at 57.629°C. This is way too much of a jump, clearing past 85°C. This means that our convection coefficient of h=75 W/m^2K was too much to disperse the heat of the chips to reach 85°C. This led us to lower our h to find the sweet spot.

The Sweet Spot (85°C) - h = 35-40 W/m^2K

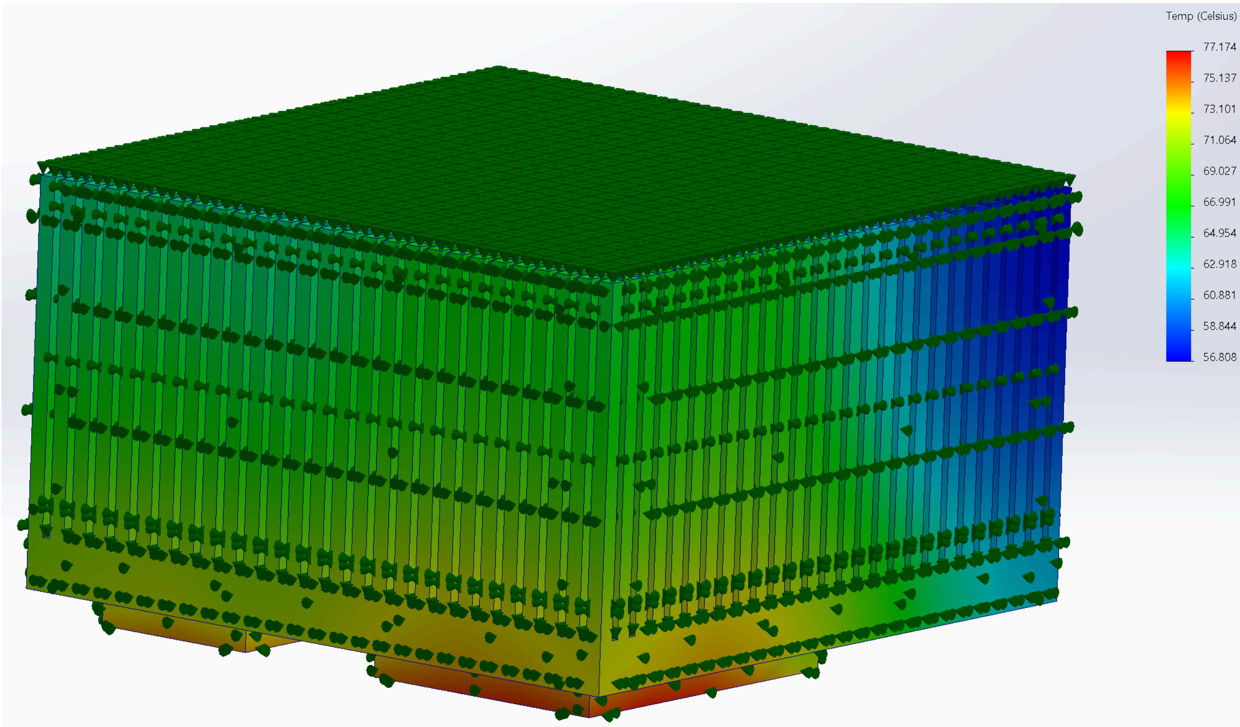


Figure 4: Solidworks Simulation with silicon chips, aluminum heat sink, and h=40 W/m^2K. Heat of the system ranges from 56.808°C at the edges of the heat sink to 77.174°C at the base of the chips.

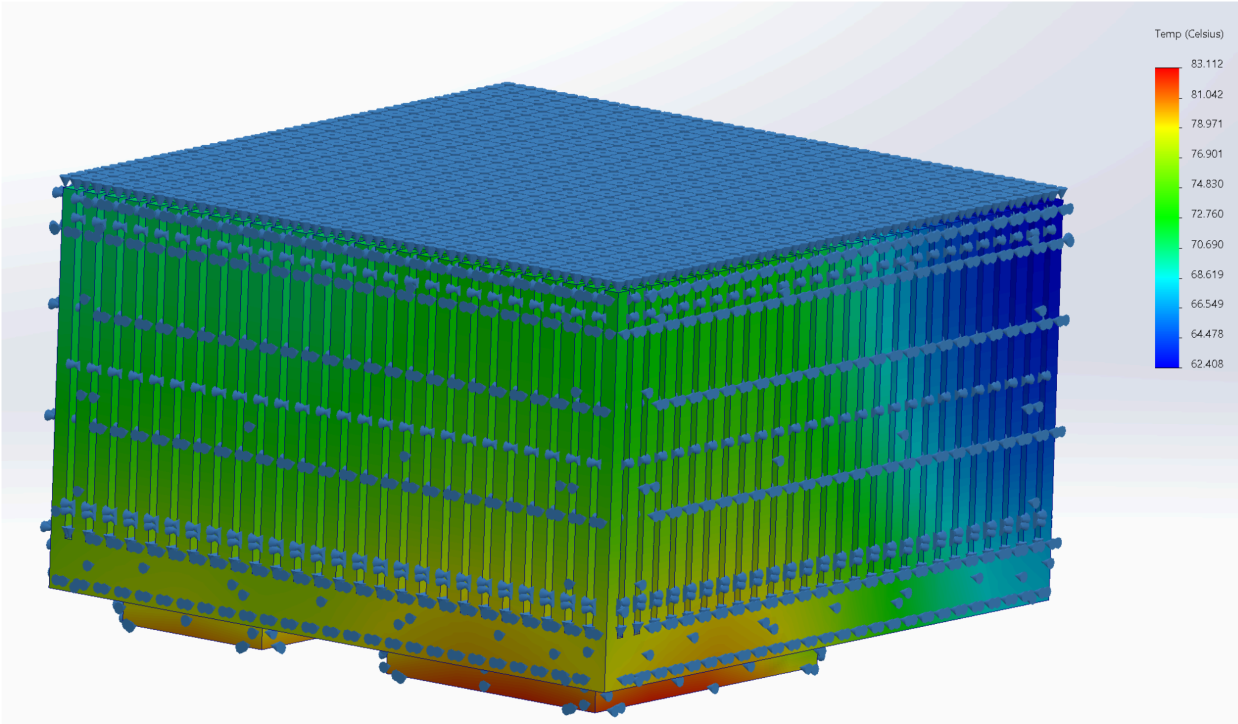


Figure 5: Solidworks Simulation with silicon chips, aluminum heat sink, and h=35 W/m^2K. Heat of the system ranges from 62.408°C at the edges of the heat sink to 83.112°C at the base of the chips.

Through our first three trials, we were able to estimate an h=40 W/m^2K to hit the 85°C mark. Based on figure 4, this was too much, but we were getting closer to an 85°C temperature at the chips. This prompted us to do our final trial of h=35 W/m^2K. This trail, shown in figure 5, was extremely close, just a few degrees under our desired 85°C. Through these 5 trials above (figures 1-5), we give an estimate of h=33-35 W/m^2K to hit that 85°C mark. To be safe though, h=35 W/m^K is confirmed to be just under 85°C.

There are a multitude of ways in which we could increase our h. These could include just simply increasing the airflow. This would cause more thermal energy to be transferred to the surrounding air, resulting in the desired temperature. If increasing airflow isnt possible, a redesign of the heat sink would also increase our h. If a more commonly used fin design was used, there would be more surface area to disperse the heat. This would require less airflow to achieve our desired 85°C.

Graph Analysis

Figure 6: Graph of h=20 W/m^2K simulation's top of fins.

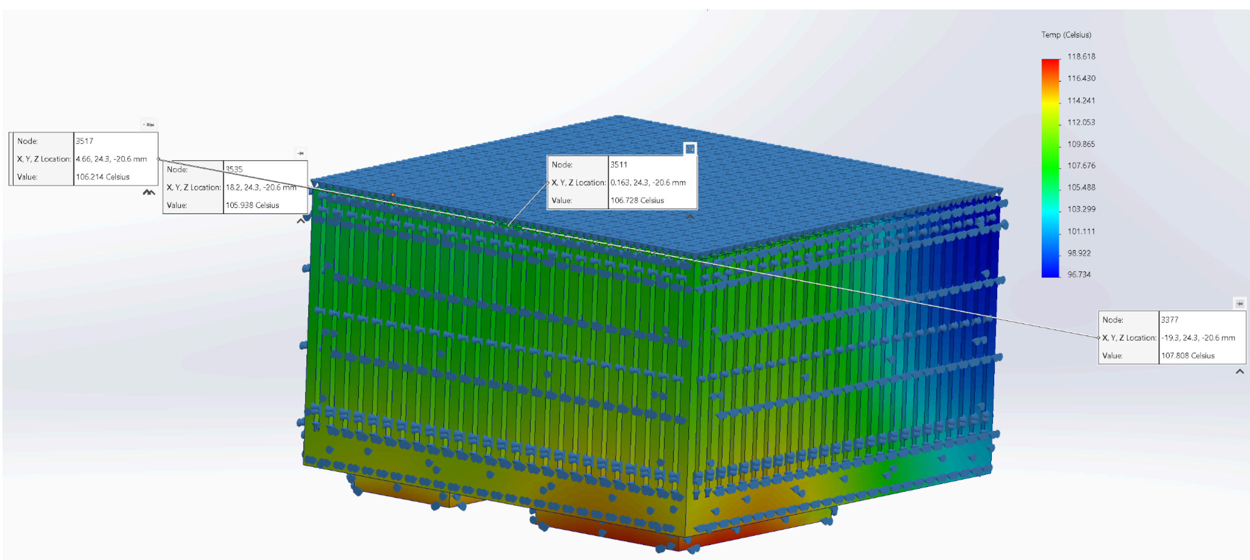


Figure 7: Location of the points taken for the graph in Figure 6.

There are 2 noticeable peaks in the graph in Figure 6. These peaks can be attributed to chips 1 and 3 (chips labeled by number in Figure 1) at the bottom shown in figure 7. As chip 1 is larger, and at a higher temperature, it makes sense that it is the cause of a higher peak on the graph at #3497 with a temperature of ~108.6°C. Furthermore, as chip 3 is smaller and produces less heat, it makes sense that the graph has a peak at #3525 with a lower temperature of ~106.6°C.

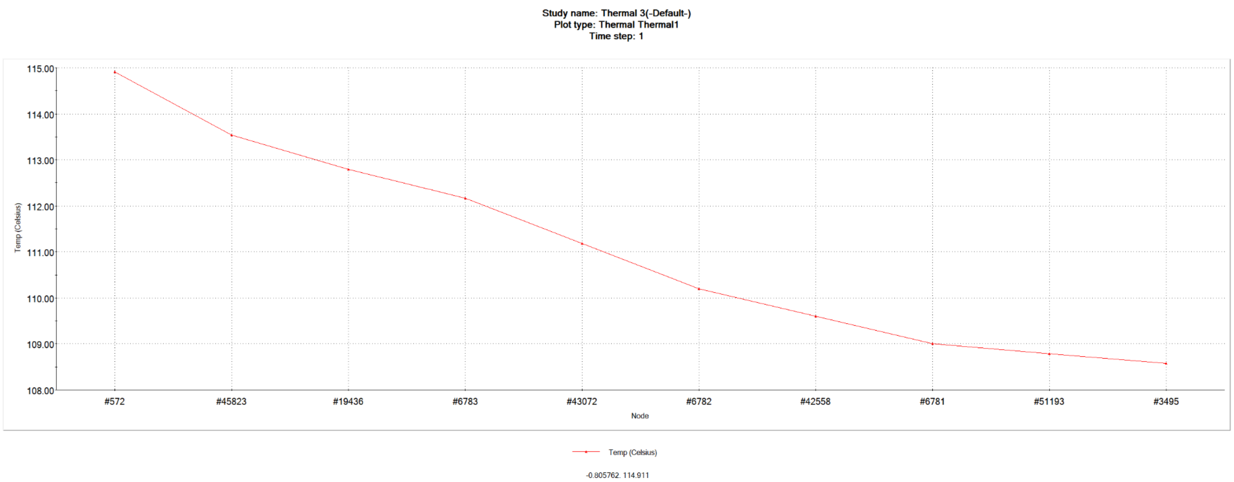


Figure 8: Graph of h=20 W/m^2K simulation's side

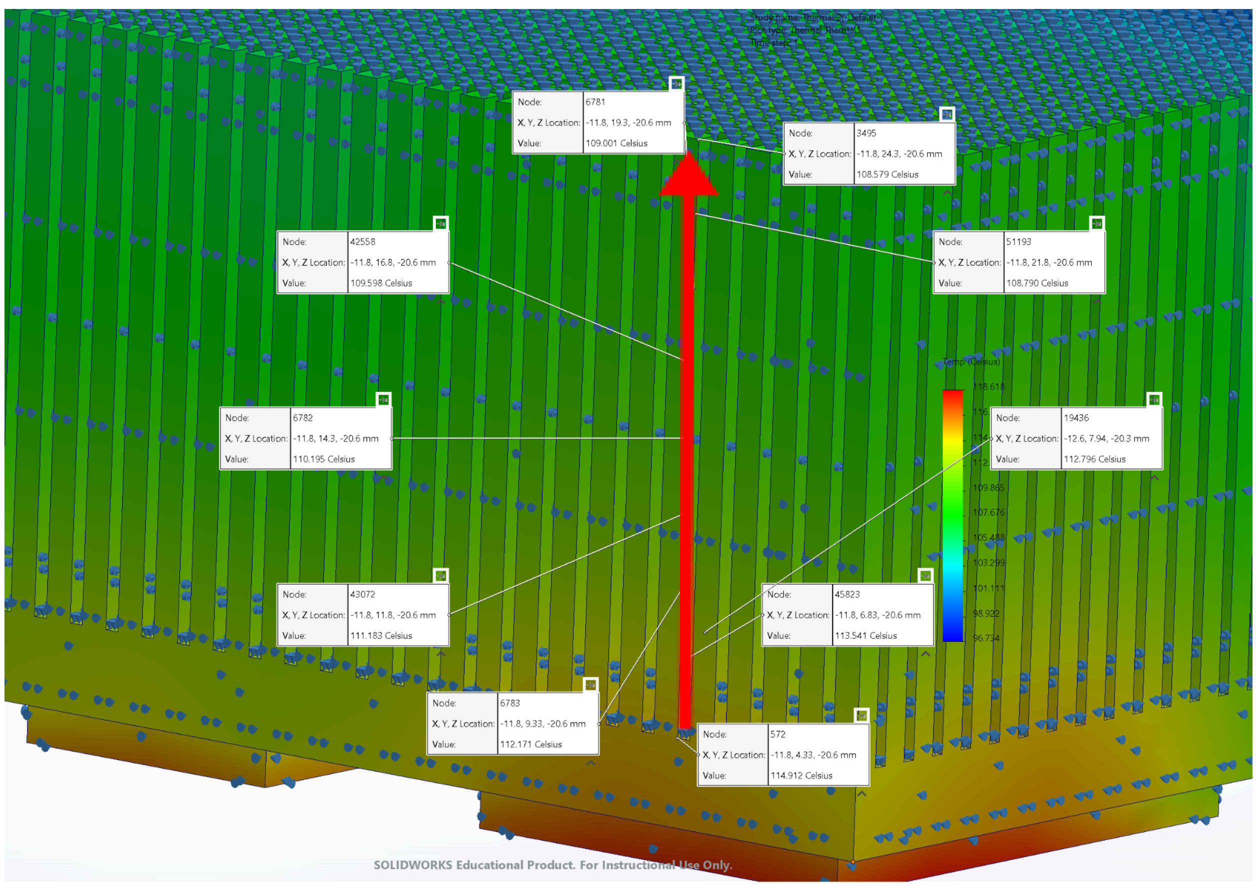


Figure 9: Location of the points taken for the graph in Figure 8.

The graph in Figure 8 is gradually sloped downward as the points reach the edge of the fins. This makes sense and is what we should expect, as the heat from the chips would gradually disperse as it makes its way to the edge of the fins.

Temperature vs. Time

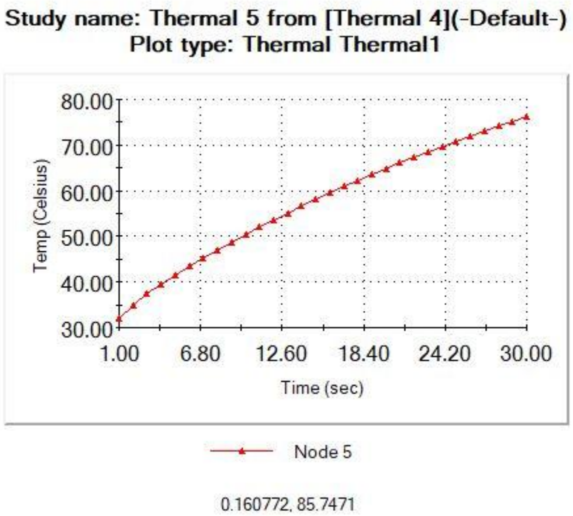
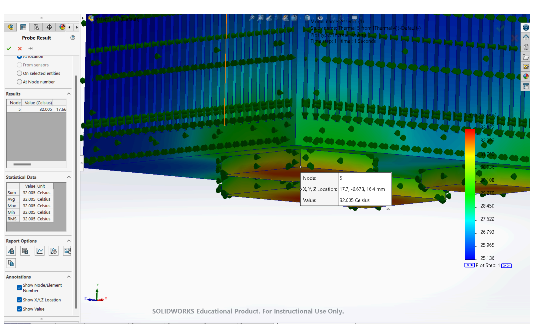


Figure 10: Time vs Temp graph from t=1 to t=30



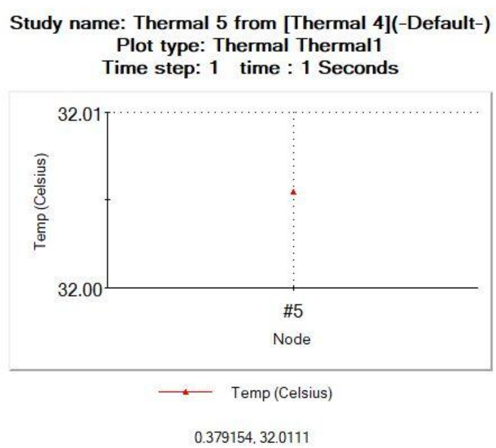


Figure 11: Time simulation/graph at T=1.

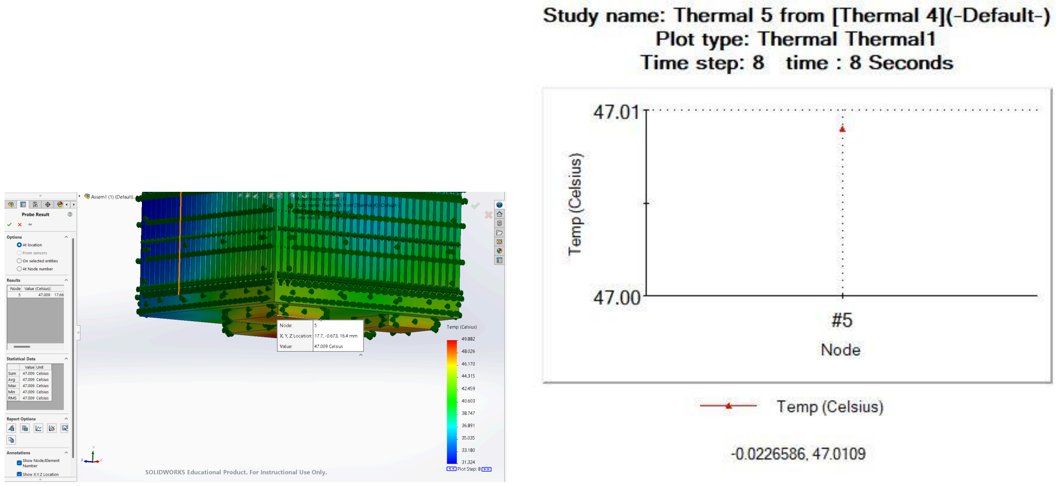


Figure 12: Time simulation and graph at T=8 sec.

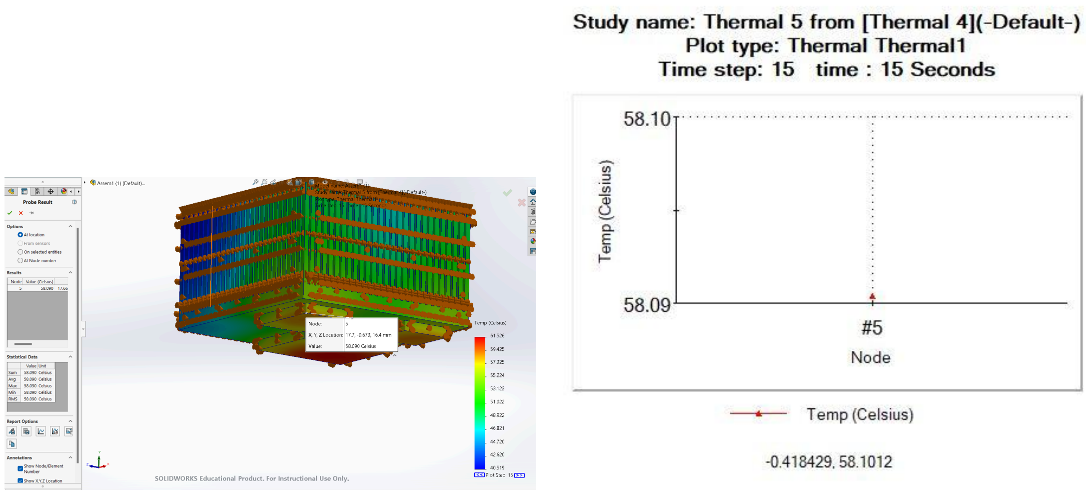


Figure 13: Time simulation and graph at T=15 sec.

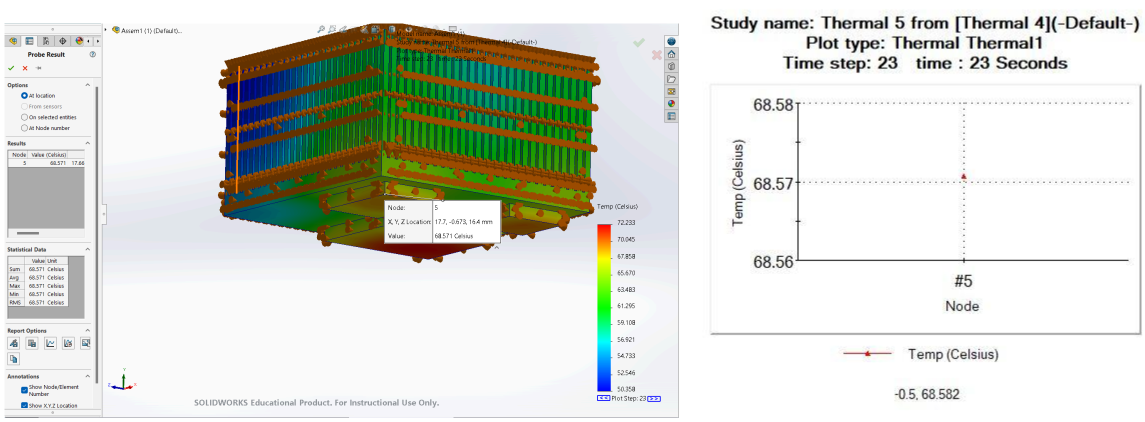


Figure 14: Time simulation and graph at T=23 sec.

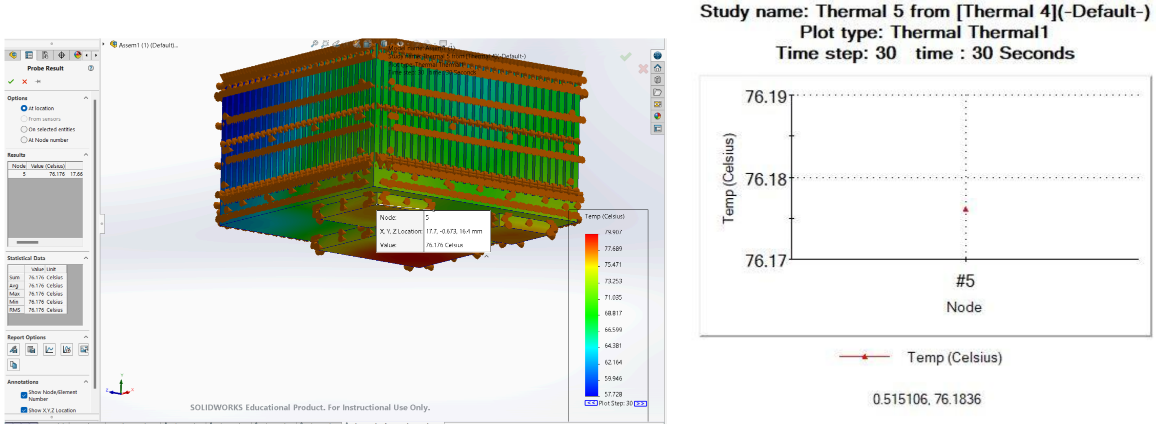


Figure 15: Time simulation and graph at T=30 sec.

The max temp (temp of the chip) increased from 25°C to ~33°C in 1 second. After 15 seconds, the temperature rose to 61.946°C. After an additional 15 seconds, the temp increased to 79.907°C. This small test shows that as the time increases the Δtemperature slowly decreases each second, which is estimated to be about logarithmic. This means that the length of fins matter, but there are diminishing returns.

Design of the Fin Configuration

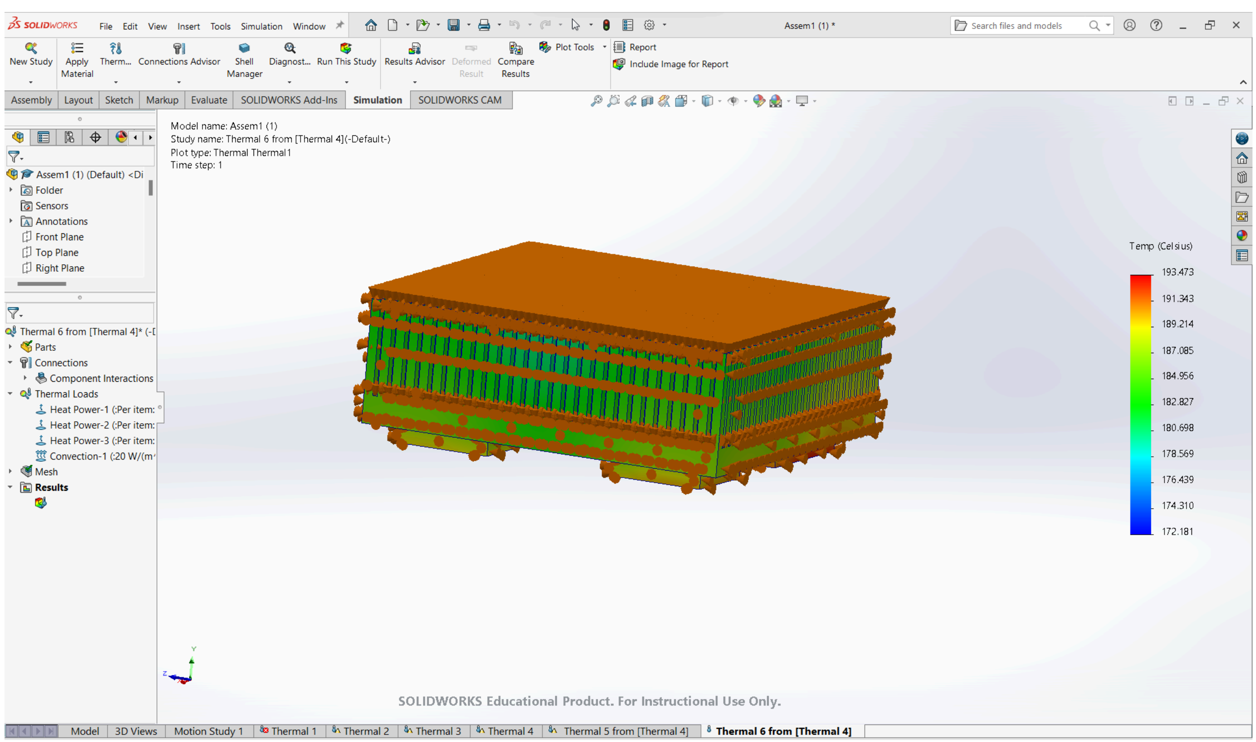


Figure 16: Same design as part 2 but with 10 mm long fins (underdesigned)

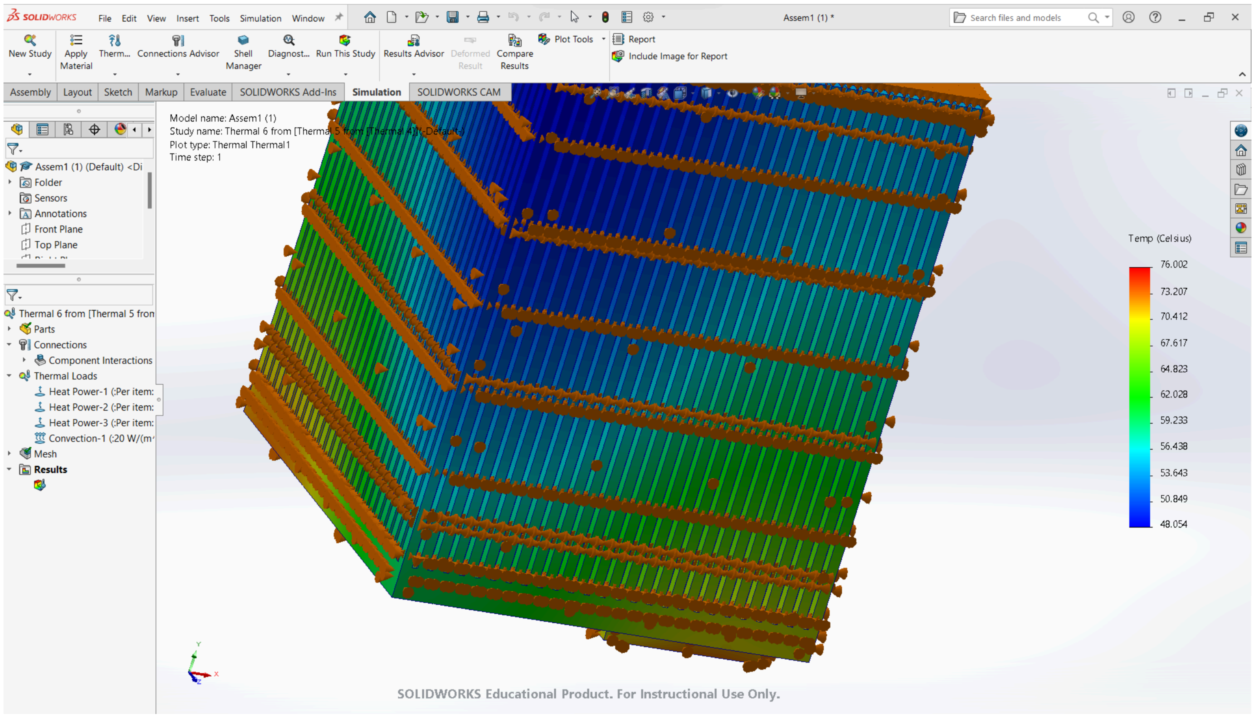


Figure 17: Same design as part 2 but with with 40 mm long fins (overdesigned)

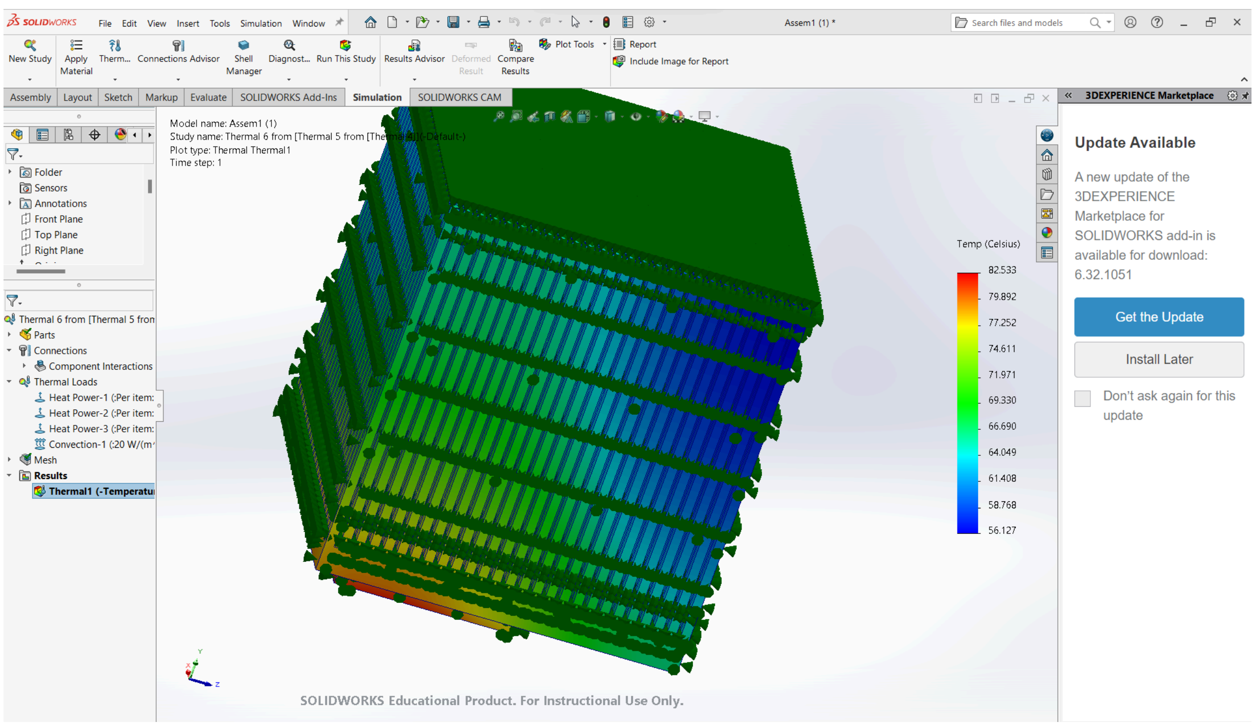


Figure 18: Same design as part 2 but with with 50 mm long fins (designed for 85°C)

The shortest fin design in figure 16 (10mm) was not sufficient for cooling at 193.473°C. Our longest fin design in figure 17 (50 mm) was too efficient, with the chips at 76.002°C. Our third design in this section, figure 18 (40 mm), was perfect for staying just under the 85°C mark, landing at 82.533°C.

Conclusions

In conclusion, our project aimed to design an effective heat sink for silicon chips, crucial for maintaining operational temperatures. Through simulations, we observed the significant impact of varying convection coefficients on chip heat. We identified a narrow range of convection coefficients, approximately 33-35 W/m^2K, to maintain chip temperatures just below 85°C for our design.

Furthermore, our analysis of graph trends and temperature-time simulations provided insights into system thermal behavior. By refining our heat sink design with appropriately sized fins, we successfully tailored the cooling system to meet our temperature target. This project highlights the importance of comprehensive simulation and iterative refinement in optimizing heat sink performance for electronic devices.