# Design for Manufacturing, Reliability, and Economics

## Team 13

## Designing & Testing Thermal Management System for SiC PV Converter


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# Table of Contents

# Table of Figures

# Abstract

The goal of this project, sponsored by Power America, was to design a cost-effective, lightweight thermal cooling system for a Silicon Carbide photovoltaic inverter being developed by researchers at the Center of Advanced Power Systems (CAPS). Their goal for this inverter is to have the highest power density in the world. However, the original heat sink that was dissipating heat from the power modules in the inverter was overdesigned, accounting for a significant portion of the weight of the system. By reducing the weight of the thermal cooling system, Team 13 helps CAPS increase the power density from 2.5 kW/kg to 6.54 kW/kg. The objective was completed by using three different approaches: theoretical analysis, experimental testing, and thermal simulations using COMSOL Multiphysics. A heat source emulator was developed for testing, and an optimized heat sink was designed after simulations, calculations, and testing were verified with one another. The final solution was to have 4 active heat sinks that housed 2 power modules each. Each heat sink has a thermal resistance of about 0.3 K/W, and weighs 211 grams. The optimized cooling system had a 71% reduction in weight from the original cooling system, and is designed to keep the power modules well under their max operating temperatures. In this report, the team explains the design manufacturing, reliability, and economics of the project.

# Acknowledgments

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# 1. Introduction

## 1.1 Problem Statement

Silicon Carbide(SiC) switching devices are wide bandgap semiconductors that are the future of semiconductor devices. SiC devices can cut power losses in half compared to its counterpart silicon. This is because they switch at higher frequencies and operate at higher temperatures and high voltage. These wide bandgap devices are more efficient but more expensive than the popular silicon choice. Applications of wide bandgap power electronics can impact electrical devices such as computer chargers, which can be made smaller and more efficient, as well as large solar farms and wind turbines, which can be connected to the grid efficiently. Many industry leaders, including PowerAmerica, wish to make SiC a viable, cost-effective option for power electronic device manufacturers. To do so, research in converters that incorporate SiC switching devices must be done to lower the overall system cost. One way to reduce the cost of power converters is to improve the thermal management system that is used to cool these devices.

Usually, heatsinks are used to remove the heat generated as a by-product from power electronic devices. However, these heatsinks have a flaw in their design – they are rarely optimized for the specific application and this can significantly impact the overall performance. Not optimizing a heatsink can result in a much larger, more expensive, and heavier thermal management system. This project proposes a way to improve the thermal management system for a SiC photovoltaic converter to make the system cost effective, smaller, and lighter

## 1.2 Project Goals and Objectives

The project was aimed towards creating a lightweight thermal structure for future photovoltaic converters. This allows for easier and faster installation time of the future PV converters. Decreasing the weight of the heat sink and fan assembly helped increase the power density of the converter. The thermal management consisted of 4 optimized bi-modular pin fin heatsinks with a fan mounted to the base of each. The fan was selected with care to allow optimal performance of the silicon carbide PV converter to be reached. Team 13 also created a heatsink selection guide that provides insight in selecting the appropriate heatsink and fans for the overall system. During this process, collaboration between the electrical and mechanical students was crucial to come up with a reliable heatsink design.

## 1.3 Approach

To implement a smaller, lightweight heatsink design for a SiC PV converter, two aspects were explored. One was optimizing the overall heatsink design through with the help of calculations and simulations, and the second was testing this design.

# 2. Design for Manufacturing

## 2.1 Heat Source Emulator

The heat source emulators were built using two different methods, one included copper plates and the other method did not. Both methods of building the heat source emulators included the use of two 50-watt, 5-ohm power resistors, three connection wires, and a solder iron. This is the simplest way that Team 13 could imitate the original power converters being used by the CAPS researchers.

To build the heat source emulators a connection wire was soldered to each end of the power resistors and one connection wire was soldered in between the two power resistors making the connection. This concludes the manufacturing of the heat source emulator using method two, the first method continues with attaching the power resistors on top of a 108 mm by 46 mm copper plate using a generous amount of thermal grease.

The assembly of the heat source emulators took less time than anticipated, the most time-consuming part was waiting for the thermal grease to set. The thermal grease does not dry but Team 13 let it sit overnight so that the power resistors were not sliding all over the copper plate.

To connect the heat source emulators to the heatsinks the same method was used with the thermal grease. For the emulators with copper plate, a generous coat of thermal grease was applied onto the copper plate and that plate was laid onto the heatsink. The emulators were then also secured with six screws, four on each corner of the copper plate and two in the middle of the copper plate. The emulators without the copper plate were attached to the heatsink the same way. Thermal grease was applied to the bottoms of the power resistors and then two screws on each power resistor further secured the heat source emulators to the heatsinks.

*Figure 1: Method 1 (with copper plate)*

*Figure 2: Method 2 (without copper plate)*

## 2.2 Heatsink Design

Throughout the course of the project two cooling designs were tested and examined to see if they would have been deemed to satisfy the overall scope of the project. These designs were a plate fin heatsink and a pin fin heatsink. After a thorough analysis and comparison, the pin fin design was chosen due to its low weight, small size, and its ability to dissipate the heat produce from the power modules more effectively than the plate fin design.

The final design and build for each individual heatsink system will consist of one pin fin heatsink, four connector pieces, eight screws and one cooling fan. A total of four heatsink systems will need to be built to accommodate all eight of the power modules, the completed list of the amount of parts are four heatsinks, 16 connector pieces, 64 4-40 screws, 16 4-40 nuts and four cooling fans.

Looking at the heatsink, to lessen complications during manufacturing it has been decided that each heatsink will be made from Aluminum 6063 and ordered from a heatsink supplier where personal customization is possible. This will allow for the optimized heatsink design to be fully manufactured with the correct geometrical sizing needed. The method that the supplier will use to manufacture each of the heatsinks will be cold forging. Cold forging is the preferred forging method when working with soft metals, such as aluminum, in order to deform the material into predetermined complex shapes. This method allows for better tolerance, small impurity content, improved surface finish, and lower cost as compared to other methods. Once ordered, a total of four holes will be machined into each of the heatsink's baseplates for screws to be inserted. The L-Bracket connector pieces will be used as mounts that will secure the cooling fan firmly to the heatsink while it is in operation. Their drawing, as well as the heatsink drawing is included in Appendix A. These pieces will be made from aluminum and will be water jetted out from an aluminum block. Both the screws and cooling fans will be bought from a supplier as well. The fan to be used is specified in Appendix B, and the screws and nuts can be ordered from Home Depot. A parts list is also included in Appendix C.

Assembly for the each of the four heatsink systems is simple and straight forward. The four connector pieces will first be screwed into the side of the baseplate of each heatsink to serve as four attachment points for the cooling fan. Once the connector pieces are screwed and tightened into the baseplate, the cooling fan is then mounted to the top side of each connector piece. This will be done by inserting four screws into the premade holes of the cooling fan and aligning them with the holes of the connector pieces. Once the screws are inserted in conjunction with the holes of the cooling fan and connector pieces, it will then be tightened to form a rigid and stiff connection. This assembly process will ensure that the fan is perfectly aligned with the center of the heatsink and that none of the parts will shift during operation. The time that it takes to assemble each heatsink system is estimated to be about 15 minutes. The exploded view for the assembly process can be seen in Fig 3.

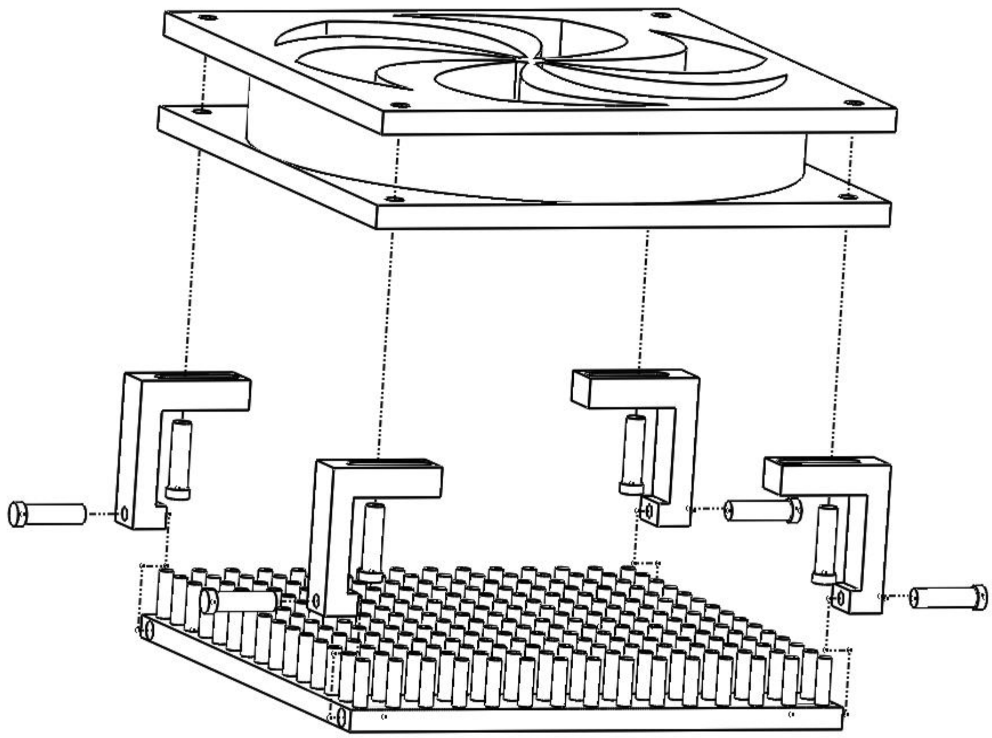

*Figure 3: Exploded View of Heatsink System*

When being used with the power modules, the modules will be screwed into the top of the baseplate. They must have a separation of at least 15 mm between them, but for this design they will be 19 mm apart. Thermal grease will be applied to ther bases prior to mounting them to the heatsink.

# 3. Design for Reliability

For this design to be feasible, each heatsink system needs to be able to be assembled multiple times along its lifetime to ensure proper maintenance and function throughout multiple uses. In practice these heatsink systems will rarely need to be disassembled, however making sure the heatsink can dissipate the required amount of heat for long periods of time is of prime importance to ensure reliability.

The main factor that would cause the system to fail was identified to primarily be from the cooling fan either not working properly or failing to work at all. Without the proper cooling of air flowing through the heatsink, the power modules are bound to reach high temperatures within minutes, resulting in them overheating. To mitigate this potential failure, cooling fans were selected with values that ensured long lifetimes from continues operation. The cooling fan selected was from the manufacturer Sunon-Fans with an estimated life expectancy of 70,000hrs at 40°C. Even though the fan is not directly touching the heatsink baseplate, it is still good to look at the previous non-optimized baseplate temperature to ensure that the surrounding space will fall within the 40°C range. From previous testing of the non-optimized heatsink, the baseplate had an average temperature of 37.9°C when dissipating 120 W. This will ensure that the surrounding space of the heatsink system will remain under 40°C allowing the cooling fan to run its full lifetime of 70000hrs. This is a good indication that minimal failures should occur during the operation of this system. However, it should be noted that each 4 heatsinks should be set at least a distance of 1 inch apart from one another to be sure that the temperatures remain low.

# 4. Design for Economics

Team 13 was given a specified budget of $400, which covered the price of designing an optimized heatsink for a PV converter, a selected manufactured heatsink to use for testing, and the materials needed to build multiple heat source emulators.

The total cost of Designing and Testing a Thermal Management System for a SiC PV Converters thus far is $291.68. This price includes multiple heatsinks, fans, power resistors, screws, and nuts. As can be observed in Figure 4, the heatsinks make up a majority of the cost at $204. The connectors, copper, thermal grease, wiring, plate fin heatsinks, the three original fans used for testing, and the two power supplies were not a burden on the team's budgeting.

The money spent allowed Team 13 to purchase 3 pin fin heatsinks, 2 fans, 10 power resistors, 100 screws, and 100 nuts. Team 13's sponsor, Dr. Li, provided the team with the 2 plate fin heatsinks that were tested, the copper used under the emulators, the 3 original fans that were used for testing, the power supplies that were used for the tests, and the wiring and thermal grease that were needed to build the heat source emulators. The connectors that Team 13 used to connect the fans and the heatsinks were built by the FAMU-FSU College of Engineering Machine Shop.

Because of the components provided to the Team by Dr. Li and the manufacturing done by the Machine Shop, Team 13 could stay under budget while still purchasing enough materials to run multiple tests without fear of not having a backup.

Researching other heatsinks that are currently on the market was a big part of choosing the heatsink specifications that Team 13 would use and optimization. The original heatsink used for the PV converter was a plate fin heatsink, after extensive research a pin fin heatsink was chosen for all future testing, simulations, and analysis of the converter. A pin fin heatsink would get rid of excess material while still achieving the thermal resistance needed and the maximum power density. While there are different pin fin heatsinks available, many of the manufacturers did not have a heatsink with the specifications Team 13 was searching for. The one found was from Cool Innovations measuring 113.7 mm by 113.7 mm by 17.8 mm, with a thermal resistance of 2.2 °C/W. This heatsink was used for all testing and the basis of Team 13's optimized design.

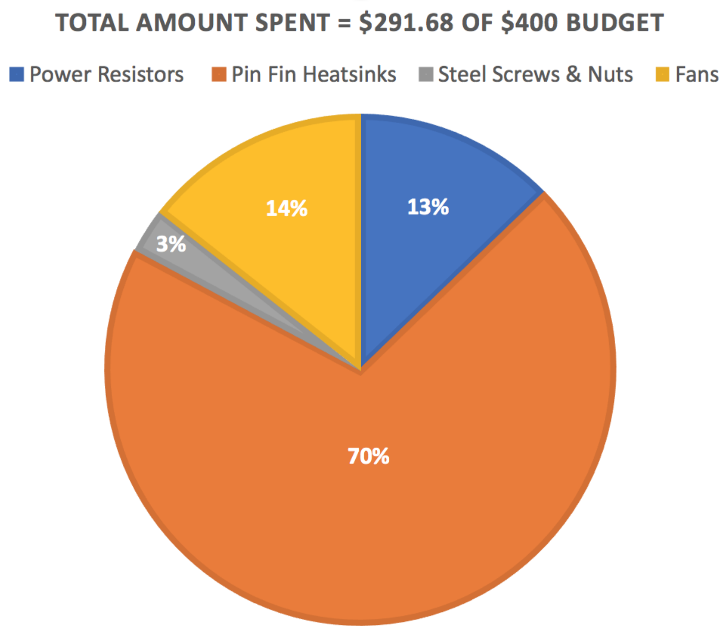


*Figure 4: Percent of money spent on each component*

# 5. Conclusion

The Center for Advance Power Systems is interested in developing a cooling system that will be used inside a SiC PV converter. Through comparison, analysis, and optimization, Team 13 was able to develop a heatsink design that is lightweight, small, and able to dissipate the necessary amount of heat being produced from the power modules in the converter. The design consists of a minimal amount of parts and has a quick assembly time of 15 minutes. Upon looking at the feasibility of the design the appropriate modes of failure were identified and solved by checking the appropriate specification sheet of the cooling fan and it operation parameters at a temperature of 40°C. By using standard engineering methods, Team 13 was able to make a reliable, low cost, and manufacturable cooling system that will achieve the intended goal of cooling the power modules in the PV converter.

# References

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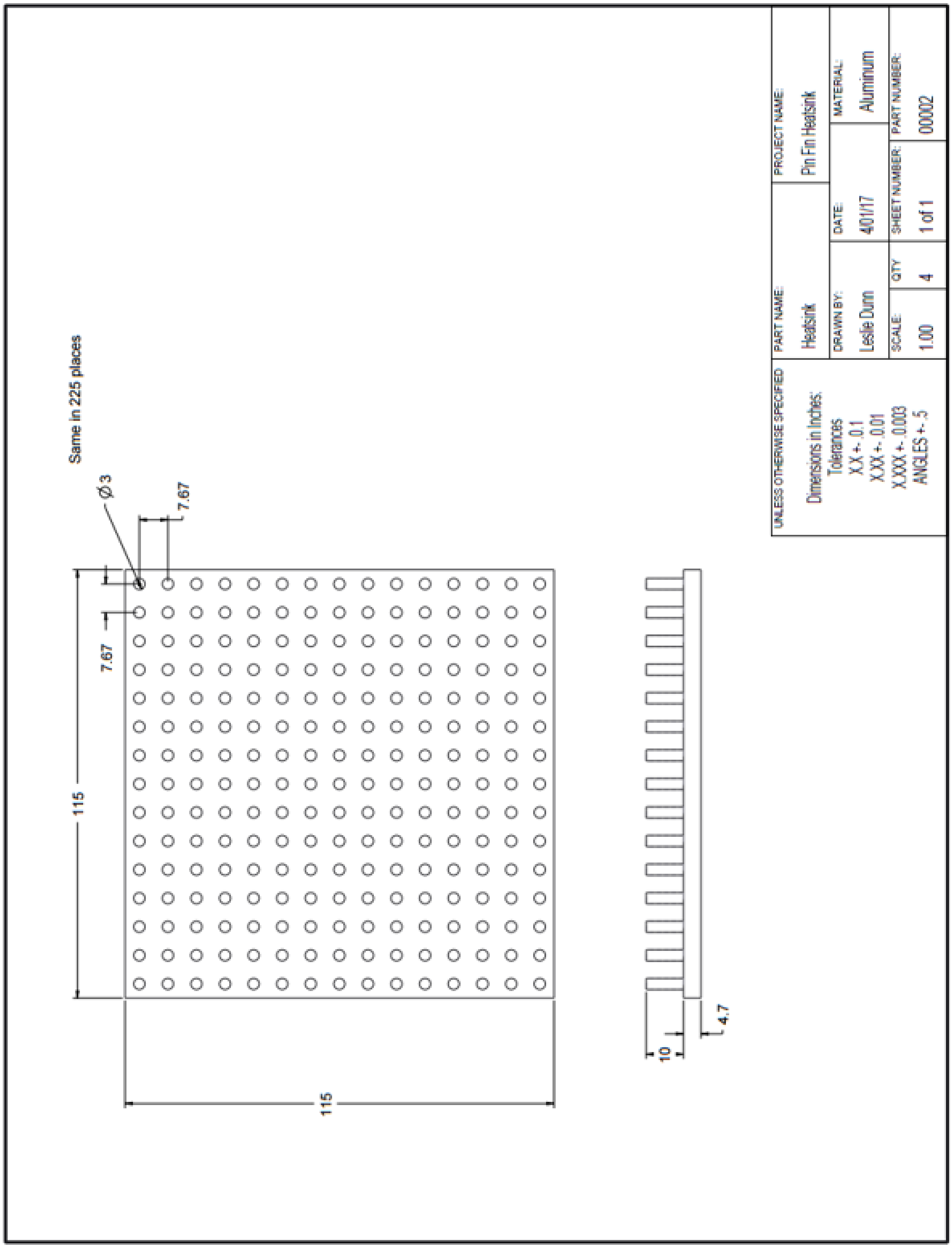
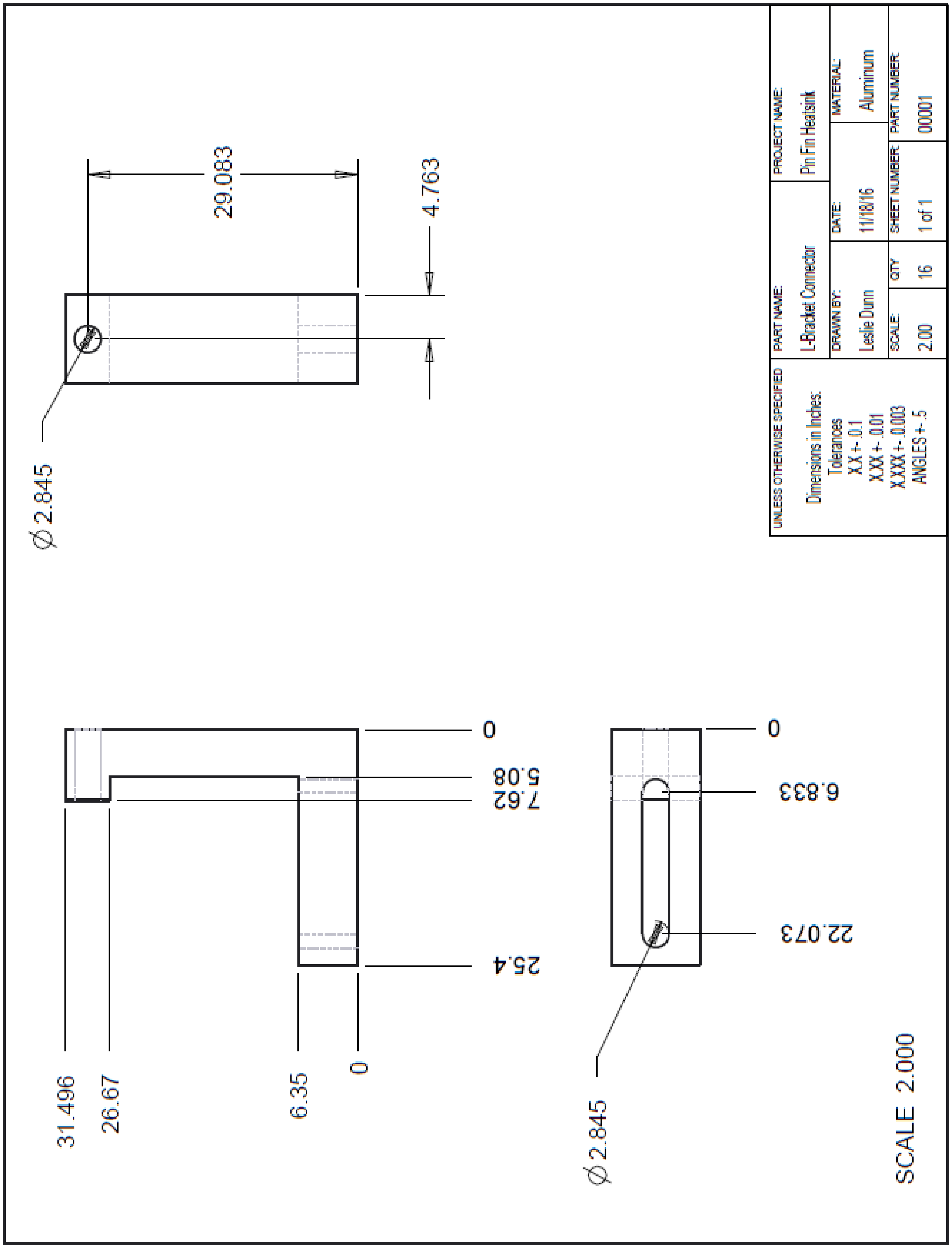
[3] "Sunon Fans." *DigiKey*. DigiKey Electronics. <http://www.digikey.com/product-detail/en/sunon-fans/EEC0251B1-000U-A99/259-1479-ND/2021107>.

[4] "Everbilt Zinc-Plated Flat-Head Phillips Drive Machine Screw." *The Home Depot*. <http://www.homedepot.com/p/Everbilt-4-40-tpi-x-1-2-in-Zinc-Plated-Flat-Head-Phillips-Drive-Machine-Screw-8-Piece-803611/204274652?MERCH=REC-_-SearchPLPHorizontal1_rr-_-NA-_-204274652-_-N>.

[5] "Aluminum Machine Screw Nuts." *The Home Depot*. <http://www.homedepot.com/p/4-40-Aluminum-Machine-Screw-Nuts-4-Piece-809018/204274541>.

# Appendix A: CAD Drawings





29.083
4.763
Ø2.845
0
5.08
7.62
25.4
31.496
26.67
6.35
0
0
6.833
22.073
Ø2.845
SCALE 2.000
UNLESS OTHERWISE SPECIFIED
Dimensions in Inches:
Tolerances
X.X +- .0.1
X.XX +- .0.01
X.XXX +- .0.003
ANGLES +- .5
PART NAME:
L-Bracket Connector
PROJECT NAME:
Pin Fin Heatsink
DRAWN BY:
Leslie Dunn
DATE:
11/18/16
MATERIAL:
Aluminum
SCALE:
2.00
QTY
16
SHEET NUMBER:
1 of 1
PART NUMBER:
00001

# Appendix B: Fan

| Product Overview | |
|---|---|
| Digi-Key Part Number | 259-1479-ND |
| Quantity Available | 632<br>Can ship immediately |
| Manufacturer | Sunon Fans |
| Manufacturer Part Number | EEC0251B1-000U-A99 |
| Description | FAN AXIAL 120X25MM 12VDC WIRE |
| Lead Free Status / RoHS Status | Lead free / RoHS Compliant |
| Moisture Sensitivity Level (MSL) | 1 (Unlimited) |
| Manufacturer Standard Lead Time | 14 Weeks |

| Documents & Media | |
|---|---|
| Datasheets | EEC0251B1-0000-A99 Spec Sheet |
| Product Training Modules | DR MagLev Fan Series |
| Video File | Sunon DR Maglev |
| RoHS Information | RoHS Certificate |
| Featured Product | E Series Fans |
| Online Catalog | DR (E), DRMagLev® Series |

| Product Attributes | | Select All ☐ |
|---|---|---|
| Categories | Fans, Thermal Management | ○ |
| | DC Fans | ◉ |
| Manufacturer | Sunon Fans | ☐ |
| Series | DR MagLev® | ☐ |
| Part Status | Active | ☐ |
| Voltage - Rated | 12VDC | ☐ |
| Size / Dimension | Square - 120mm L x 120mm H | ☐ |
| Width | 25.00mm | ☐ |
| Air Flow | 108.2 CFM (3.06m³/min) | ☐ |
| Static Pressure | 0.280 in H2O (69.7 Pa) | ☐ |
| Bearing Type | Ball | ☐ |
| Fan Type | Tubeaxial | ☐ |
| Features | AutoRestart | ☐ |
| Noise | 44.5 dB(A) | ☐ |
| Power (Watts) | 5.30W | ☐ |
| RPM | 3100 RPM | ☐ |
| Termination | 2 Wire Leads | ☐ |
| Ingress Protection | - | ☐ |
| Operating Temperature | 14 ~ 158°F (-10 ~ 70°C) | ☐ |
| Approvals | CE, CUR, TUV, UL | ☐ |
| Weight | 0.346 lb (156.94g) | ☐ |
| Current Rating | 0.445A | ☐ |
| Voltage Range | 6 ~ 13.8VDC | ☐ |
| Material - Frame | Polybutylene Terephthalate (PBT) | ☐ |
| Material - Blade | Polybutylene Terephthalate (PBT) | ☐ |
| Lifetime @ Temp. | 100000 Hrs @ 40°C | ☐ |

# Appendix C: Parts List

| Part Name | QTY | Source |
|---|---|---|
| Pin Fin Heatsink Body | 4 | Custom Manufacturer |
| 12 V DC Fan | 4 | digikey.com |
| L-Bracket Connector | 16 | Machined in shop |
| 1/2” 4-40 screws | 64 | Homedepot.com |
| 4-40 Nuts | 16 | Homedepot.com |