Design a Cooling System for the Readout Boards of a Satellite

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Project Overview

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Project Scope is to create a functioning satellite that will be able to detect X-rays released by dark matter. Dark matter is an unknown substance that makes up 85% of the mass of the universe. Dark matter does not emit light making it impossible to see.

Project Benefit: ***These X-rays will be captured and allow us to see if there are hints of dark matter.***

Inside the satellite, there are three main circuits which are called the read-out boards. **These boards are responsible for controlling the CCDs. The read-out boards produce the voltages and clock signals needed to operate the CCDs. They also collect the data (images) the CCDs produces** (10 watts of energy are released). This energy needs to be transferred from these circuits to the radiator.

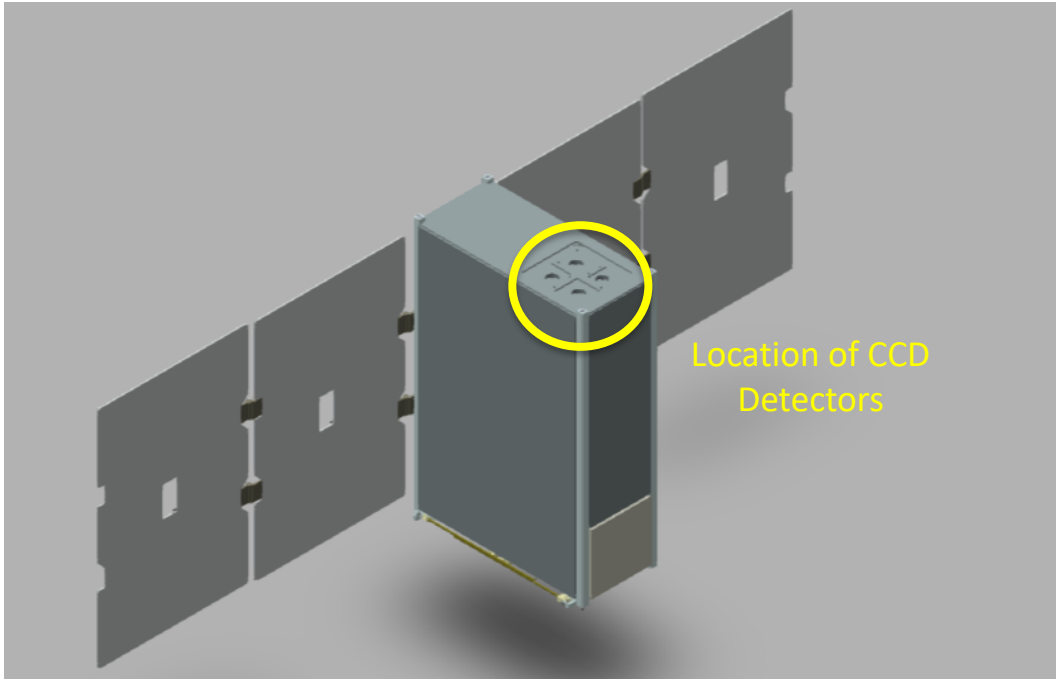
My Role is to design a cooling solution for these circuits. Cooling is an important process, especially in a satellite because space contains no air, thus making it impossible for heat transfer to occur. This is why we need a separate cooling method is needed.

CCD Detectors and Dark Matter

The satellite we are building uses CCD detectors to capture the X-Rays released by dark matter. It's important to understand how CCD detector's function.

What is a CCD?

- CCD is an acronym for **Charged Coupled Device**
- **CCD's take in photons** which hit a silicon sensor, these photons release electrons. A capacitor is attached to the silicon sensor to catch the electrons. All of these electrons will help form pixels.
- 100% Quantum Efficiency is obtained when we get one electron from each photon
- We are working with two 95% Quantum Efficiency CCDs



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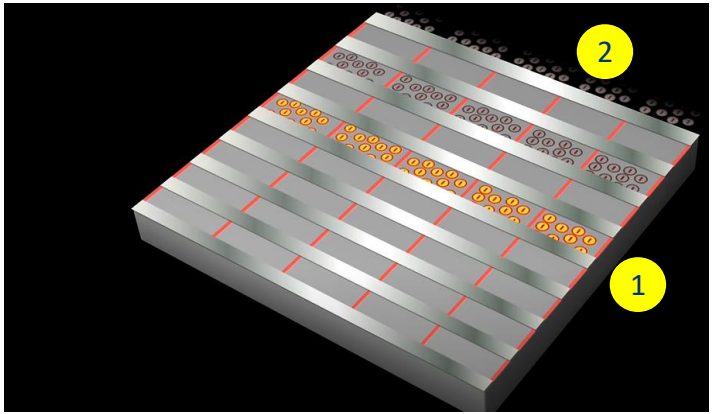
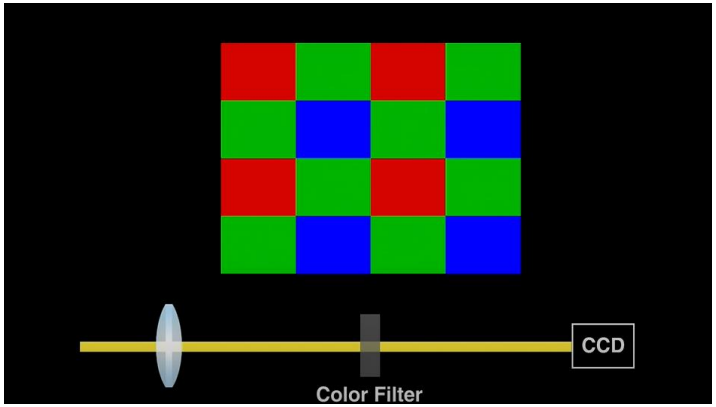
How CCD Image Processing Works



- The CCD transfers an image into a camera's memory or into a computer. This is done by taking the charge from each pixel and putting it into the silcon wells. 1
- The CCD then takes the image from the silcon and reads its charges row by row. 2



- Since CCDs create black and white images, a color filter array is used to sort the particles. They are sorted as being either Red Green or Blue.
- If there is an unknown pixel the pixels around are used to be averaged and determine the color of that unknown pixel.

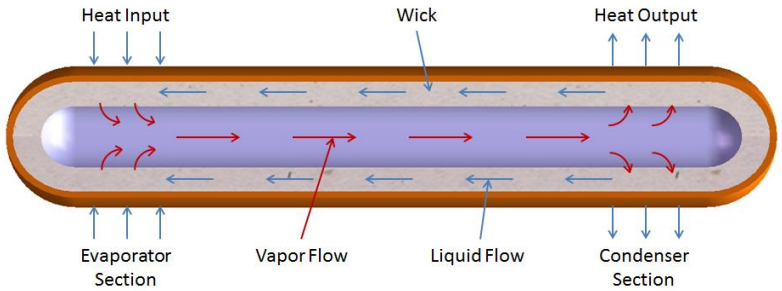
Our Six-Week Journey to Develop a Cooling System

1. Determine Cooling Method
2. Calculate Dimensions for Thermal Straps
3. Create Prototype for Casing
4. Add Thermal Strap to Design
5. Aluminum Fabrication

Determining a Cooling Method

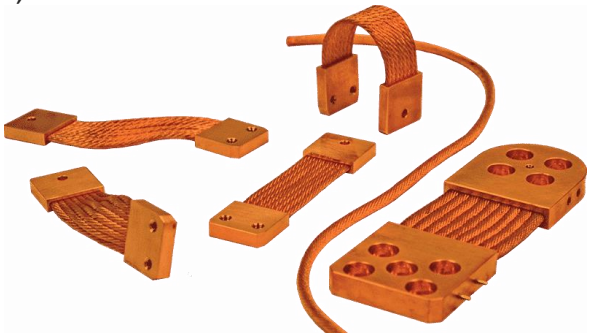
Two popular cooling methods include Heat Piping and Thermal strapping.

Heat Piping: Transfers heat from one surface to another using fluid. The fluid transfers heat from the evaporator to the condenser of the heat pipe, and then returns to the evaporator.



Material Types Available: Copper & Aluminum (Conductors)

Thermal Strapping: Leverages thermal straps to transport heat passively. Thermal Straps are a better alternative than heat piping, they are more easily accessible, significantly cheaper, and flexible.



Material Types Available: Copper & Aluminum (Conductors)

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Thermal Strap Calculations

Copper vs Aluminum

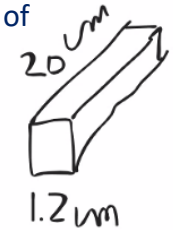
- First, we solved for the surface area for each thermal strap
- Then we calculated the mass of the thermal strap for each material.
- Finally, we compared the masses to identify the lighter option.

Copper has higher thermal conductivity than aluminum. After calculating the dimensions for the thermal strap, aluminum was still an option. Aluminum will require a larger opening for the thermal strap versus copper.

Calculations for Aluminum

Our Findings:

- ✓ An aluminum thermal strap will have a larger surface area and half the mass of a copper strap. (Mass: aluminum 77.76g, copper 155g)
- ✓ We can use a thermal strap made of aluminum with the dimensions of 1.2cm by 1.2 cm. With a length of 20cm.



$$K = \frac{Qd}{A\Delta T}$$

K = thermal conductivity

Q = amount of heat transferred = 10 W

d = distance between the two isothermal planes = 0.2m

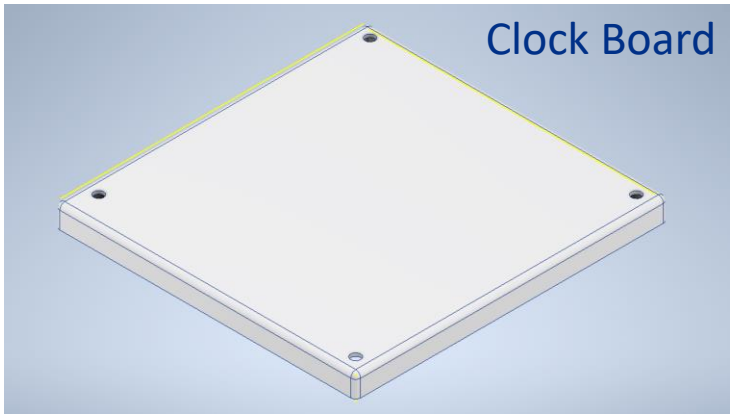
A = area of the surface

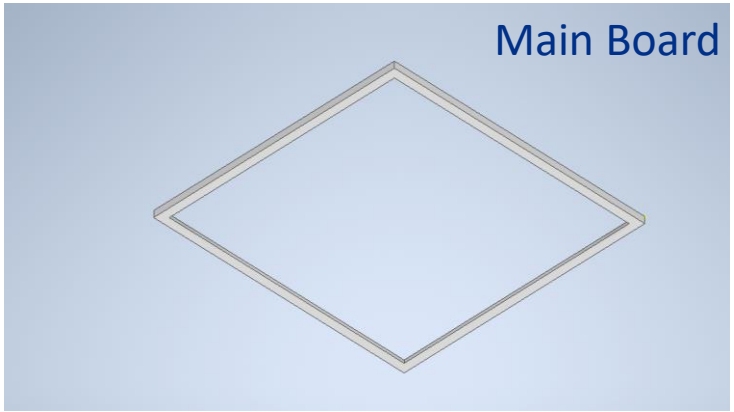
ΔT = difference in temperature = 60 K

Prototype Casing for Readout Boards (Original Design)

Our Original Design included:

- Casing covers top and bottom circuits
- Rods align with openings to hold circuits in place
- Single side of casing is covered to reduce mass





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Prototype Casing for Readout Boards (Final Design)

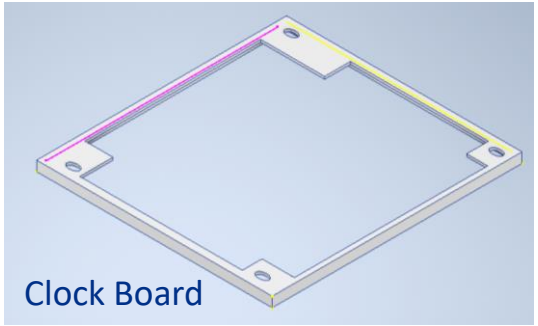
Recent Revisions

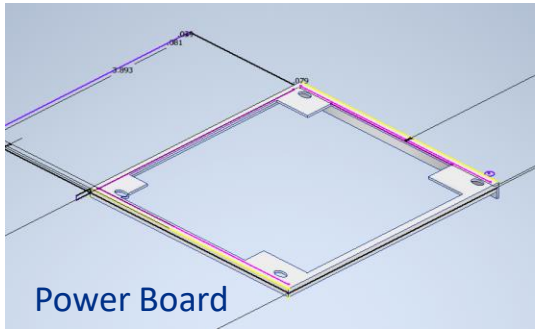
- **Maximized heat transfer** – with three layers of casing between circuits
- **Increased contact area** with casing and circuits, each circuit has rectangular support based on layout of components
- **Added more stability** – with oval shaped slots tightly fitting the rods

Biggest Improvement

Now each board will come into direct contact with the copper sides of each circuit. Resulting in heat from the circuits to transfer to the casing more efficiently.

The original prototype lacked this. It failed at moving heat from all three circuits and only moved heat from the bottom circuit properly.





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Prototype Casing for Readout Boards (Final Design)

Clock Board

Power Board

Main Board

Copper Strips

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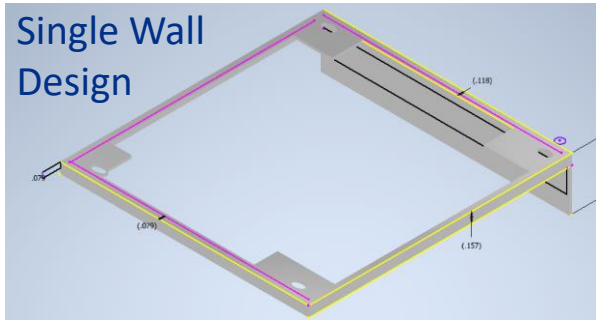
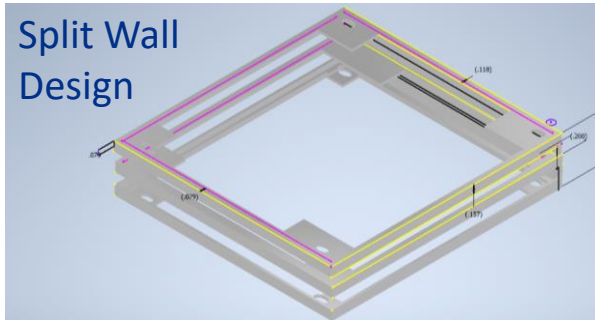
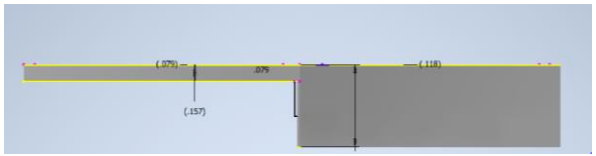
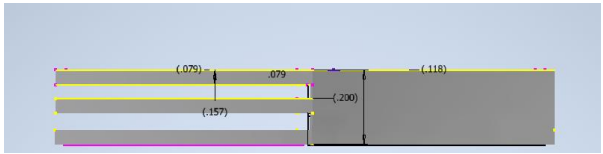
Add Thermal Strap to Design

- A thermal strap will attach to the casing of the circuit we are creating.
- The casing will come in contact with each circuit.
- Allowing the 10 watts to move from the circuits to the casing.
- The straps will be attached to the casing moving heat from the casing to the radiator.









In conclusion, the split wall design worked better. This design provided more stability when it came to mounting the rods to keep the circuits in place.

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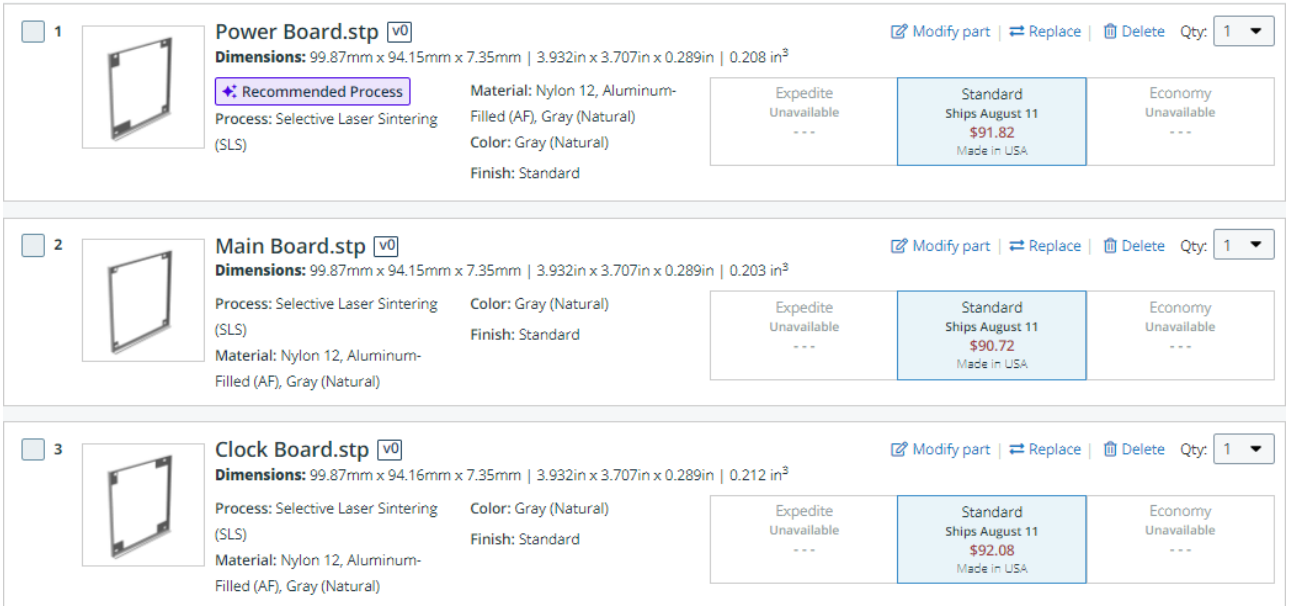
Aluminum Fabrication Cost & Prototype Fabrication Cost

Aluminum Fabrication

Our Final Product, contains three casings made of aluminum. The cost for this project was **$274.62**. The average cost of each casing was **$91.54.**

Prototype Fabrication

Throughout this project we created multiple prototypes. In total we spent **$8.50** on different versions of the prototypes



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Thank you!

Spencer, Juan and Brody