Final Results of a Solid-State Cooling Mechanism for Cubesat Imaging Sensors

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Overview

Any imaging or remote sensing system suffers from sensor noise and a measure of the quality of a sensor is its Signal-To-Noise Ratio (SNR). The higher the SNR, the better quality data scientists and citizens can receive. As small satellites grow, the market for observation satellites grows as well, leading to higher demand for high quality sensing data. The ability to cool sensors on small satellites provides higher quality image data without the need for major spacecraft design overhauls. Large cryocoolers are not able to fit into small satellites neatly, and increase mission risk. However, using a solid-state thermoelectric module provides ample cooling to increase sensor SNR, while decreasing mission risk and increasing mission lifetime.

The Peltier Effect

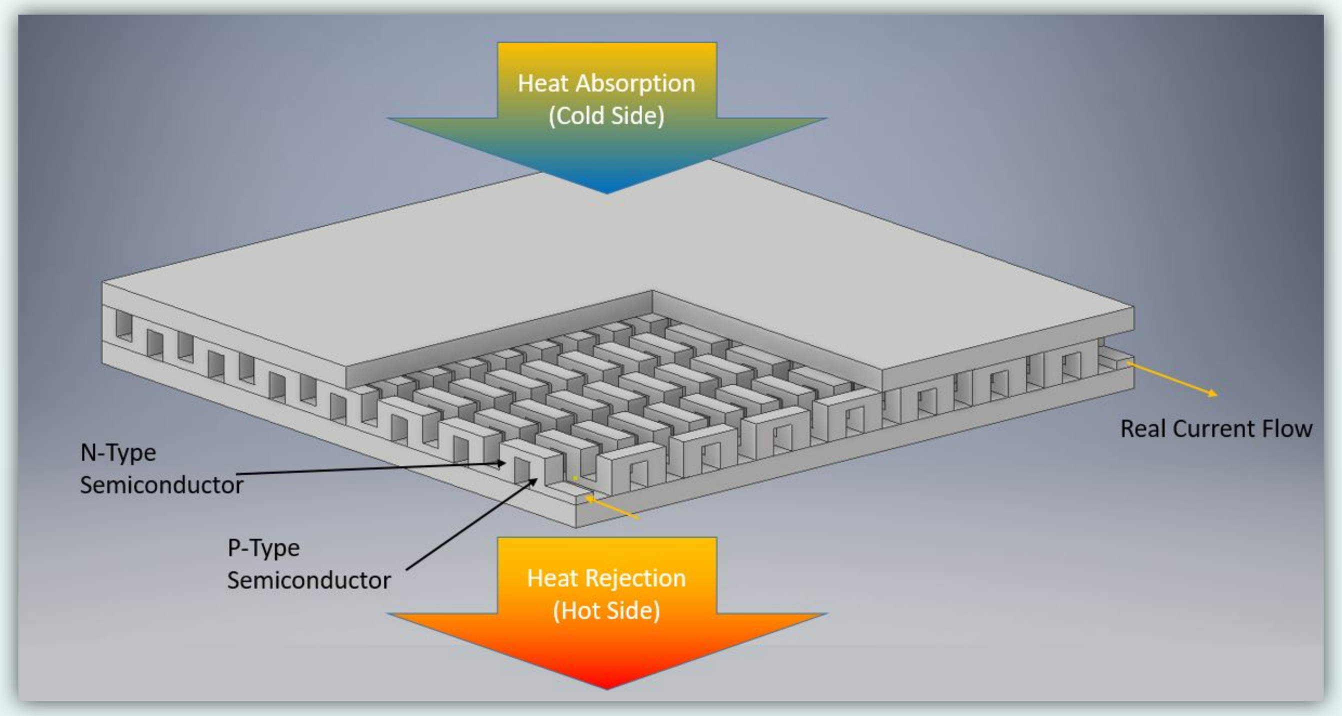

Figure 1

A thermoelectric module (TEC) utilizes the Peltier Effect. This effect occurs when an electric current is run through a series of differently charged conductors, like semi-conductors. Because electrons are passing through the differently charged conductors, heat passes from one side of the module, to the other, see Figure 1. In TEC's, a patterned array of semi-conductors is placed in the middle of two alumina plates. The semi-conductors are connected in series, alternating between positively and negatively charged. Electrons are forced into new orbitals, requiring energy from the surroundings to be absorbed and released with each positively and negatively charged semi-conductor, respectively, when a current is passed through the TEC. The absorption and release of energy, heat, is how the TEC is able to operate as a heat pump with no moving parts.

Unlike other active cooling solutions, like cryocoolers, a thermoelectric system is not limited by the amount of coolant onboard the spacecraft and does not involve any moving parts. Because of this, a thermoelectric system can extend mission lifetime and buy down mission risk, all while meeting mission requirements.

Testing the Model

To take full advantage of the cooling capabilities of the TEC system, the TEC is required to be as close to the imaging sensor as possible. Since most imaging spacecraft payloads are developed from scratch, this is a reasonable requirement, and the TEC can be interfaced with the back of the sensor board. Because the TEC is dumping heat to one side, that heat must be dissipated away. A passive heat strap attached to the spacecraft structure thus provides ample heat dissipation during imaging operations. Figure 2 illustrates how the system would come together inside the spacecraft.

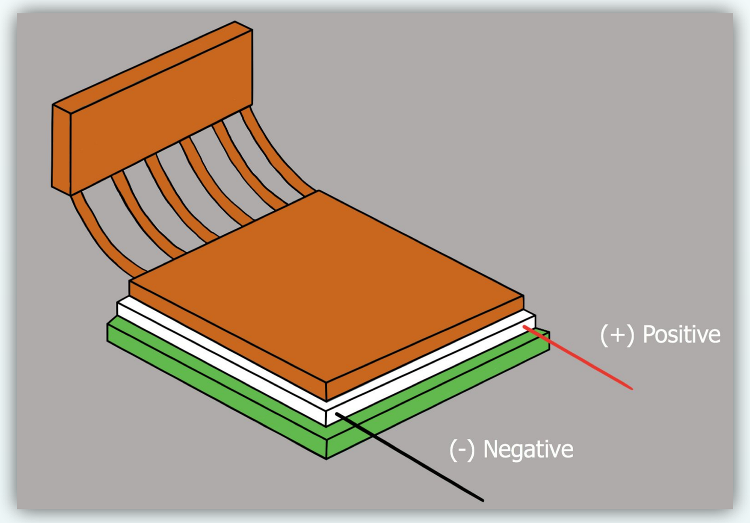

Figure 2

In order to test the feasibility of the system, a minimal prototype was created under the auspices of a College of Engineering Senior Capstone project. This prototype model involved a Canon XSi as as sensor baseline, a Marlow thermoelectric module, and a Corsair CPU water cooler. The water cooler served as a simulation of dissipating heat away from the thermoelectric module, much like how the spacecraft heat strap would function with the system. Figure 3 shows the prototype setup.

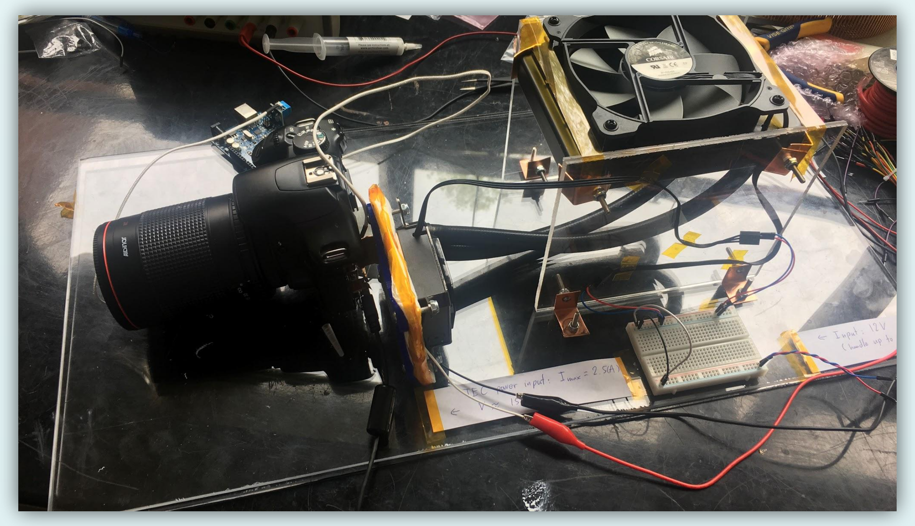

Figure 3

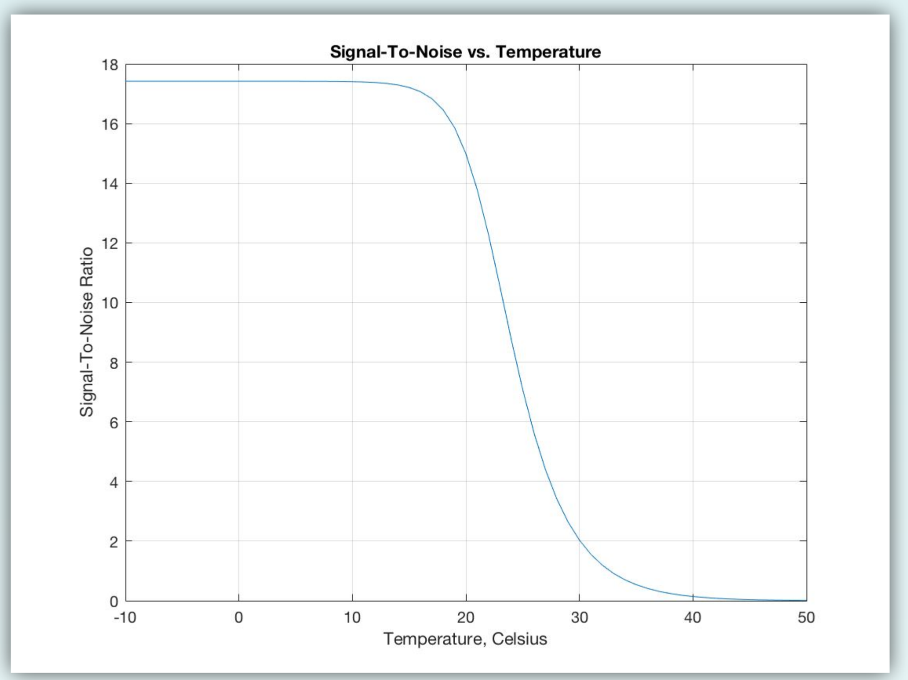

Figure 4

The Canon XSi sensor's dark noise figure was determined through a series of dark frames. The correlation between sensor temperature and SNR can be determined after careful dark frame measurements, as seen in Figure 4. SNR values are low, and this is because dark frame signal values were used. However, the correlation between peak SNR and temperature does not change with non dark frame images.

The prototype system was able to bring the sensor temperature from 25 degrees Celsius to 9 degrees Celsius, showing that the system can work. By using a feedback control loop to control power, a temperature setpoint can be maintained.

FEA Analysis

To test whether the system could fully operate in space, the system was simulated in ANSYS with a 3U radiator pointed at Earth, a somewhat common pointing configuration. ANSYS shows that a TEC is capable of deep cooling of a sensor. Figure 5 shows how quickly a TEC enabled system can lower a sensor's temperature from ambient spacecraft to a desired temperature while using only 2 Watts of power. Figure 5 essentially serves as a graphical method of showing feasible temperature setpoints, given the system is constrained inside a CubeSat. Figure 6 illustrates the TEC system after it reaches an example setpoint of -10 degrees Celsius.

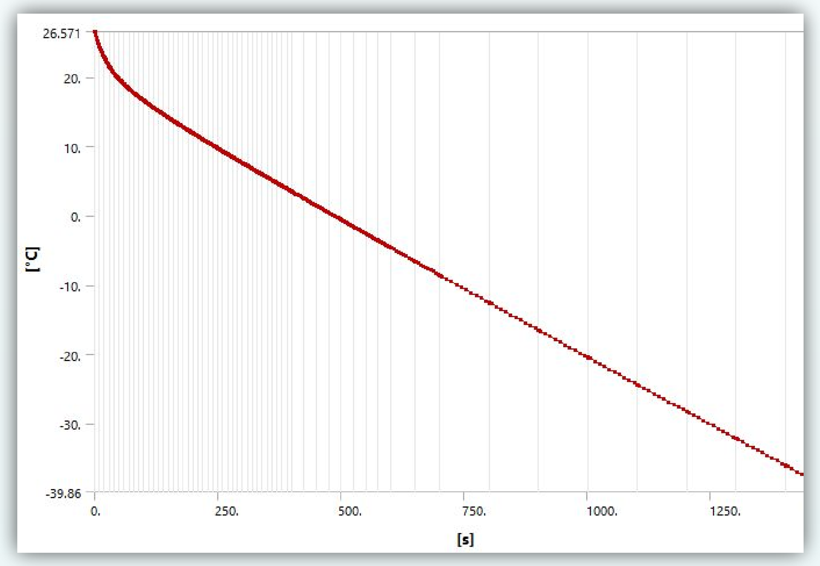

Figure 5

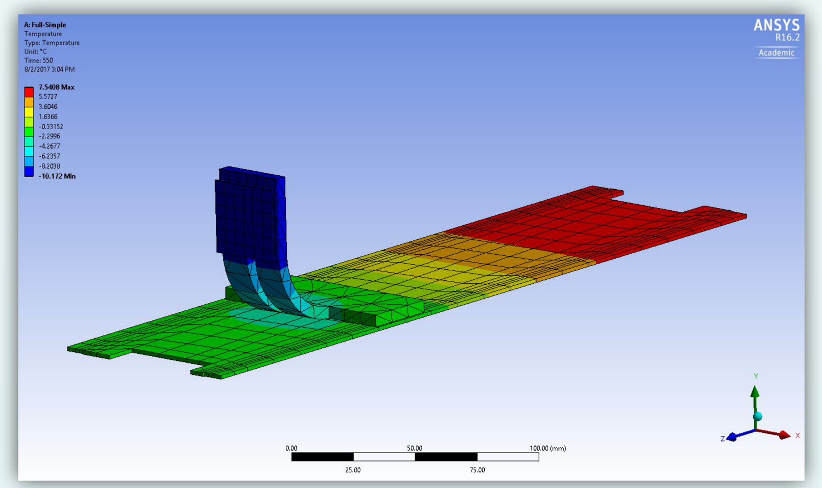

Figure 6

Potential System Integrations

As a case study, there are existing CubeSat systems which could benefit from a TEC cooling mechanism. The OnSemi KAI-29050 CCD, similar to what Planet uses, could receive a performance improvement in low-light situations. Figure 7 shows how SNR can increase if the sensor was cooled to -20 degrees Celsius, instead of being subject to ambient temperatures in the "Tuna Can." A TEC cooling system would be readily available to provide added performance for even more Earth coverage.

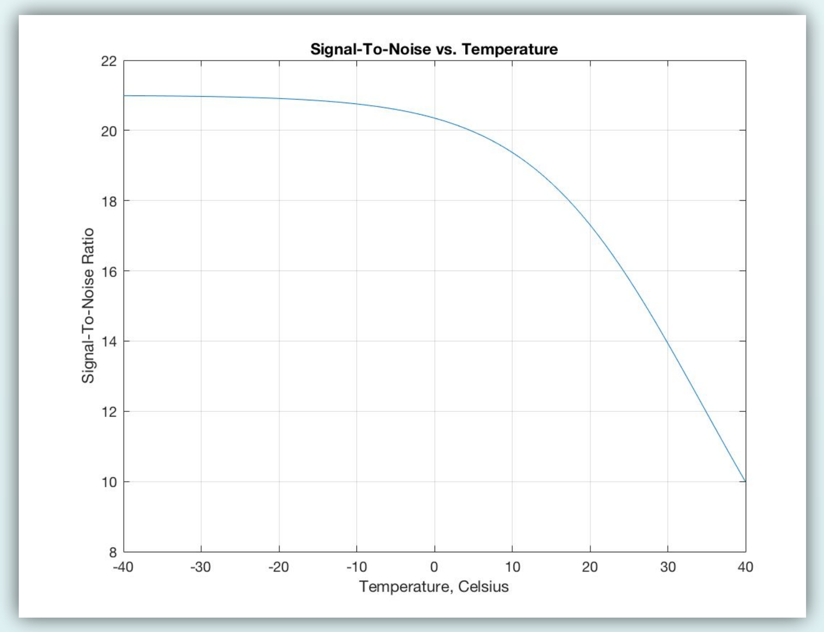

Figure 7

Additionally, CubeSat missions with the goal of studying the infrared spectrum require cooling of the sensor, as the sensor temperature can affect the data. A TEC system can easily be implemented on these missions, as it does not require an extreme amount of space, mass, or power.

The authors would like to thank the others members of the senior capstone project that contributed to this work Khoa Ngo, Megan Le Corre, and Paul Keith