Enhancement of Space-Borne Sensors through Adaptive Temperature Control and Thermoelectric Modules

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Overview

The advent of small satellites and their ability to perform orbital science on a small and relatively cost effective basis has resulted in a near-exponential growth of the market since inception. Due to their convenience, many of these small satellites use image sensors to study the Earth and astronomical events. The small package these sensors are housed in can be degraded though, due to the higher impact of heat generation from the satellite, as indicated in Figure 1. Past research using thermoelectric modules to cool satellite sensors has shown strong promise and interest, and has encouraged the further development of a feedback control system to optimize temperature set-point and energy consumption. The feedback system includes coding and tuning of a Proportional-Integral-Derivative (PID) controller to control the thermoelectric module to a stable and set low temperature through different environments, like extreme vacuum. The system also integrates additional hardware, including thermocouples and processors. The combined thermoelectric and feedback system will demonstrate the ability of the system to efficiently operate the thermoelectric module within 5 degrees Celsius and low input power. The combined feedback system with the thermoelectric module has far reaching applications, from enabling higher quality cameras to faster & more efficient computers.

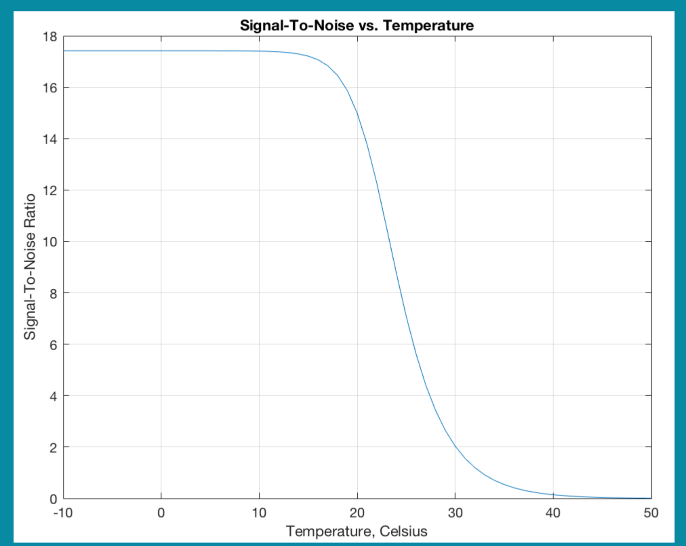

Figure 1

System Operation

The heart of the sensor cooling system is the thermoelectric module, a solid-state system with near infinite lifetime. Using the Peltier Effect, the transfer of heat across the module occurs with the passage of electricity through dissimilar semiconductors. The heat transfer allows for one side of the thermoelectric module to become chilled, cooling the satellite sensor, demonstrated in Figure 2. As indicated in Figure 1, the Signal-to-Noise ratio increases with lower sensor temperature. This data was gathered under prior research. Although the thermoelectric module is advantageous in satellite systems for its size, mass, and lack of moving parts, it becomes increasingly inefficient with prolonged use due to Joule heating and the First Law of Thermodynamics. As the sensor becomes colder, the heat dumping side of the thermoelectric module becomes hotter, leading to higher power draw and unwanted inefficiencies on a satellite platform.

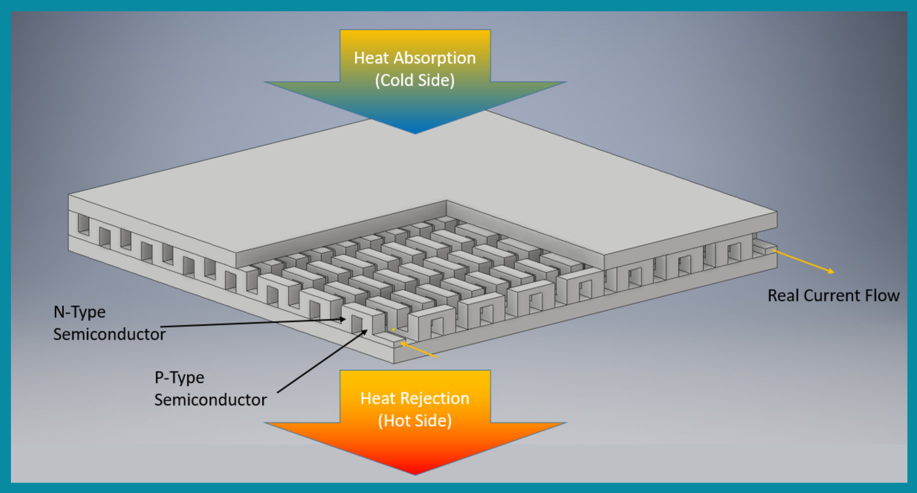

Figure 2

Feedback Control

In order to enhance the efficiency of the thermoelectric module and make it more suitable for use onboard a spacecraft with strict power constraints, a closed loop feedback control system can be developed. Figure 3 shows how the ability to remove heat, cool the sensor, with the TEC decreases as the TEC temperature difference grows.

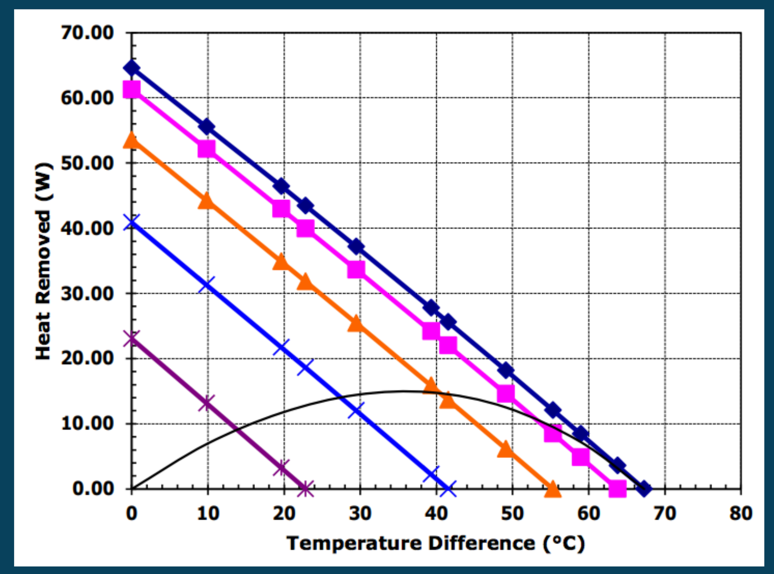

Figure 3, Source: TE Technology

Figure 4 illustrates how the feedback control loop will compensate for the actual sensor temperature, maintain efficiency, and act to keep the temperature near the set temperature. The controller includes Proportional (P), Integral (I), and Derivative (D) coefficients which dictate the sensor temperature response, including deviation, maintenance on TEC temperature difference, and speed of cooling. The TEC operates with constant voltage and different cooling parameters with correlating currents. Therefore, the controller will take in temperature data and output a correlating current to the TEC. An area of concern is the disturbance to the sensor cooling due to external/internal heating from the sun and satellite components, which is also reflected in Figure 4.

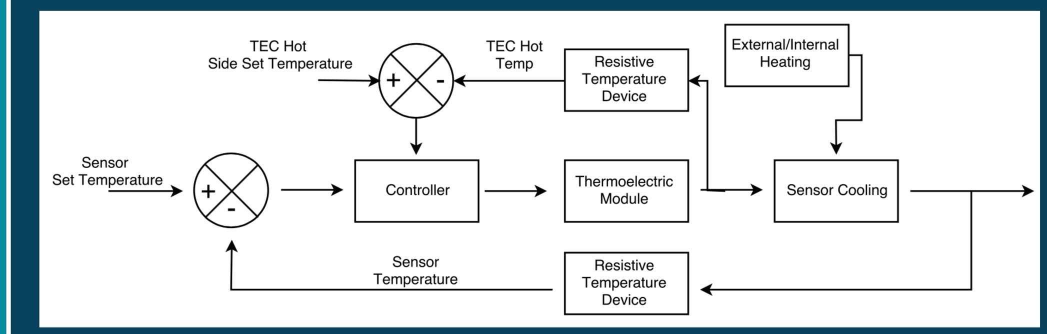

Figure 4

As a simplification, the efficiency feedback will be neglected under the assumption that the heat sink attached to the TEC is adequately sized as to maintain the temperature difference across the TEC near zero. This leaves a straightforward feedback loop, of which the PID values can be estimated using the Ziegler-Nichols method and simulated Simulink data. Figure 5 shows the tuned simplified system response using the estimated PID values compared to an untuned system. With the x-axis in units of seconds and the y-axis in the unit of Kelvin, the system is able to respond quickly and accurately.

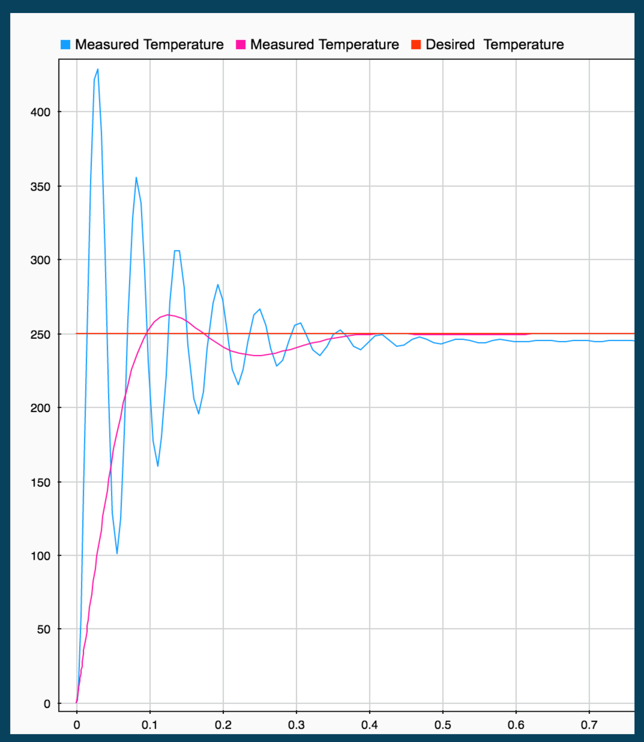

Figure 5

Estimated PID Values		
P	I	D
2.187	22.749	0.0521

Table 1

Hardware Selection

As part of this research project, specific hardware to support the feedback control mechanism was selected with an initial plan of developing the hardware. There are three main hardware areas of concern: 1) Temperature Detection Devices, 2) Feedback Controller logic, and 3) Thermoelectric Module. Importantly, the hardware selected must also be easily adapted into space platform.

Preliminary Hardware Specifications	
Temperature Sensor	Omega F2010-1000-B-100
Microcontroller	22.749
TEC	TE-127-1.4-1.15
Power	5 Volt, 1 Amp
Internal Satellite Interface	PC/104 +
External Satellite Interface	JTAG

Table 2

Most researchers often default to using thermocouples when wanting to sense environment temperature. However, thermocouples require a reference temperature device in order to operate. Due to the variety of heat generation sources in close vicinity in a satellite platform, the reference temperature can be greatly influenced causing inaccuracies in the system. Instead, a resistive temperature device (RTD), specifically the Omega F2010-1000-B-100, is selected for its accuracy, absolute temperature sensor, and size.

The RTD will sense the temperature at the sensor and the hot side of the TEC, but it is up to the Feedback Controller to transduce that information into usable data. Additionally, the Feedback Controller can be configured with different PID values. The controller selected is an RPC56EL70L3 micro controller from ST, which provides aerospace compliance and ample capability. Figure 6 shows the block diagram of the micro controller.

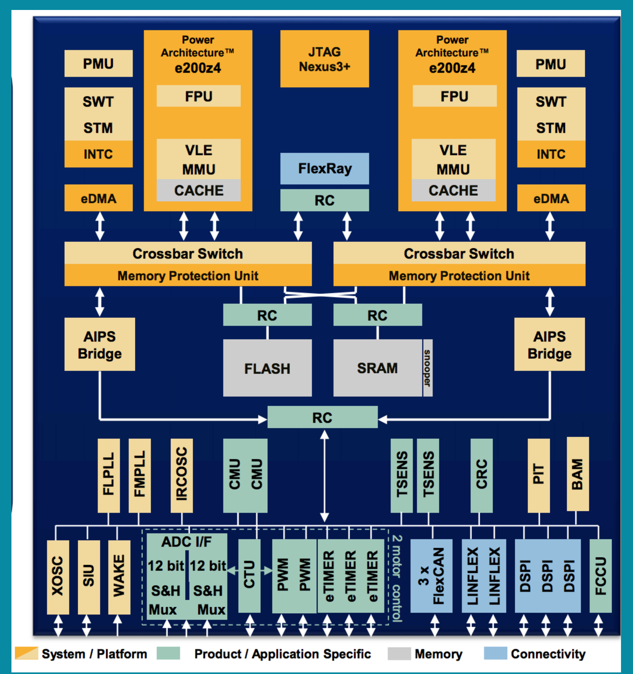

Figure 6

The TEC is what makes the whole system work, thus reliability is an important aspect of the system. Thus, the TE-127-1.4-1.15 from TE Technology is selected as the preliminary TEC hardware. Prior work with a similar system has had reliable operation under harsh testing conditions.

Future Work

Unfortunately, the full implementation of a closed loop feedback control mechanism was not able to be fully developed during this segment of research. However, with this research and selection of hardware, the next steps of this research includes finalizing the feedback control loop and development of the hardware aspect into a satellite compatible platform. The authors would like to thank the Center for Undergraduate Research Opportunities, Franklin College of Arts & Sciences, the College of Engineering, and the Small Satellite Research Lab for their support.