An Investigation of Temperature Control Using Computer-Controlled Peltier Devices

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Introduction

Our project has been one small part of the overall goal to create a radio astronomy interferometer at PARI. For this goal to be achieved, all potential sources of noise between the signal and the astronomer must be analyzed and controlled. One such potential noise source is the radio dish electronics themselves in their environment of constantly varying temperature. Our project has focused specifically on this issue concerning the electronics in the feed boxes of the 26 meter dishes. The end goal of the project is to be able to control the temperature in the feed box to within 1 degree Celsius, and to control the temperature inside the smaller enclosure containing the low noise amplifiers to within 0.1 degree Celsius.

Project Requirements

To meet the overall goals of this project, several conditions must be met. The temperature regulators must be low maintenance, of reasonable cost, relatively small in size, able to work in all weather, and able to work in any orientation. A control scheme must be developed which can adapt to seasonal variations, sense and control temperature in the feed box remotely, and be easy to use. We would need adequate power supplies to run the temperature regulators and a way to mount them near the feed box, protect them from the weather, and allow them to vent. The feed box would need to be insulated and perhaps fitted with a thermal mass to help stabilize temperature fluctuations. Anything mounted in, on, or near the feed box must contribute little or no noise.

Experimental Design

We have concentrated on solid state Peltier coolers as the device for cooling and heating because of their compact size, dependability, versatility, and their ability to work in any orientation. The proposed plan is to use several air-cooled Peltiers to control the temperature of the main feed box and a liquid cooled Peltier to maintain the temperature in the LNA enclosure. Our experiments have focused on testing these two types of coolers for their abilities to maintain stable temperatures in a variety of situations.

The physical preparation for our experiments involved creating a set-up in the lab which mimicked the actual situation in the feed box as closely as possible. We built a 4x4x4 ft. box out of 2-inch thick Styrofoam as our model of the feed box itself. Inside this box we built a smaller box, about 1x1x2 ft. in dimension, out of 1-inch thick Styrofoam as our inner LNA enclosure. We cut a hole in the outer box into which the air-cooled Peltier fit tightly. We also cut a small door into the front of the box so that a heat source could be inserted. We used a hot plate connected to a variable power supply as a controllable heat source to mimic a heat load from the sun in the main box. It should be noted here that we experimented with using light bulbs as heat sources but found that the wattage indicated on the bulb did not correspond to the actual heat output. The inner enclosure was designed to accept a heat exchanger which could connect directly to the liquid-cooled Peltier just outside the main box. We bolted two 4 Ohm resistors to the heat exchanger in order to simulate a heat load due to the electronics.

The temperature probes in our control scheme were modified in house for use with the USB and Ethernet LabJacks, except for the sensor of the TC-24-25 controller, which was a MP-2379 sensor. This sensor was used in TS-67 mode with a control range of -20C to +100C. The other sensors were connected to the LabJacks in the more stable differential input mode. The outer box sensors were fed in through a small capped hole toward the center of the top of the box and were given approximately one foot of slack to hang from the ceiling. The reasoning for this location was that the enclosure is so small that the fan of the Peltier is powerful enough to mix the air evenly except in regions close to the Peltier and heat source. In the inner box the sensors were located midway between the two power resistors to simulated the heat from electronics, such as the preamplifier.

We used LabView to create a data acquisition program which would allow us to record, regulate, and control temperature through the Peltier coolers. LabView has an intuitive graphical programming interface that is easy to work with by people with limited programming experience. It is also designed with device I/O and data acquisition in mind. LabView programs may be exported to be controlled over the web, but programs exported this way currently have limited interactivity. Programs can also be converted to executable files for computers without LabView access.

Both the USB and Ethernet LabJacks had preexisting I/O subroutines that could be downloaded for communication in LabView. The code implemented for these two devices included a user defined averaging period, comma delimited save file creation and comment for easy data access in spreadsheet programs, and the ability to pause the acquisition briefly to make comments on settings or observations while automatically writing a time stamp. Data was in two columns: time elapsed versus temperature, with the beginning of the acquisition marked by a time stamp during file creation. Additionally, graphs were wired that displayed the current temperature relative to a hard-wired fixed set or goal temperature, which was changed over to be user defined in the RS-232 program version.

It was found that the Ethernet LabJack had a faster acquisition that the USB and supported more sensors per LabJack. Unfortunately, the stability of communications with the Ethernet LabJack appears to be subject to the amount of load placed on Ethernet communications on the computer the LabJack is running on. However, it should be noted that even when the computer's communications with the controller board is severed the board continues controlling using the last defined settings. Additionally, upon reset or power on to the controller the last settings written to non-volatile EEPROM memory are used.

Direct communication using hex code with the controller came as a result of the prepackaged software's inability to function with the RS-232 over Ethernet interface using SitePlayer. This means that the control program functionality had to be rewritten using the commands located in the manual .pdf of the controller board. In addition, it was now possible to enable the user to save preferred control settings to file and later load them when desired. It may be possible in the future to have the controller dynamically update control schemes based on weather input or other methods.

Experiments Specific To Our Project

In order to learn about how well the air-cooled Peltier could remove heat, we decided that it was necessary to determine how much heat leaks out of our box passively. We performed an experiment to determine the R-value of the box by turning on the heat source inside the box to a specific wattage, allowing the box to reach an equilibrium temperature, then using this information along with the ambient room temperature and the surface area of the entire enclosure to calculate our result. Our experiment gave an R-value of 7.6, compared to the manufacturers stated R-value of 10 for the 2 in. thick Styrofoam.

Experiments with the MicroTech pump used showed it to behave non-linearly with respect to flow rate versus pump setting. The pump setting also affected the amount of heat the pump put into the water, on the order of 10W across the pump setting range. Surprisingly, it was found that the pump added considerable noise to the temperature probe measurements above a pump setting of 4. The noise was reduced when the pump was moved to a separate power strip, but not eliminated due most likely to other electronic devices in the chain. The noise was on the order of 0.01C. The pump setting should be taken to be 4 unless otherwise stated in measurements using the liquid Peltier

Experiments Pertinent to the Interferometer Project Goals

We performed experiments on both the air-cooled and the liquid-cooled Peltier which show the ability of the coolers to maintain a stable temperature at several different heat loads. To do this, we set the cooler to its optimal settings and then increased the heat load a specific number of Watts about every five minutes. This experimentation also allowed us to learn the maximum heat wattage that the cooler could consistently remove.

To simulate a more realistic heat load situation, we tested the Peltiers' abilities to maintain a stable temperature during drastic changes in wattage input.

We experimented with the liquid-cooled Peltier to determine how the flow rate of the water affects the performance of the cooler. This experiment required consideration of the different amounts of heat delivered by the pump itself at different settings.

The PID (Proportional-Integral-Derivative) settings for controlling the Peltier's heating and cooling required systematic tinkering in order to achieve optimal results. Proportional Bandwidth is the range over which full power will not be used, with a minimum setting of 1.0 degree. This means that the power of the cooling or heating can reach its maximum when the temperature reading varies as little as 1.0 degree from the set temperature. This can cause oscillations due to the Peltier working against itself, but it was found that this minimal setting providing the best ability to stay near the set temperature. Integral Gain is a repetition rate measured in minutes of the adjustment of Peltier power to make the set temperature and actual temperature match. While in earlier tests it appeared that an Integral Gain setting of 1.0 helped maintain actual temperatures near the set temperature the best, in later tests turning integral gain to the default value of 0.0 seemed to work best. Derivative Gain uses temperature changes to predict the Peltier power needed when the load fluctuates quickly. The manual warned that it is very difficult to apply, and dependent on the conditions of the system of use, so little experimentation was done using the Derivative Gain. When the Peltiers are actually installed in the two dishes the optimal control scheme can be more readily and successfully determined.

Conclusion

Through our quantitative experiments and qualitative observations we are able to make several conclusions:

The air-cooled Peltier can control temperature reliably for heat loads of up to about 150 Watts, but loses control for loads of more than 150 Watts.

The Liquid-cooled Peltier can control temperature reliably for heat loads of up to about 150 Watts plus pump-heat wattage (~10 W), but loses control for loads of more than 150 Watts plus pump-heat wattage (~10 W).

Given a constant heat load, the air-cooled Peltier is able to maintain temperature to within 1.0

degree Celsius.

Given a constant heat load, the liquid-cooled Peltier is able to maintain temperature to within 0.1 degrees Celsius.

Both the liquid-cooled and the air-cooled Peltier perform more poorly when under the stress of large heat load fluctuations, yet are still able to maintain temperature within about 2.0 degrees for the air-cooled Peltier and about 1.0 degrees Celsius for the liquid-cooled Peltier. It is unlikely in the final application that the liquid-cooled Peltier will see large heat load fluctuations due to the nature of what its heat load is and the stability of the outer box.

The optimal control settings for our experiments are having both Peltiers set to Proportional Bandwidth at 1.0, Integral Gain at 0.0, and Derivative Gain at 0.0. In the final application these could be fine tuned to best suit the user's wishes.

For a specific pump, there seems to be an optimal flow-rate which would allow the liquid Peltier to perform at its peak. Above this flow-rate the heat added by the pump cancels out any improvements in performance. Within a relatively large range of flow-rates, however, differences in flow-rate have only a small effect on Peltier performance.

The highest average heat load from the sun that could be expected in the Rosman area is about 420 Watts per square meter. (Source NREL.gov)

There appears to be no need for a reservoir in the liquid-cooled Peltier system.

Toward the end of the project cold-plate Peltiers designed for use on smaller loads were suggested as an alternative to the liquid-cooled Peltier system in the electronics box. This has several advantages, such as smaller size, a liquid-less system, and a capability more appropriate to the loads that would be experienced.