Temperature-Agnostic Microelectronic Cooling System

Xiaoli Yan
Nathan Thomason

TA: Ankit Jain
[1] Design

1.1 Design Overview

This project proposes an active cooling system for microelectronic devices that uses a Thermoelectric Cooler (TEC) to pump heat from the microelectronic device (in this case, a CPU) to a traditional heatsink where the energy may be dissipated. Power and control will be consolidated on a PCB that is powered by a regular PC Power Supply Unit’s 8-pin PCIe power connector. This PCB will house all blocks listed below except the TEC and the Temperature sensors.

The TEC is placed between the traditional heatsink and the device such that the CPU will be cooled and the heatsink will be heated. Under planned operation, thermal energy will pass through the TEC from the cold (CPU) side to the hot (heatsink) side to maintain a user-defined temperature.

1.2 Block Diagram

Figure 1: Block Diagram showing high level blocks in black, and corresponding connections.
1.3 Block Descriptions

Power Supply Block

The system will be powered by a normal Power Supply Unit’s (PSU) 8-pin PCIe power connector, shown in Figure 2. According to PCIe standards, this connector supports a power delivery of 150 watts, which is greater than the estimated peak consumption of our system (~135 watts). The connector provides three +12v connections, three ground connections and an additional two logic connections that are grounded.

The 12 volts from the PSU will be attenuated to 5 volts to power the microcontroller and temperature sensors, but kept at 12 volts for the Control Block, where it will be altered according to software to power the TEC.

Sensing Block

The sensing block consists of three temperature sensors each with a specific function. The first temperature sensor will be used to measure the ambient temperature. This allows the microcontroller to understand how the heat generated by the device and system is affecting the environment.

The second and third temperature sensors work in tandem, measuring the hot and cold sides of the TEC. Measuring both temperatures allows the operating conditions of the TEC to be understood at any given moment. Thermoelectric devices have non-trivial relationships between heat transfer, temperature difference between hot and cold sides ($\Delta T$), input power, and efficiency. Monitoring these temperatures gives the software the chance to run the TEC under ideal conditions instead of resorting to an inefficient on/off algorithm.

The temperature sensors will be powered at 5v from the Power Block, and will output their temperature readings digitally to the microprocessor within the Processing Block.

Processing Block

The processing block consists of an AT Mega microprocessor circuit that will process the digital temperature readings and output an analog signal varying between 0-1 volts to the Control Block that will control TEC operation. The microprocessor will also check the AC resistance output of
the Boot Up Test Block. If the AC resistance is larger than the tolerance, the microprocessor will drive the RGB LED in the Output Block to turn red (it is green under normal/safe operation).

**Control Block**

The control block drives the TEC by amplifying the analog signal from the microprocessor from 0-1 volts to 0-12 volts using one or more MOSFETs in parallel to reduce power consumption and heat generation.

**Boot Up Test Block**

The Boot Up Test Block includes an inverter and an AC resistance test circuit. The inverter converts 12v DC into an AC signal that is used to drive the AC resistance test circuit. The test circuit drives the TEC by AC and sends a voltage to the microprocessor that is proportional to the AC resistance of the TEC. The motivation for testing the resistance is that due to the properties of a TEC, a marked increase in the AC resistance is a clear indicator of wear on the device and could mean that the TEC will fail soon, and ought to be replaced.

**Output Block**

The Output Block consists of two parts: an RGB LED as a status indicator, and the TEC, which actively transfers heat from the device to the heatsink. The RGB LED is driven by the microprocessor, and the TEC is driven by either the Control Block or the Boot Up Test Block. The two sources of power will have a switch controlled by the microcontroller, so that the TEC is only driven by one source at a time.
[2] Circuit Schematic:

Figure 4: Temperature Sensor Circuit Diagram

[3] Plots and Calculations:

Figure 4: A PC system’s temperature while under full load until ~16500 seconds. This plot is used to demonstrate the characteristics of temperature on a PC system.
Figure 4 shows the characteristic of PC system temperatures over time. The PC is under a large load, maximizing heat generation by its components, primarily the CPU. This diagram shows the sharp initial build in temperature that tapers off to an asymptote where the net heat dissipated by the cooling system meets the heat generated by the system, resulting in a stable temperature.

This diagram is used to demonstrate that a heatsink’s heat dissipation is proportional to its temperature. This property is harnessed by our design, as the Thermoelectric Cooler transfers heat from the CPU to the heatsink without requiring them to be at thermal equilibrium, which traditional cooling systems do. This allows the heatsink to dissipate more heat due to the increased temperature while keeping the CPU at a cooler temperature.

**Calculation:**
The peak power draw for the entire cooling system needs to be calculated. It must be under the 150 watt limit provided by the 8-pin PCIe power connector. The power consumption of the control block and the AC resistance block is mutually exclusive; only one of them consumes power at a time.

\[
P_{total} = P_{Crel/ACR} + P_{proc} + P_{sense}
\]

\[
P_{total} = (10.5A \times 12V) + (0.500A \times 5V) + (0.005 A \times 5V)
\]

\[
P_{total} = 128.525 \text{ watts}
\]

This estimation for peak power usage is well under the 150 watts allowed by the single connector we are using. If power consumption happens to be above this 150 watt limit, the solution is to simply connect another 8 pin connector in parallel, allowing more current to come from the PC’s PSU. The PSU we are using is rated at 650 watts, and should be more than capable of handling a 300 watt load in addition to the regular system resources.
### Requirements and Verification

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<th>Requirement</th>
<th>Verification</th>
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<tr>
<td><strong>Sensing Block</strong></td>
<td>- Connect the temperature sensors to microcontroller and print the temperature reading on the IDE terminal.</td>
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<td>- Measure the temperature of 500ml water (heated by alcohol burner) with sensors and a red alcohol thermometer at the same time.</td>
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<td>- Place the sensor and thermometer both submerged under water while maintaining the water temperature.</td>
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<td>- As the temperature sensors reach thermal equilibrium, check sensor readings on IDE terminal with the measured temperature from the red alcohol thermometer to ensure accuracy of temperature measurement.</td>
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<td>- Analyze temperature vs. time data logged by the microcontroller to verify that the sensors reach thermal equilibrium within the requirement.</td>
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<td>- Repeat above steps at 5 evenly spaced different temperature points from room temperature up to 90 degree Celsius.</td>
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### Safety Statement:

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This project includes the use of microelectronics (specifically CPUs) that are designed to withstand high temperatures. Since this project tampers with the traditional cooling system of these devices, there is a high risk for burn injuries. The team must use caution when dismantling and assembling the apparatus, especially when running stress tests between.

The design, while not using high voltages, is dealing with enough power (~150W) to damage components, which may cause injury for the team. Caution must be exercised to ensure that the project components are not powered when they are being modified. Proper wire and cable management must be undertaken to reduce the risk of accidental shorts, which could be dangerous due to the high current.

[8] Citations:

http://www.playtool.com/pages/psuconnectors/connectors.html#pciexpress8


http://www.anandtech.com/show/7982/logic-supply-coreml320-fanless-industrial-nuc-review/6