Technical Article

What to Do for Higher Power Thermoelectric Cooling Using a Peltier Device

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Abstract

This article provides thermoelectric cooler (TEC) concepts that are necessary to understand before designing a higher power TEC. It explains key Peltier characteristics that limit their cooling capability and provides ideas to design around those limitations. A couple of driver examples illustrate what is needed to control higher power TECs. Also included are issues that may be preventing existing designs from achieving their expected cooling capability.

Introduction

TECs, using Peltier modules to cool an object or to provide precise temperature control of an object, are used in a variety of applications. They are ideal for laser diode coolers[1,2], microprocessor cooling, polymerase chain reaction (PCR) systems, and medical applications such as tomography, cardiovascular imaging, magnetic resonance imaging (MRI), radiation therapy, and the list goes on. Many applications, such as laser diode temperature control use small, low power TECs with wattages in the 5 W to 15 W range. Their drivers might operate from a 5 V rail and provide 1 A to 3 A of current.

But what if we need more power? How do we go about it? What should we be looking at and what are our options? Let's look at it from two perspectives. The first scenario is when we already have a working TEC, but it's not adequate and it requires 10% to 20% more power. The second scenario is building a higher power TEC from the ground up. How much cooling capability can we get from a Peltier device? What should we use to drive it?

Before we begin, let's understand a couple of key Peltier concepts.

Maximum Heat Absorption

The maximum heat absorption (Qc) for a Peltier module will be in the data sheet but it applies to a Delta T of zero. The Delta T is the Peltier's temperature difference between the hot and cold sides. When the hot and cold sides are at the same temperature, the Qc will be what it says in the data sheet. However, it will decrease linearly as the Delta T increases until, at some point, Qc = zero. This point is also called the maximum Delta T and varies considerably, but a typical value for a single-stage module might be around 70°C. See Figure 1 for a generic example.

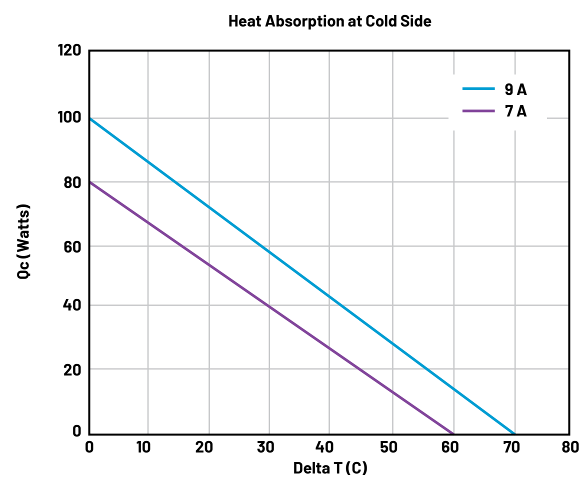

Figure 1. Heat absorption vs. temperature difference across the Peltier.

Let's assume that we would like to keep the hot side of the Peltier at a room temperature of +22°C and we would like to have the cold side at –5°C. The Peltier's maximum current is 9 A, so we plan on using a 7 A drive. From our example graph, a 27°C temperature difference at 7 A will give us a 41 W capability. However, all interfaces have thermal resistance so there will be a temperature gradient as the heat flows from the Peltier, through the heat sink, and into the room environment. Therefore, the hot side of the Peltier can't possibly be at 22°C room temperature. Let's assume the hot side is 30°C. That gives us a 35°C cold-to-hot temperature difference. Referring to Figure 1 and following the 7 A line to the 35°C Delta T point indicates that our heat extraction capability will be about 30 W—even though we purchased a 100 W Peltier!

Self-Generated Heat

One other important Peltier concept is that modules generate a lot of self-heat while doing their job. The amount of self-generated heat can be double what the absorbed heat is from the target. For example, while absorbing 25 W from the target, the Peltier may be generating another 50 W of heat. Therefore, the hot side heat sink must be able to dissipate 75 W of heat.

Improving an Existing TEC System

For the first situation where we have an existing TEC and just need a little more cooling capability, there are a few things we might look at. Some obvious problem areas are the TEC's hot side temperature, the thermoresistance of the TEC assemblies' interfaces, the voltage ripple across the Peltier device, the Delta T, and the insulation of the assembly.

It is recommended to first check the temperature of the hot side, see Figure 2. Remember, a key takeaway from Figure 1 is the importance of a small delta between the cold and hot sides of the Peltier. As the temperature difference increases, the Peltier is less capable of extracting heat from the target.

A quick way to get a feel for the hot side temperature is to check the heat sink temperature with the TEC at close to maximum power. Simply use a thermocouple, or if sending the measurement to a microprocessor, a thermistor works well. See "Thermistor-Based Temperature Sensing System—Part 1: Design Challenges and Circuit Configuration" and "Thermistor-Based Temperature Sensing System—Part 2: System Optimization and Evaluation" for two excellent thermistor articles.[3,4] If the temperature of the hot side heat sink is significantly above room temperature, a bigger heat sink and/or fan may be necessary.

Unfortunately, the quick check above doesn't tell us anything about the Peltier-to-heat sink interface. Accessing that interface may be difficult so disassembly of the unit is usually necessary. Thermal paste is often used at this interface, and we want to inspect it to figure out if there were air pockets that might have interfered with heat conduction. Since air is a poor heat conductor (0.026 W/(mK)), the purpose of the thermal paste is to eliminate air pockets. But don't use a thick layer because at 0.2 W/(mK) to 0.3 W/(mK), thermal paste isn't a good conductor either, although metallic types may be in the 4 W/(mK) range. The paste, however, is still 10 times better than air. For comparison, aluminum is 200 W/(mK), PCB copper ~380 W/(mK), PCB FR4 is around 0.3 W/(mK) to 0.8 W/(mK), water 0.6 W/(mK), and glass about 1.0 W/(mK).

Be aware that it is possible to reach a point where increasing current through the Peltier does the opposite of what one would expect, that is, it makes the cold side warmer! This is because the Peltier may be close to its maximum Delta T and increasing current makes the hot side warmer because of inadequate heat dissipation. As the hot side gets warmer, it pushes the cold side up with it.

Also, check how the voltage ripple across the TEC as ripple can decrease the Peltier's efficiency. Ripple should be no more than 10%, but 5% or less is recommended. Reducing the effective series resistance (ESR) of the load capacitors is probably the safest change. However, no matter what the change, increased frequency, added output capacitance, or larger inductor, due diligence is needed to prevent compromising the switcher's efficiency and its control stability.

New Designs

The first thing one might think about for a new high power design is whether to use a Peltier module or a Peltier assembly. The module is just the Peltier itself, the Bismuth Telluride sandwiched between ceramic substrates and the hot side (+ side) with two wires soldered to it. In this case, it is up to the customer to design the heat sinks and thermal interfaces. On the other hand, an assembly consists of the Peltier module(s) with the heat sinks already attached. A typical unit might consist of two heat sinks and two fans along with the wiring brought out to a connection terminal. The heat sinks come in a variety of styles such as air-cooled, water or glycol-cooled, and direct attach cooling. It will also likely include a frame for some type of attachment to a cabinet or some other equipment. The customer simply attaches a power supply for the fans and can then focus their attention on the driver design.

Either way, starting with a module or starting with an assembly, if building a high wattage TEC there are trade-offs and decisions. For example, Peltier modules (TEC modules) can have considerable variation in current and voltage for approximately the same wattage. It could be advantageous to use more than one module in the application, or multistage modules might be chosen to increase the Delta T. For driving the higher power modules, ADI has the LT8722 and the new LT8204 full-bridge power chips. Let's take a closer look at these issues.

The first thing to realize in selecting a Peltier module is that there can be considerable variation in their current/voltage trade-off. For example, when looking at available modules in the 95 W to 105 W range, resistances that vary from 0.34 Ω to 4.4 Ω can be found. Also, a 95 W at 27°C module featured maximum specifications of 19 A and 7.7 V while another 105 W at 27°C had 7.6 A and 21.2 V for maximums. Even though they are not exactly at the same wattage, the point is that there can be trade-offs between current and voltage, and that, in turn, determines your driver requirements.

Using multiple modules is also possible, however, they must be electrically connected in series because their resistance changes with temperature. Because of this, current sharing between parallel units would be a challenge. Of course, with series connected units, the voltage drop increases, and higher voltage drivers will be needed. Peltier units electrically connected in series, however, will still have their heat transfer as a parallel function. If the higher voltage isn't available, but two modules are still required, they will each have to be driven by their own driver. A single temperature feedback could, however, be used for both.

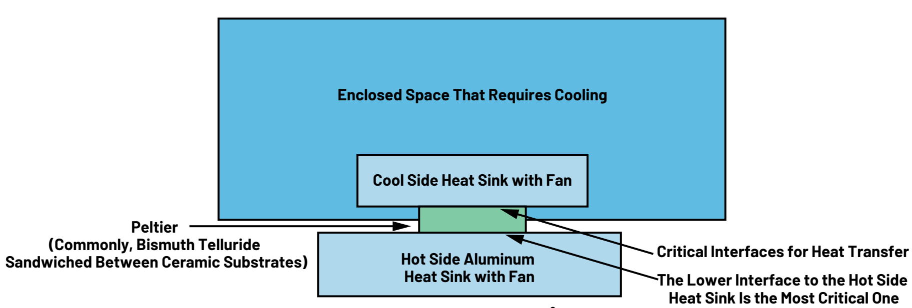

Figure 2. A simplified drawing of air-to-air TEC assembly.

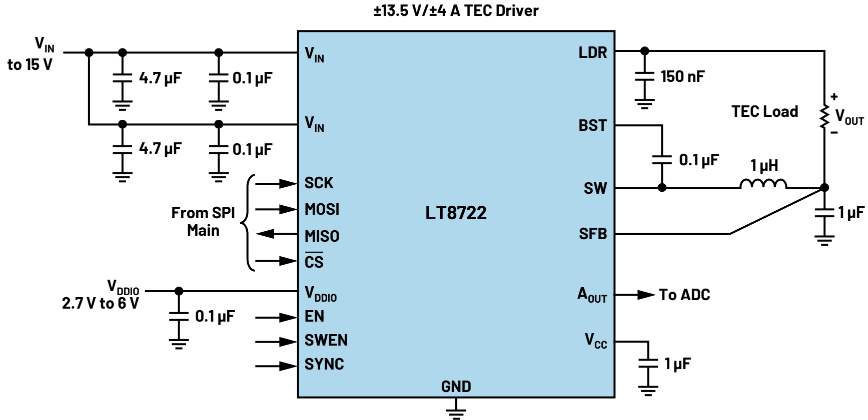

Figure 3. An LT8722 application circuit.

Another option is to use a multistage module. These modules consist of one to five modules stacked on top of each other by the manufacturer. In other words, heat transfer will be in series so the total Delta T increases, making it possible to cool to a lower temperature. This is not, however, a magic bullet. Remember, that each module's hot side must dissipate the heat removed from the target plus its self-generated heat. Thus, the next attached module's cold side must transfer both self-generated and target heat from the first unit, and a third module in the series would have to be capable of dissipating the heat from the target plus the self-generated heat from all three units. That extra temperature capability comes at a cost of considerably more heat dissipating. Multistage modules usually look like a pyramid because the module furthest from the target has a lot of heat to transfer and must be bigger.

A 15 V/4 A Driver for More Power

It's obvious that to increase the power of a TEC, a higher drive voltage is frequently needed. The LT8722 does just that, its V_{IN} voltage is 15 V and its integrated FETS have a 4 A rating. The regulator was designed with a highly accurate temperature control in mind. It uses an integrated 25-bit digital-to-analog converter (DAC) to receive information from the serial peripheral interface (SPI) so that an accurate differential voltage can be set across the TEC. Two additional integrated 9-bit DACs set the positive and negative output current limits.

The architecture is a full-bridge DC-to-DC converter with one side a pulse width modulation (PWM) buck power stage and the other side a linear stage that provides an efficiency of 92.6% at 4 A, 15 V_{IN}, and 3 MHz. Even with one of the outputs as a linear output, efficiency is maintained because at high currents, the switcher controls the current and the linear drive will be either high or low causing little voltage drop. During transitions that reverse the current flow, the linear output will be in its linear region, but the current is small. Thus, the linear drive does not significantly affect efficiency. With this architecture, not only is high efficiency achieved, but the footprint is smaller since only one inductor is required. The switcher also uses Silent Switcher® techniques to minimize electromagnetic interference/electromagnetic compatibility (EMI/EMC) emissions.

The SPI interface manages all aspects of control, including enabling, startup, peak current, frequency, differential output voltage, and current limit. The SPIS_STATUS register provides for six faults and five additional status conditions while the AMUX monitors 13 analog functions. The LT8722 is a low noise (only 1 side is a switcher), small footprint (only 1 inductor) H-Bridge with auxiliary functions already integrated into the chip. See Figure 3.

A 40 V Driver with External FETS for Even More Power

For additional cooling capability, ADI's 40 V LT8204 H-bridge controller with external power FETS can be used. This provides the ability to design the current level for any application. The LT8204 is a versatile driver. It makes a good Peltier driver but can also be used for any inductive, capacitive, or resistive load, such as motors, solenoids, battery charging, automatic test equipment power supplies, and heating systems—any application that requires either a half-bridge or a full-bridge driver. Its control mode can be either voltage-mode, or current-mode control, and it can control either the output voltage or the output current. Control of output current is especially useful for driving TEC modules.

The controller has an SPI interface and is fully controlled by a microprocessor. Two integrated 16-bit DACs provide an accurate interface from the microprocessor for either a dual half-bridge or a full-bridge configuration. In addition, integrated low input-offset current amplifiers provide for accurate bidirectional current sensing. A fault register provides for 16 fault indications that can be communicated back to the processor. In effect, much of the work that would be required to take a bare-bones H-Bridge controller and make it into an accurate TEC driver has already been integrated into the controller. See Figure 4.

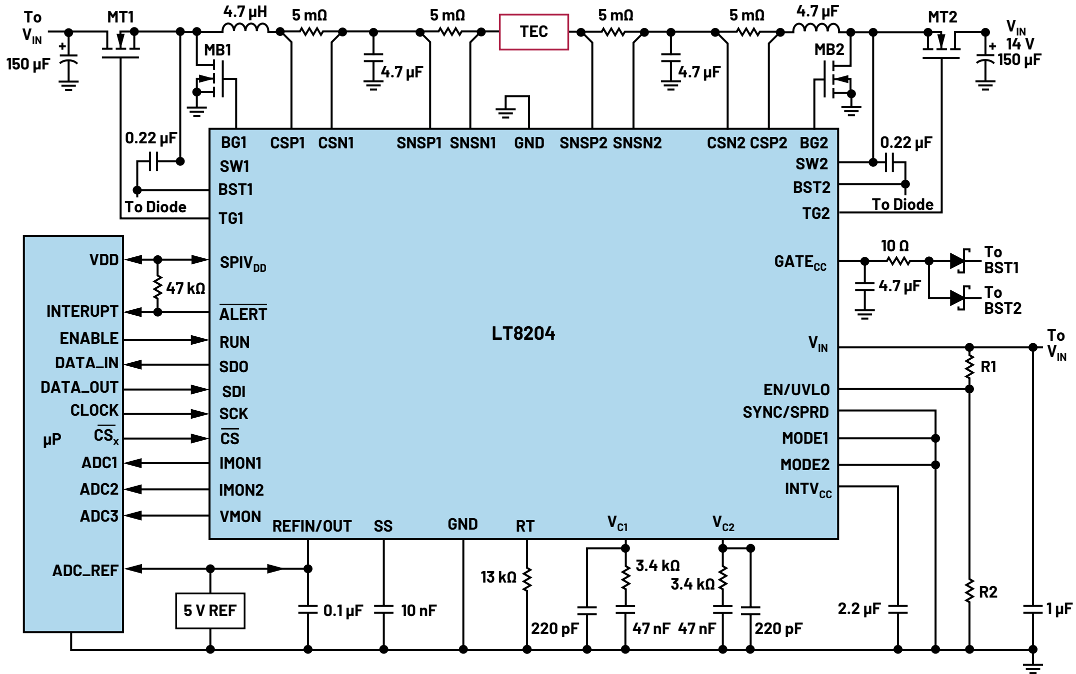

Figure 4. An LT8204 application circuit.

Conclusion

Whether an existing TEC needs to be looked at to increase its cooling capability, or a new, higher power design is planned, the procedure is not that complicated. Older designs may have thermal or efficiency issues that can be fixed. New designs will require a higher power Peltier module, multiple modules connected in series, or possibly, a multistage module if a higher Delta T is required. The driver will, undoubtedly, need higher voltage and current capability, and preferably, have built-in functions to accurately control temperature.

References

[1]"Thermoelectric Cooler Control Using the DS4830A Optical Microcontroller." Analog Devices, Inc., February 2015.

[2]Yajung Tu. "TEC Controller Applications in Telecommunication Systems". Analog Devices Inc., February 2016.

[3]Jellenie Rodriguez and Mary McCarthy. "Thermistor-Based Temperature Sensing System—Part 1: Design Challenges and Circuit Configuration." *Analog Dialogue*, Vol. 56, No. 3, July 2022.

[4]Jellenie Rodriguez and Mary McCarthy. "Thermistor-Based Temperature Sensing System—Part 2: System Optimization and Evaluation." *Analog Dialogue*, Vol. 56, No. 3, August 2022.

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