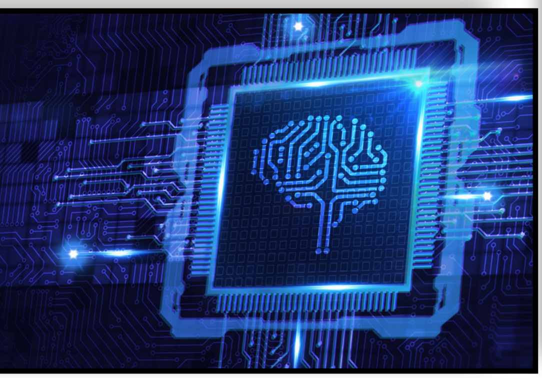
WHITE PAPER

Traditional Thermoelectric Cooling Technology

sheetak

Advanced Thermoelectrics



With the rise in various forms of technology including artificial intelligence and augmented and virtual reality, data centers and data systems around the world are being worked at all-time high intensities and generating unprecedented levels of heat. Thermoelectrics provide a solution for growing thermal management needs in those industries and many more.

Executive Summary

In the US, data center power consumption is expected to more than double by 2030 from levels measured in 2022. An earlier study, from 2016, by McKinsey calculated that the volume of data in the world doubled every three years.

The deluge of online information through AI, IoT, data mining, AR/VR applications and more is resulting in more powerful systems and networks. But it's also generating ever-increasing quantities of heat, an enemy of system performance and component life.

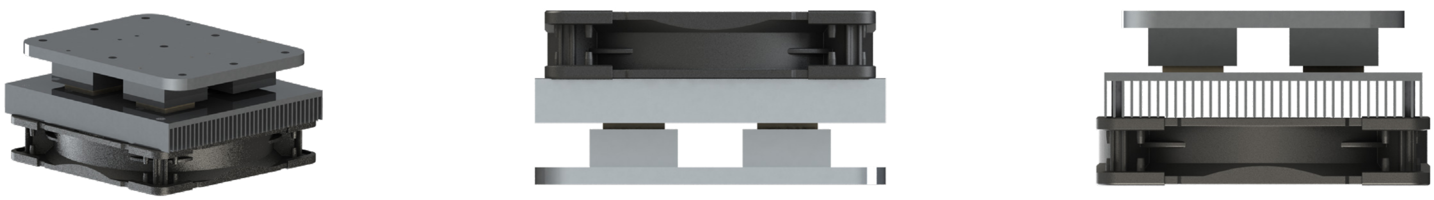
Thermoelectric coolers are one solution to battle these rising temperatures and protect the life and performance of electronic systems. However, they aren't limited to just that. TECs have a broad range of applications in other fields like photonics, opto-electronics, refrigeration, medical, industrial and much more.

The Thermoelectric Effect

Thermoelectrics revolves around two effects that are opposite sides of the same coin – the Peltier effect and the Seebeck effect.

The Peltier effect is where a current passed through two different conductors can generate heat at one end and will absorb it at the other.

The Seebeck effect is the reverse and explains how thermoelectric materials can generate electricity when a temperature difference is applied to them.



Pictured above is a cooling engine assembly shown in a wide-shot (left), side-on view (center) and front-on view (right).

How TECs Work

Thermoelectric coolers utilize the Peltier effect. Traditional single-stage TEC devices are made up of semiconductor couples, which are pairs of two types of semiconductors connected electrically in series and thermally in parallel. These couples are sandwiched between two ceramic layers – typically AlN or Al2O3. Figures 1.01 and 1.02 display this traditional configuration.

For greater cooling requirements, there are multi-stage TEC options. By stacking couples into multiple layers (typically up to four layers), a greater temperature difference can be achieved though it also requires greater power. Figures 2.01 and 2.02 display this configuration.

Figure 1.01

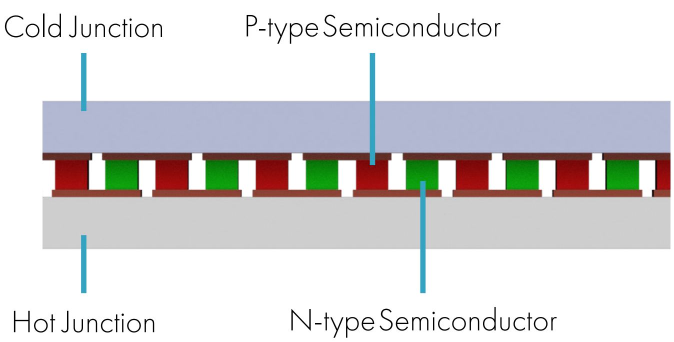


Figure 1.02

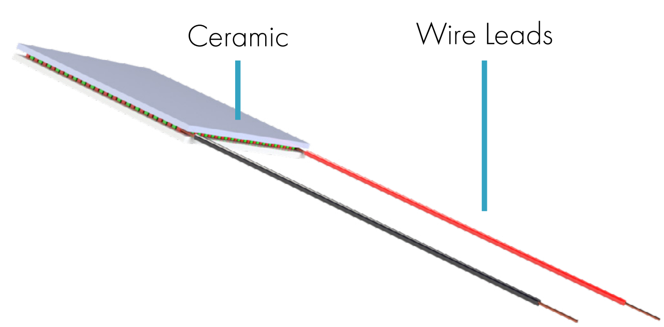


Figure 2.01

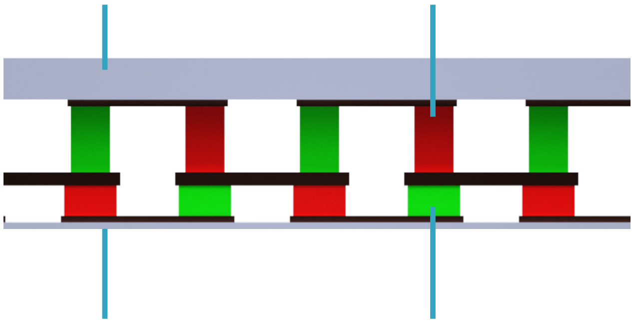
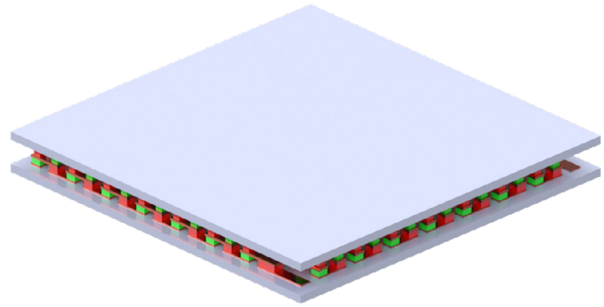


Figure 2.02



Benefits

Unlike conventional compressor coolers, TECs have no moving parts, which is why they're also known as solid-state coolers. This greatly reduces the chance of mechanical failures and allows them to be mounted with more freedom and omnidirectionally.

The small size of TECs are their biggest advantage over other cooling mechanisms. They're ideal for spot cooling, meaning they can cool a specific component of the system without affecting what's around it. TEC devices can also fit where other cooling systems can't. Many optoelectronics, telecom and datacom thermal management needs are in tight spaces where compressor or other cooling methods aren't desirable, or in some cases, even feasible.

TECs are also more precise than other cooling mechanisms. They can cool to within a tenth of the required temperature and get to that level faster than other cooling systems.

Applications

Camera Sensors
Imaging Sensors
Photo Detectors

Medical Refrigeration
Low-Temp Cooling

Scientific Instrumentation
Test & Measurement

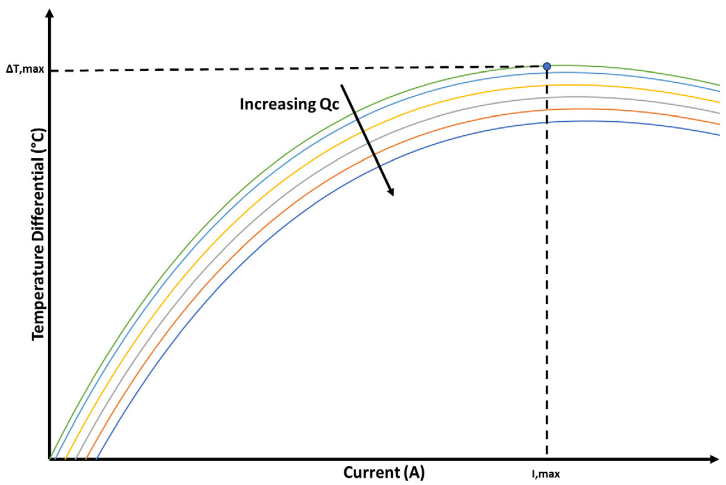
Consumer Electronics

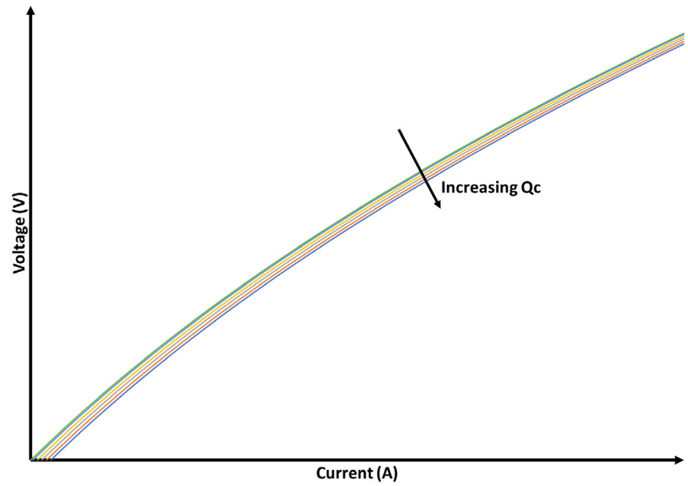
Aerospace
Defense

Key Metrics

ΔT_{max} (°C)	A performance metric that describes the maximum temperature differential that can be achieved across a TEC device. A higher number correlates to more cooling/heating potential.
Q_{max} (Watts)	The maximum amount of heat that can be pumped by the TEC device when the temperature differential across the device is zero. This can serve as a minimum threshold point-of-reference for your TEC selection.
COP	The coefficient of performance is the amount of power a TEC device needs in order to deliver a certain cooling capacity. This can serve as another great point-of-reference for how a TEC device can fit into another system.
I_{max} (Amps)	The amount of current needed to reach the maximum temperature differential defined above.
V_{max} (DC Volts)	The voltage corresponding to the current defined above.
T_{hot} (°C)	The temperature the device is operating in. Typically, data sheets will show values or when the device is operating in 27°C and 50°C conditions.

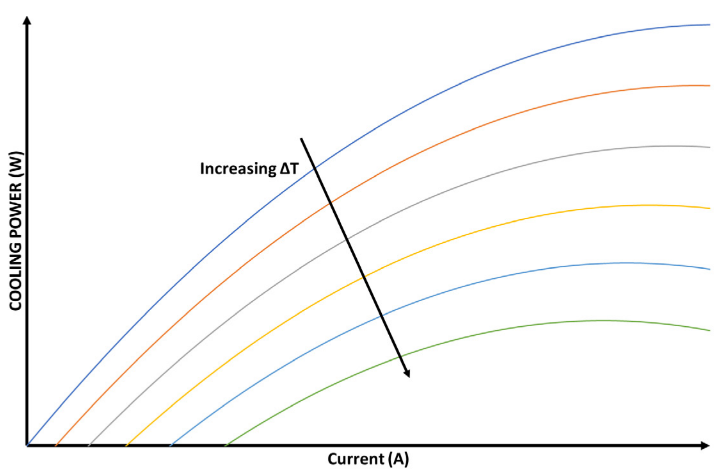
Key Graphs

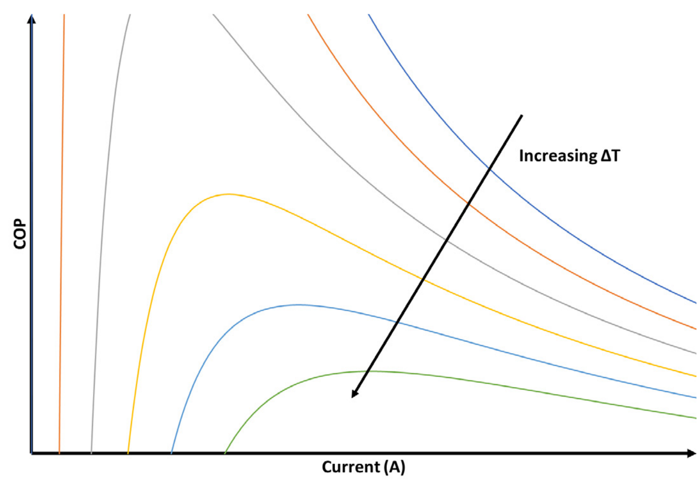




The current being passed through the device mapped with the temperature difference being created. Qc is the wattage being cooled, and each curve represents an increment that QC is being increased. As Qc inreases, more current is needed to reach the same temperature differential, and the max temperature differential reachable is lowered.

Current is mapped with voltage. Again, each curve represents an incremental step of Qc. However, compared to the other graph, the decrease in voltage as Qc is increased is much less significant than the decrease in temperature differential.





Here, current is mapped with cooling power, which is the amount of wattage that can be cooled by a TEC device. In this case, each curve represents an increment of temperature difference. As a higher ΔT is reached, the maximum cooling power that can be reached is reduced.

Current is being mapped with COP, or the coefficient of performance, which is the amount of wattage that can be cooled divided by the amount of wattage needed to cool it. Again, each curve represents an increment of temperature difference. And again, a higher desired temperature difference will cause the COP to go down.

CENTUM® Advantage

CENTUM® C3 multi-stage devices improved on the traditional design described above to deliver higher performance and efficiency metrics while maintaining a thickness akin to single-stage devices. Our patented architecture creates industry-leading temperature differences and cooling densities by eliminating the extra ceramic layers that competitors' products use. The traditional pyramid-design of our competitors is shown in Figure 3.01 and 3.02.

Figure 3.01

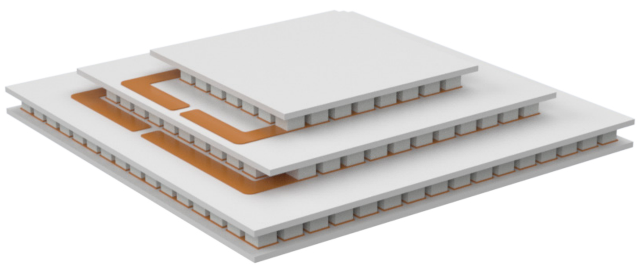
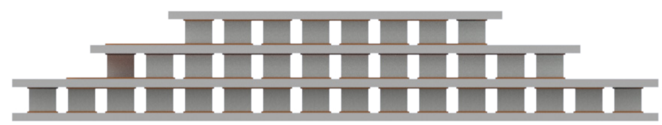
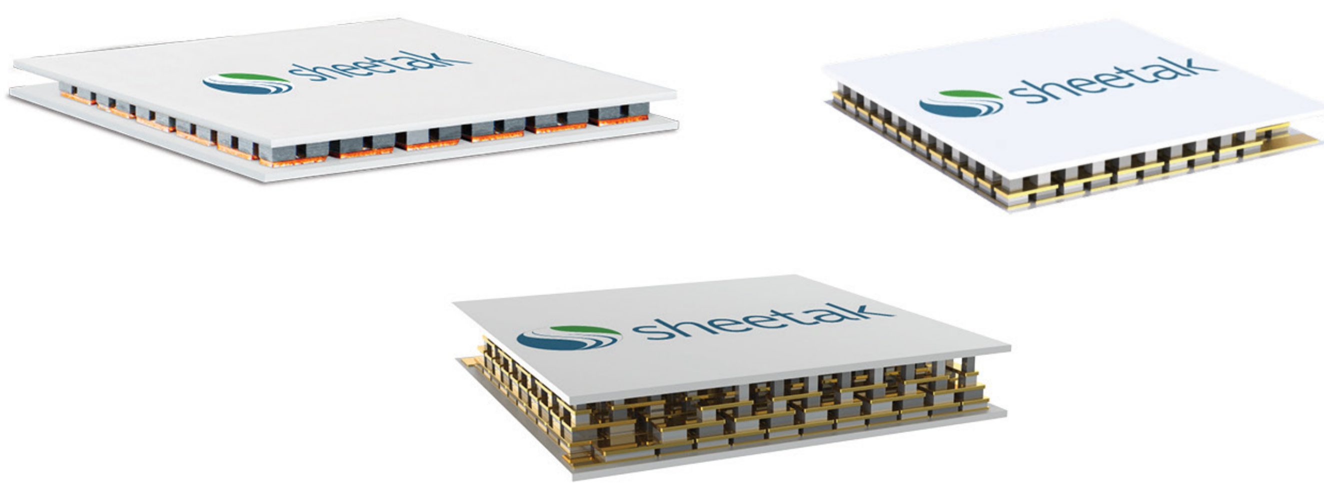


Figure 3.02



Because of the heightened temperature differences the device can reach, CENTUM® C3 is poised to broaden the scope of where multi-stage TEC devices can be used.

It's ideal for applications that require greater cooling than what was previously possible using thermoelectric coolers. At the same time, CENTUM® C3's small form factors allow it to service applications with limited space to insert thermal management solutions.



CENTUM® C3 two-stage cooler and four-stage cooler. Click here for more information.

Use Case: High Power Cooling

The following explains how to best select a TEC for cooling projection lasers, UV LED and air conditioning. Heat fluxes for these applications can be quite high, and as with many electronic devices, maintaining the temperature is crucial for reliability and performance.

Design Requirements

Ambient	Up to 35°C
Qc	600W
Tc	60°C
Voltage	≤12V

The biggest challenge for these applications is the heat rejection. We will need the hot-side heat sink thermal resistance to be on the order of 0.05°C/W to keep the hot-side temperature down. This requires looking at water cooling or a heat pipe solution.

In this case, space is not an issue, so the load can be distributed across a number of TECs. We have chosen to divide the load among an array of eight TECs (75W of cooling needed per TEC). A single stage device should be able to handle this load at a ΔT of around 30°C.

If we want to design a custom solution for these applications that optimizes the COP, we start by calculating the number of couples. The number of couples needed is driven by the voltage and ΔT, along with known thermoelectric material properties. In this case, if the hot-side temperature can be maintained at 90°C, then the number of couples needed is 263. The optimal COP is also a function of the hot and cold side temperatures and the ΔT. Knowing the COP and the desired cooling power, you can get back out the optimal operating current, which in this case is around 4.45A. This leads to a given leg aspect ratio between the leg height and cross-sectional area.

Operating Conditions if Custom Design is Used

T_h	90°C
ΔT	30°C
I	4.45A
V	12V
Q_c	75W

A custom solution is not always necessary and an existing off the shelf solution may make more sense.

We find that a TEC that was designed for another high Q application (room air-conditioner) will operate at approximately the same overall power level. Below are the predicted operating conditions if we use this pre-existing design. For some customers, the specific current and voltage needed will be less flexible, and the custom solution would be required.

T_h	90°C
ΔT	30°C
I	7.6A
V	7.31V
Q_c	75W

In some cases where a high ΔT is needed, such as a freezer application, a multi-stage device is needed. In those cases, our CENTUM® C3 provides superior cooling.

About Sheetak

Sheetak is a disruptor in the thermoelectrics space, developing cutting-edge thermal management and energy harvesting chips for a broad set of market applications. With more than 25 granted patents in thermoelectrics and related technologies, Sheetak is setting new industry standards.

Located in Austin, TX, Sheetak delivers optimal material compositions, fabrication methods, quantum thermoelectric device designs, circuit designs, architecture and volume manufacturing.

We're pushing the edges of thermoelectric performance, so you can push the boundaries of the modern world.

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