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Application Note

Thermoelectric Modules for Charge-Coupled Devices

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Thermoelectrics are small devices that encompass high cooling capacities and cool to below zero temperatures. With a wide range of small- and medium-sized units, Thermoelectric Modules (TEMs) are the only effective thermal management solution for Charge-Coupled Devices (CCDs).

Many CCDs have tight space constraints and low weight requirements, making thermoelectrics a better choice than alternate cooling technologies. In addition, TEMs have no moving parts, experience no outgassing in vacuum environments, and can be mounted in any orientation.

TEMs offer the ability to cool down to well below room temperature, DC operation with reverse polarity to accommodate precise temperature control, and are easily optimized to minimize vibration and noise.

The units also can be customized to accommodate unique CCD systems used to capture images. All of these factors, as well as being environmentally friendly and no maintenance over the product life cycle, make thermoelectrics an excellent choice for CCD applications.

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Thermoelectric Modules for Charge-Coupled Device Applications

Thermoelectric Operation

TEMs are solid-state heat pumps that require a heat exchanger to dissipate heat utilizing the Peltier Effect. During operation, DC current flows through the TEM to create heat transfer and a temperature differential across the ceramic surfaces, causing one side of the TEM to be cold, while the other side is hot. A single-stage TEM can achieve temperature differentials of up to 70°C and transfer heat at a rate of up to 150 watts. In order to increase the amount of heat pumping capacity, the TEM's modular design allows for the use of multiple TEMs mounted side-by-side, which is called a TE Array.

TEMs are composed of two ceramic substrates that serve as electrically insulating materials and house P-type and N-type semiconductor elements. Heat is absorbed at the cold junction by electrons as they pass from a low-energy level in the P-type element onto a higher energy level in the N-type element. At the hot junction, energy is expelled to a thermal sink as electrons move from a high-energy element to a lower-energy element.

Reversing the polarity changes the direction of heat transfer. TEMs are rated at maximum parameters (ΔT_{max}, I_{max}, V_{max}, and Q_{max}) under no load conditions, with temperature control accuracy achieving ±0.01°C under steady-state conditions. TEMs can be used as power generators and create 1 to 2 watts of energy per TEM. They can cool to -100°C (6-stage) and pump up to 150 watts of heat, with higher heat pumping capacities achieved by wiring TEMs into an array. Their geometry can vary from 2x2mm to 62x62mm and are much more efficient in heating mode than resistant heaters. They also fit into tight geometric space constraints that cannot accommodate a much larger compressor-based system.

Thermoelectric Modules

Different TEMs are used to meet the thermal demands for specific applications.

- **Standard Modules** offer reliable cooling capacity in the range of 10 to 100 watts. They have a wide product breadth that is available in numerous heat pumping capacities, geometric shapes, and input power ranges. These modules are designed for higher current and larger heat pumping applications with a maximum operating temperature of 80°C.

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- **Miniature Modules** have a geometric footprint less than 13x13mm and are used in applications that have lower cooling requirements of less than 10 watts. These modules offer several surface finishing options, such as metallization or pre-tinning to allow for soldering between TEM and mating conduction surfaces.
- **Multistage (Cascade) Modules** offer the highest temperature differential, (ΔT). Each stage is stacked one on top of another, creating a multistage module. Available in numerous temperature differentials and geometric shapes, these modules are designed for higher current and lower heat pumping applications.
- **Thermal Cycling Modules** are designed to operate in thermal cycling conditions that require reliable performance in both heating and cooling mode (reverse polarity). Thermal stresses generated in these applications will cause standard modules to fatigue over time. These modules are designed for higher current and higher heat pumping applications with a maximum operating temperature of 175°C.
- **High Power Density Modules** offer the highest heat pumping capacity within a surface area. Heat pumping densities of up to 14 W/cm^2, or twice as high as standard modules, can be achieved. The cooling capacity can range from 100 to 300 watts. TEMs are also ideal for applications that require low temperature differentials and high coefficient of performance (COP).

Charge-Coupled Device Applications

Charge-Coupled Devices (CCDs) are electronic devices that transform a light pattern (image) into an electrically charged pattern, creating an electronic image. CCDs are used in applications that are not visible to the naked eye, such as high-speed testing, night vision, medical diagnostics, and quality control inspection systems. The detector head collects electrons to form the electronic image. Those electrons generate heat, which is usually low at less than 10 watts. A TEM can be integrated into the CCD system to cool the CCD to low temperatures and increase the light spectrum captured by the CCD. Operating a CCD at room temperature, TEMs can cool the detector head from -100°C to -30°C in a vacuum environment.

Another source of heat in the detector head is a thermally generated charge that is created as a by-product when the detector head is collecting the image. The thermally generated charge saturates the collector, further distorting the image. TEMs cool the detector head, allowing for longer exposure times and creating little or no noise, which also distorts the image.

One major concern with CCD equipment operating in vacuum environments is the issue of outgassing. Materials used in these vacuum environments can release light-weight molecules

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that collect onto the optical equipment. The collecting of these molecules interferes with image resolution, as there is not a clean and clear surface collecting the image. The rate of outgassing increases as the temperature increases. TEMs create zero outgassing in vacuum environments because they provide no evaporatable materials through their solid-state construction. This attribute, along with the other attributes associated with utilizing TEMs are very beneficial to CCD applications.

For example, astronomy CCD cameras must be remarkably sensitive in order to image very faint and distant objects in the night sky. Because of the distances and light levels involved, there sometimes has to be a considerable long exposure time. This long exposure time creates a large heat load, which distorts the image by having the detector head run at a high temperature. TEMs cool the detector head to a temperature from 20°C to 60°C below ambient temperature, which is usually in a room temperature environment, allowing for greater resolution of the image.

Likewise, TEMs cool night vision CCD cameras used in security and military applications. The cameras deliver a reliable and accurate picture by collecting visible and ultraviolet light, which increases visibility. TEMs cool the cameras to a temperature from -80°C to -45°C in a vacuum environment, increasing the sensitivity of the detector head and increasing the contrast and resolution of the image.

In the same way, CCD cameras used in high-speed applications such as crash testing, ballistic testing, and read-rates on package scanning utilize TEMs to dissipate heat. The sensitive sensors are able to produce a clear image by capturing an extremely high rate of frames per second. This imaging creates a large heat load on the detector head. TEMs remove that heat load, lowering the operating temperature to about -30°C. The lower temperature allows the detector head to gather a more clear and precise picture without distortion.

Similarly, the medical field depends highly on CCD cameras for applications such as diagnostic processes, endoscopy, fluoroscopy, and x-rays. The cameras provide outstanding contrast resolution, which is crucial in the imaging of the internal human body and for forming a diagnosis. TEMs cool the camera to an operating temperature as low as -75°C in a vacuum environment at room temperature. This lower temperature enables the camera to achieve the level of sensitivity and range that is required for these delicate medical procedures.

And finally, quality control applications use CCD cameras for automated line inspection of component contrast, wear, and placement. The camera relays images of the defined parameters while looking for variations in the defined parameters. In an ambient temperature of 25°C, TEMs cool the operating temperature of the detector head down to -30°C, greatly increasing the detection and resolution of the image.

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Summary

Thermal management of CCD components and subsystems is now more challenging than ever. Power densities continue to increase while product form factors continue to shrink. Simple thermal management solutions are no longer typically viable to meet required performance and reliability specifications. In today's complex industrial operating environment, TEMs are necessary to provide precision cooling and heating in a variety of modular platforms.

TEMs combine special benefits that make them the only effective solution for many CCD thermal management applications by offering greater performance, higher reliability, longer life, and zero outgassing. Their advanced capabilities are aided by new materials technology, thinner profile modules, and automated assembly.

About Laird Technologies, Inc.

Laird Technologies designs and manufactures customized, performance-critical products for wireless and other advanced electronics applications.

The company is a global market leader in the design and supply of electromagnetic interference (EMI) shielding, thermal management products, mechanical actuation systems, signal integrity components, and wireless antennae solutions, as well as radio frequency (RF) modules and systems.

Custom products are supplied to all sectors of the electronics industry including the handset, telecommunications, data transfer and information technology, automotive, aerospace, defense, consumer, medical, and industrial markets.

Laird Technologies, a unit of Laird PLC, employs over 10,000 employees in more than 39 facilities located in 13 countries.

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