TECool™

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Thermoelectric Cooling Modules
Application Note

1.0 INTRODUCTION TO THERMOELECTRIC COOLING

1.1 A thermoelectric (TE) cooler, sometimes called a thermoelectric module or thermoelectric device, is a semiconductor-based electronic component that functions as a small heat pump. By applying a low-voltage DC power source to a TE module, heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face simultaneously is heated.

It is important to note that this phenomenon is fully reversible whereby a change in the polarity (plus/minus) of the applied DC voltage will cause heat to be moved in the opposite direction. Consequently, a thermoelectric device may be used for both heating and cooling. This takes it highly suitable for precise temperature control applications.

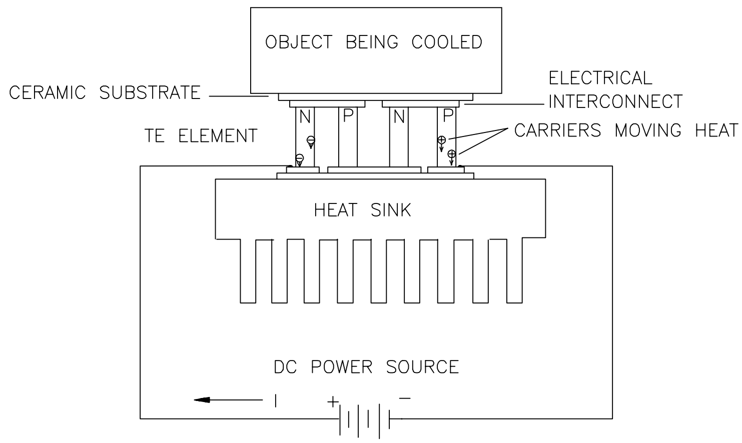
1.1.1 To provide the new user with a general idea of a thermoelectric cooler's capabilities, it might be helpful to offer this example. If a typical single-stage thermoelectric module was placed on a heat sink that was maintained at room temperature, and the module was then connected to a suitable battery or other DC power source, the "cold" side of the module would cool down to approximately -40°C. At this point, the module would be pumping almost no heat and would have reached its maximum rated "Delta-T." If heat gradually was added to the module's cold side, the cold-side temperature would increase progressively until it eventually equaled the heat sink temperature. At this point the TE cooler would have attained its maximum rated "heat pumping capacity."

1.2 Both thermoelectric coolers and mechanical refrigerators are governed by the same fundamental laws of thermodynamics and both refrigeration systems, although considerably different in form, function in accordance with the same principles. In a mechanical refrigeration unit, a compressor raised the pressure of the refrigerant (typically FREON), compresses the gas into a liquid, and circulates the refrigerant through the system. In the evaporator or "freezer" area the refrigerant boils, and in the process of changing to a vapor, the refrigerant absorbs heat causing the freezer to become cold. The heat absorbed in the freezer area is then moved to the condenser where it is then transferred to the room air.

In a thermoelectric cooling system, a doped semiconductor material essentially takes the place of The refrigerant, the condenser is replaced by a finned heat sink, and the compressor is replaced by a DC power source. The application of DC power to the thermoelectric device causes electrons to move through the semiconductor material. At the cold end (or "freezer side") of the semiconductor material, heat is absorbed by the electron movement, moved through the material, and expelled at the hot end. Since the hot end of the material is physically attached to a heat sink, the heat is passed from the material to the heat sink and then, in turn, transferred to the room air.

2.0 BASIC PRINCIPLES OF THERMOELECTRIC DEVICES AND MATERIALS

2.1 THERMOELECTRIC COOLING MODULES: A practical thermoelectric cooler consists of two or more elements of semiconductor material that are connected electrically in series and thermally in parallel. These thermoelectric element and their electrical interconnects typically are mounted between two ceramic substrates. The substrates serve to mechanically hold the overall structure together and to electrically insulate the individual elements from one another and from external mounting surfaces. After integrating the various component parts into a module, thermoelectric devices ranging in size from approximately 2.5-50 mm (0.1 to 2.0 inches) square and 2.5-50 mm (0.1 to 0.2 inches) in height may be constructed.



Schematic Diagram of a Typical Thermoelectric Cooler

Figure 2-1

2.1.1 Both N-type and P-type Bismuth Telluride thermoelectric materials are used in a thermoelectric cooler. This arrangement causes heat to move through the cooler in one direction only while the electrical current moves back and forth alternately between the top and bottom substrates through each N and P element. N-Type material is doped so that it will have an excess of electrons (more electrons than needed to complete a perfect molecular lattice structure) and P-Type material is doped so that it will have a deficiency of electrons (less electrons that are necessary to complete a perfect lattice structure). The extra electrons in the N material and the "holes" resulting from the deficiency of electrons in the P material are the carriers which move the heat energy through the thermoelectric material.

Figure (2-1) shows a typical thermoelectric cooler with heat being moved as a result of an applied electrical current (I). Most thermoelectric cooling modules are fabricated with an equal number of N-Type and P-Type elements where one N and P element pair form a thermoelectric "couple." The module illustrated in Figure (2-1) has two pairs of N and P elements and is termed a two-couple module.

Heat flux (heat actively pumped through the thermoelectric module) is proportional to the magnitude of the applied DC electrical current. By varying the input current from zero to , it is possible to adjust and control the heat flow and temperature.

3.0 APPLICATIONS FOR THERMOELECTRIC COOLING

3.1 Applications for thermoelectric devices cover a wide spectrum of product areas including military, medical, industrial, consumer, scientific/laboratory, and telecommunications. Uses range from simple food and beverage coolers for an afternoon picnic to extremely sophisticated temperature control systems in missiles and space vehicles. Occasionally, the use of a thermoelectric cooler was not anticipated during the planning stage of a new product, but later was found necessary to assure proper product operation. More typical, however, the use of a TE device is the only practical solution to a thermal management problem. Unlike a simple heat sink, a thermoelectric cooler permits lowering the temperature of an object below ambient as well as stabilizing the temperature of objects which are subject to widely varying ambient conditions. A thermoelectric cooler is an active cooling device whereas a heat sink provides only passive cooling.

Thermoelectric coolers generally may be considered for applications that require heat removal ranging from milliwatts up to several hundred watts. Most single-stage TE coolers, including both high and low current devices, are capable of pumping a maximum of 3 to 6 watts per square centimeter (20 to 40 watts per square inch) of module surface area. Multiple modules mounted thermally in parallel may be used to increase total heat pump performance. Large thermoelectric systems in the kilowatt range have been built for specialized applications such as cooling submarines and railroad cars, but systems of this magnitude are unusual.

3.2 Typical applications for thermoelectric devices include:

a) Cooling of Computer Chips and Microprocessors
b) Cooling of CCDs
c) Cooling of Low-Noise Amplifiers
d) Temperature Stabilization of Electronic Components
e) Cooling Infrared Detectors
f) Semiconductor Wafer Probers
g) Infrared Calibration Sources & Black-Body References
h) Temperature Stabilization of Laser Diodes

4.0 THE THERMOELECTRIC COOLING ADVANTAGE

4.1 Unlike conventional compressed refrigeration system, thermoelectric cooling modules are a form of solid state cooling that incorporates both semiconductor technologies and electronic assembly techniques. Therefore thermoelectric cooling modules are solid state, vibration-free, and noise-free heat pump. They are modular devices, so are simple to install and operate. Since they consist primarily of thermoelectric material sandwiched between ceramic plates and have no moving parts, they are inherently reliable. Some significant features of thermoelectric devices include:

a) Small Size and Weight
b) Ability to Cool Below Ambient
c) Ability to Heat and Cool With the same Device: Thermoelectric coolers will either heat or cool depending upon the polarity of the applied DC power.

d) Precise Temperature Control: With an appropriate closed-loop temperature control circuit, TE coolers can control temperatures to better than ± 0.1°C.

e) High Reliability: Although reliability is somewhat application-dependent, the life of typical TE coolers is greater than 200,000 hours.

f) Electrically "Quiet" Operation

g) Convenient Power Supply

h) Spot Cooling: With a TE cooler it is possible to cool one specific component or area only, thereby often making it unnecessary to cool an entire package or enclosure.

I) Environmentally Friendly: Refrigeration systems can be fabricated without using chlorofluorocarbons or other chemicals that may be harmful to the environment.

5.0 HEAT SINK CONSIDERATIONS

5.1 Rather than being a heat absorber that exotically consumes all applied heat, a thermoelectric cooler is a heat pump which moves heat from one area to another. By reducing the temperature of the "cold" face of a TE device, heat will flow the (warmer) article being cooled into the TE module and then pass through the module to the "hot" face. To complete the thermal system, the hot face of the TE cooler must be attached to a suitable heat sink that is capable of carrying away both the heat pumped by the module plus Joule heat from the electrical power supplied to the module. Since all optional characteristics of TE devices are related to heat sink temperature. heat sink selection and/or design should be considered carefully. A heat sink temperature rise of 5 to 15°C above ambient is typical for many thermoelectric applications.

Heat sink performance usually is specified in terms of thermal resistance (θs):

$$\theta s = \frac{Ts - Ta}{Q}$$

where: θs = Thermal Resistance in Degrees C per Watt
Ts = Heat Sink Temperature in Degrees C
Ta = Ambient or Coolant Temperature in Degrees C
Q = Heat Input to Heat Sink in Watts

6.0 INSTALLATION OF THERMOELECTRIC MODULES

6.1 Techniques used to install thermoelectric devices in a cooling system are extremely important and failure to observe certain basic principles may result in unsatisfactory performance or reliability. Some of the factors to be considered in system design and device installation include the following:

a) Thermoelectric devices have high mechanical strength in the compression mode but shear Strength is relatively low. As a result, a TE cooler should not be mechanical structure.

b) All interfaces between system components must be flat, parallel, and clean to minimize thermal resistance.

c) The "hot" and "cold" sides of standard thermoelectric modules may be identified by the position of the wire leads. Wires are attached to the hot side of the module, which is the module face that is in contact with the heat sink. For modules having insulated wire leads, when the red and black leads are connected to the respective positive and negative terminals of a DC power supply, heat will be pumped from the module's cold side, through the module, and into the heat sink. Note that for TE modules having bare wire leads, the positive connection is on the right side and the negative connection is on the left when the leads are facing toward the viewer.

d) The object being cooled should be insulated as much as possible to minimize heat loss to the ambient air. To reduce conductive losses, fans should not be positioned so that air is blowing directly at the cooled object. Conductive losses also may be minimized by limiting direct contact between the cooled object and external structural members.

e) When cooling below the dew point, moisture or frost will tend to from on exposed cooled surfaces. To prevent moisture from entering a TE module and severely reducing its thermal performance, a suitable moisture seal should be installed. This seal should be formed between the heat sink and cooled object in the area surrounding the TE module(s). Flexible foam insulating tape or sheet material and/or silicone rubber RTV is relatively easy to install and makes an effective moisture seal.

6.2 CLAMPING: The most common mounting method involves clamping the thermoelectric module(s) between a heat sink and flat surface of the article to be cooled. These approaches may be applied as follows:

a) Clean the module(s) and mounting surfaces to insure that all burrs, dirt, etc. have been removed.

b) Coat the "hot" side of the module(s) with a thin layer (typically 0.02mm / 01" or less thickness) of thermally conductive grease and place the module, side down, on the heat sink in the desired location. Gently push down on module and apply a back and forth turning motion to squeeze out excess thermal grease. Continue the combined downward pressure and turning motion until a slight resistance is detected. Suggested thermal greases include Wakefield Engineering Type 120, General Electric Type G641, Dow Corning Type 340, and American Oil and Supply Type 300. Note: Make sure that there are no chips, dirt, etc. at the grease interface as the presence of such material will degrade thermal performance.

c) Coat the "cold" side of the module(s) with thermal grease as specified in Step (b) above. Position and place the object to be cooled in contact with the cold side of the module(s). Squeeze-out the excess thermal grease as previously described.

d) It is important to apply uniform pressure across the mounting surfaces of the heat sink and cooled object together so that good parallelism is maintained. If significantly uneven pressure is applied, thermal performance may be reduced, or worse, the TE module(s) may be damaged.

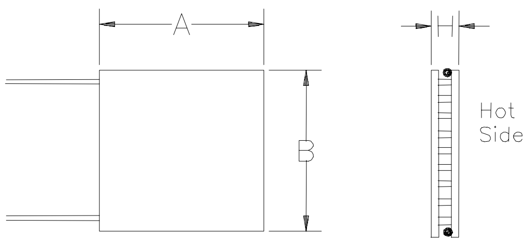
7.0 POWER SUPPLY REQUIREMENTS

7.1 Thermoelectric coolers operate directly from DC power and suitable power sources can range from batteries, to simple unregulated “brute force” DC power supplies, to extremely sophisticated closed-loop temperature control systems. A thermoelectric cooling module is a low-impedance semiconductor device that presents a resistive load to its power source. Where precise temperature control is required, a closed-loop system generally is used whereby the input current level or duty cycle of the thermoelectric device is automatically controlled. With such a system, temperature control to ± 0.1°C may be readily achieved and much tighter control is not unusual.

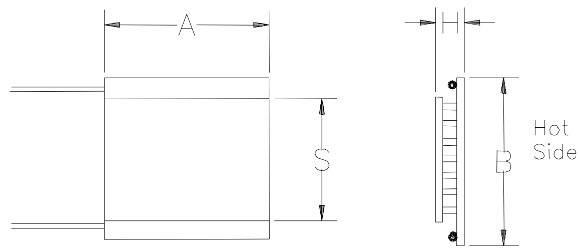
7.2 Power supply ripple filtering normally is of less importance of thermoelectric devices than for typical electronic applications. Thermoelectric module performance will degrade only about two percent with an AC ripple component of 10%, and at 20% ripple, the maximum temperature differential is reduced by less than five percent.

8.0 APPENDIX

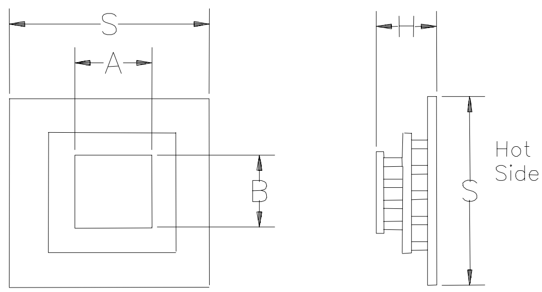
8.1 TEC types and physical layout



TEC1 Type



TES1 Type



Multi-stage Module