Designing with Thermoelectric Coolers
Revision 12/05/2001

When to consider TEC?

TEC can be applied to different application where cooling or temperature control of an object is required. In general TEC is prefer for when an object:

1. Needs to be cooled below the ambient temperature, or
2. Requires to be maintained at a consist temperature under fluctuating ambient temperature.

TEC is perfect to cool a small and low heat load object. Due to low COP (Coefficient of Performance) compare with compressor cooling, TEC looses its advantage if the cooling load is higher than 200 watts. But TEC have no moving parts, light weight, reliable, no electrical noise, can be operated at any orientation or environment, under some circumstances TEC is used to cool kilowatts of heat.

TEC is exceptional suitable to apply to the precision temperature control of an object such as a laser diode, CCD or any small object. Pair with and a DC power supply and an electronics proportional/integral (PI) controller which is package in a single chip device, TEC is able to control an object to +/- 0.1^{o}C accuracy. Today, no other cooling method yet can provide such precision, sample and convenient temperature control.

What is the operational theory of TEC?

The operating efficiency of a TEC can be defined by COP which is the rate of heat pump from the cold junction Q_c divided by the electrical power input P_i:

$$COP = Q_c / P_i$$

The Q_c depends on the three principle terms of Peltier cooling which is that due to the Peltier effect (sT_cI), minus one-half of the Joule heat that flows back to the cold junction ($0.5I^2R$), minus the conduction heat due to the temperature difference between the hot and the cold junctions (K?T):

$$Q_c = sT_cI - 0.5I^2R - K?T$$

The voltage input to the TEC is the sum of two terms; the IR rise across the semiconductors and the voltage that must overcome the Seebeck effect.

$$V = s?T + IR$$

The electrical power input is

$$P_i = VI = sI?T + I^2R$$

The TEC is function as a heat pump only if sT_cI is higher than the sum of $0.5I^2R$ and $K?T$. When sT_cI is equal to the sum of $0.5I^2R$ and $K?T$, it is at the state of maximum temperature difference. Today's commercial available single stage TEC generally has a maximum temperature difference around 65^{o}C. A commercial available 4 stages cascade TEC can deliver a ?T of 120^{o}C under vacuum. To achieving a higher the maximum temperature difference requires an efficient thermoelectric material property that is expressed as the figure of merit, Z.

$$Z = s^2s / k$$

The figure of merit for the thermoelectric material proves the basic theory of thermoelectrics derived by Altenkirch; high Seebeck coefficients, good electrical conductivity to minimize Joule heating, and low thermal conductivity to reduce heat transfer from junctions to junctions. Today the commercial TEC generally has a figure of merit around 2.5×10^{-3} $^oK^{-1}$. Figure 3 shows the calculated COP versus the ?T at various Z.

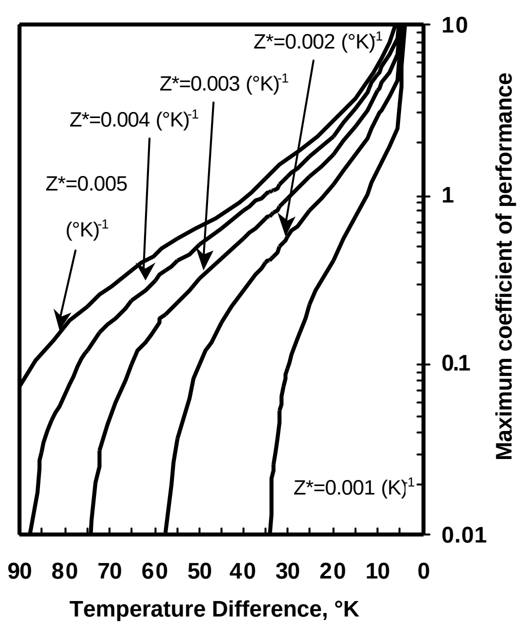

Figure 3. Calculated COP vs. ?T

What is the required balance system needed to enable a TEC?

The minimum requirement of the balance system for enabling a functional TEC is the heatsink mounted on the TEC hot size and a DC power source. As we mentioned at front that TEC is a solid state heat pump which means heat is pump from the side to the other side. The electrical energy plus the heat absorbed from the cold side will be all dumped to the hot side. Without a suitable heat sink mounted on the hot side, the TEC will be heating up to a temperature that eventually causes the solder joints melted and the TEC malfunction.
The heatsink is a general term that describes the device that can be used to dissipate heat. It can be a natural convection extruded fins, a force convention fins stack, or a fluid cooling heat exchanger. The key design requirement of the heatsink for TEC is that to maintain the TEC hot side temperature as low as possible, in a practical manner. A general guild line for thermal engineers is not to excess 10^{o}C rise over ambient air for an air cooled heatsink, and 5^{o}C rise over cooling fluid for a fluid heat exchanger. Figure 4 shows a TEC with a minimum balance system. Thermal interface between TEC and the heatsink is also a critical factor. Thermal conductive grease is commonly used to fill the gap between the two hard surfaces; the heatsink base and the ceramic substrate. In high-end applications, solder may be applied to joint th e heatsink or the heat source to a TEC which its ceramic substrates are metallized prior to soldering.

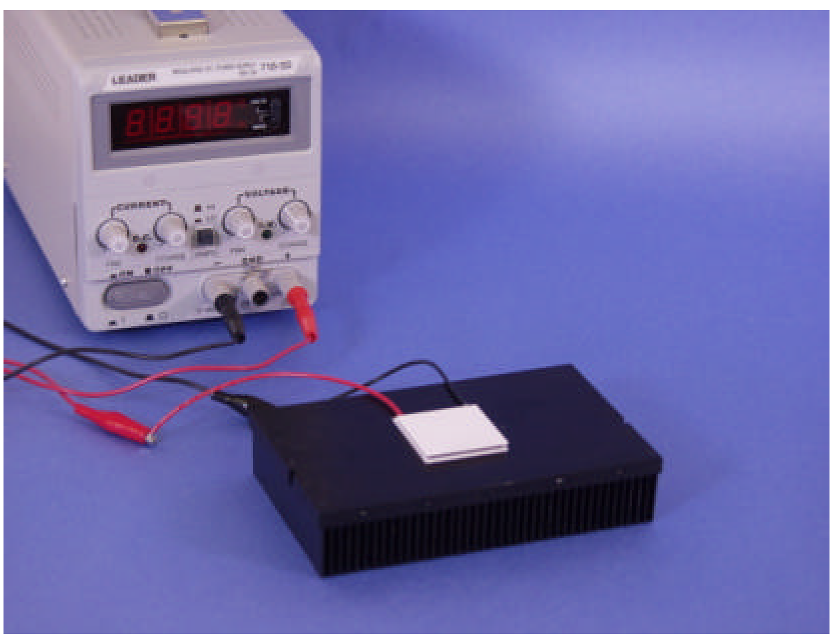

Figure 4. TEC Minimum Balance System

What are the applications for TEC?

The following applications are the few examples of what TEC can do:

1. Commercial:
    - Portable cool box
    - Beverage/wine/beer cooler
    - Drain fountain cooling
    - Compact refrigerator

2. Military/aerospace/optics
    - CCD/LED/Infrared detector cooling
    - Night vision equipment

3. Industrial
    - Heat exchanger / cold plate
    - Mini air conditioning
    - Dehumidifier

4. Scientific/Lab
    - Ice point reference baths
    - Dew point hygrometer
    - Solidification point reference
    - Oil pour point apparatus
    - Vidicon tube

5. Medical
    - Blood analyzers
    - Tissue preparation
    - DNA research

Is TEC reliable?

TEC is very reliable provided the following risk factors can be reduced or eliminated:

1. *Moisture:* The cold side of TEC typically operates below the dew point temperature which moisture will be condensed on the cold side semiconductors. When a current

is charged to TEC, the presence of water around the semiconductors will activate an electrolytic corrosion process on the solder joints and the semiconductor materials. The process will degrade and damage TEC. Excessive condensation can also electrically and thermally short circuit the TEC between cold side and hot side. Solution – moisture seal or dry atmosphere.

2. *Shock and vibration:* TEC is quite fragile under shock and vibration environment. The weakness is on solder joints and thermoelectric semiconductors. TEC is strong under compression force, but weak on tensile and share force. Solution - To design an effective TEC system operates in shock and vibration, TEC must be mechanically preloaded with compression force.

3. *Improper mounting*: Besides eliminating damage from shock and vibration, TE C also requires mechanically preload with compression for maintaining good thermal interface. A common failure on TEC is improper compression preload induced by
   - Uneven or excessive torque
   - Bolt pattern
   - Mating surface flatness

   Solution – Follow the assembly preparations and procedures from TEC manufacturer or consult Enertron engineer.

4. *Excessive thermal cycling:* Thermal cycling on a TEC produces thermal stress. The thermal stress comes from the dimensional mismatch between the hot and the cold side ceramic substrates. The dimensional mismatch is caused by the thermal expansion difference from the temperature difference between the hot and cold ceramic substrates. The rate and number of thermal cycling will greatly affect the TEC reliability. Solution – reduce the rate or the number the required thermal cycling. There are commercial available TEC's that made to withstand excessive thermal cycling. Those TEC employees a better diffusion barrier layers between the solder and semiconductors and a higher melting point solder. However, those TEC can only prolong or extent the operational life of a TEC, they are not immune from thermal stress.

5. *Overheating:* The solder used to joint TEC together does result in temperature limit on operational and storage of a TEC. The excessive temperature can activate the diffusion process from copper conductors to semiconductors and from semiconductors to solder. Copper diffuses to semiconductors results in loss of figure of merit. Semiconductor materials dissolves into solder reduce solder melting

temperature and also delaminates semiconductors. All of above cause solder joint failure and therefore TEC failure. Solution – no overheating during operation or storage, use TEC with high-temp solder for elevated temperature application.

Typical speaking, a commercially available TEC can provide a MTBF (mean time before failure) life of excess 200,000 hours.

What I can do if I need to design TEC to my application

TEC manufacturers can help you on TEC selection. However Enertron can assist you not only on TEC selection but also design and manufacture the entire TEC system. Please consult Enertron engineers, they will be able to help you in design, development, prototyping and production of a TEC system that meets your performance and cost requirements.