

Structure and Function

Since thermoelectric cooling systems are most often compared to conventional systems, perhaps the best way to show the differences in the two refrigeration methods is to describe the systems themselves.

A conventional cooling system contains three fundamental parts - the evaporator, compressor and condenser. The evaporator or cold section is the part where the pressurized refrigerant is allowed to expand, boil and evaporate. During this change of state from liquid to gas, energy (heat) is absorbed. The compressor acts as the refrigerant pump and recompresses the gas to a liquid. The condenser expels the heat absorbed at the evaporator plus the heat produced during compression, into the environment or ambient.

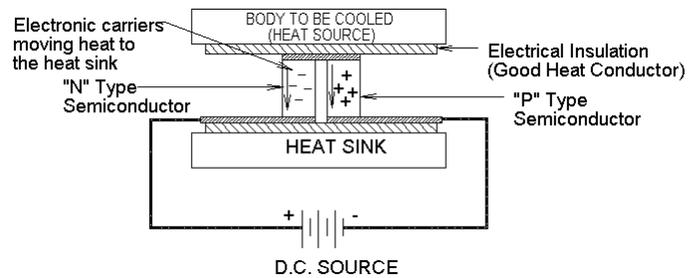
A thermoelectric has analogous parts. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. The power supply provides the energy to move the electrons through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element (p-type).

Thermoelectric Modules (TEMs) are heat pumps – solid state devices without moving parts, fluids or gasses. The basic laws of thermodynamics apply to these devices just as they do to conventional heat pumps, absorption refrigerators and other devices involving the transfer of heat energy.

An analogy often used to help comprehend a thermoelectric cooling system is that of a standard thermocouple used to measure temperature. Thermocouples of this type are made by connecting two wires of dissimilar metal, typically copper/constantan, in such a manner so that two junctions are formed. One junction is kept at some reference temperatures the other is attached to the control device measurement. The system is used when the circuit is opened at some point and the generated voltage is measured. Reversing this train of thought, imagine a pair of fixed junctions into which electrical energy is applied causing one junction to become cold while the other becomes hot.

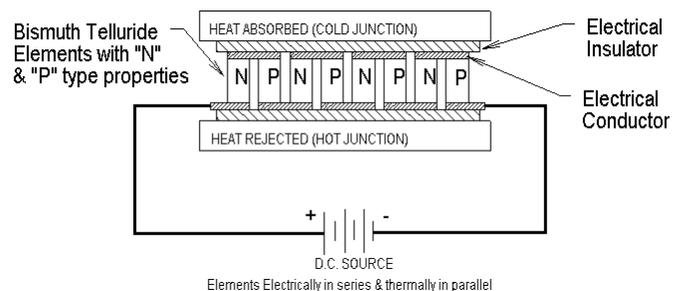
Thermoelectric cooling couples (Fig. 1) are made from two elements of semiconductor, primarily Bismuth Telluride, heavily doped to create either an excess (n-type) or deficiency (p-type) of electrons. Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to current passing through the circuit and the number of couples.

Figure 1: Cross Section of a typical TE Couple



In practical use, couples are combined in a module (Fig. 2) where they are connected electrically in series, and thermally in parallel. Normally a TEM is the smallest component commercially available.

Figure 2: Typical TE Module Assembly



TEMs are available in a great variety of sizes, shapes, operating currents, operating voltages and ranges of heat pumping capacity. The trend, however, is toward a larger number of couples operating at lower currents. The user can select the quantity, size or capacity of the module to fit the exact requirement without paying for excess power.

There is usually a "need" to use thermoelectrics instead of other forms of cooling. The "need" may be a special consideration of size, space, weight, efficiency, reliability or environmental conditions such as operating in a vacuum.

Once it has been decided that thermoelectrics are to be considered, the next task is to select the thermoelectric(s) that will satisfy the particular set of requirements. Three specific system parameters must be determined before device selection can begin.

These are:

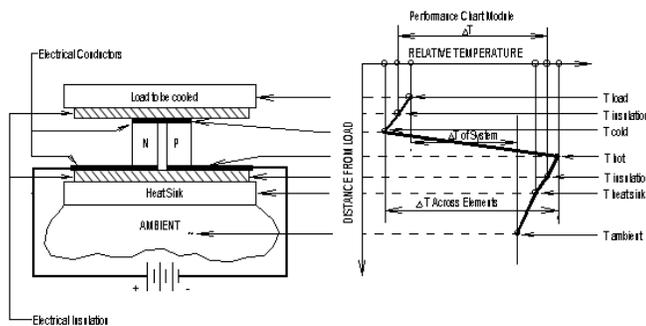
- T_c Cold Surface Temperature
- T_h Hot Surface Temperature
- Q_c The amount of heat to be absorbed at the Cold Surface of the TEM

In most cases, the cold surface temperature is usually given as part of the problem – that is to say that some object(s) is to be cooled to some temperature. Generally, if the object to be cooled is in direct intimate contact with the cold surface of the thermoelectric, the desired temperature of the object can be considered the temperature of the cold surface of the TEM (T_c). There are situations where the object to be cooled is not in intimate contact with the cold surface of the TEM, such as volume cooling where a heat exchanger is required on the cold surface of the TEM. When this type of system is employed, the cold surface of the TEM (T_c) may need to be several degrees colder than the ultimate desired object temperature. The Hot Surface Temperature is defined by two major parameters:

- 1) The temperature of the ambient environment to which the heat is being rejected.
- 2) The efficiency of the heat exchanger that is between the hot surface of the TEM and the ambient environment.

These two temperatures (T_c & T_h) and the difference between them (ΔT) are very important parameters and therefore must be accurately determined if the design is to operate as desired. Figure 3 represents a typical temperature profile across a thermoelectric system.

Figure 3: Typical Temperature Relationship in a TEC



The third and often most difficult parameter to accurately quantify is the amount of heat to be removed or absorbed by the cold surface of the TEM, (Q_c). All thermal loads to the TEM must be considered. These thermal loads include, but are not limited to, the active heat load (I^2R) from the electronic device to be cooled and passive heat load where heat loss can occur through any object in contact with ambient environment (i.e. electrical leads, insulation, air or gas surrounding objects, mechanical fasteners, etc.). In some cases radiant heat effects must also be considered.

Single stage thermoelectric modules are capable of producing a “no load” temperature differential of approximately 70°C. Temperature differentials greater than this can be achieved by stacking one thermoelectric on top of another. This practice is often referred to as Cascading. The design of a cascaded device is much more complex than that of a single stage device, and is beyond the scope of these notes. Should a cascaded device be required, design assistance can be provided by Laird Technologies Engineers.

Once the three basic parameters have been quantified, the selection process for a particular module or array of TEMs may begin. Some common heat transfer equations are attached for help in quantifying Q_c & T_h .

There are many different modules or sets of modules that could be used for any specific application. One additional criteria that is often used to pick the “best” module(s) is Coefficient of Performance (COP). COP is defined as the heat absorbed at the cold junction, divided by the input power (Q_c / P). The maximum COP case has the advantages of minimum input power and therefore, minimum total heat to be rejected by the heat exchanger ($Q_h = Q_c + P$). These advantages come at a cost, which in this case is the additional or larger TEM required to operate at COP maximum. It naturally follows that the major advantage of the minimum COP case is the lowest initial cost.

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Americas: +1.888.246.9050

Europe: +46.31.704.67.57

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