

**ISO 9001:2000  
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# **THERMOELECTRIC HANDBOOK**

**Product Information**

**Assembly Information**

**Performance and Properties**

  
**The Standard in Thermoelectrics**

a unit of  
**Laird**  
TECHNOLOGIES®



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## Thermoelectric History/ General Information

### What are thermoelectric heat pumps?

Thermoelectric heat pumps perform the same cooling function as freon-based vapor compression or absorption refrigerators. In all such units, thermal energy is extracted from a region, thereby reducing its temperature, then rejected to a "heat sink" region of higher temperature. Vapor-cycle devices have moving mechanical parts and require a working fluid, while thermoelectric elements are totally solid state.

Melcor's solid state heat pumps use thermocouples made of high performance crystalline semiconductor material. Passing a current through the heat pump generates a temperature differential across the thermocouples, with maximum ratings of 70°C and higher.

Solid state heat pumps have been known since the discovery of the Peltier effect in 1834. The devices became practical only recently, however, with the development of semiconductor thermocouple materials. Melcor utilizes bismuth telluride, a quaternary alloy of bismuth, tellurium, selenium and antimony - doped and processed to yield oriented polycrystalline semiconductors with anisotropic thermoelectric properties. The couple, connected in series electrically and in parallel thermally, are integrated into modules. The modules are packaged between metallized ceramic plates to afford optimum electrical insulation and thermal conduction with high mechanical strength in compression. Typical Melcor modules contain from 3 to 127 thermocouples; high technology applications for sophisticated instruments and communication systems require very small, low current modules, whereas low-cost, high capacity modules are in demand for a growing number of commercial applications. Modules can be mounted in parallel to increase the heat transfer effect or can be stacked in multistage cascades to achieve high differential temperatures.

### Should you use thermoelectric heat pumps?

Thermoelectric devices are not the solution for every cooling problem. However, you should consider them when your system design criteria include such factors as high reliability, small size or capacity, low cost, low weight, intrinsic safety for hazardous electrical environments, and precise temperature control.

## Modules and assemblies available from Melcor

**OptoTEC™ Series** - sub-miniature, low- and moderate-capacity, low-current thermoelectric modules for use in maintaining critical temperatures in systems where determining factors are high reliability, limited space, and minimal power consumption.

**CP Series** - low-cost, moderate- and high-capacity, general-purpose modules for cooling equipment such as instrumentation, laboratory apparatus, consumer appliances, and for commercial and military applications.

**MULTISTAGE (Cascade) Series** - Standard and custom multistage (cascade) TECs designed to meet requirements for large temperature differentials.

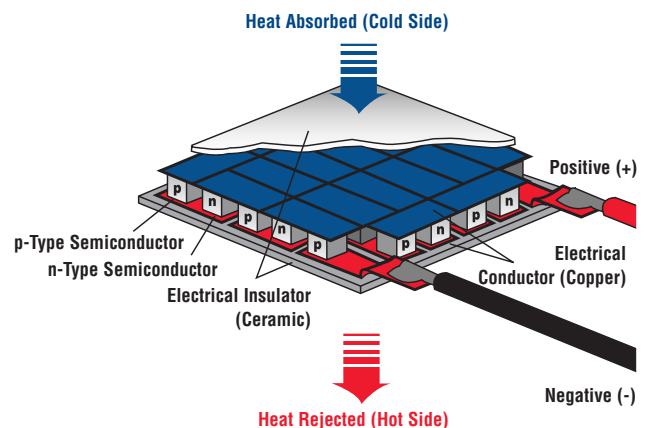
**HEATPUMP Assemblies** - packages including FRIGICHIPS® and heat exchangers, designed and fabricated to customer specifications.

## Thermoelectric Applications

Thermoelectric (Peltier) heat pumps are capable of refrigerating a solid or fluid object. Unlike conventional vapor compressor systems, thermoelectric units (modules) are miniature devices. A typical module measures 1" x 1" x 0.19". Our smallest sub-miniature modules measure 0.16" x 0.16" x 0.09". These units are easily capable of reducing the temperature to well below freezing.

### Competitive Advantages

It is possible to build thermoelectric systems in a space of less than 1 cubic inch. More typically, thermoelectric systems occupy about 20 to 30 in<sup>3</sup> of space. These systems are energized by a DC power input. In addition to the space and weight saving advantages, thermoelectrics offer the utmost in reliability due to their solid state construction. Another feature of importance is the ease with which a thermoelectric can be precisely temperature controlled, an important advantage for scientific, military and aerospace applications.



## 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.

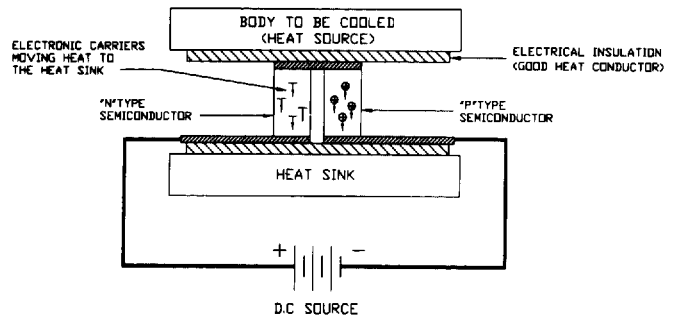
A thermoelectric has analogous parts. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. The power supply provides the energy to move the electrons through 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 Coolers 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 T.E. 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 temperature, while the other is attached to the object being measured. 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.

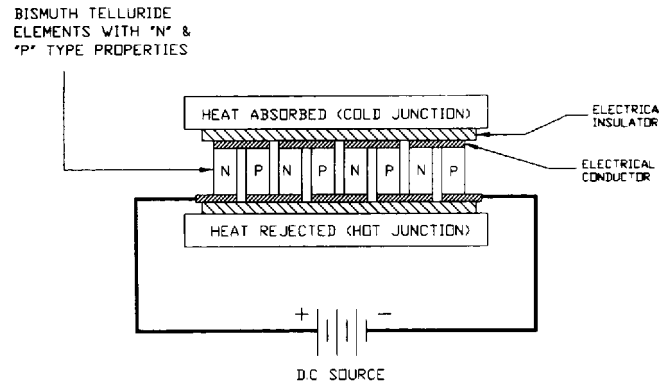
Thermoelectric cooling couples (Fig. 1) are made from two elements of semiconductor, primarily Bismuth Telluride, heavily doped to create either an excess (n-type) or deficiency (p-type) of electrons. Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to current passing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

Figure 2: Typical TE Module Assembly



Modules are available in a great variety of sizes, shapes, operating currents, operating voltages and ranges of heat pumping capacity. The present 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, reliability and environmental conditions such as operating in a vacuum. If none of these is a requirement, then other forms of cooling should be considered and, in fact, are probably desirable.

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 T.E.

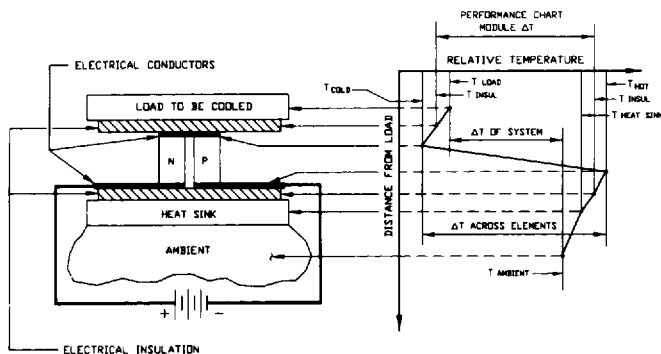
In most cases, the cold surface temperature is usually given as part of the problem – that is to say that some object(s) is to be cooled to some temperature. Generally, if the object to be cooled is in direct intimate contact with the cold surface of the thermoelectric, the desired temperature of the object can be considered the temperature of the cold surface of the T.E. ( $T_c$ ). There are situations where the object to be cooled is not in intimate contact with the cold surface of the T.E., such as volume cooling where a heat exchanger is required on the cold surface of the T.E. When this type of system is employed, the cold surface of the T.E. ( $T_c$ ) 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 T.E. and the ambient.

These two temperatures ( $T_c$  &  $T_h$ ) and the difference between them ( $\Delta T$ ) 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 T.E. All thermal loads to the T.E. must be considered. These thermal loads include, but are not limited to, the active or  $I^2R$  heat load from electronic devices and conduction through any object in contact with both the cold surface and any warmer temperature (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 devices are capable of producing a "no load" temperature differential of approximately 67°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 Melcor personnel.

Once the three basic parameters have been quantified, the selection process for a particular module or group of modules 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 (C.O.P.). C.O.P. is defined as the heat absorbed at the cold junction, divided by the input power ( $Q_c / P$ ). The maximum C.O.P. 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 T.E. device required to operate at C.O.P. maximum. It naturally follows that the major advantage of the minimum C.O.P. case is the lowest initial cost.

Power supply and temperature control are additional items that must be considered for a successful T.E. system. A thermoelectric device is a D.C. device. Any A.C. component on the D.C. is detrimental. Degradation due to ripple can be approximated by:

$$\Delta T / \Delta T_{max} = 1 / (1+N^2), \text{ where } N \text{ is \% current ripple.}$$

*Melcor recommends no more than a 10% (.10) ripple.*

Temperature control can be generally considered in two groups: Open Loop and Closed Loop, or manual and automatic. Regardless of method, the easiest device parameter to detect and measure is temperature. Therefore, the cold junction (or hot junction in heating mode) is used as a basis of control. The controlled temperature is compared to some reference temperature, usually the ambient or opposite face of the T.E.

In the Open Loop method, an operator adjusts the power supply to reduce the error to zero. The Closed Loop accomplishes this task electronically. The various control circuits are too numerous, complex and constantly being upgraded to try to discuss in this text. There are several manufacturers of control circuits and systems that are better equipped to give expert counsel in this specific area. Suffice it to say that the degree of control, and consequent cost, varies considerably with the application.



## Parameters Required for Device Selection

There are certain minimum specifications that everyone must answer before the selection of a T.E. device can begin. Specifically there are three parameters that are required. Two of these parameters are the temperatures that define the gradient across the T.E. device. The third parameter is the total amount of heat that must be pumped by the device.

The gradient across the T.E. device (Actual  $\Delta T$ ) is not the same as the apparent  $\Delta T$  (System  $\Delta T$ ). The difference between these two  $\Delta T$ s is often ignored, which results in an under-designed system. The magnitude of the difference in  $\Delta T$ s is largely dependent on the type of heat exchangers that are utilized on either the hot or cold sides of the system.

Unfortunately, there are no "Hard Rules" that will accurately define these differences. Typical allowances for the hot side of a system are:

1. finned forced air: 10 to 15°C
2. free convection: 20 to 40°C
3. liquid exchangers: 2 to 5°C above liquid temperature

Since the heat flux densities on the cold side of the system are considerably lower than those on the hot side, an allowance of about 50% of the hot side figures (assuming similar types of heat exchangers) can be used. It is good practice, to check the outputs of the selection process to reassure that the heat sink design parameters are reasonable.

The third parameter that must be identified for the selection process, is the total heat to be pumped by the T.E. device. This is often the most difficult number to estimate. To reduce the temperature of an object, heat must be removed from it, faster than heat enters it. There are generally two broad classifications of the heat that must be removed from the device. The first is the real, sensible or "active" heat load. This is the load that is representative of what wants to be done. This load could be the  $I^2R$  load of an electrical component, the load of dehumidifying air, or the load of cooling objects. The "other" kind of load is often referred to as the parasitic load. This is the load due to the fact that the object is cooler than the surrounding environment. This load can be composed of conduction and convection of the surrounding gas, "leak" through insulation, conduction through wires, condensation of water, and in some cases formation of ice. Regardless of the source of these parasitic loads, they must not be ignored.

There are other things that may be very important to a specific application, such as physical dimensions, input power limitations or cost. Even though these are important, they are only secondary. Melcor's approach to thermoelectric device selection / recommendation utilizes a computer aided design program AZTEC™ which selects an optimized thermoelectric design for the given operating hot side temperature, desired cold side temperature, and the total heat load to be pumped over the actual  $\Delta T$ .

We have enclosed a checklist to assist you in defining your application's existing conditions. If you should require any further assistance please contact one of our engineers.

# Design/Selection Checklist

The information requested below is vital to the design/selection of a thermoelectric device to achieve your desired performance.

Please attempt to define as many of your application's existing conditions and limiting factors as possible. (Please indicate units on all parameters.)

## I. Ambient Environment

Temperature = \_\_\_\_\_

- Air
- Vacuum
- Other

## II. Cold Spot

Temperature: \_\_\_\_\_

Size: \_\_\_\_\_

Insulated? \_\_\_\_\_ Type: \_\_\_\_\_ Thickness: \_\_\_\_\_

Desired Interface:

- Plate
- Fins
- Fluid Flow (parameters) \_\_\_\_\_
- Other \_\_\_\_\_

## III. Heat Sink

- Finned - Free Convection
- Finned - Forced Convection
- Liquid Cooled

Maximum Heat Sink Temp. \_\_\_\_\_

-or-Heat Sink Rating (°C/W) \_\_\_\_\_

## IV. Heat Load at Cold Spot = \_\_\_\_\_

(if applicable, above should include:)

Active:

$I^2R$  \_\_\_\_\_

Passive:

Radiation= \_\_\_\_\_

Convection= \_\_\_\_\_

Insulation Losses= \_\_\_\_\_

Conduction Losses= \_\_\_\_\_ (e.g. leads)

Transient Load= \_\_\_\_\_ (Mass - time)

## V. Restrictions on Power Available

(indicate most important)

- Current: \_\_\_\_\_
- Voltage: \_\_\_\_\_
- Power: \_\_\_\_\_
- No Restrictions

## VI. Restrictions on Size: \_\_\_\_\_

## VII. To ensure the most effective response:

Please provide a rough, dimensioned sketch of the application, indicating the anticipated physical configuration and thermoelectric module placement.

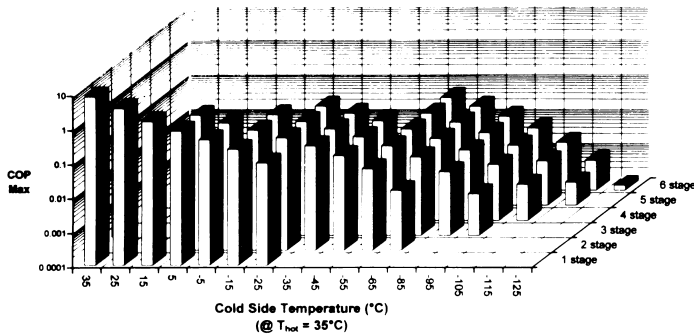
Please print this form and fill in the blanks.

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## Thermoelectric Multistage (Cascade) Devices

A multistage thermoelectric device should be used only where a single stage device does not fill the need. Figure 4, depicts  $\Delta T$ , vs. C.O.P. max, vs. Number of stages. C.O.P. is defined as the amount of heat absorbed (in thermal watts of heat pumped) at the cold side of the device, divided by the input power (in electrical watts). This figure should help identify when to consider cascades since it portrays the effective  $\Delta T$  range of each cascade. A two-stage cascade should be thought of, somewhere between a  $\Delta T$  of  $40^\circ\text{C}$  ( $T_c = -5^\circ\text{C}$ ), where the C.O.P. bars of the one- and two-stage devices begin to diverge, and a  $\Delta T$  of  $65^\circ\text{C}$  ( $T_c = -30^\circ\text{C}$ ), where a single stage device reaches its maximum  $\Delta T$ , and also, heat pumping "shutoff",  $Q_c = 0$ . Similar decisions must be made as to the number of stages to be considered at larger  $\Delta T$ s. The two important factors again are  $\Delta T$  and C.O.P.

Figure 4:  $\Delta T$  vs. C.O.P. Max as a function of # of stages



There is another very significant factor that must always be considered and that is the cost. Usually, as the number of stages increase, so does the cost. Certain applications require a trade-off between C.O.P. and cost.

As with any other T.E. system, to begin the selection process requires the definition of at least three parameters:

- $T_c$  Cold Side Temperature
- $T_h$  Hot Side Temperature
- $Q_c$  The amount of heat to be removed (absorbed by the cooled surface of the T.E.) (in watts)

Once  $\Delta T$  ( $T_h - T_c$ ) and the heat load have been defined, utilization of Figure 4 will yield the number of stages that may be required. Knowing C.O.P. and  $Q_c$ , input power can also be estimated. The values listed in Figure 4 are theoretical maximums. Any device that is actually manufactured will rarely achieve these maximums, but should closely approach this value.

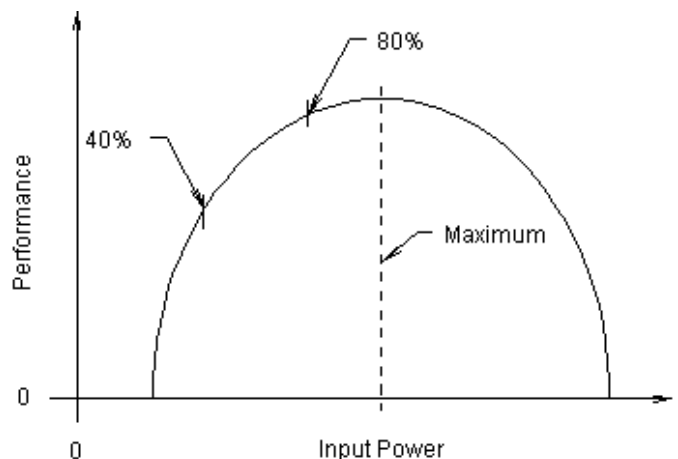
Melcor offers a line of "Standard Cascades" though there are no "Standard" applications. Each need for a cascade is unique, so too should be the device selected to fill the need. Melcor has developed a computer aided design system to help select a device. The three parameters listed are used as inputs to the programs. Other variables such as physical size, and operating voltage or current can, within limits, be used to make the final selection. More than 40,000 different cascades can be assembled utilizing available ceramic patterns. This allows near custom design, at near "standard" prices. When the three parameters have been defined, please contact Melcor for assistance in cascade selection.

## Typical Device Performance

When PERFORMANCE vs. INPUT POWER is plotted for any thermoelectric device, the resultant curve will appear as in the figure below; an inverted parabola. Performance can be  $\Delta T$  ( $T_h - T_c$ ), heat pumped at the cold side ( $Q_c$ ), or as in most cases, a combination of these two parameters. Input power can be current (I), voltage (V) or the product of IV.

When we refer to the  $\Delta T_{max}$  or  $Q_{c,max}$ , we are referring to that point where the curve peaks. The same is true when referring to either  $I_{max}$  or  $V_{max}$ . Since operating at or very near the peak is relatively inefficient, most devices are operated somewhere between 40% and 80% of Input Power MAX.

As stated, devices are normally operated on the near-linear, upward sloping portion of the curve. When automatic or closed loop temperature control is being used, current or voltage limits should be set below the MAX intercepts.





## Assembly Tips

The techniques used in the assembly of a thermoelectric (T.E.) system can be as important as the selection of the proper device. It is imperative to keep in mind the purpose of the assembly – namely to move heat. Generally a T.E. device, in the cooling mode, moves heat from an object to ambient. All of the mechanical interfaces between the objects to be cooled and ambient are also thermal interfaces. Similarly all thermal interfaces tend to inhibit the flow of heat or add thermal resistance. Again, when considering assembly techniques every reasonable effort should be made to minimize thermal resistance.

Mechanical tolerances for heat exchanger surfaces should not exceed 0.001 in/in with a maximum of 0.003" Total Indicated Reading. If it is necessary to use more than one module between common plates, then the height variation between modules should not exceed 0.001" (request tolerance lapped modules when ordering). Most T.E. assemblies utilize one or more "thermal grease" interfaces. The grease thickness should be held to 0.001 ± 0.0005" (a printers ink roller works well for this). When these types of tolerances are to be held, a certain level of cleanliness must be maintained. Dirt, grit and grime should be minimized; this is very important when "grease" joints are utilized due to their affinity for these types of contaminants.

Once the T.E. modules have been assembled between the heat exchangers, some form of insulation/seal should be provided between the exchangers surrounding the modules. Since the area within the module, (i.e. the element matrix), is an open DC circuit and a temperature gradient is often present, gas flow (which may contain water that could condense) should be minimized. Typically, a T.E. module is about 0.2" thick, so any insulation that can be provided will minimize heat leak. The presence of the insulation/seal also offers some protection from physical damage.

The insulation/seal is often most easily provided by inserting sections of closed cell polyurethane foam about the cavity and sealing with either an RTV type substance or, for more physical integrity, an epoxy coat. Whatever form is used, it should provide the protection outlined above. It is often desirable to provide strain relief for the input leads, not only to protect the leads themselves, but to help maintain the integrity of the seal about the modules.

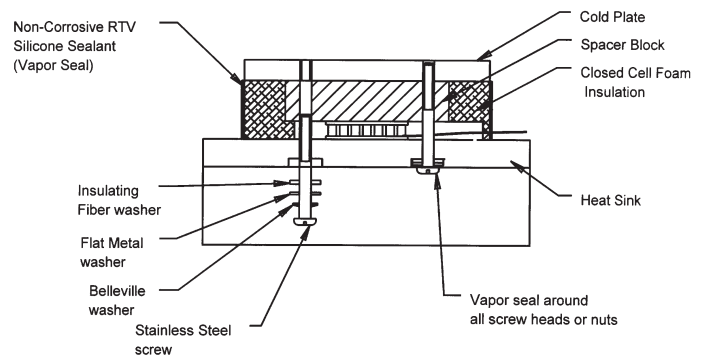
We have included an Assembly Tips drawing (Fig. 6). This drawing shows the details of the recommended construction of a typical assembly. The use of a "spacer block" yields maximum heat transfer, while separating the hottest and coldest parts of the system, by the maximum amount of insulation. The "spacer blocks" are used on the cold side of the system due to the lower heat flux density. In addition, the details of a feed thru and vapor sealing

system that can be used for maximum protection from the environment are shown.

If you follow the recommendations shown in these drawings that you will see a significant improvement in performance. When testing an assembly of this type it is important to monitor temperature. Measuring temperature of the cooling fluids, inlet and outlet temperatures as well as flow rates is necessary. This is true if either gas or liquid fluids are used. Knowing input power to the T.E. device, both voltage and current, will also help in determining the cause of potential problems.

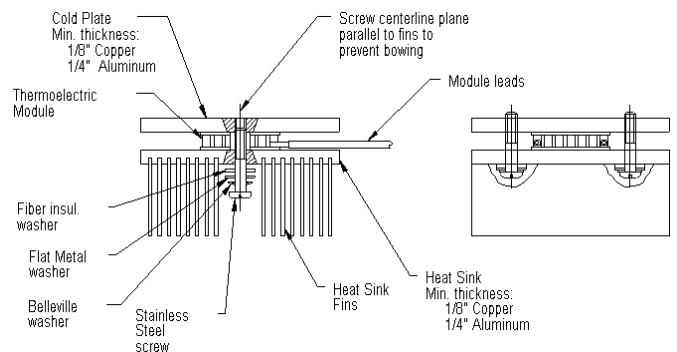
In addition we have enclosed step-by-step procedures for assembling CP and OptoTEC™ modules, Solderable or Lapped modules to heat-exchangers.

**Figure 6: Assembly Tips Drawing**



**If you should require any further assistance, please contact one of our engineers. Our many years of experience in working with customers ensuring reliable and efficient application of our products has proven to be essential to product success.**

**Figure 7: Assembly Procedures Drawing**





# Procedure For Assembling Lapped Modules To Heat Exchangers

**IMPORTANT:** When two or more thermoelectric devices are mounted between a common plate, the thermoelectric devices thicknesses should vary no more than 0.0015-in. Contact our Engineering Department for more information on close tolerance lapped thermoelectric devices.

**Step 1.** Prepare cold plate and heat sink surfaces as follows:

- A) Grind or lap flat within +/- 0.001" in module area.
- B) Locate bolt holes as close as possible to opposite edges of module (1/8" clearance recommended, 1/2" maximum), in the same plane line as the heat exchanger fins. This orientation utilizes the additional structural strength of the fins to prevent bowing. Drill clearance holes on one surface and drill and tap opposite surface accordingly (see sketch in Assembly Tips). If a spacer block is used to increase distance between surfaces, performance is greater if the spacer block is on cold side of system.
- C) Remove all burrs, chips and foreign matter in thermoelectric module area.

**Step 2.** Thoroughly clean and degrease thermoelectric module, heat exchanger and cold surface.

**Step 3.** Apply a thin continuous film of thermal grease (Wakefield Engineering Type 120 or Dow Type 340) to module hot side surface and to module area on heat exchanger.

**Step 4.** Locate module on heat exchanger, hot side down.

**Step 5.** Gently oscillate module back and forth, exerting uniform downward pressure, noting efflux of thermal compound around edges of module. Continue motion until resistance is felt.

**Step 6.** Repeat Step #3 for cold side surface and cold plate.

**Step 7.** Position cold plate on module.

**Step 8.** Repeat Step #5, sliding cold plate instead of module. Be particularly careful to maintain uniform pressure. Keep the module centered between the screws, or uneven compression will result.

**Step 9.** Before bolting, best results are obtained by preloading in compression the cold plate/heat exchanger/module assembly, applying a light load in line with center of module, using clamp or weights. For two-module assemblies, use three screws located on module center line, with middle screw located between modules. To preload, torque middle screw first. Bolt carefully, by applying torque in small increments, alternating between screws. Use a torque limiting screw driver. The recommended compression for a TEC assembly is 150 to 300 pounds per square inch of module surface area. Using the following equation you can solve for torque per screw:

$$T = (C \times D \times F \times \text{in}^2) / (\# \text{ of screws})$$

- T = torque per screw (in-lbs)
- C = torque coefficient (0.20 as received, 0.15 lubricated)
- D = nominal screw size (4/40 = 0.112, 6/32 = 0.138, 8/32 = 0.164)
- F = Force (lbs / in<sup>2</sup>)
- in<sup>2</sup> = Module surface area (length x width)

Check torque after one hour and retighten if necessary. **Use Stainless Steel Screws, fiber insulating shoulder washers, and steel spring (Belleville or split lock type) washers** (see sketch in **Assembly Tips**).

### CAUTION

1. To ensure good thermal grease interfaces, there should be no bowing of either surface due to torquing. To prevent bowing, apply less torque if one or both surfaces are less than 1/8 inch thick copper or 1/4 inch thick aluminum.
2. Lead wires are soldered to module tabs with bismuth/tin solder (136°C). If lead wire replacement is necessary, use bismuth/tin solder.

**DO NOT** use lead / tin solder (180°C).

## Procedure For Assembling Solderable Modules To Heat Exchangers

**Step 1.** Prepare cold plate and heat sink surfaces by drilling clearance holes on one surface, and drill and tap opposite accordingly (see sketch in Assembly Tips). If a spacer block is used to increase distance between surfaces, performance is greater if the spacer block is on cold side of system.

**Step 2.** Grind or lap flat cold plate (within +/- .001") in module area. Thoroughly clean and degrease thermoelectric module, heat sink, and cold surface.

**Step 3.** Heat sink surface must be solderable (either copper or copper plated aluminum). Clean module area of heat sink surface by light abrasion and degrease thoroughly. Pretin with indium-tin eutectic type solder and flux.

**Step 4.** Module surface should be degreased and fluxed lightly. Heat pretinned and cleaned heat sink surface to 120 to 130°C (250 to 265°F). The module should not go above 138°C or the internal solder will reflow. Place module in position on surface, wait a few seconds for solder on module to melt and excess flux to boil out. When all solder is molten, module will have tendency to float on solder. Light swishing of module will enhance wetting.

- Note: If after all solder is molten there is a slight dragging effect on the module, a deficiency of solder is indicated. Remove module and add additional solder to heat exchange surface. Cool unit and solidify solder. If more than one module is used in the assembly, the flattened cold side surfaces of the module must be kept in a common plane during the soldering operation (Step #3). This can best be accomplished by first fastening the modules, cold face down and in proper array, to a ground flat plate of metal or graphite with double-faced tape. This assembly of modules and flat plate facilitates soldering of the modules to the heat sink, while ensuring that all module cold surfaces are maintained in a common plane and properly arrayed.

**Step 5.** After assembly cools, rinse thoroughly to remove all traces of flux residue.

**Step 6.** Assembly is now ready for bolting to cold plate. Apply a thin continuous film of thermal grease (Wakefield Engineering Type 120 or Dow Type 340) to module top surface and to module area on cold plate and mate surfaces. Gently oscillate module back and forth, exerting uniform downward pressure, noting efflux of thermal compound around edges of module. Continue motion until resistance is felt.

**Step 7.** Before bolting, best results are obtained by preloading in compression the cold plate/heat exchanger/module assembly, applying a light load in line with center of module, using clamp or weights. For two-module assemblies, use three screws located on module center line, with middle screw located between modules. To preload, torque middle screw first. Bolt carefully, by applying torque in small increments, alternating between screws. Use a torque limiting screw driver. The recommended compression for a TEC assembly is 150 to 300 pounds per square inch of module surface area. Using the following equation we can solve for torque per screw:

$$T = (C \times D \times F \times \text{in}^2) / (\# \text{ of screws})$$

T = torque per screw (in-lbs)

C = torque coefficient (0.20 as received, 0.15 lubricated)

D = nominal screw size (4/40 = 0.112, 6/32 = 0.138, 8/32 = 0.164)

F = Force (lbs / in<sup>2</sup>)

in<sup>2</sup> = Module surface area (length x width)

Check torque after one hour and retighten if necessary. **Use Stainless Steel Screws, fiber insulating shoulder washers, and steel spring (Belleville or split lock type) washers** (see sketch in [Assembly Tips](#)).

### CAUTION

1. To ensure good thermal grease interfaces, there should be no bowing of either surface due to torquing. To prevent bowing, apply less torque if one or both surfaces are less than 1/8 inch thick copper or 1/4 inch thick aluminum.
2. Lead wires are soldered to module tabs with bismuth/tin solder (136°C). If lead wire replacement is necessary, use bismuth/tin solder.

**DO NOT** use lead / tin solder (180°C).

## Device Performance Formulae

<b>Heat Pumped at Cold Surface:</b>	$Q_c = 2N [a I T_c - ((I^2 \rho) / (2 G)) - k \Delta T G]$
<b>Voltage:</b>	$V = 2N [((I \rho) / G) + (a \Delta T)]$
<b>Maximum Current:</b>	$I_{max} = (k G / a) [(1 + (2 Z T_H))^{1/2} - 1]$
<b>Optimum Current:</b>	$I_{opt} = [k \Delta T G (1 + (1 + Z T_{ave})^{1/2})] / (a T_{ave})$
<b>Optimum COP</b>	
<b>(calculated at <math>I_{opt}</math>):</b>	$COP_{opt} = (T_{ave} / \Delta T) [((1 + Z T_{ave})^{1/2} - 1) / ((1 + Z T_{ave})^{1/2} + 1)] - 1/2$
<b>Maximum <math>\Delta T</math> with <math>Q = 0</math></b>	$\Delta T_{max} = T_H - [(1 + 2 Z T_H)^{1/2} - 1] / Z]$

## Miscellaneous Expressions

Notation	Definition
$T_H$	Hot Side Temperature (Kelvin)
$T_C$	Cold Side Temperature (Kelvin)
$\Delta T$	$T_H - T_C$ (Kelvin)
$T_{ave}$	$1/2 (T_H + T_C)$ (Kelvin)
$G$	Area / Length of T.E. Element (cm)
$N$	Number of Thermocouples
$I$	Current (amps)
<b>COP</b>	Coefficient of Performance ( $Q_c / IV$ )
$\alpha$	Seebeck Coefficient (volts / Kelvin)
$\rho$	Resistivity ( $\Omega$ cm)
$\kappa$	Thermal Conductivity (watt / (cm Kelvin))
$Z$	Figure of Merit ( $\alpha^2 / (\rho \kappa)$ ) (Kelvin <sup>-1</sup> )
$S$	Device Seebeck Voltage ( $2 \alpha N$ ) (volts / Kelvin)
$R$	Device Electrical Resistance ( $2 \rho N / G$ ) (ohms)
$K$	Device Thermal Conductance ( $2 \kappa N G$ ) (Watt / Kelvin)

## Heat Transfer Formulae

**NOTE:** Due to the relatively complex nature of heat transfer, results gained from application of these formulae, while useful, must be treated as approximations only. Design safety margins should be considered before final selection of any device.

### 1) Heat gained or lost through the walls of an insulated container:

$$Q = (A \times \Delta T \times K) / (\Delta X)$$

#### Where:

Q = Heat (Watts)

A = External surface area of container (m<sup>2</sup>)

$\Delta T$  = Temp. difference (inside vs. outside of container) (Kelvin)

K = Thermal conductivity of insulation (Watt / meter Kelvin)

$\Delta X$  = Insulation thickness (m)

### 2) Time required to change the temperature of an object:

$$t = (m \times C_p \times \Delta T) / Q$$

#### Where:

t = Time interval (seconds)

m = Weight of the object (kg)

$C_p$  = Specific heat of material (J / (kg K))

$\Delta T$  = Temperature change of object (Kelvin)

Q = Heat added or removed (Watts)

**NOTE:** It should be remembered that thermoelectric devices do not add or remove heat at a constant rate when  $\Delta T$  is changing. An approximation for average Q is:

$$Q_{ave} = (Q (\Delta T_{max}) + Q (\Delta T_{min})) / 2$$

### 3) Heat transferred to or from a surface by convection:

$$Q = h \times A \times \Delta T$$

#### Where:

Q = Heat (Watts)

h = Heat transfer coefficient (W / (m<sup>2</sup> K))

(1 to 30 = "Free" convection - gases, 10 to 100 = "Forced" convection - gases)

A = Exposed surface area (m<sup>2</sup>)

$\Delta T$  = Surface Temperature - Ambient (Kelvin)

#### Conversions:

Thermal Conductivity	1 BTU / hr ft °F = 1.73 W / m K 1 W / m K = 0.578 BTU / hr ft °F
Power (heat flow rate)	1 W = 3.412 BTU / hr 1 BTU / hr = 0.293 W
Area	1 ft <sup>2</sup> = 0.093 m <sup>2</sup> 1 m <sup>2</sup> = 10.76 ft <sup>2</sup>
Length	1 ft = 0.305 m 1 m = 3.28 ft
Specific Heat	1 BTU / lb °F = 4184 J / kg K 1 J / kg K = 2.39 x 10 <sup>-4</sup> BTU / lb °F
Heat Transfer Coefficient	1 BTU / hr ft <sup>2</sup> °F = 5.677 W / m <sup>2</sup> °K 1 W / m <sup>2</sup> °K = 0.176 BTU / hr ft <sup>2</sup> °F
Mass	1 lb = 0.4536 kg 1 kg = 2.205 lb



**TYPICAL PROPERTIES OF MATERIALS (@ 21°C)**

Material Name	Density kg/m <sup>3</sup>	Thermal Conductivity W/m-K	Specific Heat J/kg-K	Thermal Expansion Coefficient x 10 <sup>-6</sup> cm/cm/°C
Air	1.2	0.026	1004	-
Alumina Ceramic-96%	3570	35.3	837	6.5
Aluminum Nitride Ceramic	3300	170-230	920	4.5
Aluminum	2710	204	900	22.5
Argon (Gas)	1.66	0.016	518	-
Bakelite	1280	0.23	1590	22.0
Beryllia Ceramic-99%	2880	230	1088	5.9
Bismuth Telluride	7530	1.5	544	13.0
Brass	8490	111	343	18.0
Bronze	8150	64	435	18.0
Concrete	2880	1.09	653	14.4
Constantan	8390	22.5	410	16.9
Copper	8960	386	385	16.7
Copper Tungsten	15650	180-200	385	6.5
Diamond	3500	2300	509	-
Ethylene Glycol	1116	0.242	2385	-
Glass (Common)	2580	0.80	795	7
Glass Wool	200	0.040	670	-
Gold	19320	310	126	14.2
Graphite	2560	85	837	3.6
Iron (Cast)	7210	83	460	10.4
Kovar	8360	16.6	460	5.0
Lead	11210	35	130	29.3
Molybdenum	10240	142	251	4.9
Nickel	8910	90	448	11.9
Nitrogen (Gas)	1.14	0.026	1046	-
Platinum	21450	70.9	133	9.0
Plexiglass (Acrylic)	1410	0.26	1448	74
Polyurethane Foam	29	0.035	1130	-
Rubber	960	0.16	2009	72
Silicone (Undoped)	2330	144	712	-
Silver	10500	430	235	-
Solder (Tin/Lead)	9290	48	167	24.1
Stainless Steel	8010	13.8	460	17.1
Steel (Low Carbon)	7850	48	460	11.5
Styrofoam	29-56	.029	1.22	-
Teflon	2200	0.35	-	-
Thermal Grease	2400	0.87	2093	-
Tin	7310	64	226	23.4
Titanium	4372	20.7	460	8.2
Water (@ 70°F)	1000	0.61	4186	-
Wood (Oak)	610	0.15	2386	4.9
Wood (Pine)	510	0.11	2805	5.4
Zinc	7150	112	381	32.4

## Reliability & Mean Time Between Failures (MTBF)

Thermoelectric devices are highly reliable due to their solid state construction. Although reliability is somewhat application dependent, MTBFs calculated as a result of tests performed by various customers are on the order of 200,000 to 300,000 hours at room temperature. Elevated temperature (80°C) MTBFs are conservatively reported to be on the order of 100,000 hours. Field experience by hundreds of customers representing more than 7,500,000 of our CP type modules and more than 800,000 OptoTEC™ type modules during the last ten years have resulted in a failure return of less than 0.1%. More than 90% of all modules returned were found to be failures resulting from mechanical abuse or overheating on the part of the customer. Thus, less than one failure per 10,000 modules used in systems could be suspect of product defect. Therefore, the combination of proper handling, and proper assembly techniques will yield an extremely reliable system.

Historical failure analysis has generally shown the cause of failure as one of two types:

Mechanical damage as a result of improper handling or system assembly techniques.

### Moisture:

Moisture must not penetrate into the thermoelectric module area. The presence of moisture will cause an electro-corrosion that will degrade the thermoelectric material, conductors and solders. Moisture can also provide an electrical path to ground causing an electrical short or hot side to cold side thermal short. A proper sealing method or dry atmosphere can eliminate these problems.

### Shock and Vibration:

Thermoelectric modules in various types of assemblies have for years been used in different Military/Aerospace applications. Thermoelectric devices have been successfully subjected to shock and vibration requirements for aircraft, ordinance, space vehicles, shipboard use and most other such systems. While a thermoelectric device is quite strong in both tension and compression, it tends to be relatively weak in shear. When in a severe shock or vibration environment, care should be taken in the design of the assembly to ensure "compressive loading" of thermoelectric devices.

### Mechanical Mounting:

A common failure mode for thermoelectric modules is un-even compression forces induced by improper torquing, bolting patterns, and mechanical conditions of heat exchangers. The polycrystalline thermoelectric material exhibits less strength perpendicular to the length (growth axis) than the horizontal axis. Thus, the thermoelectric elements are quite strong in compressive strength and tend to be weak in the shear direction. During assembly, un-even torquing or un-flat heat exchangers can cause severe shear forces. Recommended compression value is 150 PSI. (See assembly instructions for proper mounting techniques.)

### Inadvertent Overheating of the Module:

The direct soldering process does result in temperature restriction for operation or storage of the modules.

At temperatures above 80°C two phenomena seriously reduce useful life:

Above 80°C copper diffusion into the thermoelements occurs due to increasing solid solubility in the thermoelectric material and increasing diffusion rate. At 100 - 110°C the combined solubility and diffusion rate could result in approximately 25% loss of device performance within 100 hours.

Above 85°C in the soldering process (using Bismuth-Tin Alloy) small amounts of selenium, tellurium, antimony and nickel are inherently dissolved into the bismuth-tin solder. Although the melting point of the base solder is 136°C, the combined mixture of all elements results in either a minute eutectic phase or a highly effective solid state reaction occurring at above 85°C that starts to delaminate the ends of the thermoelements by physical penetration between cleavage planes in the thermoelectric material. This results in a mechanical failure of the interface.



**The Standard in Thermoelectrics**



1040 Spruce Street • Trenton, NJ 08648 USA  
(609) 393-4178 • FAX (609) 393-9461  
WEB: [www.melcor.com](http://www.melcor.com)