

Thermoelectric Cooling Systems Design Guide



marlow industries, inc.®

Thermoelectric Cooling Systems

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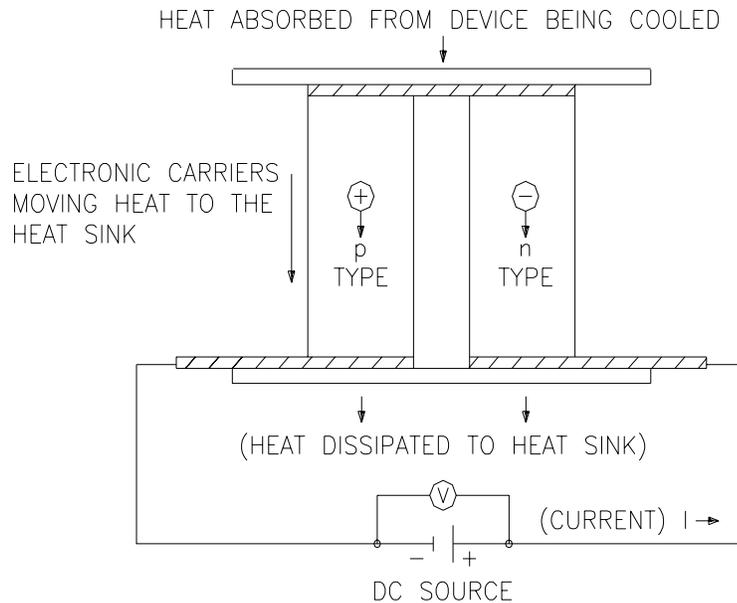
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I. Introduction

A thermoelectric cooler (TEC) is a small heat pump which has the advantage of no moving parts. TEC's are used in various applications where space limitations and reliability are paramount and CFC's are not desired. The coolers operate on direct current and may be used for heating or cooling by reversing the direction of current flow. This is achieved by moving heat from one side of the module to the other with current flow and the laws of thermodynamics. A typical single stage cooler (Figure 1) consists of two ceramic plates with p- and n-type semiconductor material (bismuth telluride) between the plates. The elements of semiconductor material are connected electrically in series and thermally in parallel.



**Typical Single Stage Cooler
Figure 1**

When a positive DC current is applied to the n-type thermoelement, electrons pass from the p- to the n-type thermoelement and the cold side temperature decreases as heat is absorbed. This heat is transferred to the hot side of the cooler, where it is dissipated into the heat sink and surrounding environment. The heat absorption (cooling) is proportional to the current and the number of thermoelectric couples.

The theories behind the operation of thermoelectric coolers can be traced back to the early 1800s. Jean Peltier discovered there is a heating or cooling effect when electric current passes through two conductors. Thomas Seebeck found two dissimilar conductors at different temperatures would create an electromotive force or voltage. William Thomson (Lord Kelvin) showed that over a temperature gradient a single conductor with current flow will have reversible heating and cooling. With these principles in mind and the introduction of semiconductor materials in the late 1950s, thermoelectric cooling has become a viable technology for small cooling applications.

II. Applications

Applications can be found in many markets and industries: military, telecommunications, commercial, laboratory, medical, and aerospace. Heat pumping rates typically range from a few milliwatts to hundreds of watts. Projects have been undertaken where heat removal was measured in kilowatts, however, these large scale applications are not typical.

Some examples of TEC applications and markets are listed below:

<u>Application</u>	<u>Market</u>
Infrared Detectors	Military guidance systems Environmental analyzers Night vision systems
Black Body References	Military
Air to Air Exchangers	Portable cool boxes Small refrigerators Electronic cabinets
Charge Coupled Device (CCD)	Commercial and military cameras Space telescopes Satellites
Liquid Exchangers	Semiconductor processing equipment Constant temperature baths Blood analyzers
Laser Diodes	Telecommunications switching Medical diagnostics equipment Commercial electronic scanners Guidance systems
High Speed Integrated Circuits	Commercial, Military

III. Estimating Heat Loads

Before the cooler or heat sink can be selected, the cooling requirements must be defined. This includes determining the amount of heat to be pumped. Minimizing the heat load allows the cooler to achieve colder temperatures or reduces the power required to reach the defined cooling level. The following describes the techniques used to estimate active and passive heat loads and applies only to steady state heat loads. If the heat load is of a transient nature, or involves more complex factors such as air or fluid flow, we suggest that you call one of our applications engineers for assistance.

Heat load

The heat load may consist of two types; active or passive, or a combination of the two. An active load is the heat dissipated by the device being cooled. It generally equals the input power to the device. Passive heat loads are parasitic in nature and may consist of radiation, convection, or conduction.

Active Heat Load

The general equation for active heat load dissipation is:

$$Q_{\text{active}} = V^2/R = VI = I^2R$$

where:

Q_{active} = active heat load (W)

V = voltage applied to the device being cooled (V)

R = device resistance (Ω)

I = current through the device (A)

For example, a typical lead selenide (PbSe) infrared detector is operated at a bias voltage of 50 volts and a resistance of 0.5 megohms. The active load therefore, is 0.005 watts.

Radiation

When two objects at different temperatures come within proximity of each other, heat is exchanged. This occurs through electromagnetic radiation emitted from one object and absorbed by the other. The hot object will experience a net heat loss and the cold object a net heat gain as a result of the temperature difference. This is called thermal radiation.

Radiation heat loads are usually considered insignificant when the system is operated in a gaseous environment since the other passive heat loads are typically much greater in magnitude. Radiation loading is usually significant in systems with small active loads and large temperature differences, especially when operating in a vacuum environment.

The fundamental equation for radiation loading is:

$$Q_{\text{rad}} = F e s A (T_{\text{amb}}^4 - T_c^4)$$

where:

- Q_{rad} = radiation heat load (W)
- F = shape factor (worst case value = 1)
- e = emissivity (worst case value = 1)
- s = Stefan-Boltzmann constant ($5.667 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$)
- A = area of cooled surface (m^2)
- T_{amb} = Ambient temperature (K)
- T_c = TEC cold ceramic temperature (K)

Example Calculation: A Charge Coupled Device is being cooled from an ambient temperature of 27°C (300 K) to -50°C (223 K).

The detector surface area (includes 4 edges + top surface) is $8.54 \times 10^{-4} \text{ m}^2$ and has an emissivity of 1. Assume the shape factor = 1

From the equation above:

$$\begin{aligned} Q_{\text{rad}} &= (1)(1) (5.66 \times 10^{-8} \text{ W/m}^2 \text{ K}^4) (8.54 \times 10^{-4} \text{ m}^2) [(300 \text{ K})^4 - (223 \text{ K})^4] \\ &= 0.272 \text{ W} \end{aligned}$$

Convection

When the temperature of a fluid (in this case, a gas) flowing over an object differs from that of the object, heat transfer occurs. The amount of heat transfer varies depending on the fluid flow rate. Convective heat loads on TEC's are generally a result of natural (or free) convection. This is the case when gas flow is not artificially induced as with a fan or pump, but rather occurs naturally from the varying density in the gas caused by the temperature difference between the object being cooled and the gas.

The convective loading on a system is a function of the exposed area and the difference in temperature between this area and the surrounding gas. Convective loading is usually most significant in systems operating in a gaseous environment with small active loads or large temperature differences.

The fundamental equation which describes convective loading is:

$$Q_{\text{conv}} = h A (T_{\text{air}} - T_c)$$

where:

- Q_{conv} = convective heat load (W)
- h = convective heat transfer coefficient ($\text{W/m}^2 \text{ }^\circ\text{C}$) (typical value for a flat, horizontal plate in air at 1 atm = $21.7 \text{ W/m}^2 \text{ }^\circ\text{C}$)
- A = exposed surface area (m^2)
- T_{air} = temperature of surrounding air ($^\circ\text{C}$)
- T_c = temperature of cold surface ($^\circ\text{C}$)

Example Calculation: A square plate is being cooled from 25°C to 5°C. The top and four sides are exposed surfaces. The plate is 0.006 meters thick and each side is 0.1 meters long.

From the Convection equation:

$$Q_{\text{conv}} = (21.7 \text{ W/m}^2\text{°C}) (0.0124 \text{ m}^2)(25^\circ\text{C} - 5^\circ\text{C}) \\ = 5.4 \text{ W}$$

It is very important to avoid allowing condensation to form when cooling below the dew point. This problem may be avoided by enclosing the cooling system in a dry gas or a vacuum environment.

Conduction

Conductive heat transfer occurs when energy exchange takes place by direct impact of molecules moving from a high temperature region to a low temperature region.

Conductive heat loading on a system may occur through lead wires, mounting screws, etc., which form a thermal path from the device being cooled to the heat sink or ambient environment.

The fundamental equation which describes conductive loading is:

$$Q_{\text{cond}} = \frac{k A \Delta T}{L}$$

where:

Q_{cond} = conductive heat load (W)

k = thermal conductivity of the material (W/m °C)

A = cross-sectional area of the material (m²)

L = length of the heat path (m)

ΔT = temperature difference across the heat path (°C) (usually ambient or heat sink temperature minus cold side temperature)

Table I
Thermal Conductivities of Various Wire Material

Material	Thermal Conductivity (W / m°C)
Aluminum	205
Copper	386
Gold	315
Platinum (90%) Iridium (10%)	31.1
Platinum	70.9
Manganin	22.2

Example Calculation: A TEC is used as a black body reference. A temperature sensor is attached to the cold surface of the TEC. It has two platinum leads which have a diameter of 25µm and are 12 mm long. These leads are attached to pins on the heat sink. The cold plate is at -20°C while the heat sink is at 30°C.

The known parameters are:

k = 70.9 W/m°C, from Table I

ΔT = [30°C - (-20°C)] = 50°C

$A(1 \text{ wire}) = \pi d^2 / 4 = \pi (25 \mu\text{m})^2 / 4$
= 4.91 X 10⁻¹⁰ m²

$A(2 \text{ wires}) = (2)(4.91 \times 10^{-10} \text{ m}^2) = 9.82 \times 10^{-10} \text{ m}^2$

L = 12mm = 0.012m

From the equation above:

$$Q_{\text{cond}} = [(70.9 \text{ W/m}^\circ\text{C}) (9.82 \times 10^{-10} \text{ m}^2)] (50^\circ\text{C}) / (0.012\text{m}) \\ = 0.0003 \text{ W}$$

Since the conductive load is inversely proportional to the length of the wire, it can be reduced by using longer wires.

Combined Convection and Conduction

The following equation can be used for estimating heat losses due to convection and conduction of an enclosure.

$$Q_{\text{passive}} = (A \times \Delta T) / (x/k + 1/h)$$

where:

- Q_{passive} = heat load (W)
- A = total external surface area of enclosure (m²)
- x = thickness of insulation (m)
- k = thermal conductivity of insulation (W/m °C)
- h = convective heat transfer coefficient (W/m² °C)
- ΔT = Temperature change (°C)

Table II
Typical Values of Convection Heat Transfer Coefficient

Process	h (W / m ² °C)
Free Convection – Air	2 – 25
Forced Convection – Air	25 – 250

Table III
Typical Values of Thermal Conductivity for Insulation

Product	Thermal Conductivity W / m °C
Styrofoam	.031
Polystyrene	.037
Polyurethane	.039

Transient Temperature

Some designs require a set amount of time to reach the desired temperature. The following equation may be used to estimate the time required:

$$t = [(\rho) (V) (C_p) (T_1 - T_2)] / Q$$

where:

- t = time (seconds)
- ρ = density (g/cm³)
- V = volume (cm³)
- C_p = specific heat (J/g °C)
- T₁-T₂ = temperature change (°C)
- Q = (Q_{t₀} + Q_{t_i}) / 2 (J/s; Note: 1 J/s = 1 W)

Q(t₀) is the initial heat pumping capacity when the temperature difference across the cooler is zero. Q(t_i) is the heat pumping capacity when the desired temperature difference is reached and heat pumping capacity is decreased. Q(t₀) and Q(t_i) are used to obtain an average value.

Heat loading may occur through one or more of four modes: active, radiation, convection or conduction. By utilizing these equations you can estimate your heat loads. The resulting information can then be used to select a suitable TEC for your application (see section IV).

IV. TEC Selection Procedure

Outlined below is a simplified selection procedure devised to allow the user to obtain initial designs and estimates of performance for single and two-stage thermoelectric coolers. Because of the non-linear behavior of TEC's and the number of variables involved in analyzing them, they can be designed and modeled more accurately by our experienced engineers using Marlow Industries' internally developed computer software. For selection of coolers with more than two stages, or if more precision is required, please consult one of our application engineers. Once the decision to use a thermoelectric cooler has been made, the actual selection of suitable modules is relatively simple.

The following pages outline a step by step procedure that will take you through determining your heat load, required ΔT , and the number of stages required to meet the ΔT .

Once you have completed the analysis you will have narrowed the field of suitable TEC's to two or three. You may then proceed to steps 5 through 10 to determine the performance of the selected TEC's within your application requirements.

1. Calculate Heat Loads

<u>Type of Load</u>	<u>Example</u>	<u>Your Case</u>
Active	8.0 W	_____ W
Radiation	0.2*W	_____ W
Convective	0.8*W	_____ W
Conductive	0.0*W	_____ W
Total Heat Load(Q)	9.0W	_____ W

* Refer to section III entitled "Estimating Heat Loads" for information on determining these loads.

2. Define Temperatures

<u>Component Temp.</u>	<u>Example</u>	<u>Your Case</u>
TEC hot side (Th)	27°C	_____ °C
TEC cold side (Tc)	-8°C	_____ °C
DT(Th-Tc)	35°C	_____ °C

3. Determine Number of Stages Required

Select the minimum number of stages from Table IV necessary to meet the required ΔT .

**Table IV
Typical maximum obtainable ΔT Values for Single- & Multi-stage TEC's**

Number Of stages	ΔT_{max} in Dry N₂ @ 1 atm (°C)	ΔT_{max} in a Vacuum (°C)
1	64	67
2	84	91
3	95	109
4	--	115
5	--	121
6	--	127

In this example, a single-stage TEC will suffice since 64°C is greater than the desired 35°C ΔT. If the number of stages required exceeds two, the following selection process is not applicable. These calculations are only accurate for one- or two-stage TEC's. For three-stage and above, call one of our applications engineers for assistance.

4. Select an Appropriate TEC

The performance graphs used in this brochure have been normalized to provide a universal curve for use with any single- or two-stage TEC for which the "Maximum" values are known. By using ratios of actual to "Maximum" performance values, performance may be estimated over a wide range of operating conditions.

- a. Determine the ratio of $\Delta T/\Delta T_{max}$.

	<u>Example</u>	<u>Your Case</u>
Record ΔT from step 2	35°C	_____ °C
Record ΔT_{max} from step 3	64°C	_____ °C
Calculate $\Delta T/T_{max}$	35°C/64°C = .55	_____

- b. On the performance graph (Figure 2) draw a horizontal line on the graph corresponding to the calculated value of $\Delta T/\Delta T_{max}$ (0.55 in this example).

- c. Obtain the optimum value of Q/Q_{max} at the intersection of the horizontal line just drawn and the diagonal Optimum Q/Q_{max} line. Interpolation between curves may be necessary.

<u>Example</u>	<u>Your Case</u>
Optimum Q/Q_{max} = 0.25	_____

- d. Obtain the maximum value of Q/Q_{max} at the intersection of the horizontal line (*drawn in step 4b*) and the right vertical axis.

Maximum Q/Q_{max} = 0.45	_____
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- e. Divide the total heat load (*from step 1*) by the Q/Q_{max} ratios above to calculate the Optimum and Maximum Q_{max} .

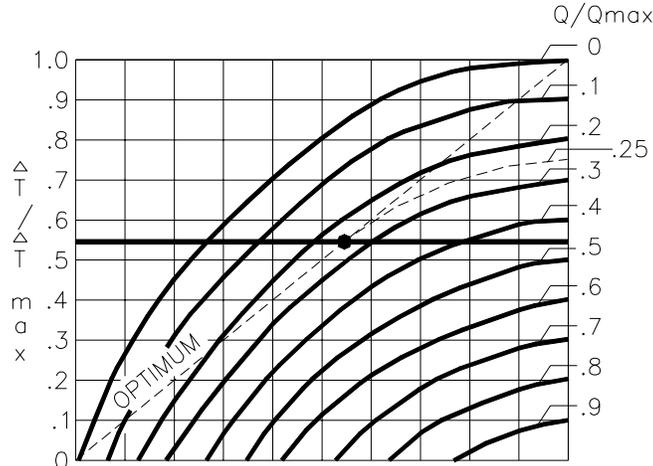
Optimum Q_{max} = 9.0W / 0.25 = 36W	_____ ÷ _____ = _____ W
Maximum Q_{max} = 9.0W / 0.45 = 20W	_____ ÷ _____ = _____ W

- f. Select a TEC from Marlow's Standard Thermoelectric Coolers product list with a Q_{max} greater than the maximum Q_{max} (20 watts in this example), but less than the optimum Q_{max} (36 watts in this example). Keep in mind that within this range, a TEC with a Q_{max} close to the optimum Q_{max} will provide maximum efficiency, and a Q_{max} close to the maximum Q_{max} will yield smaller and possibly less expensive TEC's. Reading down the Q_{max} column results in the selection of the following TEC's:

	Example TEC Values				Your Case TEC Values			
<u>Range Location</u>	<u>Model#</u>	<u>Qmax</u>	<u>I_{max}</u>	<u>V_{max}</u>	<u>Model#</u>	<u>Qmax</u>	<u>I_{max}</u>	<u>V_{max}</u>
Near Optimum	DT6-6	30	5.6	8.2	_____	_____	_____	_____
Nearer Maximum	DT6-4	20	3.7	8.2	_____	_____	_____	_____

For this example, let us assume maximum efficiency is desired. Thus, the 5.6 amp, 8.2 volt cooler is selected, because between these two potential TEC's, its Q_{max} (30 watts) is closest to the optimum Q_{max} (36 watts).

FIGURE 2



V. Estimate TEC Performance

1. TEC Performance Parameters

Now that the TEC has been selected, the next step is to determine its performance.

a. Refer again to the Table of Standard Thermoelectric Coolers and record the maximum values for the TEC whose performance is being evaluated. Note that if a hot-side temperature other than 27°C is used, the performance parameters must be adjusted to obtain more accurate results. Please call one of our applications engineers for assistance.

<u>TEC Minimum Values</u>	<u>Example</u>	<u>Your Case</u>
ΔT_{max}	65° C	_____ °C
Q_{max}	30 W	_____ W
I_{max}	5.6 A	_____ A
V_{max}	8.2 V	_____ V

b. Determine the ratio of $\Delta T / \Delta T_{max}$:

ΔT (from step 2)	35° C	_____ °C
ΔT_{max} (from step 1a)	65° C	_____ °C
$\Delta T / \Delta T_{max}$ (calculate)	35/65 = .54	_____ °C

c. On the performance graph (See Figure 3) draw a horizontal line on the upper graph corresponding to the $\Delta T / \Delta T_{max}$ (0.54 in this example).

d. Divide the total heat load (from step 1 of the TEC Selection Procedure) by the value of Q_{max} for the TEC selected (from step 1a):

$$Q/Q_{max} = 9.0 \text{ W} / 30 \text{ W} = 0.3$$

$$= \text{___} \text{ W} \div \text{___} \text{ W} = \text{___}$$

e. At the intersection of the horizontal line (drawn in step 1c) and the value of Q / Q_{max} (just calculated in step 1d), plot a vertical line on the performance graph.

f. Record the value of I / I_{max} at the intersection of the vertical line just plotted and the bottom I / I_{max} axis.

$$I / I_{max} = 0.6 \qquad I / I_{max} = \text{_____}$$

2. Calculate TEC Current

Using the value of I_{max} (obtained in step 1a) and the value of I/I_{max} (just obtained in step 1f), calculate the TEC current (I).

$$\begin{aligned} \text{TEC current} &= (I_{max}) \times (I/I_{max}) \\ &= 5.6\text{A} \times 0.6 = 3.4 \text{ A} \\ &= \underline{\quad} \text{A} \times \underline{\quad} = \underline{\quad} \text{A} \end{aligned}$$

3. Calculate the TEC Voltage

a. Draw a horizontal line through each of the intersections of the vertical line (drawn in step 1e) and the two curves in the lower half of the performance curve in Figure 3.

b. Record the values of V/V_{max} at the intersection of the two horizontal lines drawn and the left vertical axis. These values determine the range of V/V_{max} for the TEC selected. For large ΔT s (small values of Q/Q_{max}), the voltage will correspond to the high end of the range, and for small ΔT s (large values of Q/Q_{max}), the voltage will correspond to the low end of the range.

Example	Your Case
High V/V_{max} = 0.68	_____
Low V/V_{max} = 0.54	_____

c. Multiply V_{max} (obtained in step 1a) by each value of V/V_{max} just obtained to get the range of TEC voltage.

$$\begin{aligned} \text{High TEC Voltage} &= V_{max} \times (V/V_{max}) \\ &= 8.2\text{V} \times 0.68 = 5.6\text{V} \\ &= \underline{\quad} \text{V} \times \underline{\quad} = \underline{\quad} \text{V} \end{aligned}$$

$$\begin{aligned} \text{Low TEC Voltage} &= V_{max} \times (V/V_{max}) \\ &= 8.2\text{V} \times 0.54 = 4.4\text{V} \\ &= \underline{\quad} \text{V} \times \underline{\quad} = \underline{\quad} \text{V} \end{aligned}$$

4. Calculate Maximum TEC Power

Multiply TEC current (from step 2) by High TEC voltage (from step 3c).

$$\begin{aligned} \text{TEC Power} &= 3.4 \text{ A} \times 5.6 \text{ V} = 19.0\text{W} \\ &= \underline{\quad} \text{A} \times \underline{\quad} \text{V} = \underline{\quad} \text{W} \end{aligned}$$

5. Calculate Power Dissipated Into the Heat Sink

The power dissipated into the heat sink is the sum of the total heat load and the input power to the TEC.

$$\begin{aligned} Q_h &= 9.0\text{W} + 19.0\text{W} = 28.0\text{W} \\ &= \underline{\quad} \text{W} + \underline{\quad} \text{W} = \underline{\quad} \text{W} \end{aligned}$$

At this point you should have several candidate TEC's with their approximate performances and you are now ready to order.

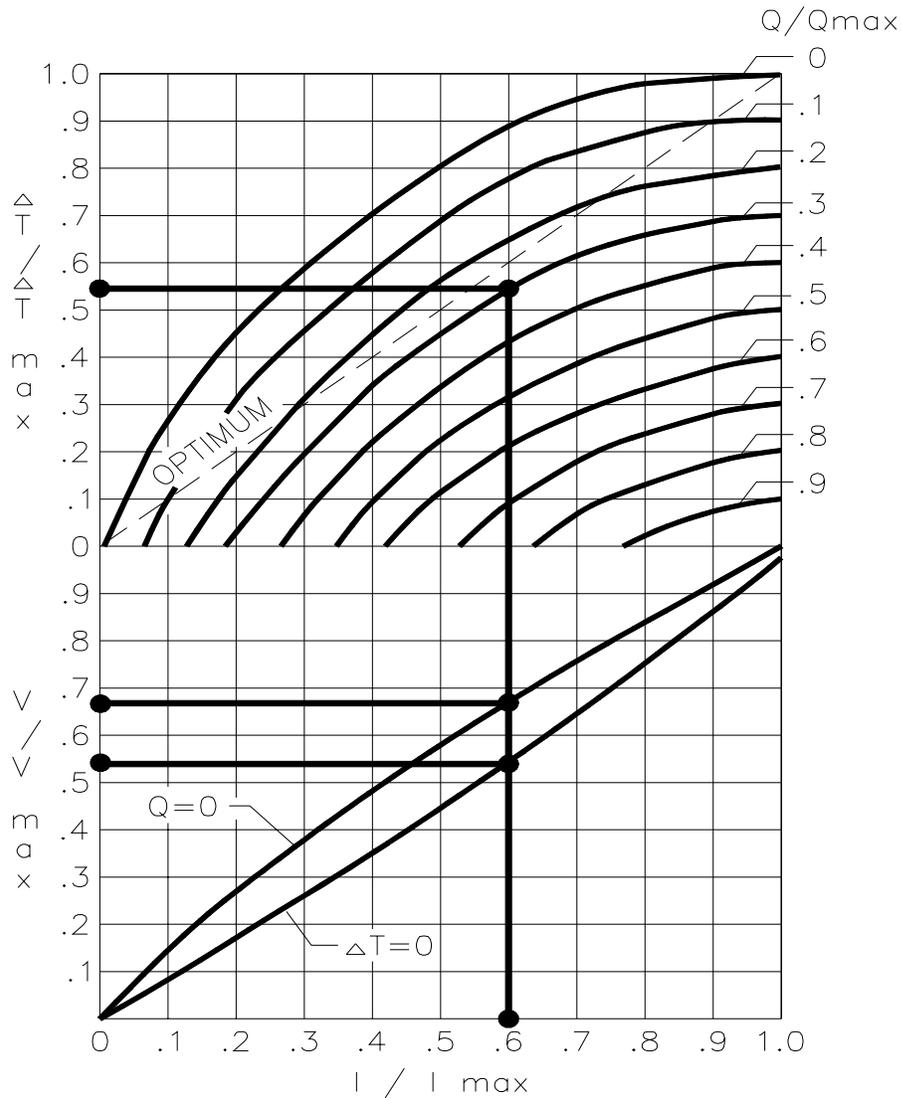


Figure 3

VI. Heat Sinks

Design or selection of the heat sink is crucial to the overall thermoelectric system operation and cooler selection. All thermoelectric coolers require a heat sink and will be destroyed if operated without one. The system temperature difference is typically quite different from the cooler temperature gradient. A typical design parameter might be to limit the heat sink temperature rise above ambient to 10 to 20°C. The heat sink temperature directly affects the cooler hot side temperature, which in turn affects the cold side temperature that can be achieved with a TEC. Heat sink resistance is the measure of the ability of the sink to dissipate the applied heat and is given by:

$$\text{HSR} = (T_1 - T_2)/Q$$

where:

HSR = Thermal resistance ($^{\circ}\text{C}/\text{W}$)

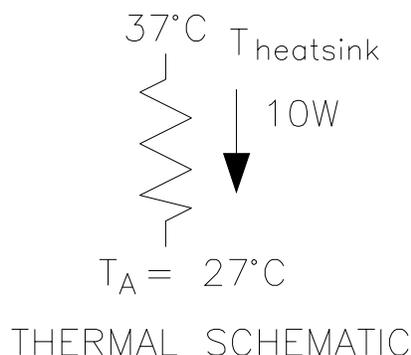
T1 = Heat sink temperature ($^{\circ}\text{C}$)

T2 = Ambient or coolant input temperature ($^{\circ}\text{C}$)

Q = Heat load into heat sink (W) (includes absorbed + TEC power)

The goal of the heat sink design is to minimize thermal resistance. This is achieved through exposed surface area and may require forced air or liquid circulation.

The following schematic shows how the heat sink resistance can be determined. Ambient temperature is 27°C , the desired rise across the heat sink is 10°C , or heat sink temperature at 37°C . The load that must be dissipated is 10W. This gives a resistance of $10^{\circ}\text{C} / 10\text{W}$ or $1^{\circ}\text{C} / \text{W}$.



The three basic types of heat sinks are: natural convective, forced convective, and liquid cooled, with liquid cooled being the most effective. Typical values of HSR for natural convective range from $0.5^{\circ}\text{C}/\text{W}$ to $5^{\circ}\text{C}/\text{W}$, forced convective from $0.02^{\circ}\text{C}/\text{W}$ to $0.5^{\circ}\text{C}/\text{W}$ and liquid cooled from $0.005^{\circ}\text{C}/\text{W}$ to $0.15^{\circ}\text{C}/\text{W}$. In general, most applications involving thermoelectric cooling require forced convective or liquid cooled heat sinks.

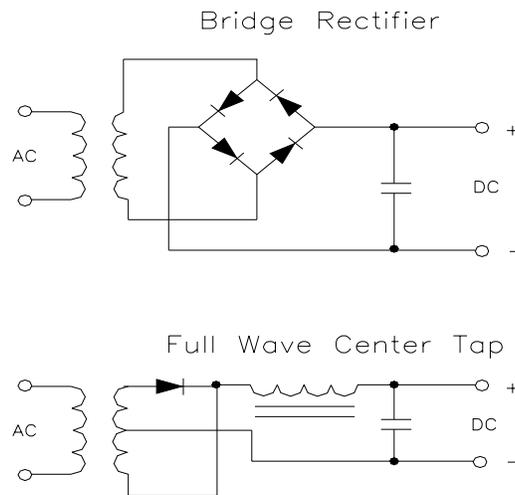
VII. Power Supplies

Thermoelectric coolers operate from a DC power input. These DC power supplies can range from simple batteries to sophisticated closed loop temperature control/power supply circuits. Both linear and switching power supplies can be used to operate TEC's. The "quality" of the DC current is important. High quality DC current is smooth and constant with very low ripple or noise. All current derived from AC sources contains ripple. Ripple is significant because it can affect the performance of the TEC. Unfiltered full-rectified AC voltage has a ripple factor of approximately 48% which can decrease the performance of the TEC by as much as 23%. Marlow Industries recommends limiting the ripple factor to less than 10% which will reduce the loss in performance to less than 1%. Listed on the following page are some examples of power supply circuits.

Pulse Width Modulation

Pulse width modulation (PWM) is a power conversion technique which converts the AC line voltage to a lower voltage DC signal. Pulse width modulation essentially controls the duty cycle as well as the frequency of the power applied to the TEC.

To prevent thermal cycling, most PWM circuits filter the DC output to provide a "smooth" DC component to the TEC. The frequency of the PWM can be as low as possible to maintain a continuous smooth output voltage.

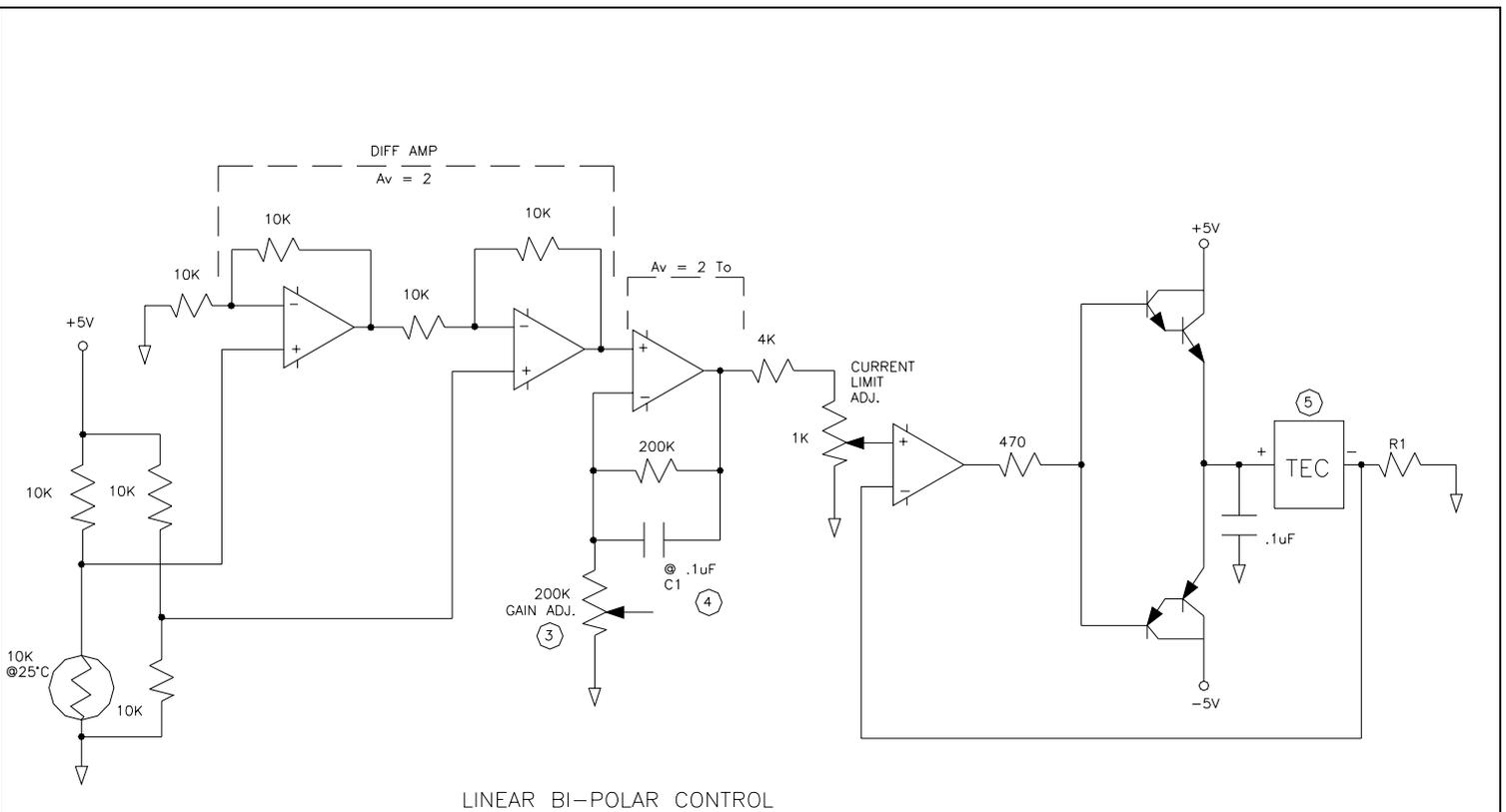


On / Off Control

On/Off, or thermostatic control, is the simplest and most crude technique for controlling the temperature of the TEC. This method of control is the least preferred. Because the power to the TEC is cycled from full ON to full OFF, thermal cycling of the TEC will occur and degrade the life of the unit.

Proportional Control

A proportional controller offers much better stability than an On/Off controller. In proportional controllers there is always a residual error, even after the controller has settled to the final state. This error is proportional to the difference between the set-point temperature and the ambient temperature. The following diagram on page 13, is a linear bipolar proportional control circuit.



NOTES:

1. OP - AMP
2. SET CURRENT LIMIT ≤ 2.0 AMPS.
- ③ INCREASE GAIN UNTIL OUTPUT STARTS OSCILLATING, THEN CUT IN HALF.
- ④ CHOOSE C1 TO OBTAIN STABILITY AT HIGH SETTINGS IN HEATING MODE.
- ⑤ TEC IS A 2A @ 2V MAX, WHEN BASE TEMP = +27°C
6. R1 IS CURRENT SENSE RESISTOR, .3 OHMS, 3 WATTS.

Proportional-Integral (PI) Control

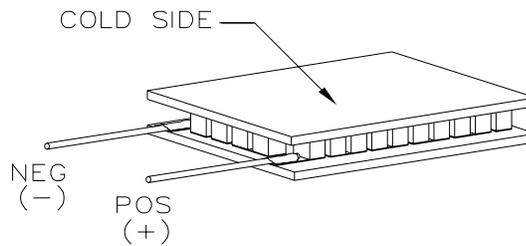
The residual error present in the proportional controller can be eliminated by the addition of an integrator. PI control is required for systems that have wide variation in either or both the thermal load and ambient temperature.

Proportional-Integral-Derivative (PID) Control

Full PID control loops are the most complex and are less common. The PID controller adds a derivative circuit to the PI controller which improves the transient response. This type of controller is mainly used in applications where large thermal loads must be quickly controlled.

VIII. TEC Mounting Methods

Thermoelectric coolers (TEC's) are mounted using one of three methods: adhesive bonding, compression using thermal grease, or solder.



In general, for a TEC with a ceramic base of 19 mm or less, you can solder or adhesive bond without fear of failure due to thermal stresses. If the TEC base is larger than 19 mm, we recommend the compression method because thermal grease is not rigid and does not transfer thermal stresses.

A thin layer of copper metallization on the hot and/or cold ceramic allows soldering as a means of attachment. Keep in mind a TEC that has no metallization on either side cannot be mounted using solder. Adhesives and greases are prone to outgassing, therefore they are not as appropriate for use in a vacuum package.

Surface Preparation

Surface preparation is important when using any of the assembly methods. No matter which method is used, the mounting surface should be flat to less than 0.08 mm over the TEC mounting area. In addition, the surface should be clean and free from oil, nicks and burrs. When multiple TEC's are placed in parallel thermally between common plates, the TEC thicknesses should vary no more than 0.05 mm.

Mounting with Adhesive Bonding

When to Use: When you want to permanently attach the TEC to your heat sink; when mounting with solder is not an option; when the TEC's need to be lapped to the same height after mounting; when moderate thermal conductivity is required.

Step One: Because of the short amount of time needed for epoxy to set up, be certain to have your TEC's cleaned and ready to mount before mixing epoxy. Clean and prepare mounting surfaces on both the TEC and heat sink using methanol, acetone, or general-use solvent.

NOTE: It is recommended that acetone and cotton swabs be available so any excess or spilled epoxy (uncured) may be quickly removed.

Step Two: Use Marlow Industries Thermally Conductive Epoxy. Follow the instructions on the package carefully. Be certain to mix the two pouches thoroughly or the epoxy will not cure properly.

- A. Remove the epoxy pack from the protective pouch.
- B. Remove the divider.
- C. Knead well until thoroughly mixed.
- D. Cut a corner and dispense. The epoxy working time is approximately one hour.

CAUTION: Avoid prolonged or repeated breathing of vapor, and use with adequate ventilation. Avoid contact with eyes, skin, or clothing. In case of contact with eyes or skin, flush immediately with plenty of water and get medical attention.

Step Three: Coat the ceramic of the TEC with approximately a 0.05 mm thick layer of epoxy.

Step Four: Place the TEC on the heat sink and gently rotate the TEC back and forth, squeezing out the excess epoxy.

Step Five: Using a clamp or weight, apply pressure (less than $689,465 \text{ N/m}^2$), and cure for two hours at 65°C to maximize thermal and physical properties. Curing time at room temperature is 24 hours.

Mounting with the Compression Method

When to Use: When a permanent bond is not desired; when multiple TEC's are used; or when your TEC is larger than 19mm.

Step One: Prepare heat sink and cold sink surfaces by machining the module area to within $\pm 0.03 \text{ mm}$.

Step Two: Locate bolt holes in your assembly such that they are at opposite sides of the cooler between 3.2mm to 12.7mm from the sides of the thermoelectric. The bolt holes should be in the same plane line as the heat sink fins to minimize any bowing that might occur.

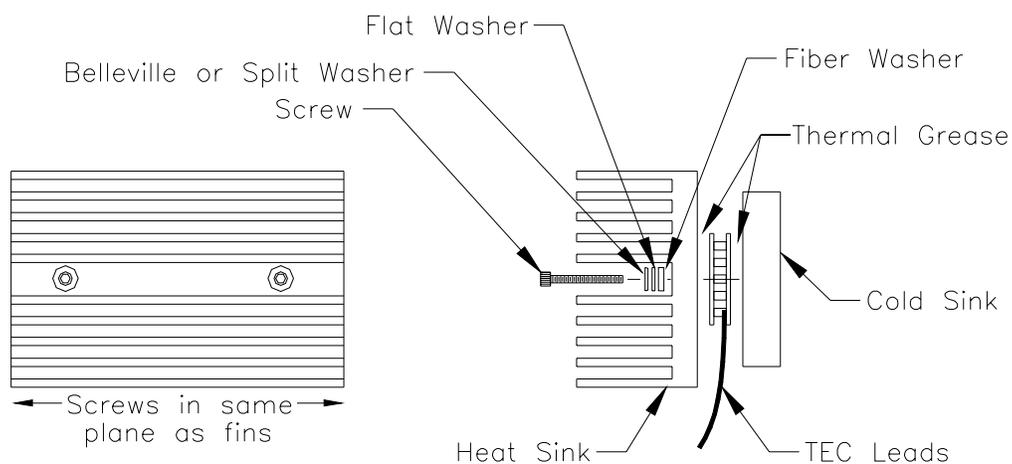
Step Three: The recommended hardware that should be used is: #4-40 or #6-32 stainless steel screws, Belleville or split lock type washers as well as a fiberinsulated washer to insulate the screw head from the heat sink.

Step Four: Remove all burrs. Then, clean and prepare mounting surface with methanol, acetone, or general-use solvents.

Step Five: Apply a thin 0.05 mm layer of Marlow's Thermal grease to the hot side of the TEC. Place the TEC on the heat sink and rotate back and forth, squeezing out the excess thermal grease until resistance is felt.

Step Six: Repeat step 5 and rotate cold plate back and forth, squeezing out the excess thermal grease.

Step Seven: In a two module system, torque the middle screw first. Be careful to apply torque in small increments, alternating between screws. In general, apply less than $1,034,198 \text{ N/m}^2$ ($\text{N/m}^2 = \text{Pascal}$) per square meter of TEC area.



Mounting with Solder

When to Use: When you need minimal outgassing; when the TEC is smaller than 19mm; when you need a high-strength junction; when high thermal conductivity is required.

IMPORTANT: The device to which the TEC is being soldered should be placed on a thermal insulator. This will allow the device to become hot enough to reflow the solder. If necessary, the device may be placed on a hot plate set at 100°C to help heat it to the solder melting point.

Step One: Clean the surfaces to be soldered with methanol, acetone, or a general use solvent to remove oils and residues which would inhibit soldering.

Step Two: With a soldering iron and a new tip, pre-tin the bottom of the TEC (the side with lead wires) using Marlow Industries' Solder 96°C or 117°C and General Purpose Acid Flux. Use small amounts. You can heat the soldering iron to a maximum of 150°C, but extreme care must be taken since most TEC's are constructed with 138°C (min.) solder.

CAUTION: Do not mix solders. Use a separate soldering iron (or a new tip) for each solder.

Step Three: With soldering iron, pre-tin the header or heat sink with the same solder and flux as used in pre-tinning the TEC. Use small amounts.

Step Four: To minimize flux residue, clean both the header and TEC. Rinse them first in hot water, then scrub with Marlow Industries' Cleaning Solution and rinse again with hot water, brushing away any excess flux residue. Finally, wash with methanol and use forced air to blow dry.

Step Five: Prior to mounting the TEC to the header, add a small amount of Marlow Industries' Blue Mounting Flux to the mounting site on the header.

Step Six: Hold TEC with tweezers and align on header. While doing this, maintain a steady, downward pressure.

Step Seven: While holding the TEC in place, put the soldering iron to the header near the solder seam. When the solder junction flows, remove the soldering iron. The downward pressure on the TEC will expel excess solder.

REMEMBER: The solder which holds the TEC together flows at 138°C (min.), so if you are using the 117°C solder do not leave the soldering iron on the header surface too long, or you will melt the TEC solder as well.

Step Eight: Continue holding the TEC in place until the solder solidifies.

Step Nine: Check along all four edges of the TEC, looking for voids, cracks, or bubbles. A smooth seam insures proper thermal conduction.

Connecting Lead Wire to Header

Step One: Trim the excess wire from the TEC. Wrap the lead wires 3/4 of a turn around the connector posts on the header.

Step Two: Using solder and Blue Mounting Flux, solder the lead wires to the wire posts. You should be able to see outlines of the wires, but they should be well covered. Wick off any excess solder with the soldering iron.

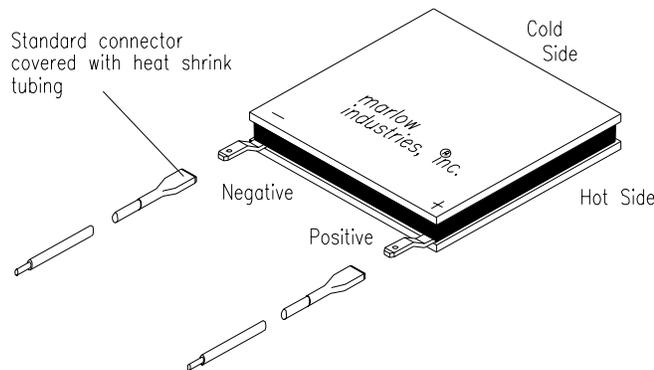
Final Cleaning and Inspection

Step One: Rinse both the header and TEC in hot water, then scrub with cleaning solution and rinse again with hot water, brushing away any excess flux residue around the pins. Wash with hot water and dry with forced air. To insure complete removal of moisture, dry the entire assembly in an oven for 30 minutes at 60°C. If an oven is not available, the forced-air blower is adequate.

Step Two: Check the solder joints for cracks or bubbles.

Lead Wire Attachment

Some thermoelectric coolers use standard 2.8 mm (0.110) spade lug connectors for lead wire attachment. The spade lugs are easily attached by hand. When designing your wiring harness, we recommend that you design the female spade lug connector into the harness. The AMP part number for this female 2.8 mm spade lug connector is 42398-1.



Insertion Procedure: Insert female spade lug over the lead tabs. Use a side-to-side motion to secure the lug on the tab. **DO NOT USE** an up-and-down motion, for this can damage the tab or the tab solder joint. Insert the lug until it seats onto the tab detent.

Preventing Problems

1. Do not use excessive amounts of solder. This can short the power leads and/or inhibit a good thermal interface.
2. Use the proper solder and flux. Marlow Industries' General Purpose Acid Flux is recommended. Without it, outgassing or overheating during soldering may occur.
3. Be sure to clean the TEC thoroughly to prevent outgassing.
4. Do not overheat the TEC with the soldering iron. Because of the narrow temperature differential between the mounting solder (117°C) and the solder used in the TEC (138°C min.), care must be taken not to overheat the TEC and reflow the solder.
5. During soldering, be sure the surface on which the soldering is being done is composed of a low thermal conductivity material. This will prevent the solder iron heat from being drawn away, which can cause difficulties with reflowing the solder.

6. When pre-tinning a large area of the TEC, pre-tin in small sections or purchase the coolers pretinned by Marlow Industries.
7. If a TEC is being soldered to a large header, it may require that the header be placed on a 100°C hot plate. This will minimize heat conduction away from the solder point.

**Table IV
Conversions**

GIVEN	USE	TO GIVE
SI Unit	Factor	English Unit
Watt	.2930711	BTU / hr
m	39.37	in
°C	1.8(°C) + 32	°F
N / m ² (Pa)	.145E-03	lbs/in ²