APPENDIX E

TELLUREX
CORPORATION

The Most Frequently Asked Questions About Thermoelectric Cooling

1. How does this technology work?

The basic concept behind thermoelectric (TE) technology is the Peltier effect—a phenomenon first discovered in the early 19th century. The Peltier effect occurs whenever electrical current flows through two dissimilar conductors; depending on the direction of current flow, the junction of the two conductors will either absorb or release heat. Explaining the Peltier effect and its operation in thermoelectric devices, is a very challenging proposition because it ultimately keys on some very complex physics at the sub-atomic level. Here we will attempt to approach it from a conceptual perspective with the goal of giving readers an intuitive grasp of this technology (i.e., without getting too bogged down in the minutia). In the world of thermoelectric technology, semiconductors (usually Bismuth Telluride) are the material of choice for producing the Peltier effect—in part because they can be more easily optimized for pumping heat, but also because designers can control the type of charge carrier employed within the conductor (the importance of this will be explained later). Using this type of material, a Peltier device (i.e., thermoelectric module) can be constructed—in its simplest form—around a single semiconductor "pellet" which is soldered to electrically-conductive material on each end (usually plated copper). In this "stripped-down" configuration (see right), the second dissimilar material required for the Peltier effect, is actually the copper connection paths to the power supply.

It is important to note that the heat will be moved (or "pumped") in the direction of charge carrier movement throughout the circuit (actually, it is the charge carriers that transfer the heat). In Figure 1 "N-type" semiconductor material is used to fabricate the pellet so that electrons (with a negative charge) will be the charge carrier employed to create the bulk of the Peltier effect. With a DC voltage source connected as shown, electrons will be repelled by the negative pole and attracted by the positive pole of the supply; this forces

Figure 1

electron flow in a clockwise direction (as shown in the drawing). With the electrons flowing through the N-type material from bottom to top, heat is absorbed at the bottom junction and actively transferred to the top junction—it is effectively pumped by the charge carriers through the semiconductor pellet.
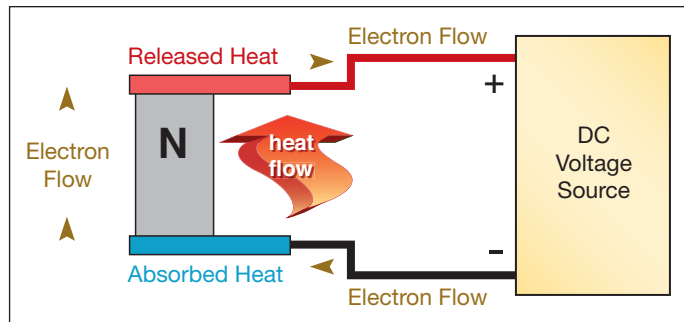
In the thermoelectric industry, "P-type" semiconductor pellets are also employed. P-type pellets are manufactured so that the charge carriers in the material are positive (known in electronics as holes). These holes enhance the electrical conductivity of the P-type crystaline structure, allowing electrons to flow more freely through the material when a voltage is applied. Positive charge carriers are repelled by the positive pole of the DC supply and attracted to the negative pole; thus hole current flows in a direction opposite to

Figure 2

that of electron flow. Because it is the charge carriers inherent in the material which convey the heat through the conductor, use of the P-type material results in heat being drawn toward the negative pole of the power supply and away from the positive pole. This contrasting heat-pumping action of P and N-type materials is very important in the design of practical TE devices (as will be explained in the next question). While Figure 2 —for
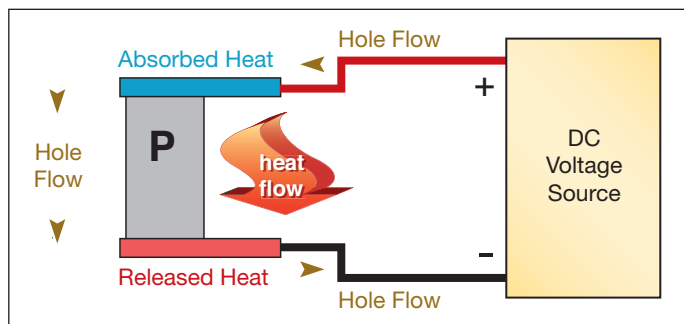
simplicity's sake—shows hole flow through the connections to the power supply, in reality, electrons are the charge carriers through the copper pathways.

2. Why are two types of material (P and N) required?

Unfortunately, while you can make a simple thermoelectric device with a single semiconductor pellet, you can't pump an appreciable amount of heat through it. In order to give a TE device greater heat-pumping capacity, multiple pellets are used together. Of course, the initial temptation would be to simply connect them in parallel—both electrically and thermally—as shown in Figure 3. While this is possible, it does not make for a very practical device. The "fly in the ointment" here, is that the
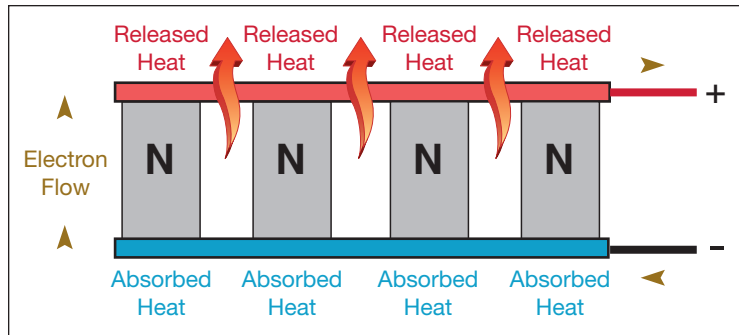

Figure 3

typical TE semiconductor pellet is rated for only a very small voltage—as little as tens of millivolts—while it can draw a substantial amount of current. For example, a single pellet in an ordinary TE device might draw five amps or more with only 60 mV applied; if wired in parallel in a typical 254-pellet configuration, the device would draw over 1000 amps with the application of that 60 mV (assuming that the power supply could deliver that sort of current).

The only realistic solution is to wire the semi-conductors in series, and doing so in a way that keeps them thermally in parallel (i.e., pumping together in the same direction). Here, we might be tempted to simply zig zag the electrical connections from pellet to pellet (see Figure 4) to achieve a series circuit. This is theoretically workable, however, the interconnections between pellets introduce thermal shorting that significantly compromises the performance of the device. Fortunately,

Figure 4

there is another option which gives us the desired electrical and thermal configuration while better optimizing the thermoelectric effect.

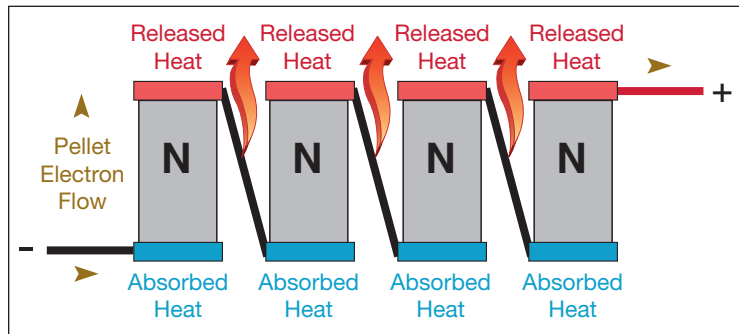By arranging N and P-type pellets in a "couple" (see Figure 5) and forming a junction between them with a plated copper tab, it is possible to configure a series circuit which can keep all of the heat moving in the same direction. As shown in the illustration, with the free (bottom) end of the P-type pellet connected to the positive voltage potential and the free (bottom) end of the N-type pellet similarly connected to the negative side of the voltage, an interesting phenomenon takes place. The positive charge carriers (i.e, holes) in the P material are repelled by the positive voltage potential and attracted by the negative pole; the negative charge carriers (electrons) in the N material are likewise repelled by the negative potential and attracted by

Figure 5

the positive pole of the voltage supply. In the copper tabs and wiring, electrons are the charge carriers; when these electrons reach the P material, they simply flow through the holes within the crystalline structure of the P-type pellet (remember, it is the charge carriers inherent in the material structure which dictate the direction of heat flow). Thus the electrons flow continuously from the negative pole of the voltage supply, through the N pellet, through the copper tab junction, through the P pellet, and back to the positive pole of the supply—yet
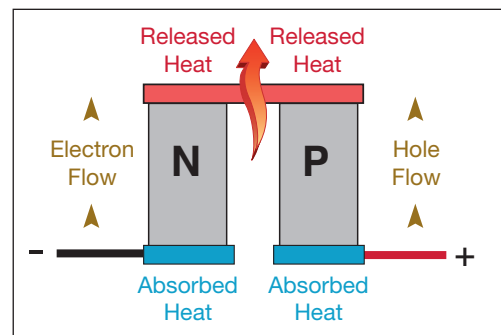
because we are using the two different types of semiconductor material, the charge carriers and heat are all flowing in the same direction through the pellets (bottom to top in the drawing). Using these special properties of the TE "couple", it is possible to team many pellets together in rectangular arrays to create practical thermoelectric modules. (see Figure 5) These devices can not only pump appreciable amounts of heat, but with their series electrical connection, are suitable for commonly-available DC power supplies. Thus the most common TE devices now in use—connecting 254 alternating P and N-type pellets—can run from a 12 to 16 VDC supply and draw only 4 to 5 amps (rather than 1000 amps at 60 mV).

Of course, in fabricating devices with multi-pellet arrays, you must have a means to mechanically hold everything together. A solution is to mount the conductive tabs to thin ceramic substrates (see Figure 7); the outer faces of the ceramics are then used as the thermal interface between the Peltier device and the "outside world". Note that ceramic materials have become the industry standard for this purpose because they represent the best compromise between mechanical strength, electrical resistivity, and thermal conductivity.
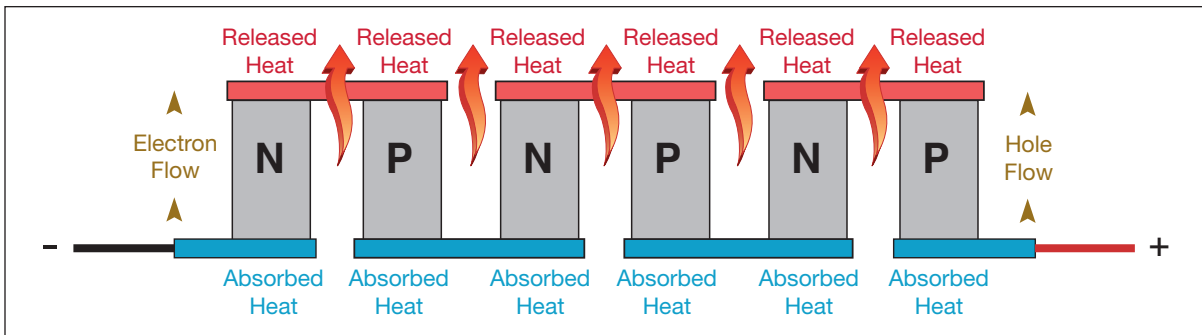

Figure 6

3. Do these P and N couples function like diodes?

No. It is easy to see why many people expect couples to work like diodes, given the pairing of P and N materials, but there is a crucial difference. In the manufacturing of diodes, a depletion region is created between the P and N layers. When the diode is forward-biased, charge carriers are drawn into the depletion region and the diode becomes conductive; when reverse-biased, charge carriers are drawn away

Figure 7

from the depletion region and the diode acts like an open circuit. Without a depletion region, a TE couple cannot act like a diode; the couple will conduct in both electrical polarities and there is no fixed voltage drop across the couple (unlike the nominal 0.6 to 0.7 VDC typically dropped across a forward-biased silicon diode).
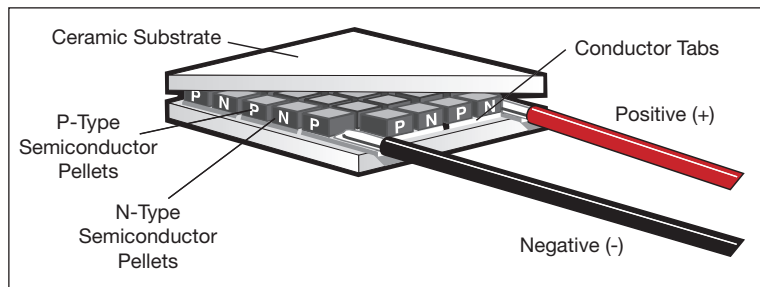
4. How is a typical thermoelectric (TE) system configured?

Let's look conceptually at a typical thermoelectric system designed to cool air in an enclosure (e.g., picnic box, equipment enclosure, etc.); this is probably the most common type of TE application. Here the challenge is to "gather" heat from the inside of the box, pump it to a heat exchanger on the outside of the box, and release the collected heat into the ambient air. Usually, this is done by employing two heat sink/fan combinations in conjunction with one or more Peltier devices. The smaller of the heat sinks is used on the inside of the enclosure; cooled to a temperature below that of the air in the box, the sink picks up heat as the air circulates between the fins. In the simplest case, the Peltier device is mounted between this "cold side" sink and a larger sink on the "hot side" of the system. As direct current passes through the thermoelectric device, it actively pumps heat from the cold side sink to the one on the hot side. The fan on the hot side then circulates ambient air between the sink's fins to absorb some of the collected heat. Note that the heat dissipated on the hot side not only includes what is pumped from the box, but also the heat produced within the Peltier device itself (V x I). Let's look at this in terms of real numbers. Imagine that we have to pump 25 watts from a box to bring

its temperature to 3°C (37.4°F) from a 20°C (68°F) ambient. To accomplish this, we might well have to take the temperature of the cold side sink down to 0° C (32°F). Using a Peltier device which draws 4.1 amps at 10.4 V, the hot side of the system will have to dissipate the 25 watts from the thermal load plus the 42.6 watts it takes to power the TE module (for a total of 67.6 watts). Employing a hot side sink and fan with an effective thermal resistance of 0.148 C°/W (0.266F°/W), the temperature of the hot side sink will rise approximately 10°C (18°F) above ambient. It should be noted that, to achieve the 17° C drop (30.6°F) between the box temperature and ambient, we had to create a 30° C (54°F) temperature difference across the Peltier device. (see Figure 8)
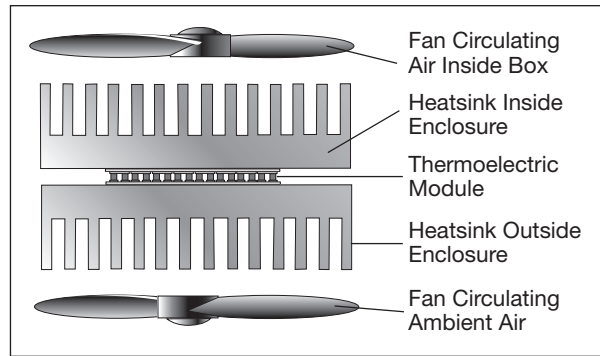

Figure 8: Conceptual drawing of air-to-air Thermoelectric Cooling System

5. Can thermoelectric systems be used for heating, as well?

Yes. One of the benefits of TE technology is that you can switch the direction of heat pumping by simply reversing the polarity of the applied voltage—you get heating with one polarity, cooling with the other. Thermoelectric modules make very efficient heaters—in fact, because of the unique properties of Peltier devices, any given TE system will have a greater capacity for heating a load than cooling it.

6. Are TE systems used only for heating or cooling air?

No. Systems are often designed for pumping heat from both liquids and solids. In the case of solids, they are usually mounted right on the TE device; liquids typically circulate through a heat exchanger (usually fabricated from an aluminum or copper block) which is attached to the Peltier unit. Occasionally, circulating liquids are also used on the hot side of TE cooling systems to effectively dissipate all of the heat (i.e., a liquid-to-liquid system). Note that liquid cooling is never achieved by immersing the Peltier device in the fluid—thermoelectric modules are not the equivalent of "electric ice cubes".

7. Do I have to use a heat sink in my design?

Whether heating or cooling a thermal load, you must employ some form of heat sink to either collect heat (in heating mode) or dissipate collected heat into another medium (e.g., air, water, etc.). Without such provisions, the TE device will be vulnerable to overheating; once it reaches the reflow temperature of the solder employed, the unit will be destroyed. When the heat sink is exchanging heat with air, a fan is usually required, as well.

8. Can these devices be immersed?

Only for cleaning purposes and never while under power. TE devices should always be dry when under use to prevent thermal and electrical shorting.

9. What type of products currently use this technology?

There are an increasing number and variety of products which use thermoelectric technology—from picnic boxes to water coolers, laser applications, and highly-specialized instrumentation and testing equipment. The compatibility of many TE's with automotive voltages, makes them especially suitable for small cooling jobs in that industry. With each new year, the imaginations of design engineers widen with the immense possibilities of thermoelectric heating and cooling.

10. Why would I want to use a thermoelectric system instead of compressor-based technology?

Both technologies have their advantages and disadvantages, but where thermoelectric technology really shines, is in making it feasible to do very small cooling jobs—ones which would be wholly impractical with a compressor-based system. Can you imagine cooling an individual integrated circuit with compressed gasses? What about thermally cycling a test tube or cooling a very small enclosure? TE's are also strong in products which demand both heating and cooling in the face of a changing operating environment; here a simple switching of TE

current polarity allows the system to shift to the mode required. In addition, unlike compressor technology, TE system components can be mounted in any physical orientation and still function properly. Of course, one other advantage of TE systems, is that they do not require evaporative chemicals which may be harmful to the environment. Thermoelectric devices open up a whole new world to cooling and heating possibilities.

11. Are there situations where compressor-based systems make more sense?

Yes. Generally, whenever a small compressor-based system would clearly be "overkill" in providing a cooling solution, TE systems become the most viable choice. You find a "gray area" amidst the medium-sized cooling jobs; here decisions ultimately come down to critical cost/benefit or design engineering considerations which are unique to each application. Given the present state of technology—unless there are unique overriding concerns—the compressor-based approach has distinct advantages in larger cooling systems such as standard-sized refrigerators and air-conditioning systems for buildings & vehicles. However, ongoing research into materials may one day make thermoelectrics practical for many of these larger applications.

12. For heat-only applications, do thermoelectric devices have advantages over resistive heaters?

Yes. Resistive devices create heat solely by virtue of the power dissipated within them. TE devices, on the other hand, not only provide this I^2R heating, but also actively pump heat into the thermal load; this, potentially, makes them much more efficient than resistive heaters. Unfortunately, the need for a DC power source and the generally higher cost of TE systems compared to resistive heaters, precludes their use in most heat-only applications. Furthermore, Peltier devices have a far more limited temperature range than most resistive heaters. Generally, TE devices are only used for heating in systems that also require cooling.

13. Why would I want to use thermoelectric technology instead of a passive cooling system (heat sink and fan alone)?

With passive cooling, at best, you can only limit the rise of temperature above the ambient condition. On the other hand, TE systems (like compressor-based approaches) can actively pull heat right out of a thermal load; this makes it possible to reach below-ambient temperatures.

14. How cold can these devices get?

That depends upon a great many things—ambient temperature, the nature of the thermal load, optimization of current delivery to the TE device, optimization of heat sinks etc. It is theoretically possible to get a ΔT (hot side to cold side) of around 75° C working against a T_{HOT} of 35° C (note that this is the temperature drop across the TE device, itself, and does not include system losses such as the hot side's temperature rise above ambient). However, this theoretical maximum only occurs if there is no thermal load—which is not going to happen in a "real" system. In a typical application, you will achieve about half of the theoretical maximum using a single-stage TE device. In order to reach colder temperatures, a multi-stage approach must be employed, either by using multi-tiered Peltier devices, or by using other technologies to create part of the desired ΔT. For example, you might use a compressor-based system to provide a below-ambient condition for the hot-side of a TE device, then employ Peltier cooling to further reduce the temperature of your load—this is sometimes done to get down into cryogenic levels. It should be noted, however, that TE devices become less efficient at colder temperatures and the ratings for ΔT will be markedly reduced when you operate under extremely cold conditions. Furthermore, even though multi-stage Peltier devices can achieve greater ΔT's, they have much less cooling capacity (in terms of watts pumped) than their single-stage counterparts and are far more expensive to produce. At this juncture, Tellurex Corporation has elected to focus its time and energies exclusively on the more efficient single-stage devices.

15. Can I physically stack TE devices to get a greater ΔT?

Yes . . . but it is not so simple as merely stacking two identical Peltier devices, one on top of the other. The critical reality here is that the second device must not only pump the heat from the thermal load plus its own internal power dissipation (I^2R), but it also must remove the heat dissipated within the first TE device. It is usually most sensible from a cost standpoint, therefore, to employ a much smaller device on the first stage than the second. Be aware in stacking modules, however, that the overall heat-pumping capacity (in watts) of the stack will be limited to the throughput of the smallest device (while DT is enhanced with multi-staging, Q is sacrificed).

16. How hot can these devices get?

This is purely a function of the melting temperature of the solder employed in manufacturing the device. The standard Z-Max® line of Peltier devices is rated for 100°C. Tellurex also manufactures another line of devices which can reach temperatures of 200° C. In either case, it is very important that users keep temperatures below the specified rating for THot; if the solder reflows, the device will be compromised or destroyed.

17. Can these devices be used at cryogenic temperatures?

Yes, but they are far less efficient in this range. Note that you cannot achieve cryogenic temperatures from a single-stage Peltier device working against a typical room temperature ambient.

18. Does ZMax® offer any performance advantages over other thermoelectric technologies?

Definitely! The technology behind the patented ZMax®, offers performance which is unachievable with the more conventional processes employed by other manufacturers. Tellurex is the only company in the world that is currently producing these unique hybrid devices—thus it is the world's *"performance leader"*.

19. How big can these devices get?

Theoretically, there is no limit, but practicality does impose some restrictions. Issues related to thermal expansion/contraction—and cost—tend to keep module sizes down. Typical devices range up to 50 mm (2") square and about 4 mm thick, but there are exceptions. In the general case, when greater cooling capacity is required, multiple TE devices will be employed in the solution rather than fabricating some sort of gargantuan module.

20. How small can these devices get?

Here again, the theoretical limit goes far beyond what is practical. Devices are commonly manufactured at sizes well below 8 mm square, many for such applications as laser diode cooling. Very small modules, however, are more expensive to produce because they are less suitable for automated processing—many of them, in fact, require manual attention under a microscope. As a result, in creating designs for very small cooling jobs, devices must be carefully optimized for cost as well as size and capacity.

21. Is it possible to purchase custom devices?

Yes, but the expense for new tooling will be included in the overall cost. Whenever possible, it is generally more cost-effective to employ a stock item. To explore the possibilites, contact a Tellurex sales representative.

22. What does the specification, TCold, mean?

This is the temperature at the cold-side mounting surface of the Peltier device (See Figure 9).

23. What does the specification, THot, mean?

This is the temperature at the hot-side mounting surface of the Peltier device.

24. How can I measure THot or TCold in a thermoelectric assembly?

This is somewhat challenging because you have to get the measuring device as close as possible to the outer

Figure 9

ceramic of the Peltier device while it is in operation. The best choice of sensor here is typically a non-sheathed thermocouple fabricated from fairly fine wire. One way to approach the placement of the thermocouple, is to take the heat sink or block which will be mounted to the TE device and cut a shallow groove at the interface. The thermocouple wire can then be placed so that it will be in close proximity to the module's center once the system is assembled. Of course, except for the exposed end of the thermocouple, the wires should be electrically insulated along the length of the groove to prevent shorting. The thermocouple should be potted into
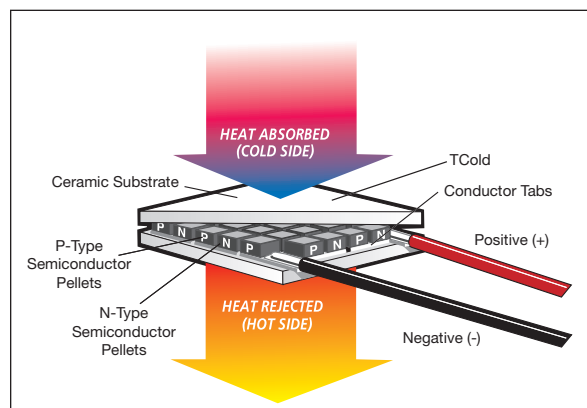
the groove using a thermally-conductive adhesive; be sure to clean off any burrs or excess adhesive to maintain the flatness of the interface.

A compromise which can sometimes be employed when using heat sinks, is to mount the thermocouple on the fin side of the sink (at the base), opposite the center of the TE module. The thermocouple should then be covered with a small piece of insulating foam. Some accuracy will be lost with this method because of the inevitable thermal gradient between the thermocouple and module surface, but it can yield an acceptable approximation.

Some people have attempted to mount fine thermocouples on the inside of Peltier devices to measure these parameters, but this is generally not a good idea. First of all, it would be difficult to successfully mount a thermocouple on an interior surface and there would be significant potential for damaging the device in the mechanical manipulation. Also, without any form of insulation on the inside, the thermocouple would actually pick up a thermal gradient between the ceramic surface and the air temperature inside the device. Other thermal gradients within the module could also effect the accuracy of the reading. If a data acquisition system is employed to measure system variables, there would also be a potential for introducing a ground loop if the thermocouple touches anything which is electrically live.

25. What does the specification, VMax, mean?

Contrary to what many people might expect, this quantity is not the maximum voltage that the device can withstand before failing. Actually, VMax is the DC voltage which will deliver the maximum possible ΔT across the thermoelectric device at a given THot. At voltages below VMax, there is insufficient current to achieve the greatest ΔT; at voltages above VMax, the power dissipation within the Peltier device begins to elevate the system temperatures and diminish ΔT. Note that VMax is temperature dependent—the higher the temperature, the higher the VMax rating for a specific device.

26. What does the specification, IMax, mean?

Again contrary to what many people might expect, this quantity is not the maximum current that the device can withstand before failing. IMax is the direct current level which will produce the maximum possible ΔT across the TE device. Operating below IMax, there is insufficient current to achieve the greatest ΔT; when drawing more than IMax, the power dissipation (I^2R) within the Peltier device begins to elevate the system temperatures and diminish ΔT. Note that IMax and VMax occur at the same operating point, i.e., IMax is the current level produced by applying VMax to a Peltier device. Unlike VMax, IMax is not especially temperature dependent— it tends to be fairly constant throughout the operating range of a device.

27. What does the specification, QMax, mean?

QMax is one of the more confusing specifications in the TE world because its practical significance is not obvious. Its definition relates to a fundamental reality: as the thermal load (i.e., "Q') increases within a given TE system, the resultant ΔT decreases. Within any given hardware environment, for example, you will have a lower ΔT with a thermal load of 40 watts than at 30 watts. At a certain load specification, the ΔT will be reduced to zero; the load which produces this condition, is known as QMax and it is quantified in watts. Note that this specification does not project the maximum amount of heat that the device can handle; if your load goes beyond QMax, you still pump heat, but your thermal load simply winds up at an above-ambient temperature. The primary relevance of QMax as a specification, is that it is commonly used as an endpoint for "load lines" on performance graphs.

28. What does the specification, ΔTMax, mean?

This is the maximum possible ΔT across a Peltier device for a given level of THot. This point always occurs when the thermal load (Q) is at zero watts. ΔTMax is the other endpoint for load lines on performance graphs.

29. What does the specification, Coefficient of Performance (COP), mean?

Coefficient of performance is an indicator of the efficiency of a thermoelectric cooling (or heating) system. It is essentially the ratio of: 1) the heat pumped by a TE module (in watts), and 2) the amount of power supplied to the TE device. Put mathematically, COP = Q / ($V_{TE} * I_{TE}$) where Q is the number of watts pumped, and V_{TE} and I_{TE} are the voltage and current supplied to the thermoelectric module.

30. Why are there separate performance graphs for different values of THot?

Because Peltier devices are temperature dependent. Peltier modules have a positive temperature coefficient with respect to resistance, DTMax, QMax, and other related phenomena, and these realities must be reflected in the performance literature.

31. Can these devices be connected electrically in series, parallel, or series-parallel?

Yes. As long as you provide sufficient voltage and current capability from your power supply, TE devices may be connected in any series/parallel configuration that makes sense for the application.

32. Are there any advantages to connecting modules in series vs. parallel or vice versa?

Under ordinary circumstances, no. The amount of heat pumped by each module will be a function of the voltage and current delivered to it; whether this delivery is a result of series, parallel, or series-parallel connections is of little consequence. Parallel wiring does, however, offer some protection against a TE device or connection failure—with parallel TE modules there will still be some cooling capacity even if part of the circuit becomes dysfunctional. With series connections, if anything in the current path opens, all cooling power will be lost.

33. Why do I need a DC power supply for this technology?

To keep heat pumping in the same direction, the polarity of the applied voltage must be maintained. This means that some form of direct current is required. If alternating current was applied instead, the polarity would change each half cycle, and so would the direction of heat pumping. As a result, the net amount of heat moved would be zero and both sides of the system would get warmer from the I^2R dissipation within the Peltier device.

34. In varying power to these devices, should I change the voltage or the current?

According to Ohm's Law, $I = V / R$. Current is the dependent variable here—while you can have voltage without current, you cannot have current without voltage. Any time you apply voltage to a resistive load, current will flow, and if you vary the level of voltage, you will vary the level of current which results—Ohm's Law must be obeyed! In most cases, you will choose a voltage level which gives you the desired results. There are some application niches where "current sources" are commonly used, but in reality, these current sources electronically control the applied voltage in order to guarantee a particular level of current; it only seems like the voltage results from the amount of current put through the TE device.

35. Are the Peltier devices purely resistive?

They are mostly resistive. While there is some capacitance in a Peltier device, it is very negligible, and given the fact that DC is applied, it presents no real barriers in applications. Inductive effects are mostly confined to the leads of the Peltier device and typically present few problems unless the device is being driven with some form of pulsed DC. If this type of power is employed, it is generally advisable to shield the leads and keep them separated from any signal wiring to minimize difficulties. You will see transient inductive effects in the leads whenever power is switched on or off; if these could be problematic, take precautions.

The most notable non-resistive characteristic is Seebeck effect. Just as charge carriers can move heat, the movement of heat through an electrical conductor will carry charge carriers along with it. Thus, whenever a temperature difference is placed across a TE device, a small voltage will develop; if an electrical load is placed across the device, current will flow. This phenomenon is called "Seebeck effect". Similarly, when a Peltier device is placed under power and a ΔT develops, the ΔT creates a "back EMF" (or "back voltage") which opposes the applied voltage. This "Seebeck voltage" is not something that you can see or measure while external voltage is powering the Peltier device, but the circuit acts as if the Seebeck voltage is subtracted from the applied voltage. This, naturally, results in a lower current level than you might otherwise expect and makes the Peltier device appear to be more resistive than it really is. Incidentally, you can measure the Seebeck voltage when TE power is disrupted, although as the ΔT decreases from the back flow of heat, the Seebeck voltage will gradually decay to zero.

36. Do I need a well-regulated DC power supply for my thermoelectric system?

This would only be required if you need well-regulated power for other circuitry that will run from the same supply. Nonetheless, many customers choose regulated switching supplies for thermoelectric systems out of consideration for size, weight, and efficiency. In high volume applications, some users have effectively employed custom, non-regulated switchers to strike a good compromise between price and performance. Those who want to keep things simple, can use a non-regulated, linear supply with a "brute force" filter capacitor; these circuits do tend to be bulky, however. In this latter case, ripple should be kept below 15% to maximize power output to the TE modules. Unfiltered DC (i.e., rectification only) at line frequencies is not recommended because of the inefficiencies and thermal stresses imposed; this sort of power is especially problematic if the peak voltage exceeds VMax (see next question).

37. If I have an available power source which exceeds VMax, can I pulse-width modulate it to reduce the effective DC level?

No! No! No! Because this sort of approach usually works with resistive heaters, a significant number of designers seize upon this idea to avoid having to translate their available DC supply voltage to a more suitable level. The only problem is that it doesn't work with thermoelectrics. Why not?

Let's say that we want to apply a pulsed DC at twice VMax with a duty cycle of 50%. If this was powering a conventional resistor, we would simply look at the effective power dissipation over the full cycle of the pulsed DC and proceed accordingly. Unfortunately, Peltier devices present some extra complexities which cannot be overlooked. The crux of the matter is that the Peltier device can only pump heat when current is flowing. We thus have to look at what is happening in each separate phase of the cycle.

When power is on (voltage high), we are driving the TE device at twice its rated VMax; what happens during this interval is no different than what happens when powering a module at twice VMax continuously. With so much power dissipated (V^2/R) within the device, there is no capacity left for pumping any heat from the thermal load—in fact, some of the excessive heat within the module will flow back into the load. When power is turned off in the other part of the cycle, it is true that no power is being dissipated within the Peltier device, but without current flow, it's not pumping any heat either. Thus when power is on, you are operating a bad thermoelectric system which creates heat rather than removing it from the load; when power is off, no active cooling work is being done. Nothing good is achieved in the process.

38. Can I use pulse-width modulation to control my Peltier device if I keep the voltage at VMax or below?

Yes, and this is one of the most electrically-efficient ways to control voltage to your device—although you must observe some precautions. As long as you keep the voltage at VMax or below, you will effectively pump heat whenever the duty cycle applies voltage to your system; when the power is turned off, the heat pumping will stop. By pulse-width modulating a suitable voltage, you can easily control the extent of heat pumping by simply varying the duty cycle of the pulses. The great thing about this approach, is that it allows you to minimize power dissipation in your control circuit—especially if you use power MOSFET's for switching (a subject which goes beyond this particular question).

Significant precautions must be employed with PWM, however. First of all, the PWM should be at a high enough frequency to minimize thermal stresses to the TE devices. The "Rule Of Thumb" recommended by Tellurex, is that thermoelectric devices should be pulsed at a frequency of 2000 Hz or higher. Another important issue is the potential for generating electro-magnetic interference (EMI) in the wiring to the TE device. If you are using PWM, always shield your power wiring and keep it away from any sensitive electrical signals.

39. If I use enough TE devices in series, can I just rectify voltage from the wall socket to get 120 VDC?

This is, indeed, a "frequently asked question" when dealing with large-capacity systems. Unfortunately, the answer is not as straightforward as it might seem.

First of all, the only way that you will get "120 VDC" from a wall socket (assuming that your electrical service is 120 VAC) is if you leave the rectified voltage unfiltered (i.e., at 100% ripple). It is important to note that the 120-volt rating is the RMS equivalent of the sinusoidal waveform; this is equal to about 70.7% of the peak voltage.

Once you use a capacitive filter on the rectified AC to create "steady-state" DC, the resulting output will only be slightly lower than the peak value—approximately 170 V (less diode drops and ripple).

To make this approach work, therefore, you would need to place additional devices in your series circuit (about 40% more, in fact) to avoid exceeding the VMax rating of the thermoelectric components.

There is another option for getting steady-state DC from an AC line at a lower voltage, but it is seldom practical in TE systems. By using an inductor in series with the TE devices (and a capacitor in parallel with them), you can get a filtered voltage at around 108 VDC (less diode drops and losses). Given the current demands for a typical TE device, however, this would require a pretty "beefy" and expensive coil. The losses in wire resistance and core currents would be significant with this solution, as well.

Figure 10

Of course, some people would be tempted to simply use the 120 VAC unfiltered, but this is not a good idea. As stated earlier, the fluctuating voltage at low frequency puts the devices under appreciable thermal stress. It is important to remember, as well, that the series circuit must still have a combined VMax rating of at least 170 VDC or heat-pumping performance will suffer greatly (just as it does when pulse-width modulating an excessive voltage—see Figure 10).
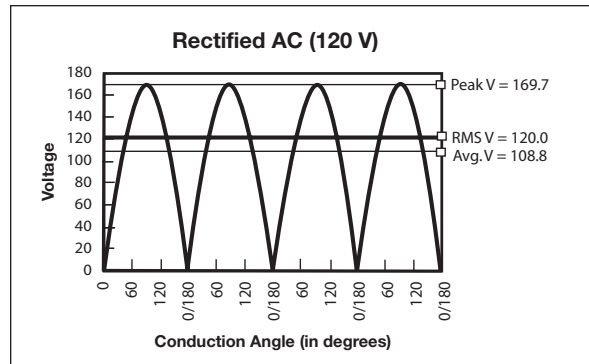
The potential problems go beyond the mathematics and filtering, however. One of the biggest concerns is safety. Thermoelectric modules are typically sandwiched between heat exchangers fabricated from electrically-conductive metals. While ordinarily this should not cause a problem, with the close proximity of components, there is a genuine risk that hazardous situations can develop when the circuit is connected directly to an AC line. It is always possible that a wire lead can get pinched or debris can cause a short between a module and the heat exchangers. With low-voltage DC, this is seldom a problem; however, when you have a series of TE modules connected to the AC line (or high voltage DC for that matter), one of the exchangers can become dangerously "live". If a designer pursues this approach in spite of the risks, a ground fault interrupter is essential; an isolation transformer is also highly recommended.

40. Can I use linear drive (either voltage or current) to regulate the temperature of my thermoelectric system?

Yes. Typically this is done by placing a bipolar junction transistor (BJT) in series with the TE device(s). Of all the options for regulating power to TE's, linear control (done properly) is the one which imposes the least thermal stress on Peltier devices. On the downside, a lot more power is dissipated in the linear BJT drivers than with MOSFET's in a PWM controller—and this will translate into greater costs for semiconductor heat management. However, when PWM cannot be easily accommodated in a system because of EMI or power conditioning considerations, linear control may be the only viable option.

41. Can I cycle the device on and off for temperature control?

Thermostatic operation (on-off) is one of the more affordable modes of control and is a tempting option. With this approach, cooling (or heating) power is turned on at one temperature and off at another. This means that the system will continually bounce back and forth between two temperature limits; as a result, it is not a good alternative if steady-state performance is desired. An additional issue here is cycle time. Slow cycle times are just like low-frequency pulse-width modulation (PWM) in their potential for thermally stressing TE devices—and we ideally want to keep PWM above 2000 Hz. If thermostatic control is to be employed, therefore, it is probably best to keep the cycle time in the range of tens of minutes or more.

42. Can I use a mechanical device like a snap switch for thermostatic control?

Yes, but make sure that you check that device's DC ratings. Most snap switches are designed for AC applications; with DC, the potential for arcing and damaging switch contacts is much greater. Usually, mechanical switching devices of any sort (including relays and toggle switches) will have much shorter life

projections and lower current ratings in DC applications. Of course, cycle time will be an issue here just as it is with electronic forms of thermostatic control. 43. Can I configure a controller to switch between heating and cooling modes?

43. Can I configure a controller to switch between heating and cooling modes?

Yes, this is commonly done. It is most often accomplished with a DPDT relay (watch for the DC ratings on any device you are considering) wired in the classic polarity-reversal configuration, but sometimes designers will employ a transistor bridge (using MOSFET's) to combine the switching and control
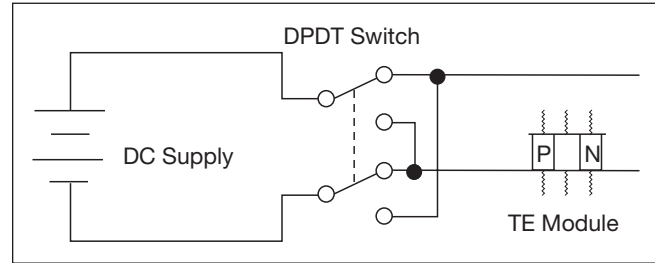
Figure 11

architectures. You can also change modes manually by toggling an appropriately-rated DPDT switch. If using anything other than a DPDT switch or relay, you must design your circuit to guard against transient conditions that can occur when mode changes are made, otherwise you may create damaging short-circuits across your power supply. In automatic controls, a suitable "deadband" for triggering mode changes is also recommended to prevent "chattering" (i.e., high frequency toggling between modes). (See Figure 11)

44. Can I use a solid state relay to drive my TE device?

Yes, but this would not be the best choice in the vast majority of situations. If you want to switch power electronically, power MOSFET's are far more advantageous—they're cheaper, smaller, and if chosen properly, dissipate much less power for a given level of TE current (because of markedly lower on resistances).

45. Can I control the temperature of my load by just using a variable power supply to set a fixed DC level?

Not usually. This can only work if there is absolutely no change in your thermal load or the ambient environment. The hallmark of temperature control is keeping the temperature steady despite disruptions caused by varying load or environmental conditions. To accomplish this, you must employ some type of temperature sensor in a closed-loop controller that will provide just enough power to the Peltier devices to hold thermal load at the desired temperature. In a cooling application, if the room temperature increases, the closed-loop control circuit will detect this change and provide extra cooling power to keep your thermal load where you want it. If the thermal load (in terms of watts) changes, the controller can detect this condition and vary cooling power as required. Without a temperature sensor and a closed-loop control circuit, any variance in your operating conditions will be reflected in a change of the temperature of your thermal load. If you want stability, you must use a "real" control circuit.

46. How closely can temperature be controlled with thermoelectric technology?

With a properly tuned, well-designed, steady-state controller (typically using some form of 'PID' control), it is possible to maintain temperatures to well within 0.1° C of set point providing there are no "dramatic" (i.e., large and sudden) interruptions in the operating environment. Indirect measurements of stability, have suggested that it is possible to achieve constancy to within a few hundredths of a degree (some even claim thousandths), but it is virtually impossible to verify this level of performance directly. In discussing the potential for stability, of course, it is important to stress that any given thermal load will show temperature gradients and parts of the load will exhibit variance from the set-point no matter how stable it may appear on a digital display—you cannot assume a homogeneous response across your entire load. Designers must also be wary of subtle long-term problems such as set-point drift or loss of calibration.

47. Is it possible to use inexpensive temperature controllers with this technology?

That depends on what your objectives are. If you can live with single mode control (i.e., just heating or just cooling), a reasonable amount of error, no display of temperatures, and a fair amount of variability in resulting temperatures, you have a real chance at keeping costs down. If it's a high-volume application, as well, you may even get the cost to under $10 per controller on an OEM basis (aggressive shopping will be required) if you

buy directly from the circuit board manufacturer. On the other hand, if you need tight control, minimal error, a display, alarms, etc., these features will come at a premium. The more demanding your needs, the more the cost will grow geometrically.

48. Are there lots of complete temperature control solutions available "off-the-shelf"?

Unfortunately, no. In many applications, some level of custom circuitry will be required to tailor a controller for thermoelectric technology. The biggest problem is that most off-the-shelf controllers are designed for other types of heating and cooling hardware (most of it driven by AC power), and they are not well-suited—by themselves—for controlling Peltier devices. For example, most PID controllers which provide a pulse-width-modulated output, have a maximum frequency of one cycle per second and this is far from ideal. Thankfully, many of these controller designs also offer options for analog outputs which can then be translated into either linear control or higher-frequency PWM; unfortunately, a custom interface circuit must be constructed for this purpose. In dual-mode applications, it is necessary to translate separate analog signals for heating and cooling, into the TE drive and mode signals which are required. Another potential obstacle for some applications, centers on the reality that the vast majority of off-the-shelf controllers run on 120 or 240 VAC power; there is a distinct void in the marketplace for options which can be powered from low-voltage DC.

There certainly are some temperature controllers which are designed specifically for Peltier technology; unfortunately, most were created for a specific system and then marketed for other types of applications where they are less optimal. Maybe they'll meet your needs, maybe they won't. Shoppers must be very wary in evaluating these types of products—many are not quite what they appear to be. For example, some ads show digital displays, but do not make it clear that the displayed value is the resistance of a thermistor or RTD rather than temperature. Many times, the TE power supply will be integrated into the controller and it may not give you the kind of flexibility that you require. In other cases, very ambitious stability figures are cited. When someone claims to deliver stability in the range of thousandths of a degree, it certainly begs questions of how this phenomenon was tested. Not only is it very difficult to dependably measure to that standard, but thermal gradients in the load, thermal noise, and thermal transients would likely swamp the published figures in many applications. All of this underscores the need to consider temperature control options very carefully.

49. Is there a limit to how many TE devices I can use in a system?

Theoretically, no, although at a certain point, compressor-based systems become more cost-effective than using a huge array of TE devices. When you employ many devices in a single fixture, there can be some challenging hardware issues related to clamping methods and managment of thermal expansion and contraction, but it certainly can be done.

50. How fast can I cool with this technology?

This is not a simple question to address because so many factors are involved in any given thermoelectric system. Cooling is not an instantaneous process and every system will have a "time constant" which characterizes its ability to pump and redistribute heat over time; this time constant will be a function of the number of TE's employed, the nature of the heat sinks and fans which are used, the quality of the thermal interfaces, etc. Your maximum ramp rate will, therefore, depend greatly on how much cooling capacity you design into your solution—and this may be limited by cost and physical practicalities. It ultimately comes down to the number of watts which have to be pumped to achieve the desired rate of cooling; you then must identify the number of TE devices it will take to do the job and configure suitable heat-sinking to make everything work. Complicating matters is the fact that, as DT increases, the amount of heat removed from the load will decrease (it takes more power to maintain the greater temperature difference), so it becomes very challenging to model and project a theoretical response curve for any specific system.

There is one more consideration which imposes a practical limitation on cooling rates—with differential expansion/contraction responses among the component materials, excessive ramp rates will destroy Peltier devices. The recommended upper limit for Tellurex devices is 1° C per second (heating or cooling) and even this

will shorten the useful life of the module. New manufacturing and materials technologies hold out the promise that this range can be extended, but generally, designers should keep ramp rates well within these specified limits to insure long product life.

51. Are there any special considerations which apply to "clamping" the device?

Generally, machine screws are used to compress the Peltier device between the hot and cold sides. Because thermoelectric devices can be crushed through improper handling, some care must be taken in designing and implementing the clamping method. For optimal results, try to use only two compression points per module (if possible) and keep them in close proximity to the device (usually within 0.25"). Naturally, the two compression points should be along the center line of the module. In bringing up tension on the machine screws, take extra care to adjust slowly at each compression point and alternate between the two frequently; in this way compression across the surface area of the module can be roughly equalized throughout the adjustment process. A common error is to tighten one side so that it tips below the top surface of the module (Fig. 12); then when pressure is increased on the opposite side, it creates leverage which crushes the module (Fig. 13). The greater the number of compression points or their distance from the module, the greater the likelihood of damaging the module in this manner. Patience is definitely a virtue here.
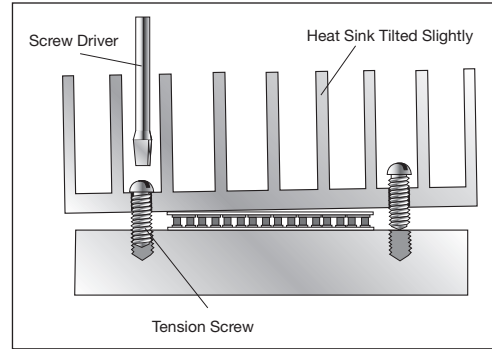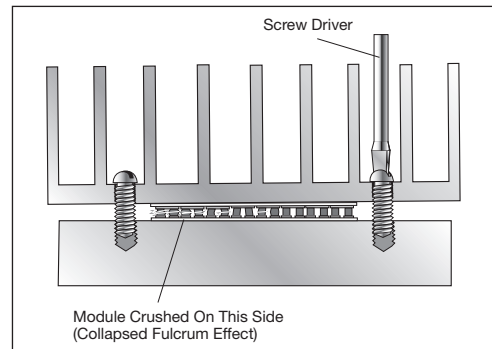

Figure 12

Figure 13

With multiple device deployment, it is not always possible to use two screws per device, and sometimes the space between the compression points will span more than one module. Here, the user must watch out for bowing of the mechanical interface; this can not only damage the Peltier devices, but compromise the thermal interface, as well. In these instances, it is usually best to decrease the amount of compression to insure flatness.

52. Where do I start in designing a TE system?

If you are doing a heat/cool application, focus first on the cooling side of the equation; if you have enough capacity for cooling, you should have plenty for heating. Establish some initial design parameters. What load temperature do you want? What is your worst-case ambient (always design against the worst case)? What is the targeted temperature rise for your hot side above the ambient? Do you have constraints on available power for your system? If so, what are they? What physical limitations do you face (space, weight, harshness of environment, etc.)? Are there sources of radiant heat in the environment?

Probably the most challenging area in design, is coming to terms with your load. Thermal load is made up of two distinct components—active and passive. The active load is the part which actually creates heat. For instance, if your thermal load is an electrical circuit, its power dissipation would be the active load. In some cases, there will be no active load—this is the situation with a picnic box, for example.

Much of the load in any TE system will be passive. Passive load is the amount of heat (in watts) which must be pumped to maintain the temperature difference between the load and the ambient environment. It is like bailing out a leaky boat; water (like heat) is continually coming in and you must labor to pour out a comparable volume to maintain the level of the boat. The greater the DT you require between your load and the ambient, the greater the passive load will be.

Once you know all of these quantities, you can begin looking for a thermoelectric solution which conforms to your requirments.

53. How can I determine the magnitude of my passive load?

The transfer of heat from a load to the ambient environment, is largely a function of two thermal processes—conduction and convection. Conduction is the transfer of heat through matter (insulation, structural components,

seals, fasteners, etc.) and is a function of the temperature difference (i.e., ΔT) across the material, the physical dimensions, and the thermal conductivity of the material (K). Convection is heat transfer across the boundary layer of air at the surface of a material. It is a function of the ΔT across the boundary layer and the rate of air movement at the surface—the faster the air movement, the greater the convection of heat.

With a well-insulated thermal load (e.g., an insulated enclosure), convection is a relatively inconsequential component and you can often focus exclusively on the conductive element. The following equation can be used to estimate a purely conductive load:

$Q = \frac{\Delta T \cdot K \cdot A}{L}$ where

Q   is the amount of heat conducted (it can be expressed in either BTU/hour or watts, although in the themoelectric industry, most support documentation is based on wattage);

ΔT   is the temperature difference between the thermal load and the ambient environment (in F° for BTU/hour calculations, in C° for watts);

K   (Kappa) is the thermal conductivity of the material expressed in either BTU/hour-feet-F° or watts/meter-C°;

L   is the thickness of the material (in feet for BTU/hour calculations, meters for watts); and

A   is the exposed surface area of the material (in square feet for BTU/hour calculations, square meters for watts).

If you want to include both the conductive and convective components of the load, you can use this equation:

$Q = \frac{A \cdot \Delta T}{\frac{L}{K} + \frac{1}{h}}$ where

Q   is the amount of heat conducted and convected (expressed in either BTU/hour or watts);

K   (Kappa) is the thermal conductivity of the material expressed in either BTU/hour-feet-F° or watts/meter-C°;

h   is the heat transfer coefficient (in still air, this ranges between 4-5 BTU/hour-feet2-F° or 23-28 watts/meter2-C°; in turbulent air, h falls in the range of 14-20 BTU/hour-feet2-F° or 85-113 watts/meter2-C°);

L   is the thickness of the material (in feet for BTU/hour calculations, meters for watts); and

A   is the exposed surface area of the material (in square feet for BTU/hour calculations, square meters for watts).

ΔT   is the temperature difference between the thermal load and the ambient environment (in F° for BTU/hour calculations, in C° for watts).

Note that the result that you get for Q with this equation, will be lower than that obtained for the formula based only upon conduction. This is because the convection/conduction equation accounts for two sources of thermal resistance to heat flow. With the calculation reflecting a slightly greater series resistance to heat leakage, it logically follows that fewer watts will be indicated to compensate for passive load.

When you are dealing with an uninsulated load, or an uninsulated portion of one (e.g., a cold plate), then it becomes very important to explore the convective part of thermal load. In these situations, convection may offer the primary resistance to the leakage of heat. Remember that in some situations (e.g., an uninsulated enclosure), you will have air movement on both the inside and outside; as a result, your DT will be split between the two boundary layers (based on the relative convectivity of each). As you will find in using the equation below to estimate your convective load, without insulation, you will need to pump a lot more wattage with your TE system.

$Q - h \cdot A \cdot \Delta T_3$ where

Q   is the amount of heat conducted and convected (expressed in either BTU/hour or watts);

h   is the heat transfer coefficient (in still air, this ranges between 4-5 BTU/hour-feet2-F° or 23-28 watts/meter2-C°; in turbulent air, h falls in the range of 14-20 BTU/hour-feet2-F° or 85-113 watts/meter2-C°);

A   is the exposed surface area of the material (in square feet for BTU/hour calculations, square meters for watts).

ΔT   is the temperature difference across the boundary layer at any exposed surfaces (in F° for BTU/hour calculations, in C° for watts).

When dealing with enclosures, you can also estimate your passive load empirically once a prototype is built. Simply place a known heat load inside (make sure that the enclosure can "take the heat"), then monitor the temperatures of the ambient and enclosure interior. Once the DT between the inside and ambient has stabilized, you can use the following equation to determine the passive load:

$$\frac{Q - P \bullet \Delta T_{DES}}{T_{AMB} - T_{ENC}} \quad \text{where}$$

Q   is the passive load, expressed in watts;

T_{AMB} is the ambient temperature after stabilization (in C°);

T_{ENC} is the enclosure temperature after stabilization (in C°);

P   is the power dissipation within the heater employed for the test (expressed in watts); and

T_{DES} is the desired DT for the system.

54. Are there things I can do to decrease the passive load?

Definitely! It is generally a good idea to insulate your load as much as possible from the ambient environment. The more insulation that you provide, the less heat will "leak" back into your load. Try to seal any places where air can get around the insulation. If you must have doors or hatches, use good quality seals to minimize leakage. If there are radiant sources of heat in the outside environment, make the outside of your load as reflective as possible. Try to eliminate any thermal shorts that might exist between your load and the outside world.

55. How can I determine what my heat sink needs are?

Once you can quantify the nature of your load and identify the power requirements for the Peltier devices that will be employed, you can get a sense of your heat sink needs. Again, we will focus on designing for cooling because that will be far more demanding than operation in heat mode. First, you determine the total number of watts that must be handled by your hot-side sink—simply add the wattage for your active load, passive load, and TE device power (V_{TE} * I_{TE}). Next, divide your targeted rise above ambient for this sink by the total wattage; this will give you an estimate of your required heat sink/fan thermal resistance. Once this thermal resistance is calculated, it's time to "hit the catalogs"—you will need to shop around to find a heat sink/fan combination that can deliver the performance that your design demands. Most heat sink catalogs will display graphs showing the interaction between air flow (in CFM—i.e., cubic feet per minute) and the resulting thermal resistance. It is not likely that you will find a combo with the exact thermal resistance that you are seeking; typically you will have to choose the best compromise and see how it impacts upon your system's performance.

Identifying a heat sink for the cold side of an air-to-air system, is a very similar process. Again you must target a temperature drop for this side of your system (i.e., the difference between the temperatures of the heat sink and the air circulating through it). On the load side of the system, the wattage is confined to your active and passive loads—that is what is passing through the sink; TE power dissipation is not an issue here. With far fewer watts to handle, the heat sink on the cold side of the system tends to be significantly smaller than the one on the hot side.

There are certain "rules of thumb" which should be observed in dealing with heat sinks in thermoelectric designs. When it is important to squeeze out as much cooling performance as possible, you will want to minimize the temperature drops across your sinks; good targets would be about a 10° C (18° F) rise on the hot side with around half that on the cold side. This means, however, using heat sinks and fans which are more thermally conductive (i.e., less resistive) and that translates into more fin area, more aluminum (or copper), and greater cost. In some extreme cases, exotic heat sink designs may be chosen to take thermal resistance to an

absolute minimum. When cost is of critical concern, however, it may well mean compromises in the thermal performance of the heat sinks; this leads to higher temperature drops across the sinks and a loss of cooling capacity. In the end, component choices will come down to cost/benefit analysis and every user's needs will be different.

56. Do I need to be concerned about water condensation within Peltier devices?

In applications where cooling below the dew point will produce condensation, it is usually advisable to provide special protection for thermoelectric modules to prevent shorting (thermal & electrical) and electrolytic effects. A typical remedy starts with a perimeter seal around the device. Some thermoelectric manufacturers have traditionally recommended RTV silicone as an appropriate sealant, but Tellurex has some concerns about this approach. While silicone is an effective barrier to water and dust, it is not impervious to vapor migration and can actually trap moisture inside the module once the vapor condenses. Unfortunately, there are only two materials known to be impervious to water vapor—metal and glass—and neither is convenient for sealing thermoelectric devices. This has left the industry to find some other effective perimeter seal which can offer high dielectric strength, low thermal conductivity, low coefficient of thermal expansion, and high resistance to vapor permeation. The solution identified by Tellurex is a proprietary polyamide epoxy sealant (ZCat) which has proven successful in over three years of field performance. Sealed devices using this technology are available by special order. It should be noted that all sealants will diminish the performance of TE modules somewhat, however, it is usually well worth it to protect units from the damaging effects of condensation.

Effective vapor protection does not stop with a perimeter seal. It is highly recommended that Peltier devices be surrounded by a two-part, closed-cell foam insulation to further seal out moisture from the interior of the sub-assembly. In addition, when insulated wire is used on the Peltier device (which is typical)—especially stranded wire—it is a good idea to seal the wire leads so that vapor cannot migrate through air passages along the leads.

57. Are there any special safety concerns?

There are two areas of concern here. First, never power up a Peltier device unless at least one side is mounted to a suitable heat sink. By "suitable", we mean one that can at least handle the wattage dissipated by the device—not some little sink made for a small transistor package (like a TO-220). A typical Peltier device may dissipate 60 W or more internally. How long can you hold a powered 60-watt incandescent bulb in your hand before it burns you? The hot side of a thermoelectric device can get even hotter—and faster—when it is not mounted to a proper sink. This is not just a safety issue, either—a device powered without proper sinking, can destroy itself very quickly.

The other safety concern is electrical. Although the electrical hazard potential associated with most thermoelectric systems is very small, there are some issues which deserve attention. Typically, Peltier devices are mounted to either aluminum or copper hardware (sinks, liquid heat exchangers, etc.). It is possible, therefore, for debris or moisture to create a short-circuit condition between the hardware and an electrically-live part of the Peltier device. It is up to the designer, therefore, to prevent such a problematic condition from occurring. From a safety standpoint, it is highly recommended that designers employ DC power which is fully-isolated and properly fused. The use of autotransformers or direct wiring to an AC service line is generally not recommended; if employed, a ground fault interrupter should be included in the design.

Be sure to use appropriately-rated wire in making connections, too. Thermoelectric devices can draw appreciable current and inadequately-sized wire may become very hot.

58. Do I have to insulate between the hot and cold sides of the system?

While there is no law requiring it, insulation is highly recommended to minimize heat leakage between the hot and cold sides. For best results, use two-part, closed-cell foam; one-part mixtures do not generally produce good results.

59. Can these devices be used for power generation?

Yes. The "flip-side" of the Peltier effect is the Seebeck effect—when thermal energy moves through an electrically-conductive material, charge carriers are transported by the heat. Thus when you create a temperature difference across a thermoelectric device, the movement of heat and charge carriers creates an electrical pressure

(called Seebeck voltage). If an electrical load is connected across the device, current will flow—if not, the pressure builds to a steady state condition and a "no-load" voltage will be present. While a standard Peltier unit can be used in this fashion, however, they seldom are. Usually when power generation is the objective, special thermoelectric modules are fabricated using materials which are optimized for that purpose.

Because TE power generation devices are fairly inefficient in converting thermal energy to electricity, their use is largely confined to applications where "waste heat" is readily available or in remote areas where dependability is more important than efficiency. In these types of situations, the power conversion process may be less than ideal, but the "fuel" is free. Furthermore, because their small size makes it possible to mount them in tight spaces, they can be used to reclaim energy in places where it would otherwise be impractical. Potential users should be mindful, however, that a ΔT still must be created across the device—there has to be a "cold" side as well as a source of heat—and this can present a challenge to designers.

In using power generation devices, one of the principle objectives will be to extract as much power as possible from the thermoelectric modules. Because power generation devices have significant internal resistance, designers who want to employ this technology should review the principles of maximum power transfer in electrical circuits. It is essential to grasp that maximum power will be transferred when the load resistance equals that of the TE device configuration. In the end, a designer must come up with a series/parallel array of modules that will assure generation of the desired voltage while coming as close as possible to a "matched load" condition. It is also critical to design to the worst-case ΔT—and to make sure that THot never exceeds the maximum rating for the device. Furthermore, if voltage regulation is important and the ΔT or load will be variable, a shunt regulator will be needed.

60. If Peltier devices can be used for power generation, will they run in a self-powered mode?

There is no such thing as a free lunch. The amount of Seebeck voltage generated by a TE device at a given ΔT, is a fraction of the voltage it takes to create that DT with the Peltier effect. Furthermore, the voltage which is generated, opposes the applied TE voltage and, therefore, has an attenuating effect on TE current.

61. What happens if I use a device with more cooling power than I need?

That depends. You can just let your system settle to a colder temperature than was originally targeted. If this is unacceptable, you essentially have three choices: 1) if possible, you can decrease the amount of voltage in your system to bring the TE response in line with your needs; 2) you can squander some of your excess capacity by using a less optimal heat sink (which might save you money, as well); or 3) you can employ a temperature controller to limit TE power as necessary. Remember, if it is critical to maintain your load at the desired temperature, the third option is the only one which can insure this result.

62. Are these products tested before shipment?

Yes, Tellurex electrically tests every module before shipping.

63. What is "AC resistance"?

This is a term which has come into common use in the thermoelectric industry as a reference to the internal resistance of TE devices. This label is not intended to imply that the resistance is in any way dependent on the type of voltage applied to a device. The "AC" refers to the fact that, short of using custom computer-based systems for testing Peltier devices, an AC voltage must be applied to a TE module to measure its resistance. Why? If DC is applied, a DT will develop across the module and this will result in the build-up of a Seebeck voltage. The Seebeck voltage will oppose the applied voltage and make the device appear to be more resistive than it is. With AC voltage applied (preferably of fairly high frequency), the polarity will change every half-cycle; as a result, only small Seebeck voltages can develop and decay. Furthermore, because the Seebeck voltages are of opposite polarity each half cycle, they effectively cancel each other out over the full conduction cycle.

64. Can I check thermoelectric devices with a conventional ohmmeter?

No. The vast majority of ohmmeters apply DC to the resistance being measured. This will result in a Seebeck voltage which makes the measurement inaccurate.

65. Can I use an ohmmeter which applies a pulsed DC voltage?

No. This, too, will result in Seebeck voltages which make measurement inaccurate. The meter must apply a waveform which reverses polarity every half cycle to cancel out the Seebeck effect; this feature will be found most often in a high-quality LCR meter.

66. I need to route wiring through the Peltier device; can I drill a hole anywhere in the module to facilitiate this?

Semiconductor pellets are used in a rectangular array throughout the device and are connected to one another through copper tabs. There are small spaces between the rows and columns. While drilling is not recommended, it is theoretically possible to put holes in these areas; this requires precision drilling and great care must be taken to avoid creating electrical problems such as shorts or opens. If you fracture a pellet or sever a tab connection, the module will become inoperable.

It is possible, on the other hand, to manufacture devices with holes in them. These modules do require extra machining and special processing, however, so the cost is significantly greater than a standard device.

67. I need to cool a tubular shape; can I get a custom device made in a cylindrical form?

Given the present state of technology, this is an exceptionally challenging proposition. Just finding a way to configure the device so that it could adequately manage thermal expansion and contraction, would be demanding enough. If you could satisfy that objective, you would then have to find a means of coping with tolerance variations in interfacing the device to a cylindrical heat sink. The biggest hurdle, however, would be creating manufacturing equipment and processes to assemble such a module. Can it be done? Yes, but the cost would be extraordinary—well beyond the bounds of viability for most projects.

The solution in most situations like this, is to machine a thermally conductive block (usually aluminum or copper) to create an interface between the tubular load and the flat surface of the thermoelectric device. While this is not as elegant, conceptually, it generally works very well and is affordable.

68. How can I order products from Tellurex?

You can call us at 231-947-0110.

69. Do you have a minimum order requirement?

Tellurex direct sales requires a minimum of $25.

70. How can I get more information?

The best place to get information is from our website—http://www.tellurex.com. You can also call us at 231-947-0110 or write us at 1248 Hastings Street, Traverse City, MI 49686.
Email may be directed to tellurex@tellurex.com.