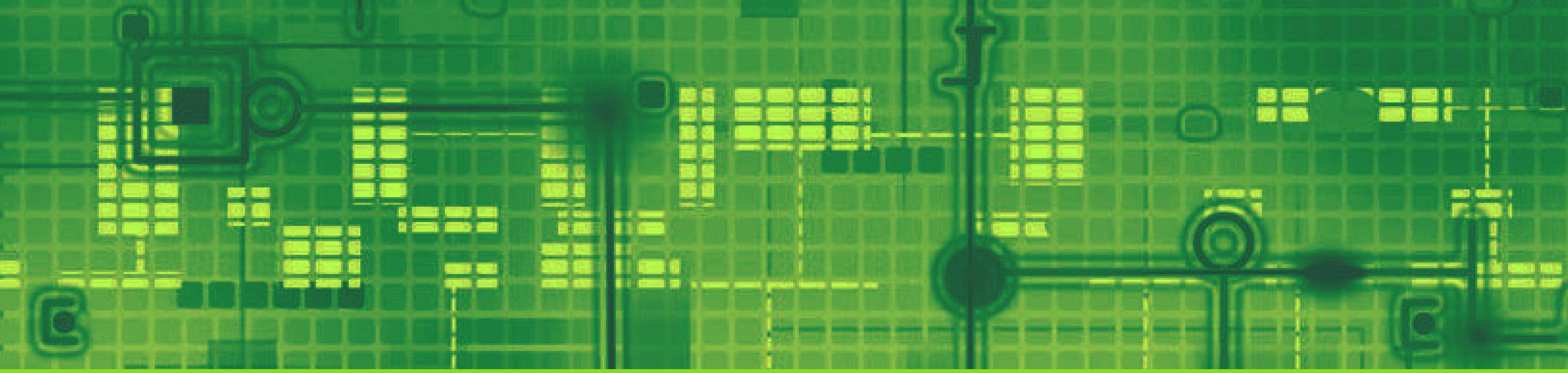

TEC Selection

in Thermal Management

With the push towards reducing component size, increasing power dissipation and lowering junction temperature, engineers must utilize different and more effective means for achieving their goals. Thermo electric coolers (TECs) are one such means to achieve their ends. TECs have been on the market for decades and their application in component cooling can be attractive, if they are designed properly or chosen correctly. Even though their COP is much lower than a Carnot cycle efficiency, they can solve some problems if the fundamentals of a TEC are well understood by the engineering team.

The optimum COP of a TEC can be shown to be:

$$COP = \frac{T_c}{\Delta T}\left[\frac{M-1-\frac{\Delta T}{T_c}}{M+1}\right]$$

Where,

T_c = cold side temperature (K)
$\Delta T = T_h - T_c$ temperature difference across TEC (K)
T_h = hot side temperature (K)

$$M = \sqrt{1 + ZT_{avg}}$$

$$Z = \frac{\alpha^2}{RK}$$

M = Figure of merit
α = Seebek coefficient (μV/K)
R = electrical resistance (Ohm)
K = thermal conductivity(W/m.K)
$T_{avg} = (T_h + T_c)/2$ (K)

The term outside the bracket is the Carnot efficiency. Lets assume Carnot efficiency of 10 or,

$$\frac{\Delta T}{T_c} = 0.1$$

For the best material in the market today, which is Bi Te, the value $ZT_{avg} \approx 1$, so COP = 1.30. This is 13% of the Carnot efficiency, if it works under ideal conditions [1].

Newer materials have $ZT_{avg} \approx 2$, so the COP = 2.28, which means the TEC works at 22.8% of the Carnot efficiency under ideal conditions. Even under ideal conditions, the COP is much lower than the COP of a vapor compression cycle.

Bell [1] has devised a thermodynamic cycle to increase the COP of the TEC by isolating the TE elements on the hot and the cold sides, compared to traditional ways of assuming constant cold and hot temperature on the sides of the TEC. Figure 1 shows the traditional concept and the enhanced concept. In this concept, the temperature of the two fluids on the hot and cold side is not uniform, as opposed to the standard way of assuming that they are constant. The fluid on the hot side

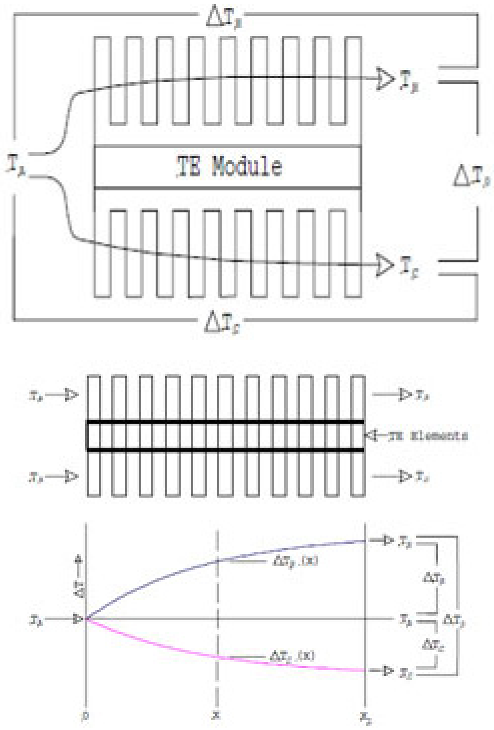

Figure 1. (a) Traditional Application of a TEC, (b) Enhanced Thermodynamic Cycle of a TEC [1]

gradually heats up from ambient to T_h and the fluid temperature on the cold side decreases from ambient to T_c. The heat exchangers are separated so each element of the TEC, as opposed to the entire TEC, is in contact with a separate heat exchanger.

Comparing the traditional concept in (a) with the enhanced cycle (b), it is evident that for the enhanced cycle at each axial location x,

$\Delta T(x) < \Delta T_0$
$T_{c(x)} > T_{c(x1)}$
Hence
$\Delta T(x)/T_{c(x)} < \Delta T_0/T_{c(x1)}$

By looking at the Equation 1 for COP, the smaller $\Delta T/T_c$ leads to a higher COP. The authors [1] elaborate on the same concept with the fluids coming in two different directions (counter flow). Their analysis shows that this concept increases the COP several times.

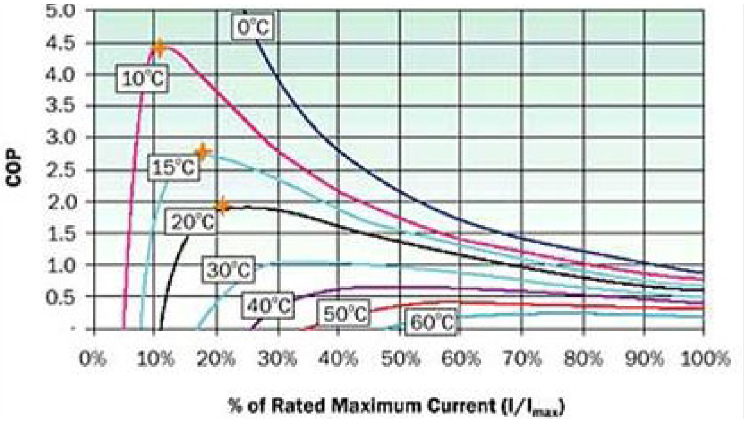

Figure 2. COP of a TEC as a Function of Percentage of Current at Different Temperature Differences [2]

Figure 2 shows the COP of a TEC as a function of the percentage of maximum rated current for different temperature differences. The graph clearly shows that the maximum current causes the COP to degrade very quickly. In fact, at lower temperature differences, i.e. less than 20 °C, the effect is more pronounced. The graph also shows that at low temperature differences, the percentage of maximum current is about 10 to 20% for optimum COP.

Let us apply this TEC to a hypothetical heat sink and see what the effect on the case temperature is.

Assume we have a component dissipating 120 watts. We want to compare the T_{case} before and after the application of the TEC. Figure 3 shows the arrangement of the heat sink, TIMs and the TEC before and after the application of a TEC.

The following assumptions are made [2]:
T_{amb} = 40 °C
Θ_{fins} = 0.18 °C/W (heat sink thermal resistance)
Θ_{spread} = 0.08 °C/W (spreading resistance)
P = 120 watts (Power dissipation)
A_{TEC} = 64 cm^2 (TEC surface area)
$A_{package}$ = 9 cm^2 (package surface area)
$\Theta_{TIM2} = \Theta_{TIM3} = \Theta_{TIM4}$ = 0.2 cm^2-°C/W
(thermal interface resistance)

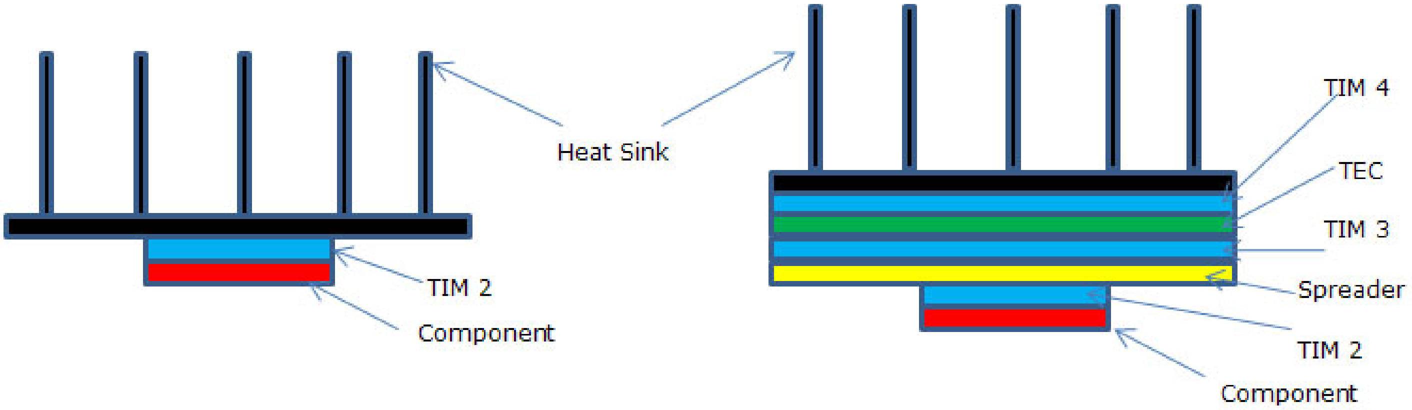

Figure 3. Left (Heat sink Assembly), Right (Heat Sink and TEC Assembly)

Figure 4 shows the resistance paths between the case temperature and the ambient with just a simple heat sink (left) or a combination of heat sink and a TEC (right).

For a simple heat sink assembly, the case temperature can simply be calculated from:

$$T_{Case} - T_{amb} = Px(\theta_{TIM2} + \theta_{Spread} + \theta_{Fins})$$

$$T_{Case} = 73.9\ ^{o}C$$

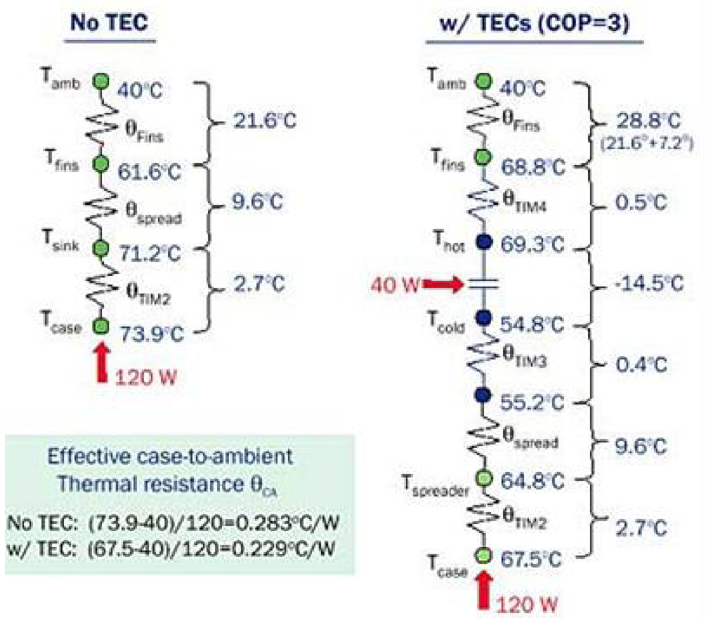

Figure 4. Resistance Path for Heat Sink Assembly (Left), Heat sink and TEC Assembly (Right) [2]

For the heat sink and TEC assembly, we assume that we can implement a TEC with a COP of 3. From Figure 2, at a COP of 3 at optimum point, the TEC has a temperature difference of $\Delta T = 14.5\ ^{o}C$ across the TEC. With a COP of 3, the power input to the TEC is 40 W to pump 120 W. It is to be noted that, if we try to use a TEC with a higher COP, the temperature difference across the TEC will be much lower and the use of a TEC will not be justified. The case temperature can be calculated by solving the following simultaneous equations:

$$T_{Case} - T_{Cold} = Px(\theta_{TIM2} + \theta_{Spread} + \theta_{TIM3})$$

$$T_{Hot} - T_{amb} = (P+ 40)x(\theta_{TIM4} + \theta_{Fins})$$

$$T_{Hot} = T_{Cold} + 14.5$$

$$T_{Case} = 67.5\ ^{o}C$$

This is a 6.4 °C reduction in temperature. In terms of thermal resistance:

For a simple heat sink $R_{ca} = 0.283\ ^{o}C/W$

For a heat sink and TEC assembly, $R_{ca} = 0.229\ ^{o}C/W$, which means using a TEC has resulted in a 23% reduction of the case to ambient thermal resistance. However, it should be noted that an extra 40 W is spent to run the TEC.

Now the question is: How many TECs do we need to use? Assume we are using 4 TECs. Each TEC has to pump 30 W. Assume a typical ΔT_{max} = 68 °C which is typical of commercial TECs:

$\Delta T/\Delta T_{max} = 0.21$

Figure 5 plots $\Delta T/\Delta T_{max}$ as a function of I/I_{max}, the line of optimum performance and the values of Q/Q_{max}. From the figure, it can be found that Q/Q_{max} = 0.17, which leads to Q_{max} = 30/0.17 =176 w. If we had used 3 TECs, then Q_{max} = 40/0.17 = 235 W. With fewer TECs, the base of the heat sink might not be fully covered, which contributes to extra spreading resistance. If we had assumed that we just use one TEC, then Q_{max} = 120/0.17 = 705 W. It could be quite a challenge to find a TEC with this characteristic; however, the recent advancements in TECs have made this choice available.

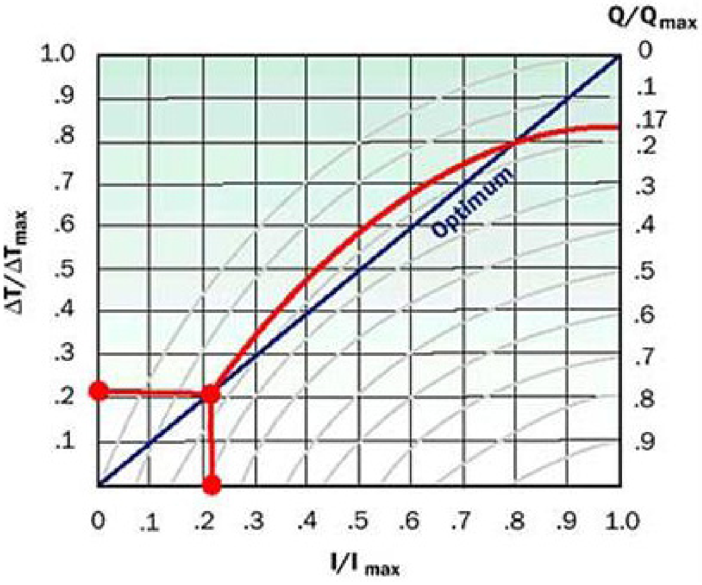

Figure 5. Typical Performance Curve of a TEC [2]

Typically, for the TEC to enhance performance, a very high performance heat sink is required; so, the extra work input to the TEC, which causes a raise in heat sink temperature, will be compensated for by the temperature difference across the TEC. Application of a TEC in component cooling is exciting and also requires detailed analysis and consideration of parameters such as coefficient of performance, availability of the required TEC, increase in power consumption, spreading resistance, reliability, increase in cost of deployment and detailed heat sink design.

References:

1. **Bell, L., "Use of thermal isolation to improve thermoelectric system operating efficiency", BSST LLC**

2. **Johnson, D., Bierrschenk, J, "Latest developments in thermoelectrically enhanced heat sinks", Electronics Cooling Magazine, August 2005**

Turn up the heat with the new

CLWT-115™

ATS ADVANCED THERMAL SOLUTIONS, INC.
Innovations in Thermal Management®

The new benchtop, research-quality, Closed Loop Wind Tunnel from ATS creates a uniform flow and temperature distribution ensuring you will know how a device will function at high temperatures.

Request a Quote

ADVANCED THERMAL SOLUTIONS, INC. | 89-27 ACCESS RD | NORWOOD, MA 02062 USA | 781.769. 2800 | WWW.QATS.COM