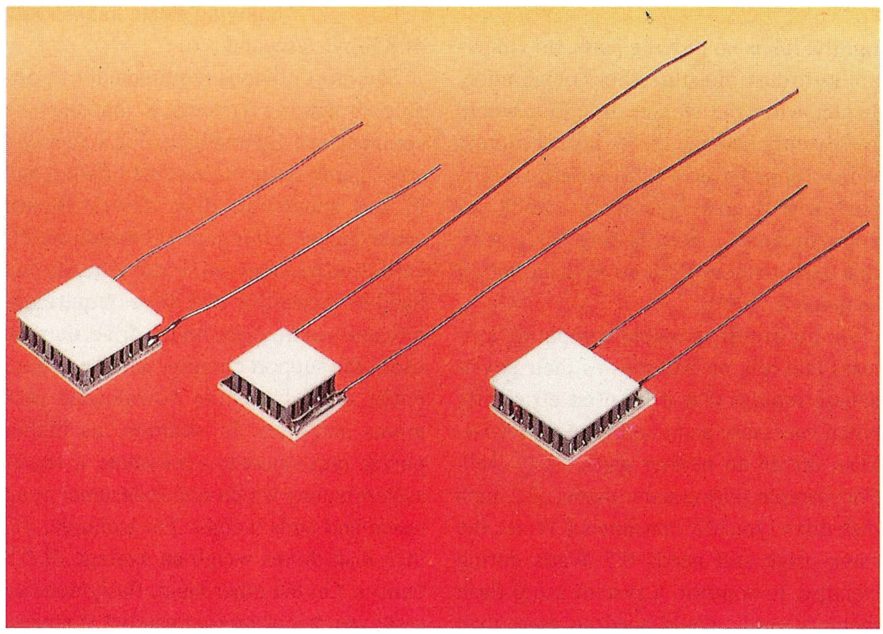
26 Thermoelectric devices: The power to keep cool. J. G. Stockholm. Electronics International Vol 1 No 2 Summer 1991.(Cornhill Publications Ltd. London England p 34-36)

Thermoelectric devices: the power to keep cool

Thermoelectric devices give a dependable cooling system that can control temperatures to 0.01 of a degree and are not damaged even by a rocket launch. John G Stockholm on why they are the ultimate choice.

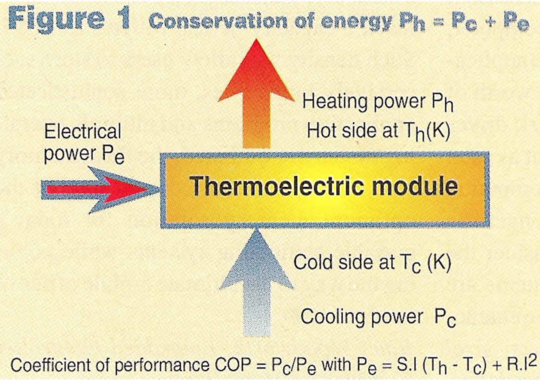


Spot cooling modules: cooling powers go from a fraction of a watt to tens of watts

The two most common ways to evacuate heat from electronic components is by heat conduction through the support, and by natural convection of the air surrounding the component. When this is not sufficient one can blow the air over the components and the support. This is forced convection. In both cases, the components always remain hotter than the support and the ambient air. When the component needs to be at a temperature lower than the support or ambient air then a heat pump is required. A thermoelectric cooling device is a solid state heat pump and it operates as the reverse of the thermocouple used to measure temperatures.

When an electrical current flows through a thermoelectric material, thermal energy is transferred across it and a temperature difference is created between the two sides of the thermoelectric material, resulting in a solid state heat pump which is schematically represented in *Figure 1*. *Figure 2* gives the cooling power P_c, of a module as a function of the electrical current I. The Peltier cooling term is decreased by the heat flowing from the hot side to the cold side and by the Joule heating in the thermoelectric module. The useful operating range for this module is between about 2 and 6A.

Figure 1 Conservation of energy $P_h = P_c + P_e$

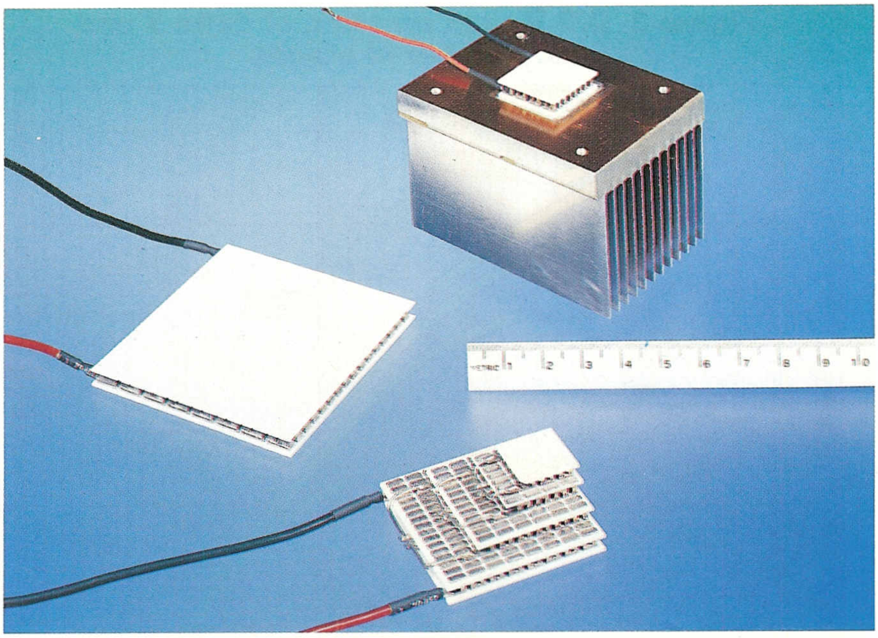


Coefficient of performance $COP = P_c/P_e$ with $P_e = S.I\,(T_h - T_c) + R.I^2$

The areas of use for thermoelectrics are numerous, many of them military, and there are constant new applications. Some examples are:

- Spot cooling: The contact areas vary from areas of one mm^2 to tens of cm^2. The cooling powers go from a fraction of a watt to tens of watts. It can be in scientific instruments such as dew point meters, hygrometers, blood analysers and so on, the components can be ICs, CCDs, infra-red and other detectors, laser diodes, etc.
- Circuit board cooling: Some boardst require specific cooling, which can be done at the level of the card holder. The cooling powers are of the order of a hundred watts.
- Space cooling: The air inside equipment is cooled so that the components inside operate at a lower temperature. There is a consumer market for picknet coolers; for example, a medical application is a cooled box for transporting blood. The cooling powers go from hundreds of watts to kilowatts of cooling. There are circumstances when thermoelectric cooling should not be installed, such as when cooling powers exceed several hundred watts and when there are no severe operating conditions, or reliability requirements. Then compression cycle systems using CFCs or other fluids should be considered because they have a much higher coefficient of performance (COP) at full load and are cheaper.

Thermoelectrics are used for basically two purposes; cooling, when the temperature of the component must be lowered below that of its environment; and temperature stabilisation. Thermoelectric devices and systems most often operate in



Clockwise from top: a module on a heat air exchanger, a 4-stage cascade device, and a single large module

the cooling mode. The cooling or heating power is controlled by varying the polarity and magnitude of the electrical current so temperature stabilities of 0.01°C or better can be obtained.

The areas of use for thermoelectrics are numerous, many of them military, and there are constant new applications

The prevailing characteristics of thermoelectrics are numerous: a fundamental one is that the Peltier effect only requires a semiconductor (there is no intermediate fluid such as a CFC), so therefore it is a static heat pump which is silent with no moving parts, except for large systems where there can be fans and pumps. They are also reliable – thermoelectric devices and systems have been operated for hundreds of thousands of hours without a failure and can withstand very severe conditions, such as a rocket launching and vibrating environments like vehicles and railway equipment. Medium and large systems are always designed on a modular basis called subunits, to as to avoid excessive mechanical stress in the subunit. This means that it is often interesting to disperse the subunits where they are effectively needed.

Because a thermoelectric device is a heat pump, the transient cooling at start up and during any abrupt change in operating conditions is very powerful, which also explains why it is so good for temperature stabilising.

A thermoelectric device's operating voltage depends essentially on the number of elements that it contains in series electrically. Depending on the application the performance objectives can be the COP or the cooling power. The COP of the system depends first of all on the temperature difference ΔT between the hot side T_h and the cold side T_c of the thermoelectric device, and on the number of stages in the device. A cascade device consists of several modules above each other and each one is a stage.

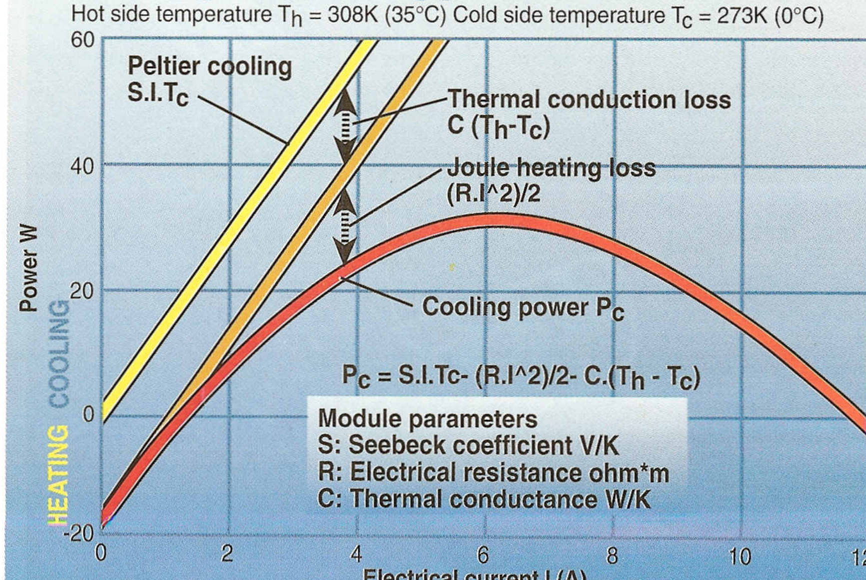
Devices and systems are often designed to operate with a COP between 50 and 75 per cent of the maximum, to optimise cost-performance trade-offs. *Figure 3* gives the values of maximum COP as a function of ΔT and the number of stages in the device, one sees how quickly the COP decreases with the number of stages. For space cooling the objective is to operate at a high COP. In the kilowatt range COP can be between 1 and 2 as electrical power is often limited. For spot cooling the main objective is to obtain a given temperature on the cool side of the thermoelectric device, not necessarily a given COP. This is especially true when very low temperatures are required such as 170K. There are exceptions, for instance, when the equipment must be transported or hand held (night vision equipment) then the COP which to start with is very low, for instance 10^{-3}, must be optimised.

The cooling power depends primarily on the amount of thermoelectric material in the device. By this we mean the total cross-section of material and the current density through the thermoelectric material. A typical current value is 1 A/mm^2, with ΔT=30K this gives a cooling of 4 W/cm^2 of material. Commercially available modules cover the range between 0.5 mm^2 and 10 mm^2 of thermoelectric material.

The dimensioning of a thermoelectric device or system is an analogous process,

Figure 2 Cooling power of a module

Hot side temperature T_h = 308K (35°C) Cold side temperature T_c = 273K (0°C)



whether it is for a very small cascade module that cools a detector to 200K, or a space cooling system of 1kW. To start one must determine the temperature at which the cold side of the thermoelectric device must be, and the cooling power required to maintain the component or environment at a given temperature. The temperature on the hot side of the thermoelectric device is a function of the temperature of the fluid that will evacuate the heat. With these three values one can choose the most appropriate thermoelectric device or system.

Thermoelectric cooling is extensively used in electronics. The major application is spot cooling with small temperature differences and cooling requirements of less than 100W. The two extremes are cascade devices that enable one to reach lower temperatures pumping very small heat loads, and space cooling of electronics where the cooling power of systems has reached the kilowatt range and is increasing. When reliability is the major factor then thermoelectrics is the ultimate choice. ●

John G Stockholm, Director Thermoelectric Cooling Systems, Marvel SA

Figure 3 C.O.P. max function of delta T and the number of stages