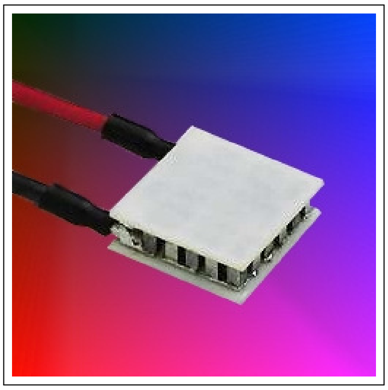
Thermoelectric Generators
Seebeck Elements

Thermoelectric generators, also called SEEBECK elements, are devices that generate electric power from heat flux as long as a temperature difference between the two sides of the part is kept. Constructed in the same way as PELTIER elements that are based on the PELTIER effect for cooling purposes by electric power, SEEBECK devices are based on the SEEBECK effect for producing electric power. Please note that both effects cannot be separated from each other and occur simultaneously.
For generating the maximum power it is essential to chose the right elements and means of heat dissipation.

We will gladly assist you in choosing appropriate elements and accessories for your individual application.



Product Range

Size			Maximum Electric Power			Remarks
$15mm \times 15mm$	to	$40mm \times 40mm$	$0,3W$	to	$10W$	up to $120°C$
$30mm \times 30mm$	to	$50mm \times 50mm$	$8,8W$	to	$40W$	up to $200°C$

other sizes and specifications for OEM production on request

Typical Applications

- **Consumer**
  Power supply of wristwatches by body temperature
- **Industry**
  Supply unit of DH test points by temperature difference of pipelines
  Power generation using waste heat of combustors or solar panels
- **Automotive**
  Power generation using waste heat of exhaust gases
- **Research**
  Calorimetry
  Experimental research how to use waste heat

Accessories and related Products

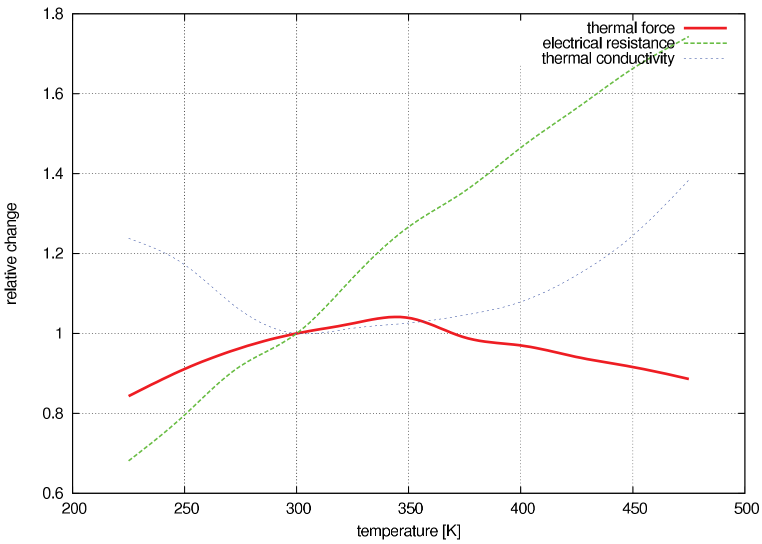
- **OEM Elements and High Temperature Elements**
  Seebeck elements are only a small part of our product range. You will find the whole range of thermoelectric devices in the section on peltier elements on our website. Most of these elements are available in small quantities, too. We also provide elements for applications up to $200°C$.
- **Industrial Elements**
  The industrial-class contains a representative range of the most frequently used elements. These are regularly produced in high quantities and can also be delivered in low numbers at a good value from stock.

The dimensioning of the SEEBECK effect is much more complex than the general use of a peltier element. In most cases a trial-and-error procedure will not give the expected results. On the next pages you will find the technical data of the Seebeck elements offered by EURECA Messtechnik GmbH, as well as information how to estimate the performance of your setup (even a quick and dirty estimation for first ideas).

Type	Thermal force α_{300K}	Electric Resistance ρ_{300K}	Thermal Conduction κ_{300K}	Maximum Open Circuit Voltage U_i	Maximum Short Circuit Current I_s	Maximum Electric Power P_{max}	Size $L \times B \times H$	Maximum Operation Temperature T_{max}
				at $\Delta T = 100K$:				
TEG2-15-15-0.3/100	$0.013\,V/K$	$1.4\,\Omega$	$0.04\ W/K$	1.3 V	0.9 A	0.3 W	$15 \times 15 \times 4.4$	$120°C$
TEG2-30-30-2.2/100	$0.052\,V/K$	$2.8\,\Omega$	$0.4\ W/K$	5.1 V	1.7 A	2.2 W	$30 \times 30 \times 3.1$	$120°C$
TEG2-40-40-4.7/100	$0.053\,V/K$	$1.5\,\Omega$	$0.8\ W/K$	5.3 V	3.5 A	4.7 W	$40 \times 40 \times 3.4$	$120°C$
				at $\Delta T = 200K$:				
TEG2-30-30-8.8/200	$0.052\,V/K$	$2.8\,\Omega$	$0.4\ W/K$	10.2 V	3.4 A	8.8 W	$30 \times 30 \times 3.1$	$200°C$
TEG2-40-40-19/200	$0.053\,V/K$	$1.5\,\Omega$	$0.8\ W/K$	10.6 V	7.0 A	19 W	$40 \times 40 \times 3.4$	$200°C$
TEG2-50-50-40/200	$0.052\,V/K$	$0.7\,\Omega$	$1.9\ W/K$	10.3 V	15.3 A	40 W	$50 \times 50 \times 3.4$	$200°C$

Notes:

- The tolerances of the mechanical parameters are $\pm 1mm$ for side lengths, and $\pm 0.25mm$ for height. The tolerance of electric and thermal parameters is $\pm 15\%$.
- The module parameters given above are valid for $300K$. As these parameters depend on the absolute temperature (measured in K), they have to be corrected using the correction chart below:



$$\alpha(T) = \alpha_{300K} \cdot \text{thermal-force}(T)$$

$$\rho(T) = \rho_{300K} \cdot \text{electric resistance}(T)$$

$$\kappa(T) = \kappa_{300K} \cdot \text{thermal-conduction}(T)$$

- The device has two ceramic plates, one on the hot and one on the cold side. The values for the thermal conduction shown above do not include the influence of these ceramic plates. The plates have a thickness of $\leq 1mm$ and a thermal conductivity of $\geq 15\ W/K \cdot m$ which should be used for calculations.

The heat flow needed on the hot side of the element can be calculated as follows:

$$\dot{Q}_{hot} = \alpha(\tilde{T}_{hot}) \cdot I \cdot \tilde{T}_{hot} - \frac{\bar{\rho}}{2} \cdot I^2 + \bar{\kappa} \cdot (\tilde{T}_{hot} - \tilde{T}_{cold})$$

The voltage occurring at the element is:

$$U = \alpha(\tilde{T}_{hot}) \cdot \tilde{T}_{hot} - \alpha(\tilde{T}_{cold}) \cdot \tilde{T}_{cold} - \bar{\rho} \cdot I$$

The electric power emitted by the element is:

$$P = U \cdot I$$

The effective temperatures are to be calculated this way:

$$\tilde{T}_{hot} = T_{hot} - R_{th,hot} \cdot \dot{Q}_{hot}$$

$$\tilde{T}_{cold} = T_{cold} + R_{th,cold} \cdot (\dot{Q}_{hot} - P)$$

The mean value of the electric resistance is:

$$\bar{\rho} = \frac{\int_{\tilde{T}_{cold}}^{\tilde{T}_{hot}} \frac{\rho(T)}{\kappa(T)} \cdot dT}{\int_{\tilde{T}_{cold}}^{\tilde{T}_{hot}} \frac{1}{\kappa(T)} \cdot dT}$$

The mean value of the thermal conduction is:

$$\bar{\kappa} = \frac{\int_{\tilde{T}_{cold}}^{\tilde{T}_{hot}} \frac{1}{\kappa(T)} \cdot dT}{\int_{\tilde{T}_{cold}}^{\tilde{T}_{hot}} \frac{1}{\kappa(T)^2} \cdot dT}$$

Legend:

- T_{hot}: absolute temperature applied at the hot side (heat source)
- $R_{th,hot}$: thermal resistance on the hot side (ceramic plate, thermal compound, etc.)
- $\tilde{T}_{hot}$: effective temperature on the hot side
- T_{cold}: absolute temperature on the cold side (heat dissipation)
- $R_{th,cold}$: thermal resistance on the cold side (ceramic plate, thermal compound, heat sink, etc.)
- $\tilde{T}_{cold}$: effective temperature on the cold side
- $\dot{Q}_{hot}$: heat flow needed on the hot side
- U: voltage generated at the element
- I: current flowing through the element
- P: electric power emitted by the element
- $\alpha(T)$: corrected thermal force
- $\rho(T)$: corrected electric resistance
- $\kappa(T)$: corrected thermal conduction
- $\bar{\rho}$: effective electric resistance of the element
- $\bar{\kappa}$: effective thermal conduction of the element

Notes for operating: The efficiency of the elements depends on the temperatures and the electric load in accordance with the following rules:

- The degree of efficiency increases with the temperature difference $\Delta T = T_{hot} - T_{cold}$
- The degree of efficiency decreases with the average temperature $\frac{T_{hot}+T_{cold}}{2}$ *(Attend to a sufficient heat dissipation)*
- The degree of efficiency is optimal with a current consumer which complies with an ohm resistive load of $\bar{\rho}$.
- Make sure to use temperature resistant thermal compounds only. The compound has to be attached very carefully and it must be guaranteed that the layer of compound is thin, homogeneous and contains no air bubbles.
- Handling a small device is much easier than the handling of a big one. In many cases the use of two smaller devices gives better results compared with only one big device!
- When using a heat sink for natural convection please note that the effective thermal resistance depends on the flow of heat! As an estimation can be used:

$$R_{th,eff} \simeq \sqrt[5]{R_{th,catalog}^4 \cdot \frac{100\,K}{\dot{Q}}}$$

The general handling instructions for thermoelectric devices apply!

Quick and Dirty Estimation of maximum Power

To give you a very first impression of what your application might achieve, you can use these estimations:

1. Estimation of the maximum heat flux through the element:
   - Find correction factor of κ for T_{hot} in sketch
   - Find correction factor of κ for T_{cold} in sketch

$$\dot{Q} = \frac{1}{2} \cdot \left(\text{correction factor}(T_{\text{hot}}) + \text{correction factor}(T_{\text{cold}})\right) \cdot \kappa \cdot (T_{\text{hot}} - T_{\text{cold}})$$

   This is the amount of heat that has to be provided on the hot side and that has to be dissipated on the cold side. Please make sure that you can provide the amount of heat and cooling!

   Please make sure that the thermal resistances between the heat source and the TEG as well as between the TEG and the heat sink is low enough to transport this amount of heat without significant temperature loss!

2. Estimation of Open-circuit-Voltage:
   - Find correction factor of α for T_{hot} in sketch
   - Find correction factor of α for T_{cold} in sketch

$$U(\text{open circuit}) = \text{correction factor}(T_{\text{hot}}) \cdot \alpha \cdot T_{\text{hot}} - \text{correction factor}(T_{\text{cold}}) \cdot \alpha \cdot T_{\text{cold}}$$

3. Estimation of average resistance:
   - Find correction factor of ρ for T_{hot} in sketch
   - Find correction factor of ρ for T_{cold} in sketch

$$R(\text{average}) = \frac{\text{correction factor}(T_{\text{hot}}) + \text{correction factor}(T_{\text{cold}})}{2} \cdot \rho$$

4. Estimation of short circuit current:

$$I(\text{short circuit}) = \frac{U(\text{open circuit})}{R(\text{average})}$$

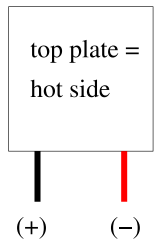
5. Estimation of maximum Power:

$$P(\text{max}) = \frac{1}{4} \cdot I(\text{short circuit}) \cdot U(\text{open circuit})$$

Please note that this does not replace an exact calculation or simulation!

Frequently asked questions:

- **Where is the hot and where the cold side of the thermoelectric generator?**



Lay the element on the table in front of you with the wires facing you, with the red wire on the right. In this position the wires are attached to the bottom ceramics plate, which should be the cold one. So the side facing up is the one to be heated.
Please note: the wires are colored to fit the polarity convention in standard peltier use. So in this special case of using the element as a generator, the red wire is minus and the black/blue wire is plus.

- **The polarity is different than I expected. Why?**

  Please see question above.

- **I do not get the power out that I expected to get. Why?**

  There may be several causes:

  1. **Loss over the thermal compound:**

     especially for high power elements there is a highly dense thermal flow through the element. This causes a temperature difference between both sides of the thermal compound, if the thickness of the layer is too high or if the layer is not homogenous. This lowers the temperature difference applied to the generator and the performance drops.

     Applying the thermal compound in a proper way and/or choosing multiple smaller elements to reduce the density of heat flow would solve this problem.

     It is very important to make sure that the thermal contact at the cold side is very efficient, if not, the temperature difference drops and thus the performance.

  2. **An inductive, capacitive or switched load is used:**

     a thermoelectric generator is an ohmic device. For best performance it is important to use an ohmic load which electrical resistance matches the one of the generator. The output power of the system depends on the ratio of the electrical resistance of the generator and the load. It gets maximal, if both electrical resistances are identical.

  3. **The electrical resistance of the load does not match the electrical resistance of the element:**

     the electrical resistance of the generator depends on the absolute temperatures of the hot and the cold side. It is recommended that the resistance of the load matches the resistance of the generator at operating conditions or, if the temperature of the operating conditions are not well defined, follows the resistance of the generator.

  4. **The temperature dependence of the parameters was ignored:**

     all thermoelectric parameters depend on the temperature. The maximum output powers shown in the table only represent a special operating condition with a mean temperature about 300K. If operated at other temperatures, especially at higher ones, the performance drops as the electrical resistance of the generator increases and the thermal force decreases.

Additional Products

EURECA offers a wide product range for the use with peltier elements and coolers. Please find below a short summary of available products. For further information please contact us.

Thermally Conductive Compounds

We offer thermally well conductive pads for the use with our peltier and Seebeck elements.

Heat Sinks and Heat Exchangers

For transferring heat to the surrounding air we offer a variety of heat sinks that are delivered in various lengths e. g. 50 mm, 100 mm, 150 mm and 200 mm.

Fans

For improving the performance of heat sinks special fans are used, which are optimized for a permanent operation.

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