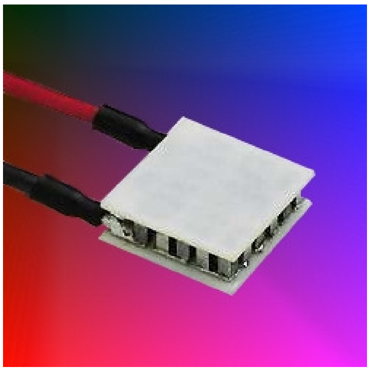
Thermoelectric Generators
Seebeck Elements

Thermoelectric generators are constructed like peltier elements. In contrast to the PELTIER effect, the SEEBECK effect generates electric energy directly from the temperature difference on both sides of the element. (This is not the reversal of the PELTIER effect! Both effects act at the same time and cannot be separated from each other!)



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

Product Range

Size	Maximum Electric Power	Remarks
$10mm \times 10mm$ to $40mm \times 40mm$	$0,2W$ to $10W$	up to $120°C$
$10mm \times 10mm$ to $50mm \times 50mm$	$0,8W$ to $40W$	up to $200°C$

other sizes and specifications for OEM production on request

Typical Applications

- **Consumer**
  Supply unit 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 temperature of the exhaust
- **Military**
  Non-mechanical generation of electric energy current by fuel (catalytic and free combustion) e.g. to supply transmitter of distress signals
- **Research**
  Calorimetry
  Experimental research how to use waste heat

Accessories and related Products

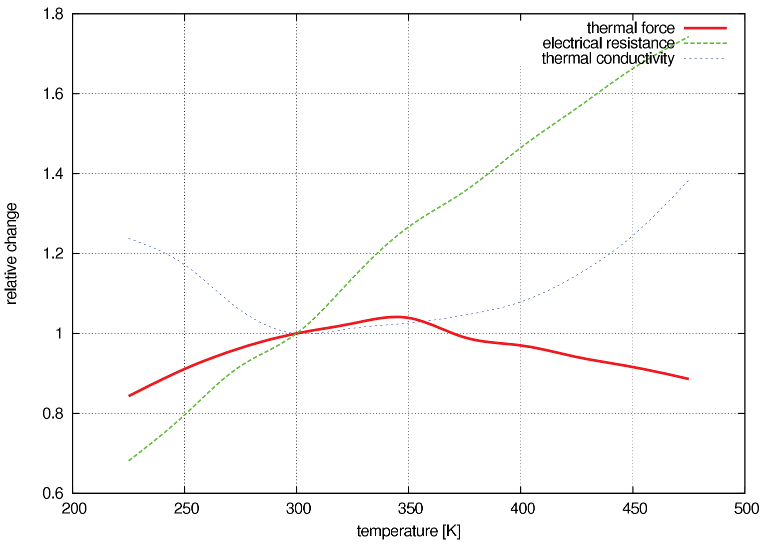
- **Heat Sinks, Heat Exchangers and Heat Conductive Pastes and Adhesives**
- **OEM Elements and High Temperature Elements**
  Seebeck elements are only a small part of our product range. You will find the whole range of thermoelectric devices in the section peltier elements on our website. Most of these 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 an trial-and-error procedure will not give the expected results. Please use the constants and formulas below to select and calculate the thermoelectric generators offered by EURECA Messtechnik GmbH.

Type	Thermal force α_{300K}	Electric Resistance ρ_{300K}	Thermal Conduction κ_{300K}	Characteristics at $\Delta T = 100K$: 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}
TEG1-9.1-9.9-0.2/100	$0.027\,V/K$	$9\;\Omega$	$0.03\,W/K$	2.7 V	0.3 A	0.2 W	$9.1 \times 9.9 \times 2.3$	$120°C$
TEG1-30-30-2.1/100	$0.054\,V/K$	$3.4\,\Omega$	$0.3\;W/K$	5.4 V	1.6 A	2.1 W	$30 \times 30 \times 3.6$	$120°C$
TEG1-40-40-4.7/100	$0.054\,V/K$	$1.5\,\Omega$	$0.7\;W/K$	5.4 V	3.5 A	4.7 W	$40 \times 40 \times 3.4$	$120°C$
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	$40 \times 40 \times 3.4$	$120°C$
TEG1-40-40-10/100	$0.082\,V/K$	$1.7\,\Omega$	$1.6\;W/K$	8.2 V	4.9 A	10 W	$40 \times 40 \times 3.2$	$120°C$
				Characteristics at $\Delta T = 200K$:				
TEG1-9.1-9.9-0.8/200	$0.027\,V/K$	$9\;\Omega$	$0.03\,W/K$	5.4 V	0.6 A	0.8 W	$9.1 \times 9.9 \times 2.3$	$200°C$
TEG1-30-30-8.5/200	$0.054\,V/K$	$3.4\,\Omega$	$0.3\;W/K$	10.8 V	3.2 A	8.5 W	$30 \times 30 \times 3.6$	$200°C$
TEG1-40-40-19/200	$0.054\,V/K$	$1.5\,\Omega$	$0.7\;W/K$	10.8 V	7.0 A	19 W	$40 \times 40 \times 3.4$	$200°C$
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 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 tolerances of the mechanical parameters are $\pm 0.25mm$. The tolerances of electric and thermal parameters are between 2% and 5% for the TEG1-series and between 5% and 10% for the TEG2-series.

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 scetch
   - Find correction factor of κ for T_{cold} in scetch

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

   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 scetch
   - Find correction factor of α for T_{cold} in scetch

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

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

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

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 element?**

  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 refer to the above question.

- **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 drops the performance.

     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 of best quality, as an increasing mean temperature decreases 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 eletrical 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 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, the performance drops, because 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 a variety of thermally well conducting materials for usage with Seebeck and Peltier elements as well as a single-component polyurethane adhesive with low thermal conductivity:

TCSA-1530: thermally very well conductive single-component silicone adhesive

TCAP-5590: thermally very well conductive pad

PUSA-0100: thermally ill-conductive single-component PU adhesive

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. Beside some standard lengths of e. g. 50 mm, 100 mm, 150 mm and 200 mm also customized lengths are possible.

Fans

For improving the performance of heat sinks special fans are used, which are optimized for a permanent operation. Some of the heat sinks already have a suitable size for mounting such fans.

Although there are many manufacturers of fans, we have chosen the products by PAPST, since the products of this manufacturer provide an excellent cost/performance ratio and a very long lifetime.

Most fans are available with Sintec bearing as well as with ball bearing.

Tel: +49 (0) 221 / 952629 - 0
info@eureca.de
www.eureca.de

EURECA Messtechnik GmbH
Deutz-Kalker Str. 35
50679 Cologne, Germany