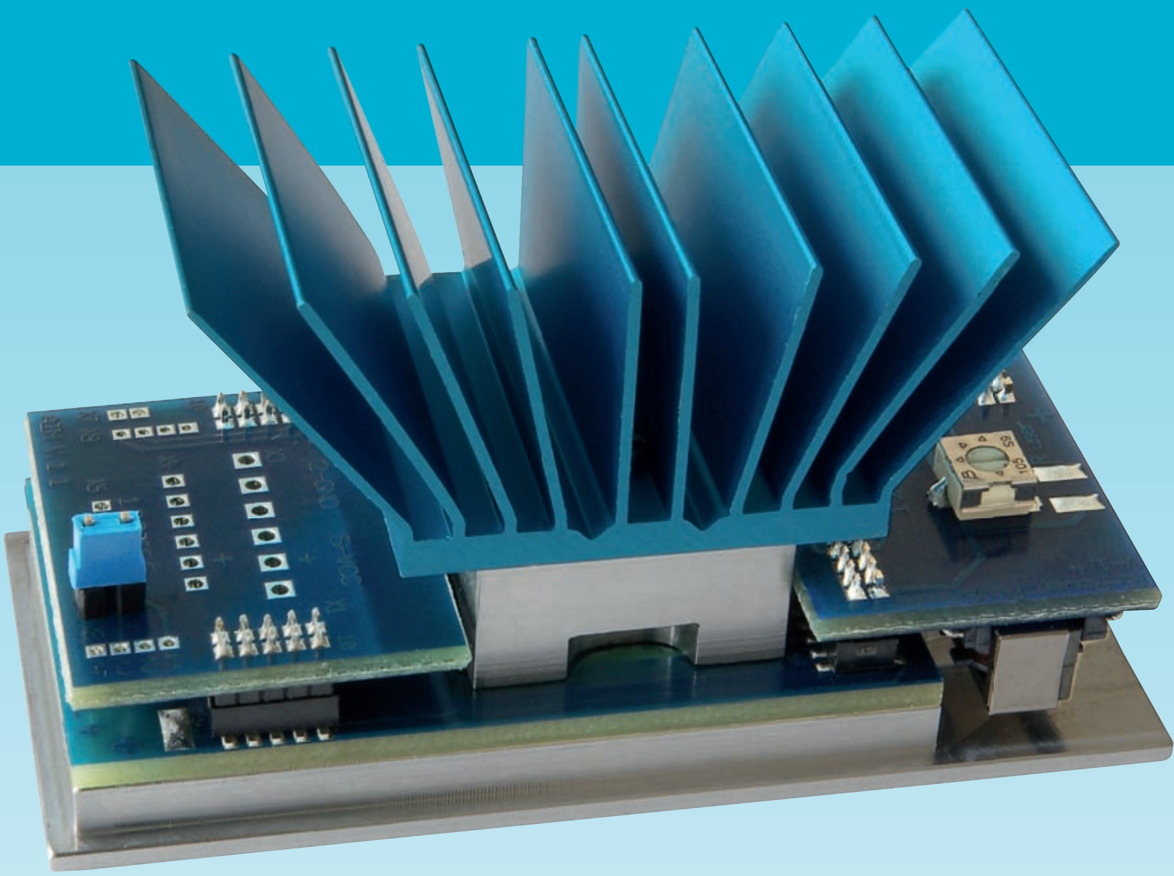
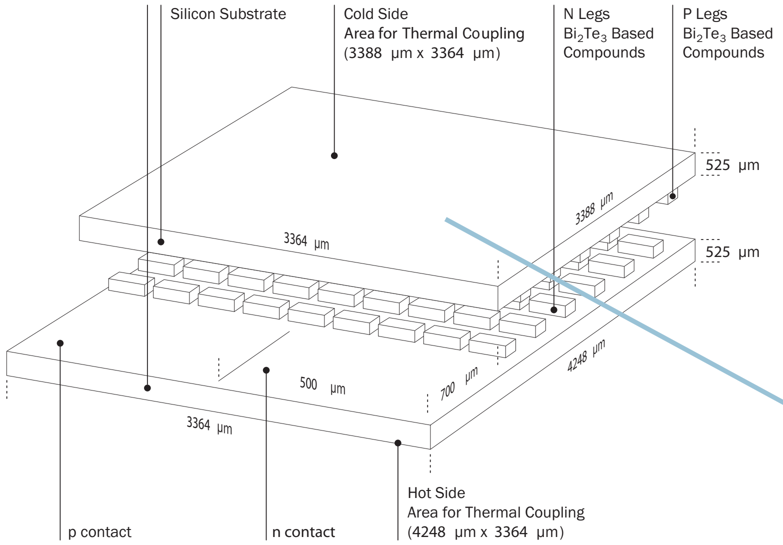
TE-Power ONE
TE-Power PLUS

Modular Thermogenerator
Evaluation System
Direct Output & Stabilized Voltage

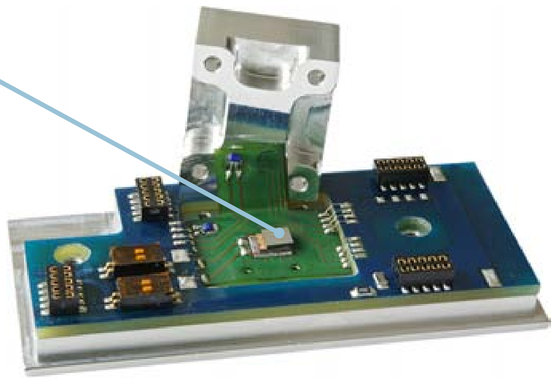


micropelt
Power generation.

1. Technology Principles - Milliwatt Energy from Waste Heat



MPG-D751 thermoelectric generator chip mounted on Al heat collector along with digital and analog temperature sensors.



Thermoelectric (TE) power generation is based on the 'Seebeck-Effect' describing the generation of a voltage from a heat flux through one or more TE leg pairs (thermocouples) each composed of p-type and n-type thermoelectric semiconductor materials. Micropelt uses compounds of Bismuth (Bi), Antimony (Sb), Tellurium (Te) and Selenium (Se) because of their useful performance at operating temperatures from below room temperature up to 200 °C.

The output voltage generated is proportional to the number of thermocouples, the applied temperature gradient ΔT across the generator element, and a constant α which describes the material properties.

$U = N_{legpairs} \times \Delta T \times \alpha$

U is not dependent on the size of the thermocouple! This simply means: More thermocouples, regardless of size, the higher the output voltage from a given gradient! Our patented MEMS-like thin film micro-structuring process produces thermogenerators with the world's highest feature density of up to 100 thermocouples per mm^2. This enables a *400 times higher* output voltage compared to conventional TE devices.

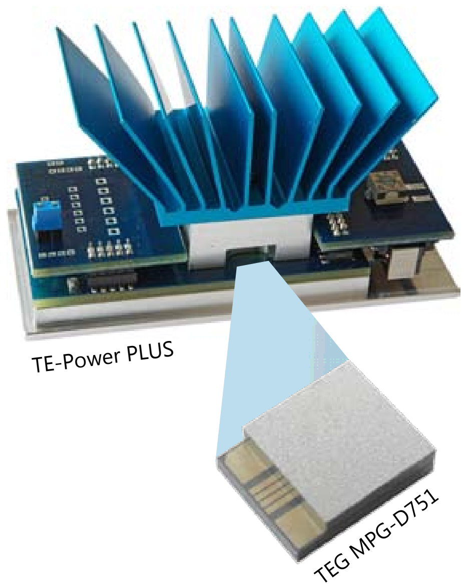
Wafer-based production ensures easy volume scalability and attractive economies of scale, making this technology a preferable option for high volume self-powered applications.

Still there are the intricacies of designing an efficient thermal path in order to make the best out of the given temperature gradients found in harvesting target locations. The fourth generation of thermal path design is implemented in the TE-Power BASE which serves as primary power source in all systems of the family. A single thermogenerator MPG-D751 generates the power.

- TE-Power ONE is targeted for primary TEG power and thermal path evaluation, with direct power and temperature sensor output interface.
- TE-Power PLUS is the fixed voltage source for applications which already contain duty cycle oriented power management. Energy is buffered in a capacitor which can be customer-extended via a solder terminal connected in parallel. For best efficacy matched load operation is recommended.

2. TE-Power - Evaluation Unit

Micropelt's chip-sized energy harvesting technology replaces a finite battery-based energy supply with infinite free power generated from local excess heat. Any low power duty-cycle oriented application can be powered by a thermoharvester. The concept is simple: Use a small energy buffer which contains at least the energy for a couple duty cycles. The harvester refills energy consumed by the system's active cycle during the much longer latency periods. The system will run as long as the average incoming power exceeds the average system power consumption - i.e. with a positive energy balance.



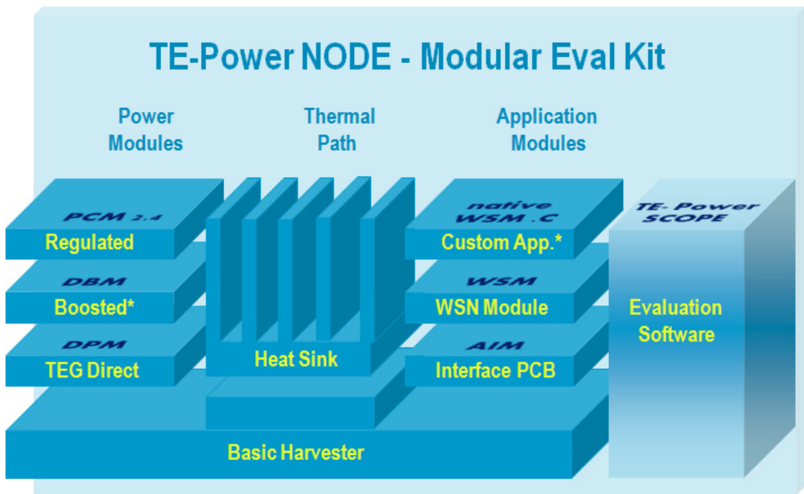
Gross ΔT [K] (ambient to heat source)	mAh per year	Equivalent number of AA type batteries
35 (20°C—55°C)	3,628	2-4
75 (20°C—95°C)	21,207	11-20

TE-Power ONE—PLUS—NODE evaluation systems help determine the behavior of a chip TEG, the implications of thermal coupling, the real-life thermoharvesting power budget, and they test-drive customer applications.

Evaluation System Family Overview		Plug-On Modules *					Other *	
Evaluation Kit Overview	Description	Direct Power Module **DPM**	DC Booster Module **DBM**	Power Conditioning Module **PCM**	Application Interface Module **AIM**	Wireless Sensor Module **WSM**	USB Radio Receiver	TE-Power SCOPE
TE-Power NODE	**Wireless 2,4 GHZ temp. sensing system with power management**	√		√	√	√	√	√
TE-Power PLUS (this document)	**DC-boosted variable output voltage (1.6 - 5.0 V)**	√	√		√			
TE-Power ONE (this document)	**Direct TEG output power with temp. sensor**	√						

TE-Power NODE System Family

All aspects of thermoharvesting evaluation and power budget exploration are covered by this comprehensive system. Depending on actual customer needs and targeted applications the system is divided into three levels of integration. They all build on the same base module which contains the TEG chip and a set of analog and digital sensors for ΔT measurements. Power modules include direct output, boosted constant and fully regulated voltage, complemented by versatile upgrade and connection interfaces.



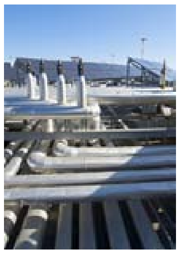
2.1 Features & Benefits of the TE-Power PLUS

- High voltage micro-thermogenerator coupled with best DC conversion efficiency for useful voltages from smallest gradients.
- Analog and digital sensors for precise thermal measurements
- Modular, upgradeable, plug-and-play layout for flexible exploration of all harvesting and power budgeting aspects.
- Flexible on-board interfaces for custom enhancements
- Optional add-on modules facilitate test-driving of target application

2.2 Applications

Wireless Sensor Networks (WSN) for:

- Process Monitoring
  - Refineries, chemical plants
  - Steel, paper, food production
- Condition Monitoring
  - Motors, engines, bearings, gears, shafts, etc.
- Building Automation and HVAC energy optimization
- Enhanced Automated Meter Reading with real-time energy control features
- Active Data Loggers
- Thermal triggering & self-powered switching

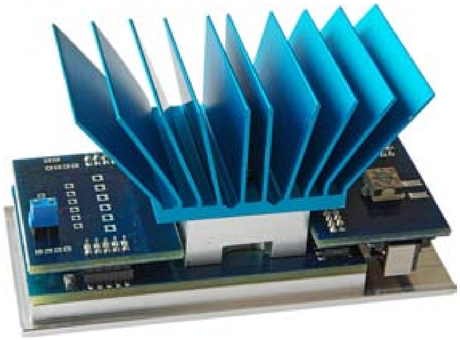





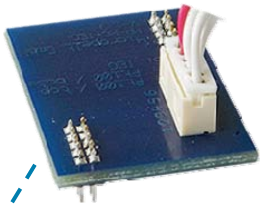


3. System Overview

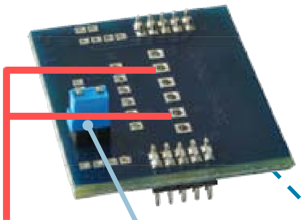
3.1 Electrical



Direct Power Module (DPM)
provides raw thermogenerator output and net ΔT sensor connections. Also for system diagnostics.

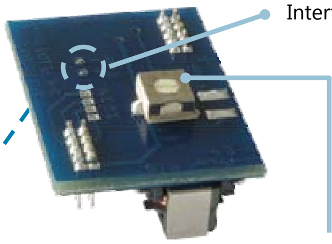


Application Interface Module (AIM)
connects custom applications to the power conditioning module and provides access to built-in sensors.



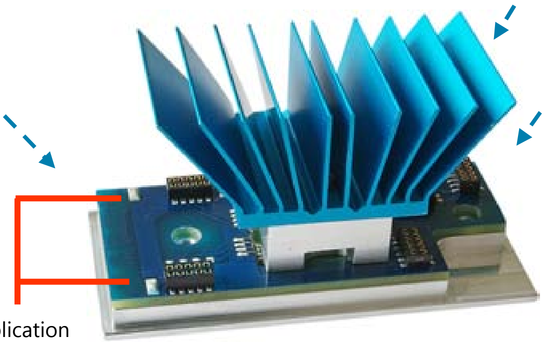
Application Power Interface

Serial Power Conditioning Interface



Capacitor Extension Interface

Voltage setting and fixed resistor terminal

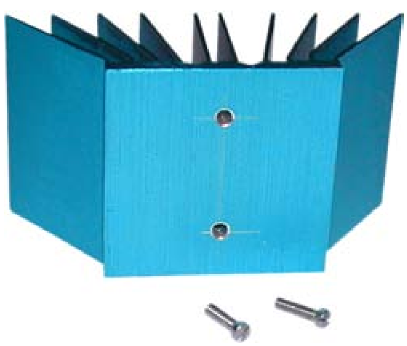


Fixed Application Power Interface (not with DPM)

DC Booster Module (DBM)

- Fixed voltage 1.6 ... 5 V
- 100 µF capacitor buffered
  - Parallel extension interface
- Fixed resistor terminal

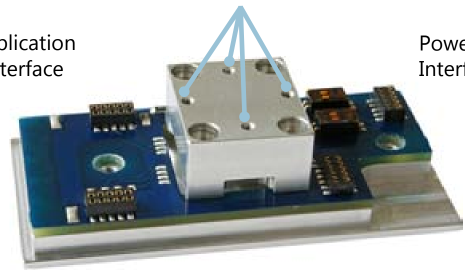
3.2 Mechanical



4 x M1.6 tap holes for heatsink attachment

Application Interface

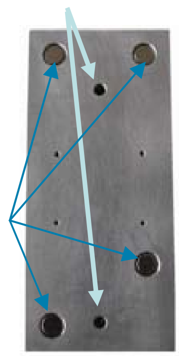
Power Interface



TE-Power BASE with heatsink adaptor and routing PCB. Module interfaces and TEG polarity-inverting DIP switches.

2 x M2.5 tapped through-holes

Permanent magnets



Bottom view of TE-Power BASE
4 permanent magnets and tapped through holes ensure easy attachment to multiple surfaces and custom adaptors.

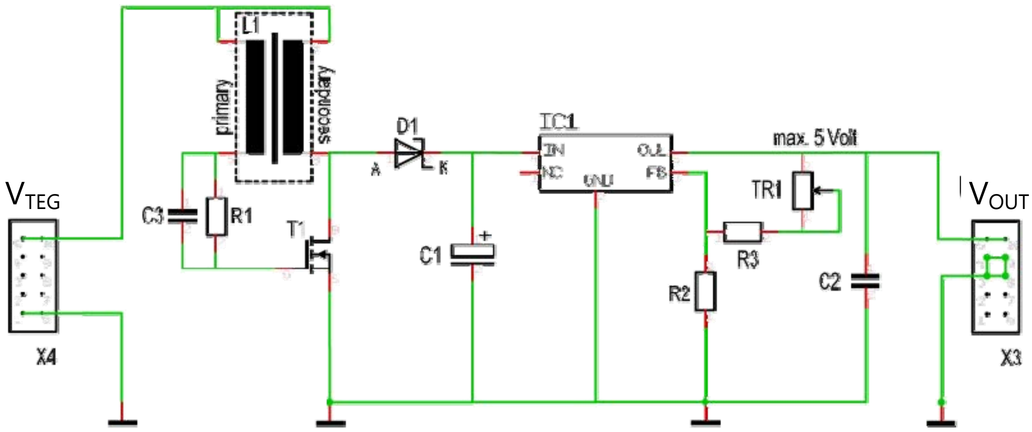
3.3 Power Output

Energy harvesting using a thermoelectric generator (TEG) is ideal for low power duty cycle applications. The raw TEG output is converted to a constant voltage by our custom DC converter. The generated power directly feeds the system's sleep power consumption. Surplus energy is stored in a capacitor or rechargeable battery for use during the load's active cycle. The following power supply modules are compatible with the TE-Power BASE harvester:

DPM: Direct Power Module for direct access to the TEG output. Requires external power conversion and conditioning. TEG output voltage increases with ΔT. This module is part of each kit.

DBM: DC Booster Module providing an adjustable output voltage in the range of 1.6 … 5V. This module requires external power conditioning (not part of the kit).

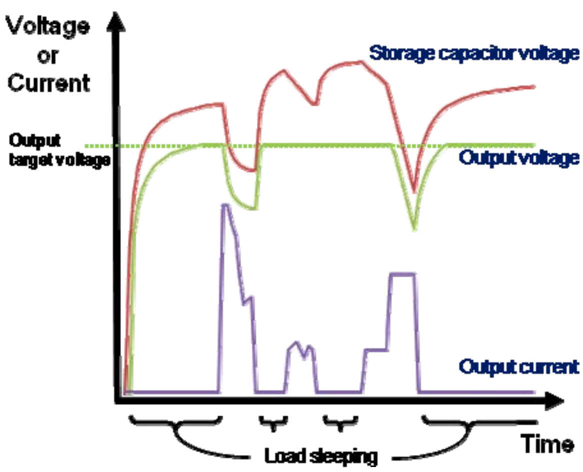
3.4 DBM Functionality



The DC Booster Module accepts the low-voltage TEG output and delivers a higher, user-adjustable output voltage ranging from 1.6 to 5.0 V.

The central element of the circuit is storage capacitor C1 (refer to schematic diagram). The harvested energy gradually charges C1 while the load draws current out of it. The charge current of C1 is related to the thermal gradient that the TEG experiences, the load current depends on the application.

It's important that the application itself manages its power intake to prevent C1 from discharging below the set voltage (TR1), leading to the DBM's output dropping out of regulation. Thus, if a specific threshold voltage is under-run, the attached application must temporarily revert to a sleep state with minimum current draw so that C1 can recover charge.



4. Electrical Parameters of TE-Power ONE

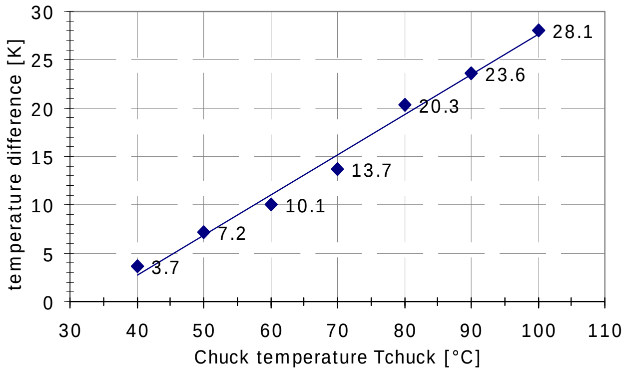
Test Conditions: Natural convection, vertically mounted (Fig. B, page 7), no airflow (lab environment)

typical thermoelectric characteristics of the assembly before DC boosting

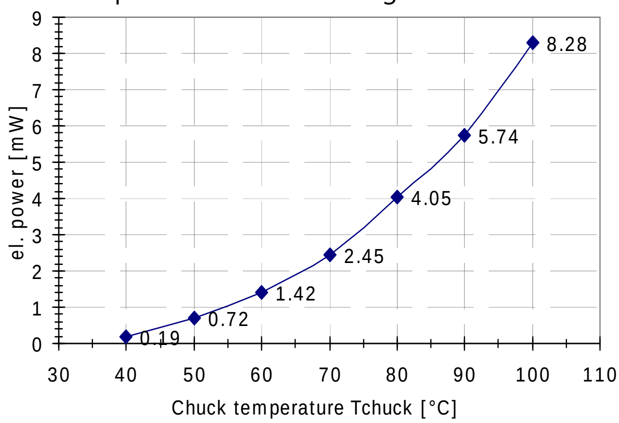
Tchuck* [°C]	Net ΔT [°C] across TEG	TEG open circuit voltage [V]	TEG power at load matching [mW]
40	3,7	0,6	0,2
50	7,2	1,2	0,7
60	10,1	1,7	1,4
70	13,7	2,3	2,5
80	20,3	2,9	4,1
90	23,6	3,6	5,7
100	28,1	4,3	8,3

* Tchuck = temperature of heat source

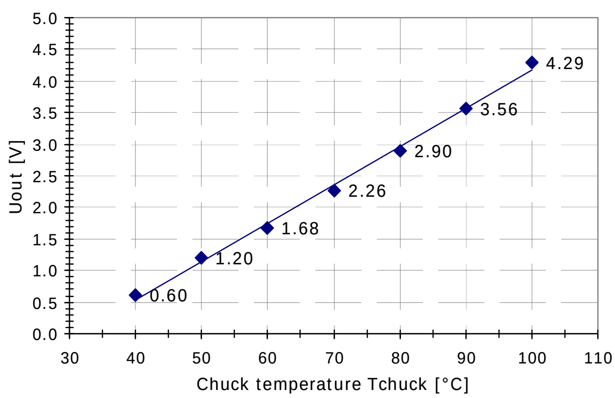
temperature difference (ΔT) across MPG-D751



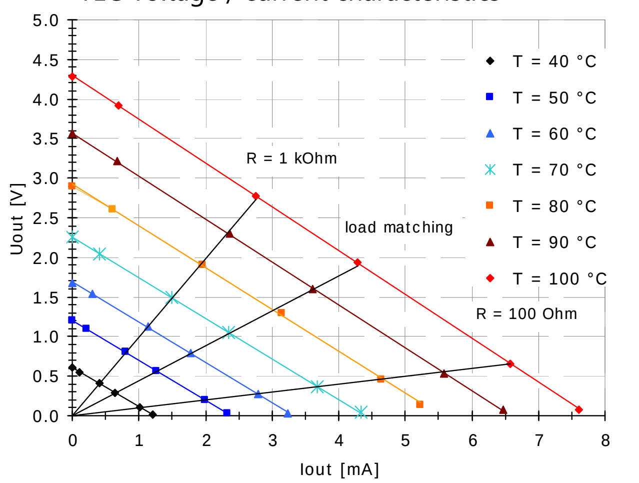
TEG power at load-matching



TEG open-circuit voltage ($R_L = \infty$)

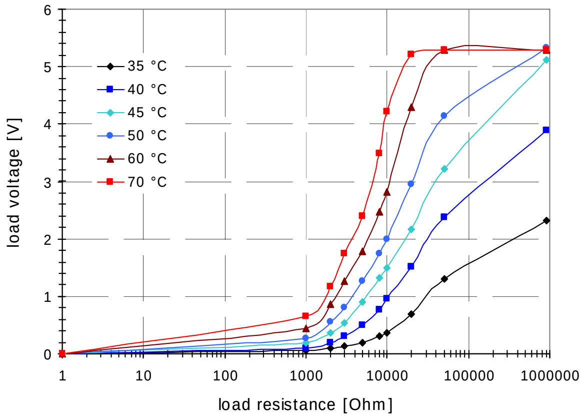


TEG voltage / current characteristics

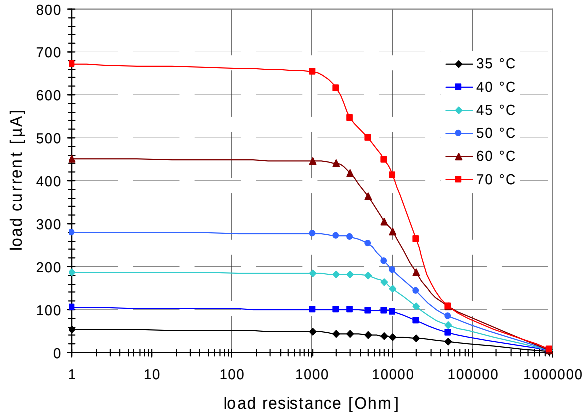


5. Electrical Parameters of TE-Power PLUS

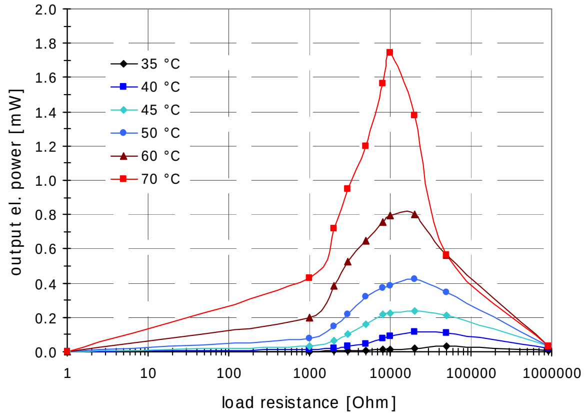
Below diagrams illustrate the behavior of the DBM output as a function of various parameters.
Test Conditions: Natural convection, vertically mounted (Fig. B, page 7), no airflow (lab environment)



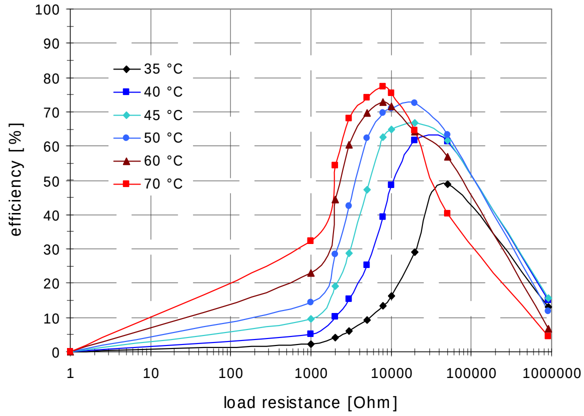
DBM output voltage vs load and hot side temperature at 25 °C ambient



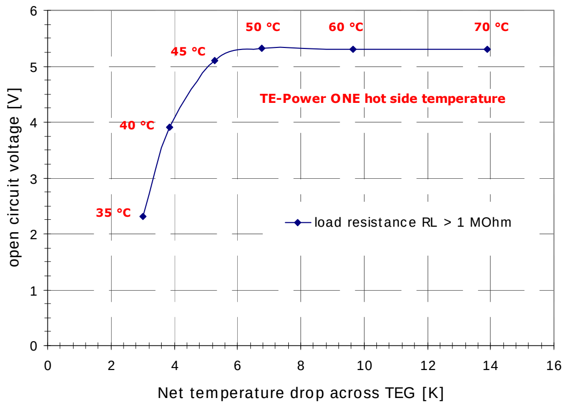
DBM output current vs load and hot side temperature at 25 °C ambient



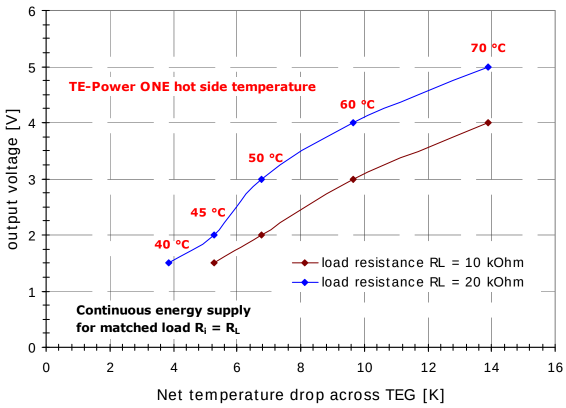
DBM output power vs load and hot side temperature. Maximum power is achieved with loads from 8 - 30 kOhm. Ambient temperature is 25 °C



DBM efficiency vs load and hot side temperatures. Maximum efficiency is achieved with loads from 8 - 30 kOhm. Ambient temperature is 25 °C



DBM open circuit output voltage vs net ΔT across the TEG. Hot side temperature figures refer to 25 °C ambient



DBM open circuit output voltage vs net ΔT across TEG at 10 and 20 kOhm load. Hot side temperature figures refer to 25 °C ambient

6. Application of the TE-Power PLUS

6.1 Attaching the Assembly to a Harvesting Target

Attachment of a thermoharvester to its target heat source is a critical factor in any application. The TE-Power PLUS helps to explore the effects of mounting pressure, surface flatness / roughness and various thermal interfaces materials on the harvesting result. The base of the assembly attaches to the target either through magnetic force or through 2 tapped mounting holes (M2.5).

6.2 Heatsink Positioning and Orientation

Both positioning and orientation of the TE-Power PLUS are of major importance for the power yield, particularly when the power density of the heat source is low. The alignment of the heatsink fins relative to the heat source and the direction of natural convection deserves special attention. To help optimize this, the heatsink adaptor has been designed so that the heatsink can be removed and then re-attached perpendicular to its default orientation. Note that it is inefficient to place the TE-Power PLUS horizontally on top of a heat source (Figure A). A forced air flow over the heatsink however maximizes power, regardless of position and orientation.

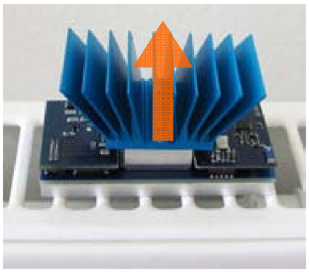


Figure A: Inferior positioning

TE-Power PLUS mounted atop the heat source with the heatsink in a bubble of hot air. This arrangement yields low ΔT and low power output.

Figure B: Preferred positioning

TE-Power PLUS mounted on a vertical surface with the heatsink fins aligned horizontally. Results in acceptable performance.

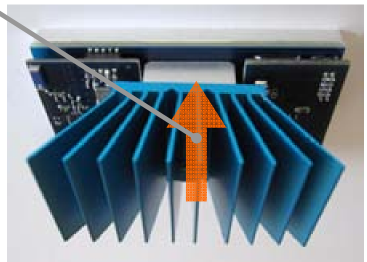


Figure C: Ideal positioning

TE-Power PLUS mounted on a vertical surface with the heatsink fins aligned vertically. This is best supporting natural convection and results in the highest possible ΔT and power output.

6.3 Radiation Suppression

Hot surfaces radiate in the infrared spectrum. This can cause the TE-Power PLUS's heatsink to heat up, diminishing effective ΔT and thus the power output of the device. In such cases it may be helpful to cover the hot surface near the TE-Power PLUS such that radiation is inhibited. Alternatively, a block of thermally conductive material may be used to increase the distance between radiating surface and heatsink, thereby improving natural convection.

6.4 Thermal Path Optimization

The standard heatsink of the TE-Power ONE and PLUS is a compromise between physical size and thermal performance. The heatsink is an off-the-shelf part, selected for good performance with lower temperature gradients. For high temperature gradients and any cutting edge application the heatsink should be re-considered and tested against other makes, sizes and shapes.

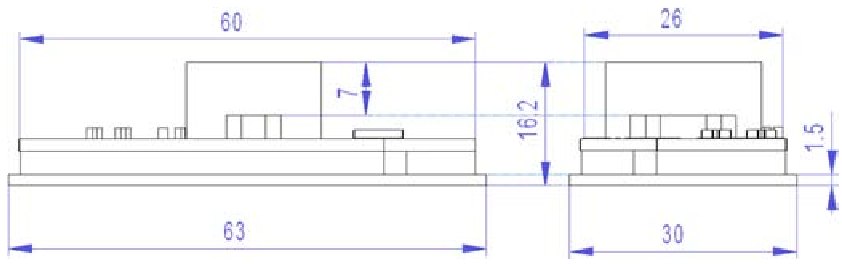
To facilitate the attachment and evaluation of different heatsink designs, the aluminum heatsink adaptor features 4 tapped holes (M1.6). This allows for thorough and comprehensive exploration of the thermal path under varying thermal conditions. A more suitable heatsink will, under otherwise identical conditions, stay cooler. Both the cold side temperature measured by Pt100 and the power yield of the TEG will reflect this. The output voltage and power will both increase accordingly.

7. Technical Data

	Parameter	Value
General	Max. operating temperature	
	hot side	105°C
	ambient air	85°C
Thermal Path	Base	
	Footprint	30 mm x 63 mm
	Mounting holes	2x M2.5 threaded through hole
	Thermogenerator	MPG-D751
	Footprint	3.3 x 4.2 mm
	Thermovoltage	140 mV/K
	Thermal resistance	12.5 K/W
	Heatsink adaptor	
	Mounting face	20.6 x 17.8 mm
	Heatsink attachment	4x M1.6 x 4 mm tapped blind hole
	Heatsink (standard blue fin type)	ATS-52250P-C0-R0, Advanced Thermal Solutions Inc
	Thermal resistance	approx. 31 K/W under natural convection
Power Modules	DBM - DC Booster Module	
	Max. operating temperature	105°C
	Output voltage	1.6 ... 5 V adjustable
	Capacitor extension interface	Through hole for solder connection
	DPM - Direct Power Module	
	Max.. operating temperature	105°C
	Connector signals:	6 wires, open end
	TEG cold side temperature pins 1-2	Pt100 sensor
	TEG hot side temperature, pins 3-4	Pt100 sensor
	TEG voltage output, pins 5-6	ΔT x thermovoltage (140 mV/K)
Custom Applications	Application Interface Module	
	Signals made available	Output of power module, such as DBM
		Analog temperature sensor hot side
		Analog temperature sensor cold side
		Digital temperature sensor hot side (SCL, SDA)
		Analog temperature sensor cold side (SCL, SDA)
		Storage capacitor voltage
Dimensions	Base / heat spreader W x L	30 mm x 63 mm
	Total height incl. standard heatsink	33.6 mm
	Height with heatsink adaptor only	16.2 mm
	Weight TE-Power PLUS with 2 plug-on modules	49 g

Technical drawing

Heat sink adaptor mounted on heat spreader, side view (dimensions in mm)



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Power generation.