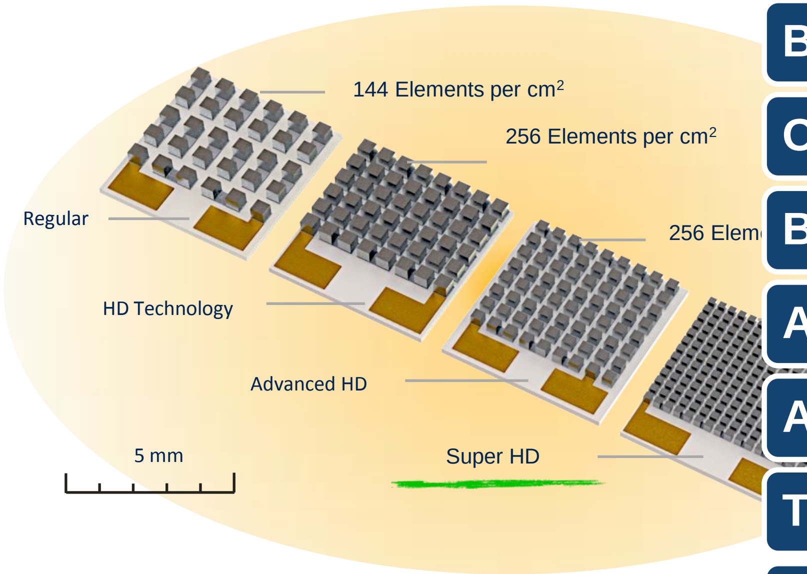
ENERGY HARVESTING: RMT COMPONENTS, SOLUTIONS, DEVELOPMENTS.

G.Gromov

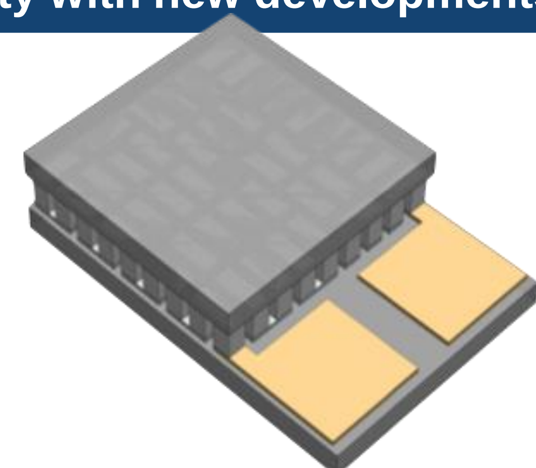
RMT Ltd

RMT Ltd

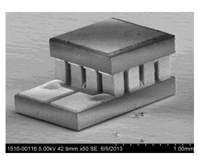
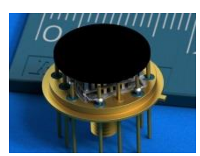
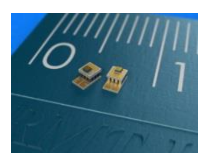
- ✓ 20 YEARS AT THE THERMOELECTRIC MARKET
- ✓ NOMENCLATURE OF MORE THAN 2 000 TYPES OF TECS
- ✓ PRODUCTION CAPABILITY OF MORE THAN 5M UNITS PER YEAR
- ✓ ISO 9001:2008 CERTIFIED



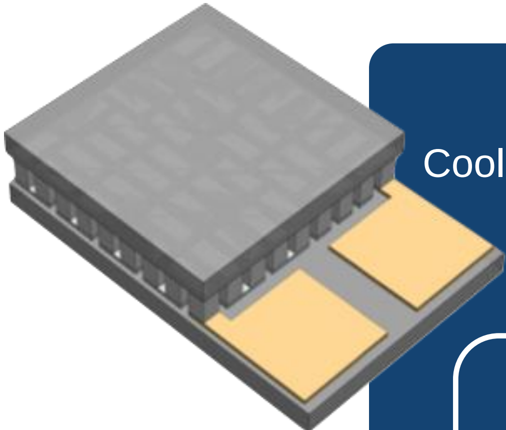
- **Bulk Technology**
- **Own high-performance Bi-Te material**
- **Best Price-Performance ratio on the market**
- **Automated manufacturing**
- **All in-house**
- **Telcordia GR-468 qualified**
- **RoHS compliant solutions by default**
- **Full-featured flexibility with new developments**



THERMOELECTRIC COOLING MICROMODULES

THERMOELECTRIC MICROMODULE APPLICATIONS

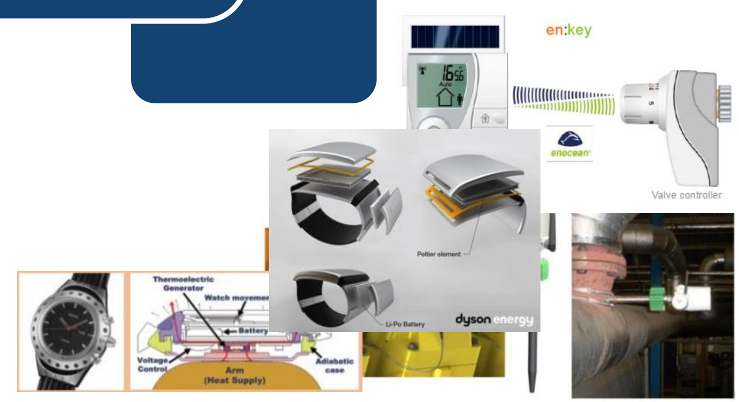


Coolers

Generators

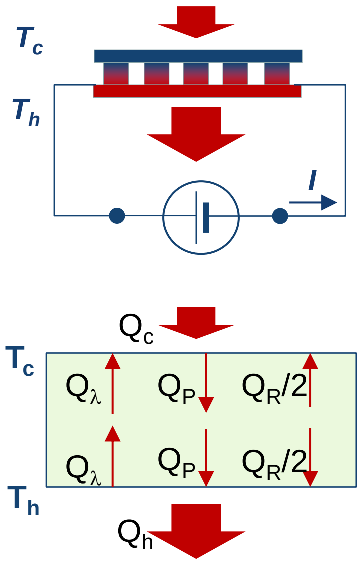
Sensors

Thermoelectric Micromodules



THERMOELECTRIC MICROMODULE APPLICATIONS

COOLER



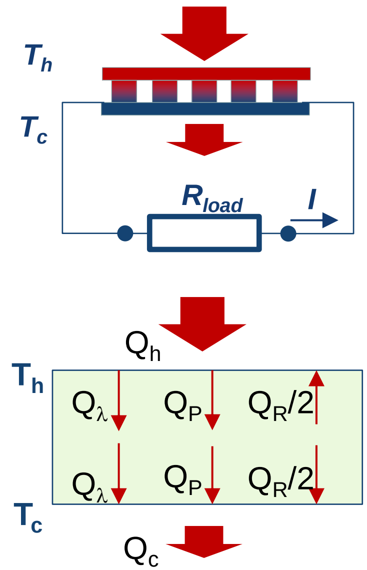
Peltier

$$Q_C = 2N\alpha T_c I - \frac{I \times ACR}{2} - K\Delta T$$

$$Q_{max} = \frac{(2N\alpha)^2 \times T_c}{2 \times ACR}, T_{max} = 0$$

$$\Delta T_{max} = \frac{1}{2} Z T_c^2, Q_{max} = 0$$

GENERATOR



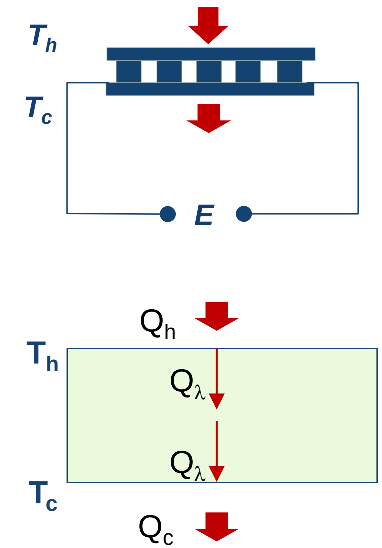
Seebeck - Peltier

$$I = \frac{E}{R_{load} + ACR}$$

$$P = E^2 \times \frac{R_{load}}{(R_{load} + ACR)^2}$$

$$\eta = \frac{Z \times \Delta T}{4}$$

SENSOR



Seebeck

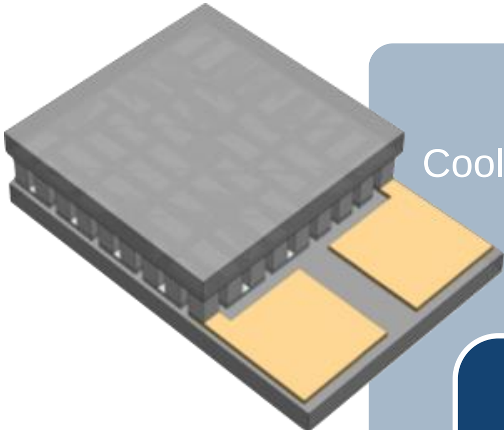
$$\Delta T = Q \times R_T$$

$$E = a \times 2N \times (T_h - T_c)$$

$$S_a = \frac{1}{f} \times \frac{\alpha}{k}$$

$$S_a = \frac{1}{a \times 2N} Z \times ACR$$

THERMOELECTRIC GENERATORS for ENERGY HARVESTING

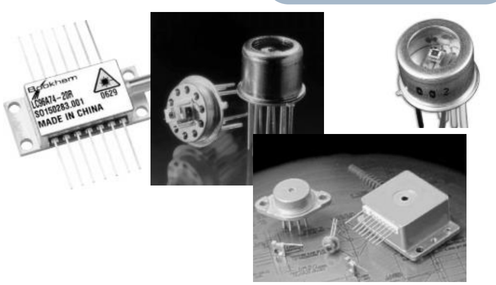


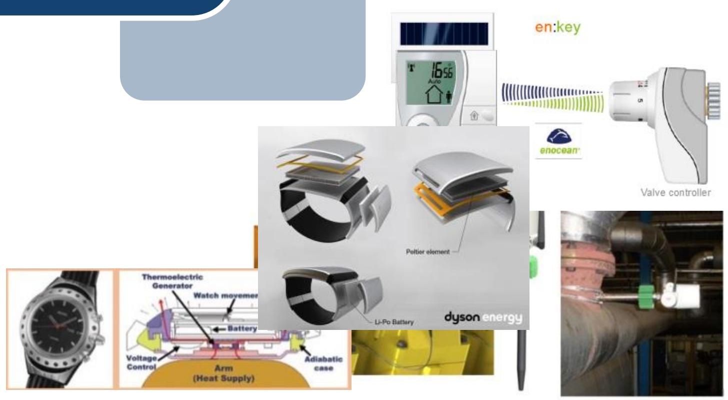
Coolers

Generators

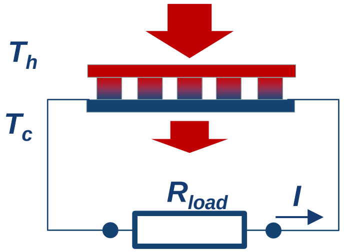
Sensors

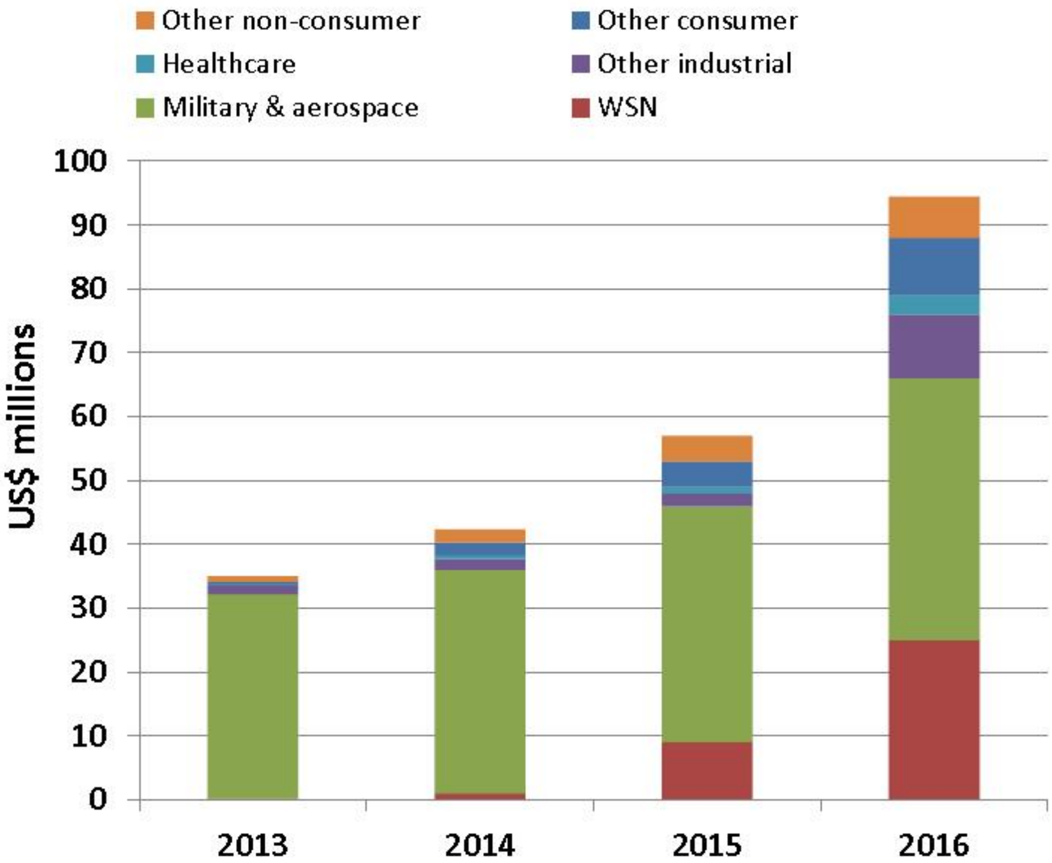
Thermoelectric Micromodules





THERMOELECTRIC ENERGY HARVESTING MARKET





$900 million to 2024

Harry Zorvos. Successful commercial Energy Harvesting deployments in Wearable, Industrial Controls, Transportation, Medicine, Handhelds, Fitness and Building Control" IDTechEx, 2013

THERMOELECTRIC ENERGY HARVESTING MARKET

Solid-State Device

No Moving Parts

Reasonable prices

Reliably for over 30 years

Why Thermoelectric Energy Harvesting

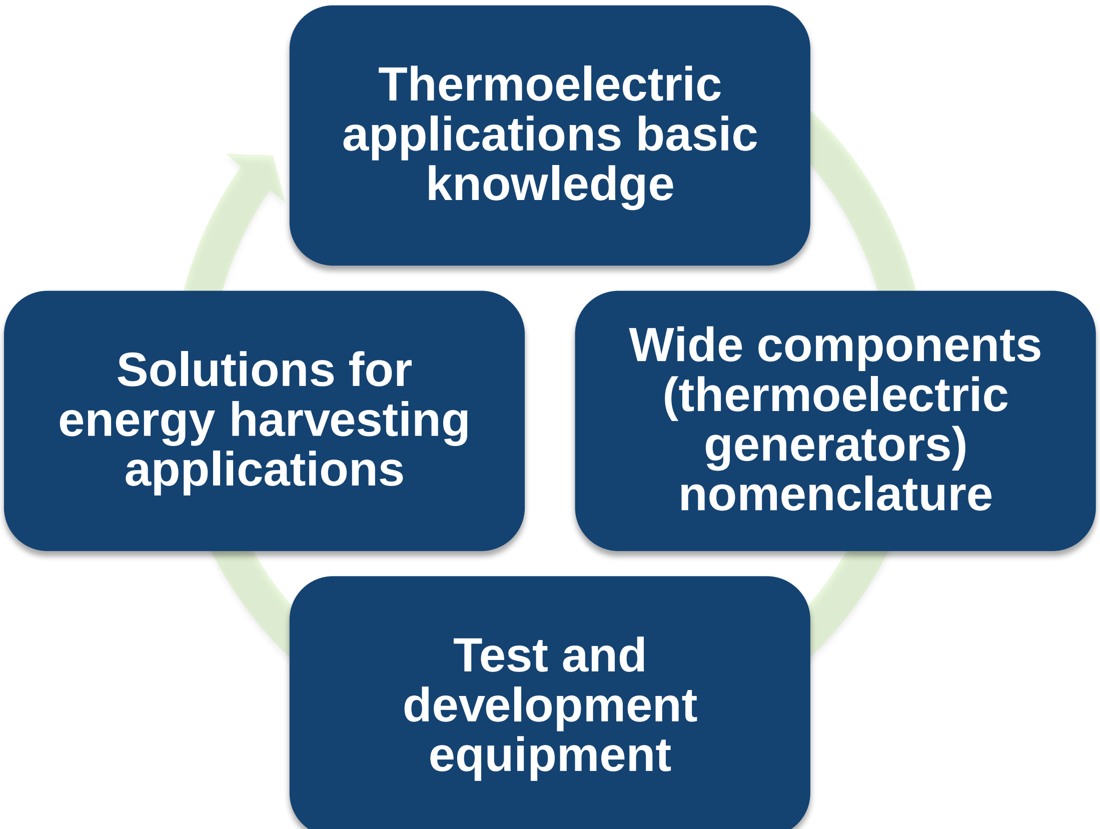
Maintenance-Free

Small Heat Sources

Small Temp. Differences

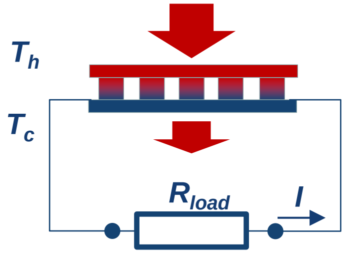
Compact, Simple and Scalable

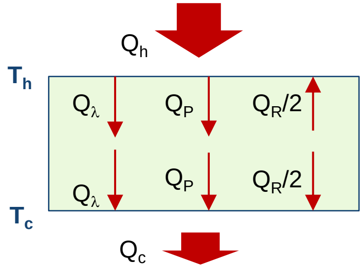
RMT for THERMOELECTRIC ENERGY HARVESTING



BASIS. HOW IT WORKS

THERMAL BALANCE EQUATIONS





$$Q_h = 2Nk\Delta T + 2N\alpha I T_h - \frac{1}{2} I^2 (2NR)$$

$$Q_c = 2Nk\Delta T + 2N\alpha I T_c + \frac{1}{2} I^2 (2NR)$$

$$E = 2N\alpha\Delta T$$

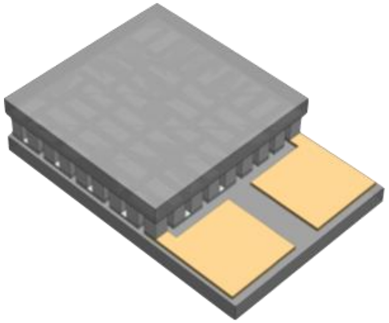
$$I = \frac{E}{R_{load} + ACR}$$

$$m = \frac{R_{load}}{ACR}$$

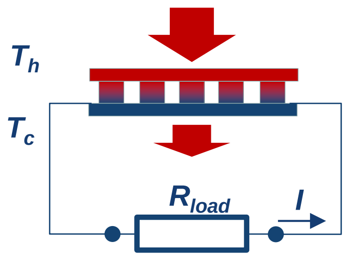
$$U = IR_{load} = E\frac{R_{load}}{(R_{load} + ACR)^2}$$

$$P = E^2 \times \frac{R_{load}}{(R_{load} + ACR)^2}$$

$$P_{max} = \frac{E^2}{4 \times ACR}$$



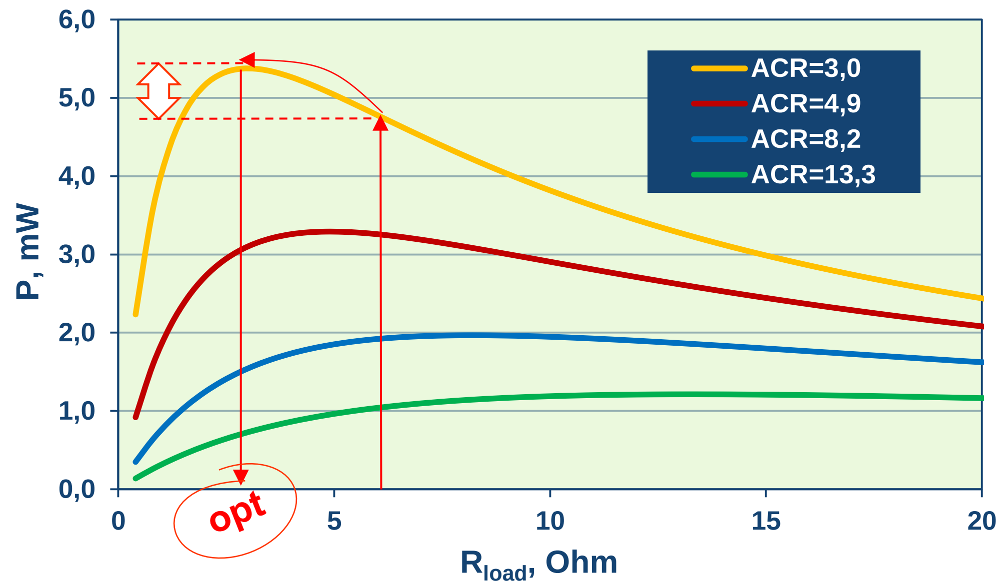
MAXIMAL POWER *vs* LOAD RESISTANCE R_{load}



$$P = E^2 \times \frac{R_{load}}{(R_{load} + ACR)^2}$$

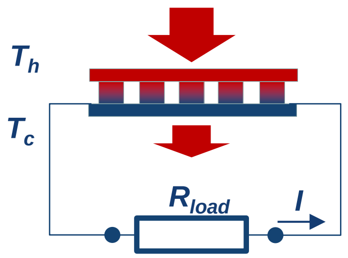
$$P_{max}$$

$$R_{load} = ACR$$



$$P_{max} = \frac{E^2}{4 \times ACR}$$

MAXIMAL EFFICIENCY *vs* OPTIMAL LOAD m_{opt}



$$R_{load} = m \times ACR$$

$$m_{opt} = \sqrt{1 + Z \times \frac{T_h + T_c}{2}}$$

$$P_{opt} = \frac{E^2}{ACR} \times \frac{m}{(1+m)^2}$$

$$\eta_{max} = \frac{\Delta T}{T_h} \frac{m_{opt}}{m_{opt} + 1 - \frac{\Delta T}{T_h}}$$

$$\eta_{max}$$

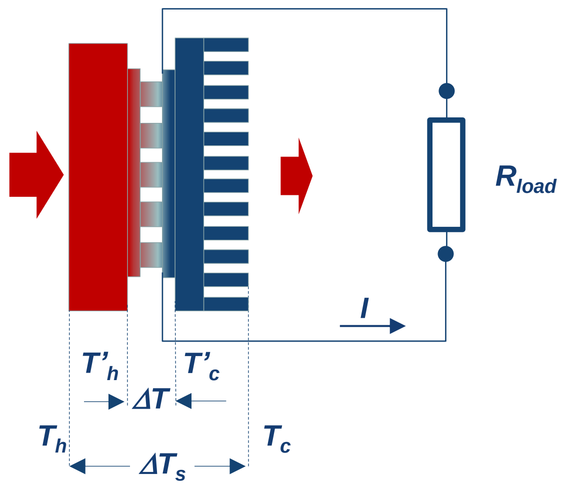
⇩

$$R_{load} = m_{opt}\, ACR$$

$$m_{opt} \sim \sqrt{2}$$

$$R_{load} \sim 1.0 \ldots 1.4\ ACR$$

MAXIMAL POWER *vs* THERMAL RESISTANCES R_{TEG} , R_c



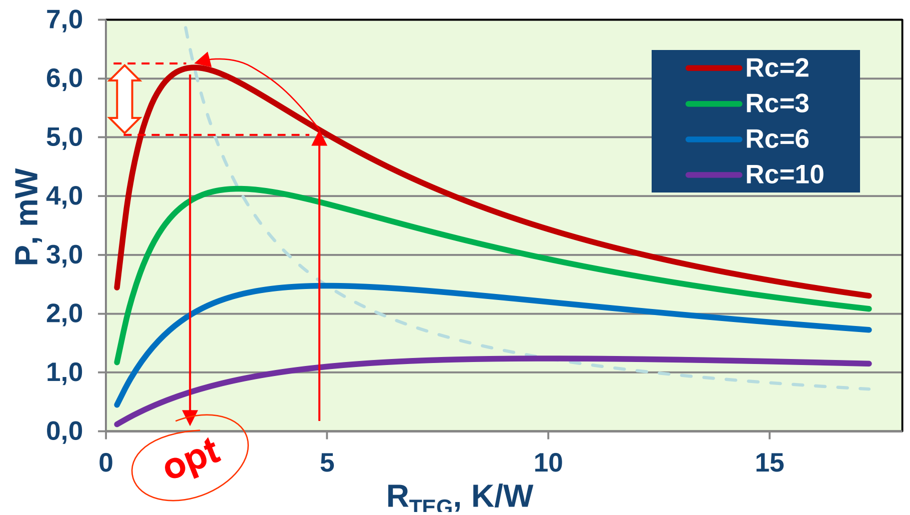
$$\Delta T < \Delta T_s$$

$$R_s = R'_{TEG} + R_c$$

$$R'_{TEG} = \frac{1}{K'} \approx \frac{R_{TEG}}{1 + \frac{ZT_c}{(1+m)}}$$

$$P_{max}$$

$$R_c = R'_{TEG}$$



$$P_{max} \approx \frac{Z \times \Delta T_s^2}{4} \times \frac{R'_{TEG}}{(R'_{TEG} + R_c)^2} \times \frac{1}{1 + \frac{ZT_c}{(1+m)}}$$

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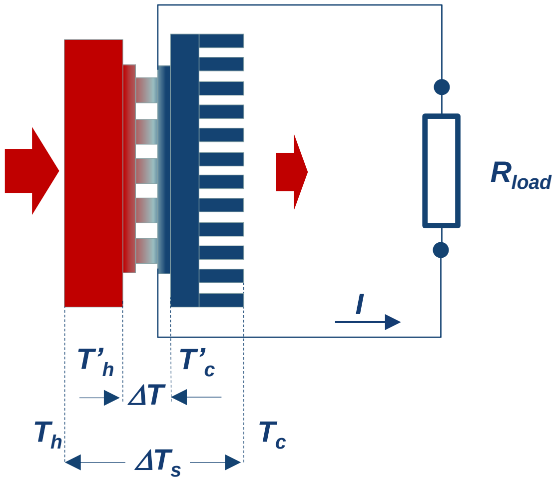
OUTPUT VOLTAGE

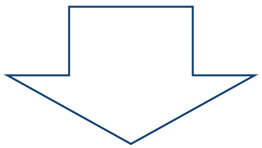


$$E = 2N \times \alpha \times \Delta T$$

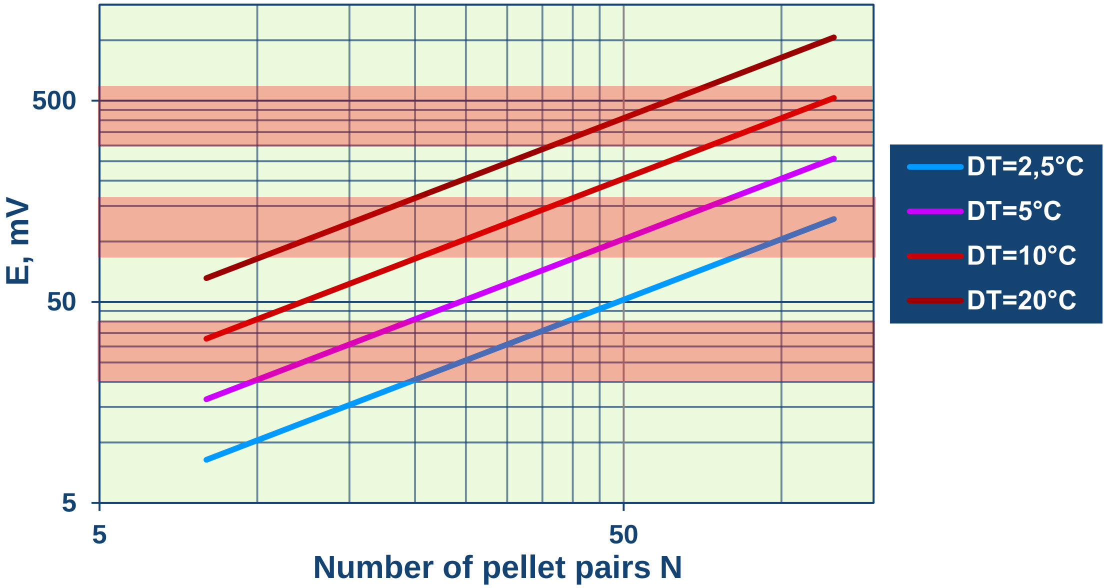
$$U = E \times \frac{R_{load}}{R_{load} + ACR}$$

$$U_{PMAX} = \frac{E}{2} \text{ at } R_{load} = ACR$$

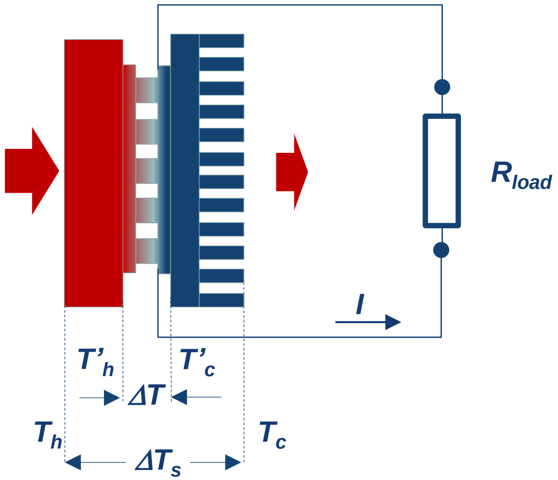
$$U_{RMAX} \approx E \text{ at } R_{load} \gg ACR$$



$U_{max} \sim 0.5\text{-}1.0E$



PERFORMANCE



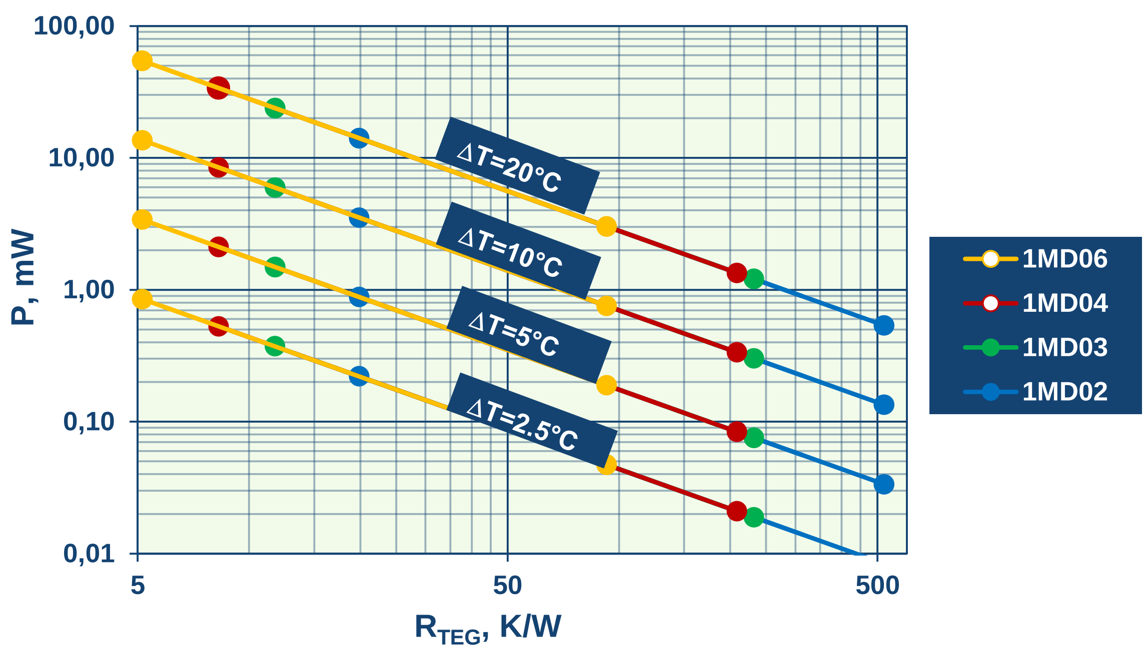
$$P_{max} = 2N \times \frac{Z}{4} \times \Delta T^2 \times f \times k$$

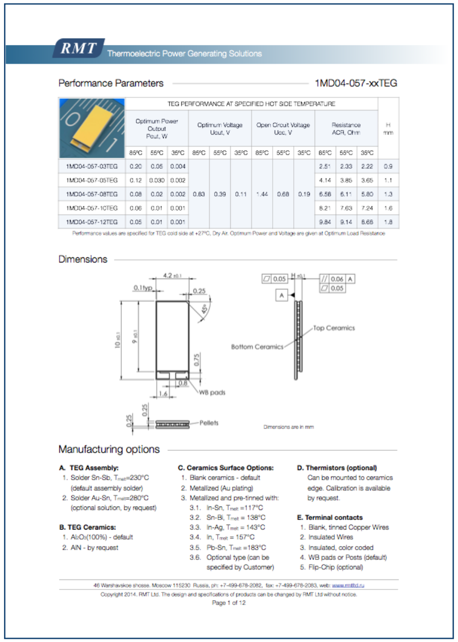
$$R_{TEG} = \frac{1}{2N \times f \times k}$$

$$P_{max} = \frac{Z}{4} \times \Delta T^2 \times \frac{1}{R_{TEG}}$$

$1/R_{TEG}$

P_{max}





RMT Thermoelectric Power Generating Solutions

Performance Parameters — 1MD04-057-xxTEG

	TEG PERFORMANCE AT SPECIFIED HOT SIDE TEMPERATURE												H mm
	Optimum Power Output Pout, W			Optimum Voltage Uout, V			Open Circuit Voltage Uoc, V			Resistance ACR, Ohm			
	85ºC	55ºC	35ºC	85ºC	55ºC	35ºC	85ºC	55ºC	35ºC	85ºC	55ºC	35ºC	
1MD04-057-03TEG	0.20	0.05	0.004	0.83	0.39	0.11	1.44	0.68	0.19	2.51	2.33	2.22	0.9
1MD04-057-05TEG	0.12	0.030	0.002							4.14	3.85	3.65	1.1
1MD04-057-08TEG	0.08	0.02	0.002							6.58	6.11	5.80	1.3
1MD04-057-10TEG	0.06	0.01	0.001							8.21	7.63	7.24	1.6
1MD04-057-12TEG	0.05	0.01	0.001							9.84	9.14	8.68	1.8

Performance values are specified for TEG cold side at +27ºC, Dry Air. Optimum Power and Voltage are given at Optimum Load Resistance

Dimensions

Dimensions are in mm

Manufacturing options

A. TEG Assembly:
1. Solder Sn-Sb, T_{melt}=230°C (default assembly solder)
2. Solder Au-Sn, T_{melt}=280°C (optional solution, by request)

B. TEG Ceramics:
1. Al_2O_3(100%) - default
2. AlN - by request

C. Ceramics Surface Options:
1. Blank ceramics - default
2. Metallized (Au plating)
3. Metallized and pre-tinned with:
   - 3.1. In-Sn, T_{melt} =117°C
   - 3.2. Sn-Bi, T_{melt} = 138°C
   - 3.3. In-Ag, T_{melt} = 143°C
   - 3.4. In, T_{melt} = 157°C
   - 3.5. Pb-Sn, T_{melt} =183°C
   - 3.6. Optional type (can be specified by Customer)

D. Thermistors (optional)
Can be mounted to ceramics edge. Calibration is available by request.

E. Terminal contacts
1. Blank, tinned Copper Wires
2. Insulated Wires
3. Insulated, color coded
4. WB pads or Posts (default)
5. Flip-Chip (optional)

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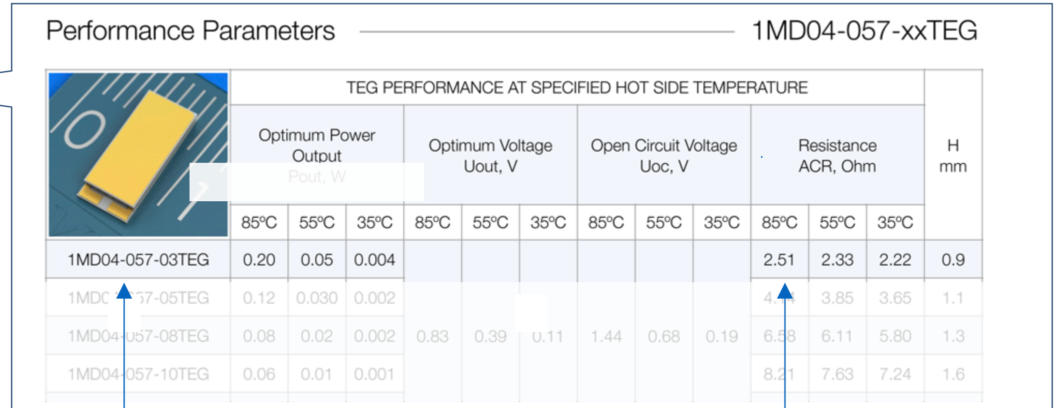
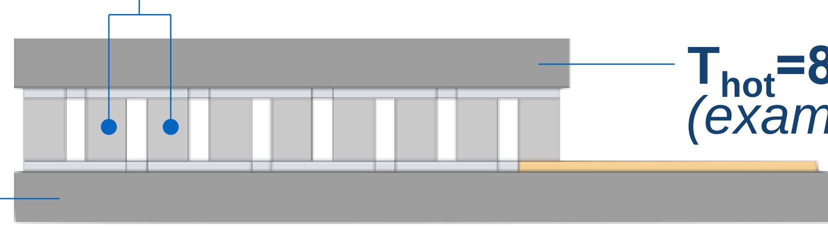


Performance Parameters — 1MD04-057-xxTEG

	TEG PERFORMANCE AT SPECIFIED HOT SIDE TEMPERATURE												H mm
	Optimum Power Output Pout, W			Optimum Voltage Uout, V			Open Circuit Voltage Uoc, V			Resistance ACR, Ohm			
	85ºC	55ºC	35ºC	85ºC	55ºC	35ºC	85ºC	55ºC	35ºC	85ºC	55ºC	35ºC	
1MD04-057-03TEG	0.20	0.05	0.004							2.51	2.33	2.22	0.9
1MD04-057-05TEG	0.12	0.030	0.002							4.14	3.85	3.65	1.1
1MD04-057-08TEG	0.08	0.02	0.002	0.83	0.39	0.11	1.44	0.68	0.19	6.58	6.11	5.80	1.3
1MD04-057-10TEG	0.06	0.01	0.001							8.21	7.63	7.24	1.6

1MD04-057-03 R_{teg} **= 2.51Ohm @**T_{hot}**=85ºC**

N couples = 57

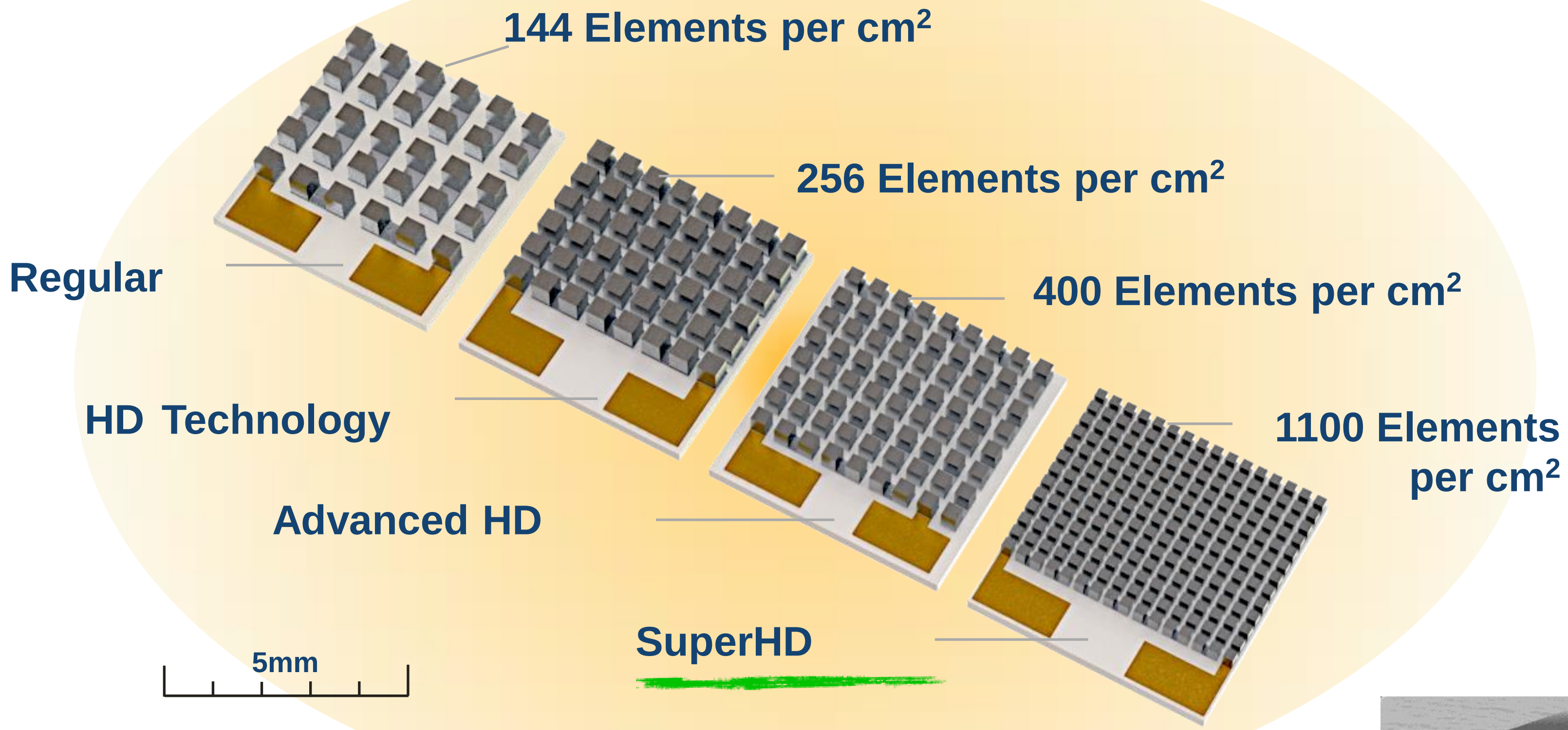


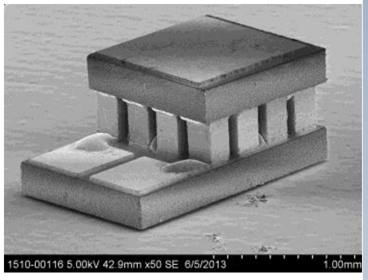
T_{hot}=85ºC
(example value)

T_{cold}=27ºC
(example value)

RMT TEG datasheets contain all info for simplified TEG estimations

RMT MICROMODULE TECHNOLOGY





ADVANTAGES

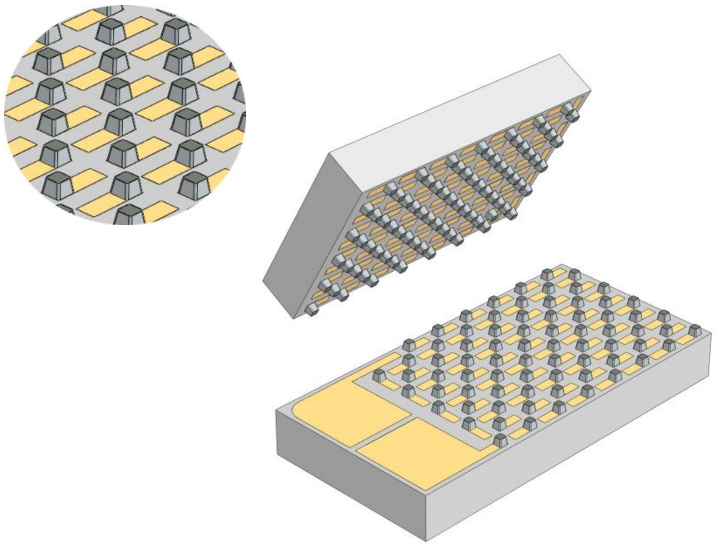
RMT TEGs

- Bulk Technology process
- Maintenance-free
- Environmentally conscious
- Miniature dimensions
- Long lifetime operating
- High performance
- World widest range
- Best Performance-Price ratio

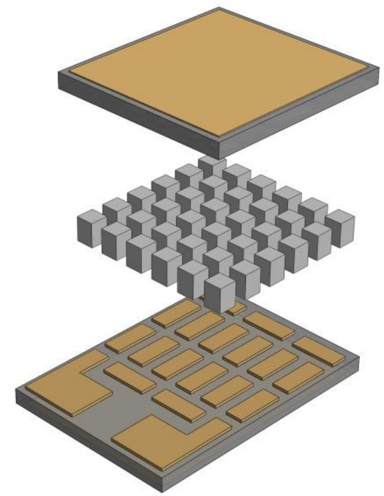
RMT bulk-Technology TEGs Seebeck coefficient per pair - α=400μV/K
As a reference - thin-film Technology TEGs have only 250 μ V/K

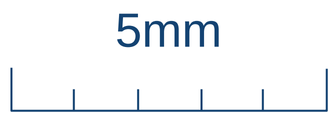
BULK or THIN-FILM TECHNOLOGY

THIN-FILM MODULE



BULK TECHNOLOGY MODULE



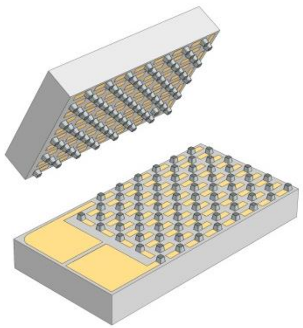


BiTe pellets are grown on a substrate by thin-film process. Two substrates are soldered together

BiTe materials manufactured in ingots, cut into pellets and soldered between two metallized ceramics

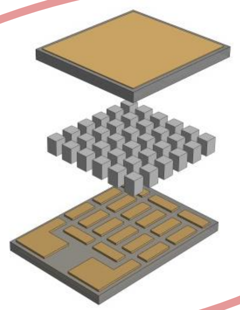
BULK or THIN-FILM TECHNOLOGY

THIN-FILM MODULE



“T” *VS* “B”

BULK TECHNOLOGY MODULE



Voltage

THE SAME HEAT FLUX

$$\frac{E_B}{E_T} \approx 0.5 \ldots 0.6$$

Efficiency

THE SAME TEMPERATURE DIFFERENCE

$$\frac{\eta_B}{\eta_T} \approx 2,2 \ldots 2,5$$

Power

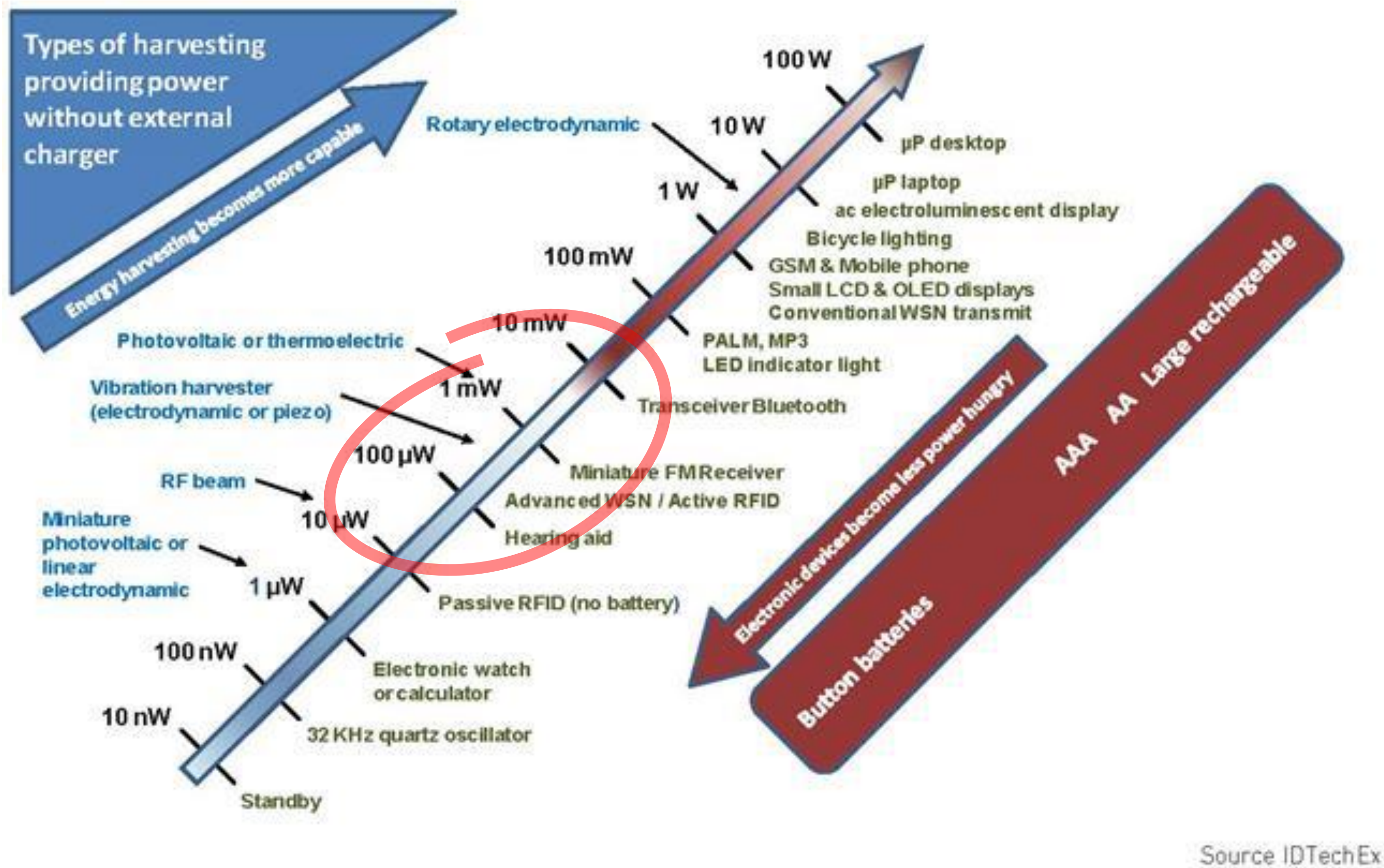
MAXIMUM POWER ($R_{load} = ACR$)

$$\frac{P_B}{P_T} \approx 1.5 \ldots 3$$

THE SAME HEAT FLUX

$$\frac{\eta_B}{\eta_T} \approx 6,5 \ldots 7,5$$

ENERGY HARVESTING APPLICATIONS



Dr. Harry Zervos, Dr. Peter Harrop and Raghu Das. IDTechEx. Energy Harvesting and Storage 2014-2024: Forecasts, Technologies, Players.

THERMOELECTRIC ENERGY HARVESTING APPLICATIONS

5-10°C Low power heat sources. Typical – human body.

- Watches, sport trackers, wireless sensors.

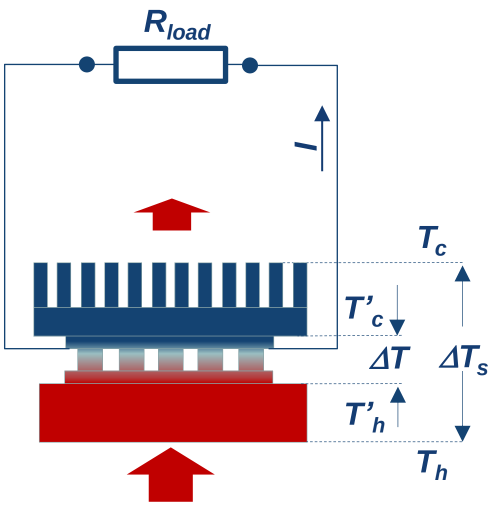
10-20°C Middle range heat sources. Industrial and natural heat sources.

- Power for wireless sensors, WNS.

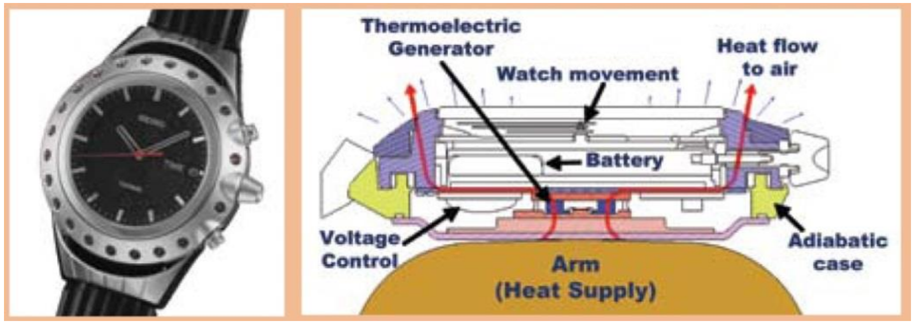
20-50°C High power heat sources. Mostly industrial nature.

- Power for wireless sensors, remote control.

OPTIMAL SOLUTION ALGORITHM



$$\Delta T_s = 5\,°C$$



$$\Delta T_s = \Delta T + \Delta T_c$$

$$\Delta T = \frac{1}{2} \times \Delta T_s = 2.5\,°C$$

$$S \approx \mathbf{15}\ \text{см}^2$$

$$R_c = \mathbf{57}\ K/W$$

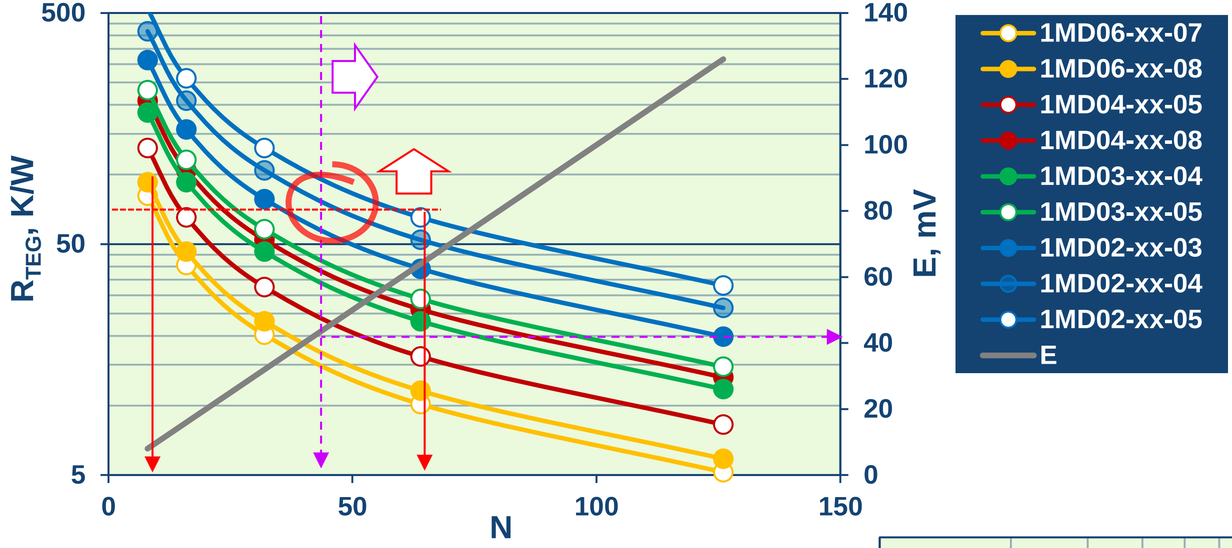
$$R'_{TEG} \cong R_c = \mathbf{57}\ K/W$$

$$R_{TEG} \approx R'_{TEG} \times 1.35$$

$$E = 2 \times U_{TEG} \geq 2 \times 20\ mV$$

DC-DC input voltage >20 mV

OPTIMAL SOLUTION ALGORITHM



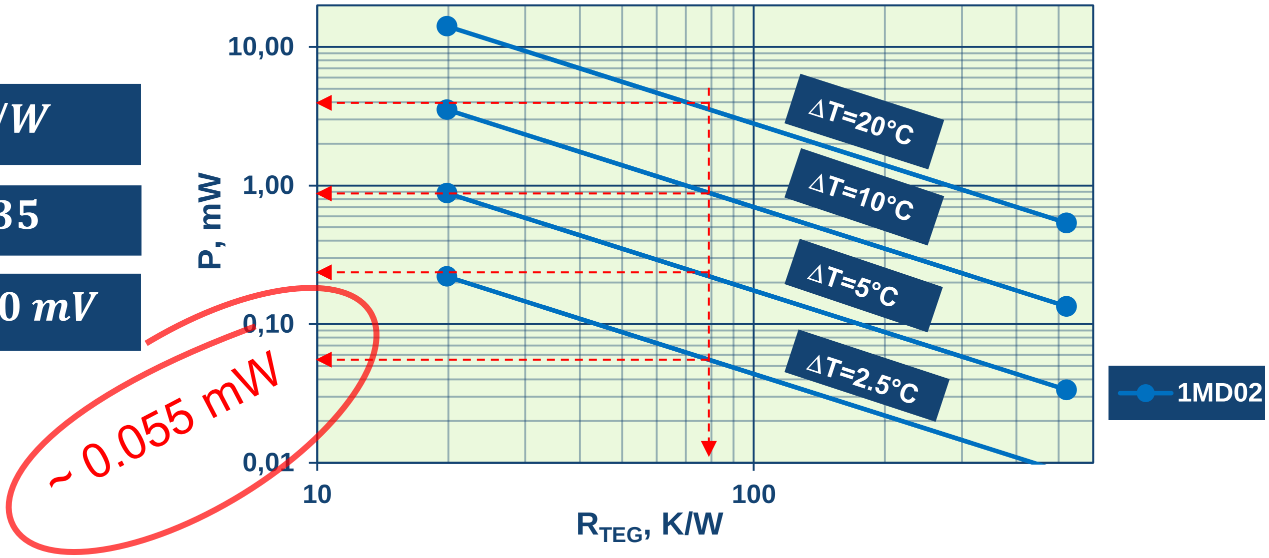
Optimal solution
1MD02-044-04

2.7x4.0 mm²
44 pairs
(0.2x0.2x0.4mm³)

$$R'_{TEG} \cong R_c = 57\ K/W$$

$$R_{TEG} \approx R'_{TEG} \times 1.35$$

$$E = 2 \times U_{TEG} \geq 2 \times 20\ mV$$



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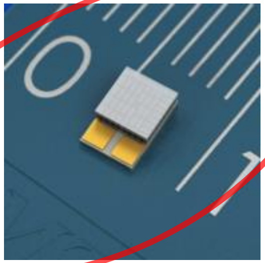
OPTIMAL SOLUTION ALGORITHM

~ 1 Year *x*

Optimal solution
1MD02-044-04

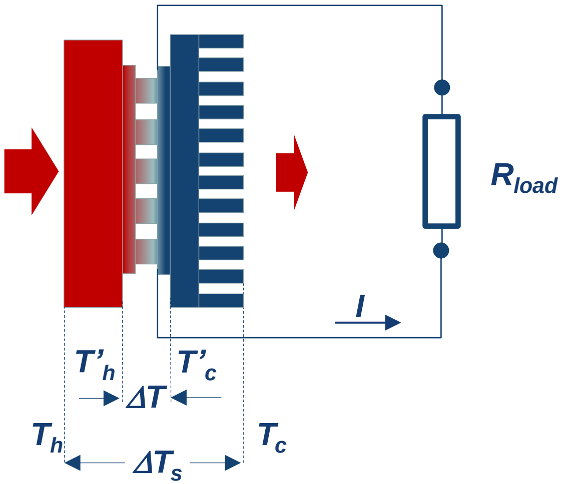


2.7x4.0 mm^2
44 pairs
(0.2x0.2x0.4mm^3)

~ 0.055 mW

RMT TEGS

MicroTEGs with 0.05-25 mW power for Harvesting Applications

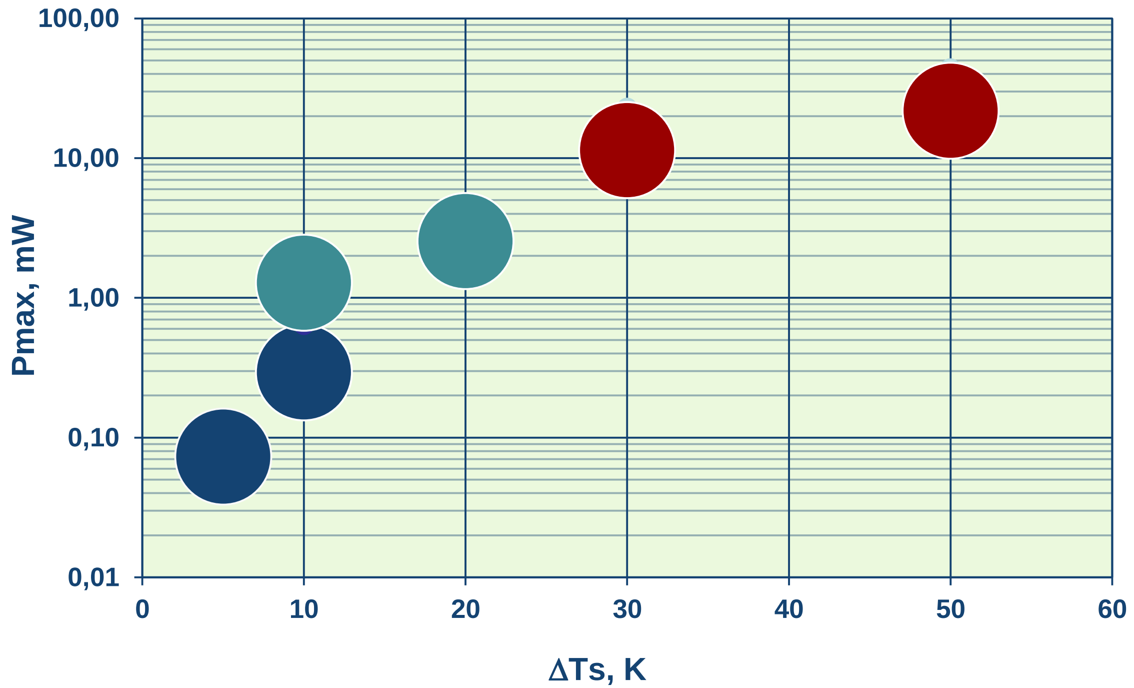


5 - 10°C   10 - 20°C   30 - 50°C

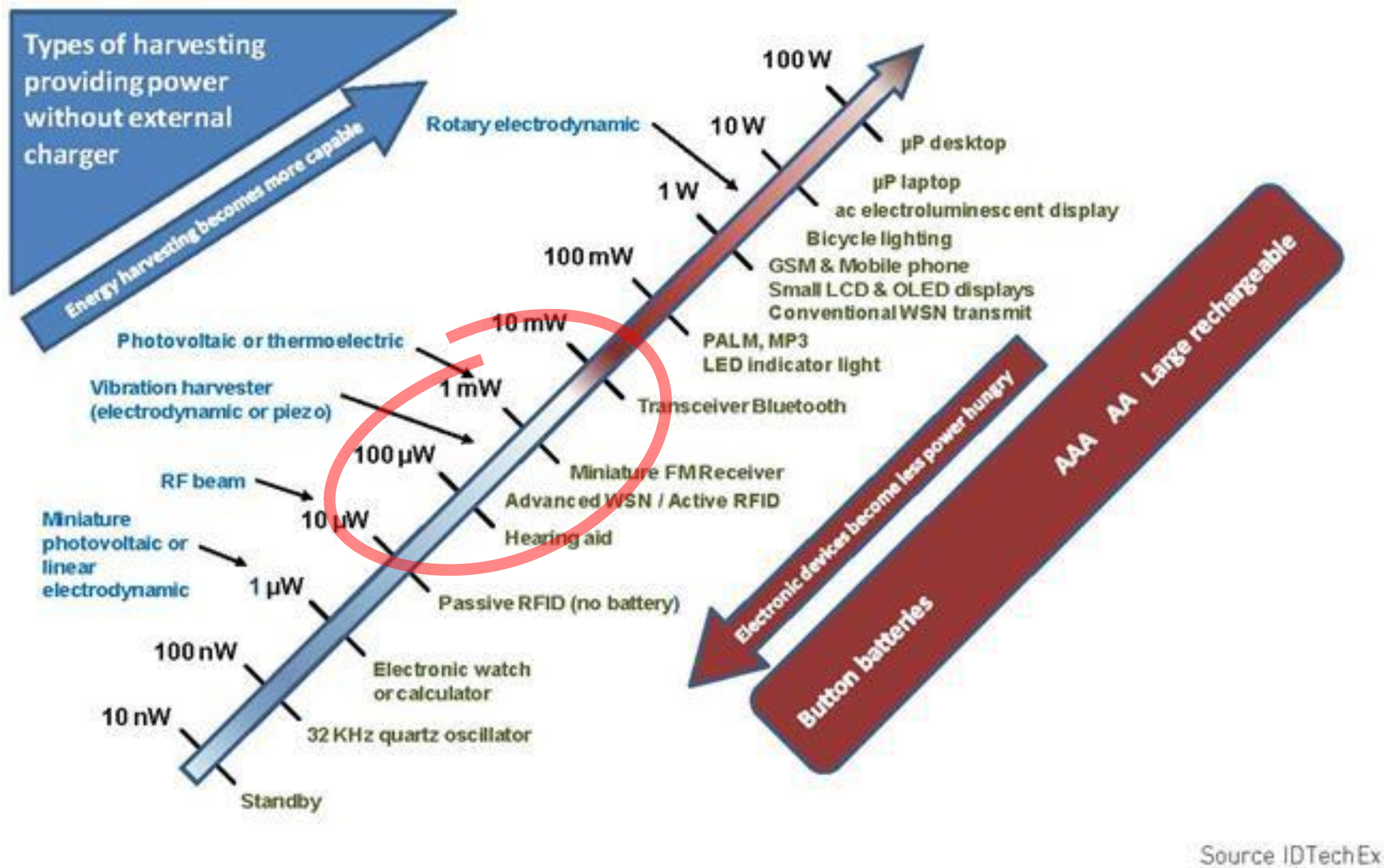
10 - 25 mW

1.0 - 3.0 mW

0.05 - 0.5 mW



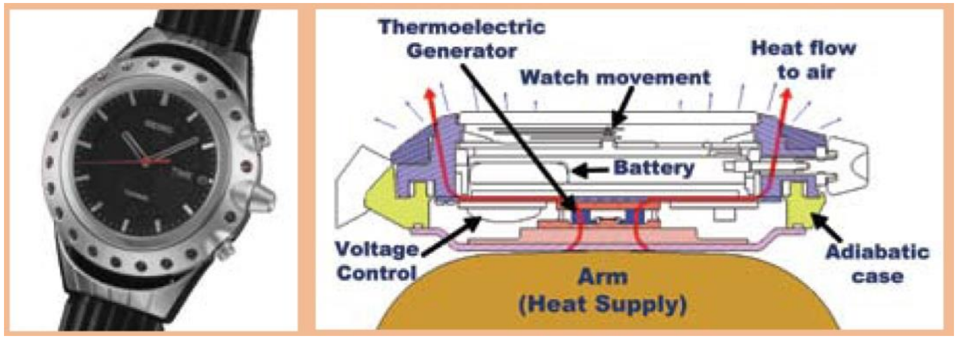
ENERGY HARVESTING APPLICATIONS



Dr. Harry Zervos, Dr. Peter Harrop and Raghu Das. IDTechEx. Energy Harvesting and Storage 2014-2024: Forecasts, Technologies, Players.

WRISTWATCHES

The watch is driven by body heat converted into the electrical power by the thermoelectric. At least two models have been built, one by Seiko and another by Citizen. The Seiko watch under normal operation produces 22 μW of electrical power.



WEARABLE CHARGER CONCEPT

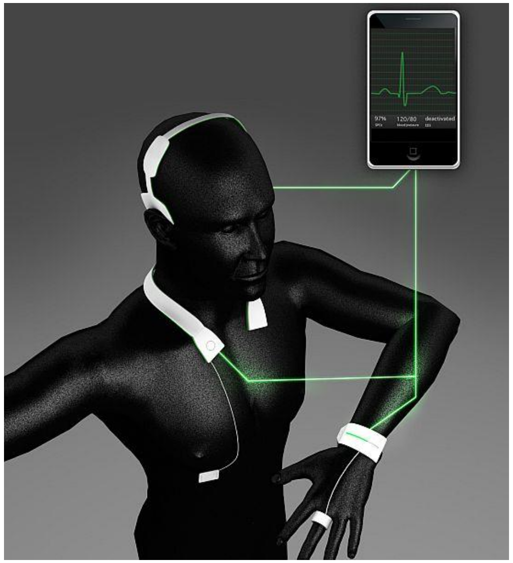
Thermoelectric effects connect a difference of temperatures with electricity. In other words, when two parties of a bracelet have different temperature, between them there is a current. Certainly, the difference of body temperature of the person and environment, has to promote it.

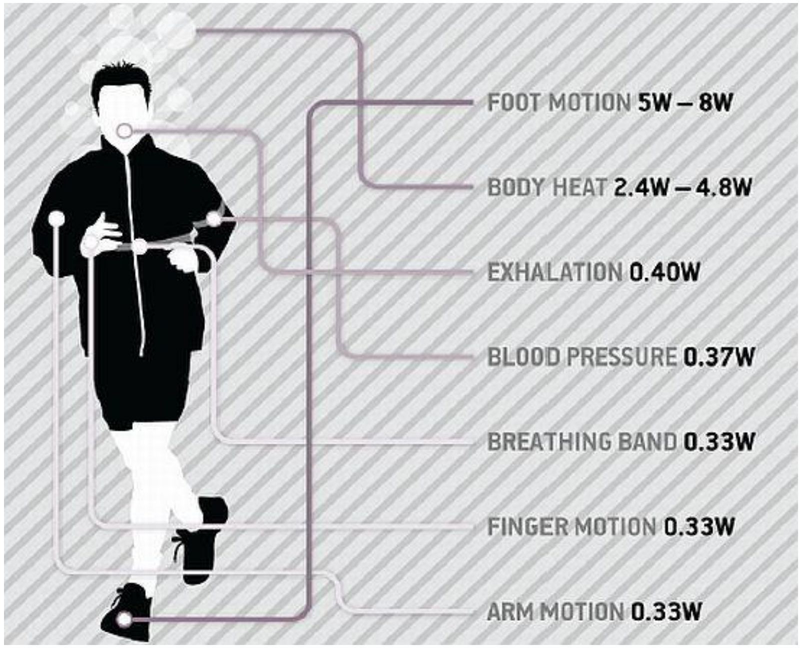
http://www.mobipower.ru/modules.php?name=News&file=article&sid=250.

DEVELOPMENTS

WEARABLE HEALTH MONITORING

Germany-based industrial designer Olga Epikhina has conceived a parasitic, wearable health monitoring system that relies on the power generated by human body heat and vibrations to monitor body temperature, blood pressure, brainwave and heartbeats. Each piece of the set comes complete with a vibration energy harvester, a thermoelectric generator and a capacitor for energy storage





http://www.greendiary.com/healthpals-body-heat-powered-wearable-health-monitoring-system.html

ENERGY-AUTONOMOUS RADIATOR ACTUATOR

Although we have already seen mobile phone concepts and even cooking pots utilizing thermoelectric energy harvesting, thermoelectric radiator valves are currently becoming very popular, with the temperature difference between a radiator and the ambient air being the source for the generated power. Honeywell, Moeller, Kieback&Peter, Tahydronics are some of the companies that already have such products available on the market.

Perspectives

- ✓ ***Temperature sensors, occupancy sensors***
- ✓ ***Enabling users to control the heating system, automatically switch their home appliances on and off.***

Room sensor Valve controller

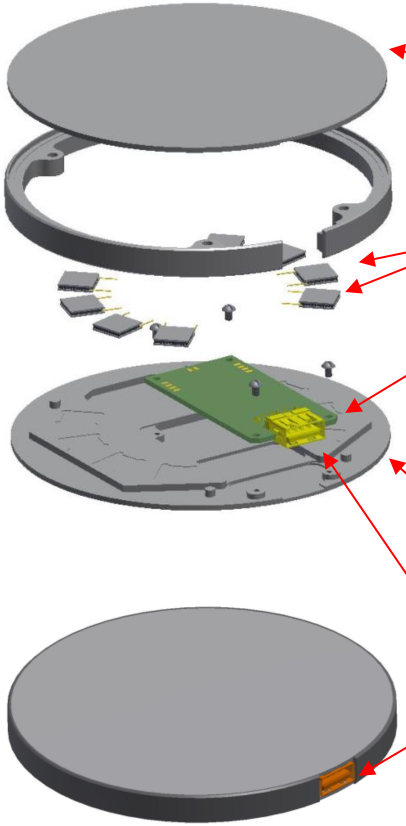
TEMPERATURE TRANSMITTERS

Supplied to Robinson Brothers for use its specialty chemical manufacturing process. ABB's energy harvesting wireless temperature transmitter needs a minimum of 30 degrees temperature difference.

UNIVERSAL CHARGER CONCEPT

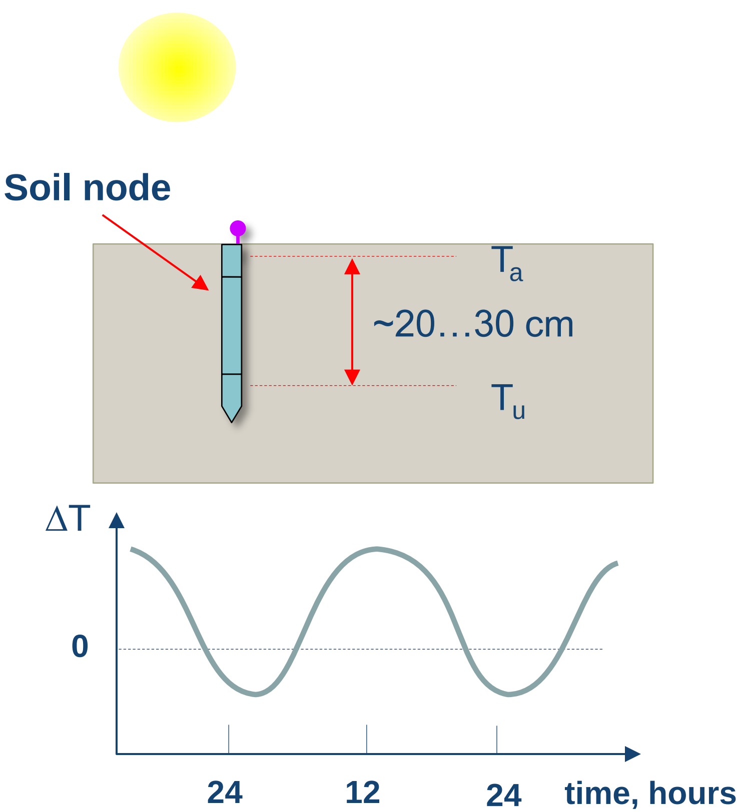
The charger can work with different heat sources: hot/cold water cap; hot stone; solar radiation falls to earth and others.

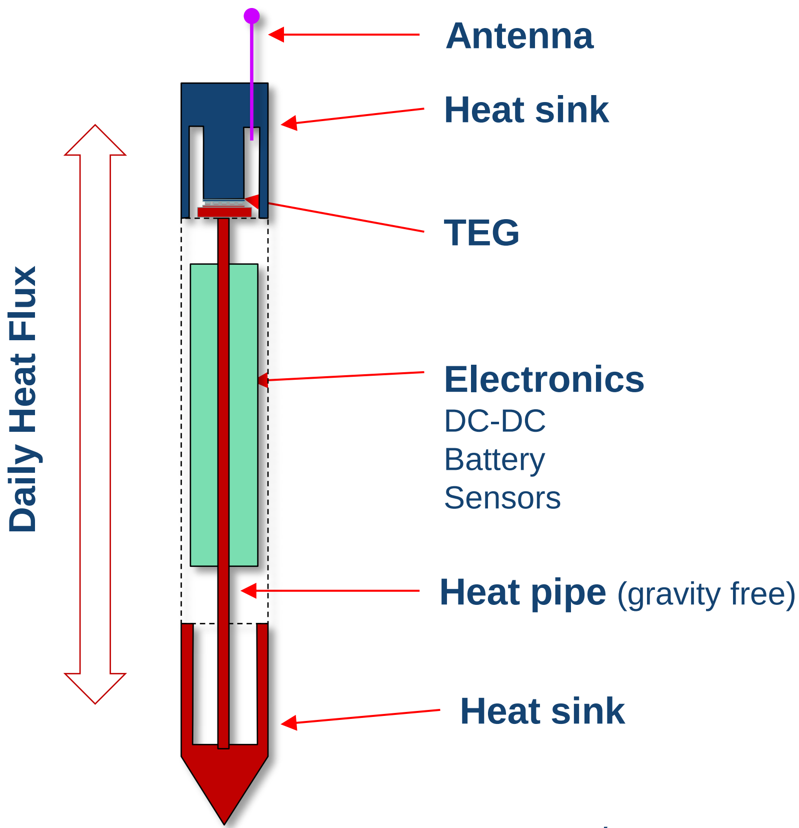
The RMT concept



SOIL GENERATOR CONCEPT

There is natural daily dynamical temperature difference at top soil layer about 20-30 centimeters. Heat flux in the soil ~ 100 W/m^2. Variable temperature difference ±10…20°C. To use it with help of TEG and heat pipe.



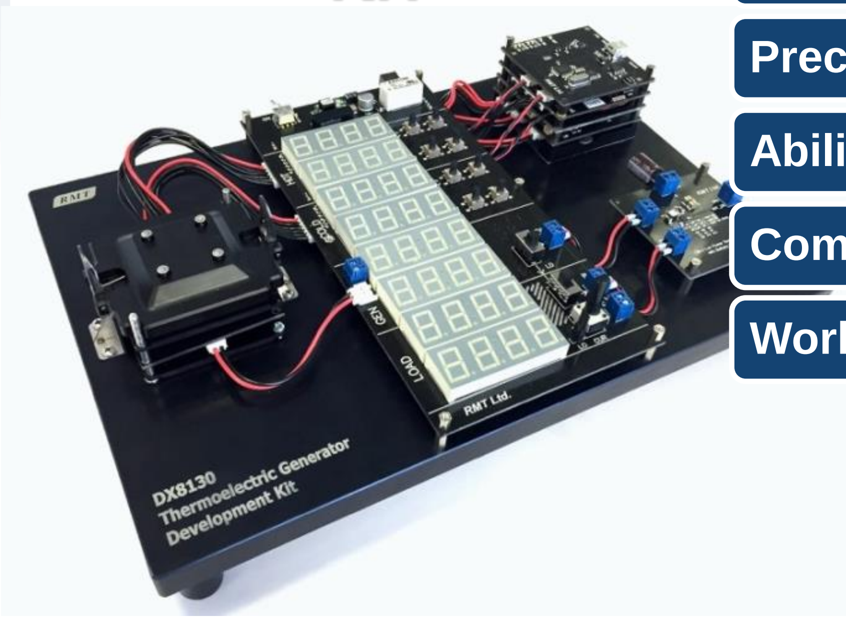


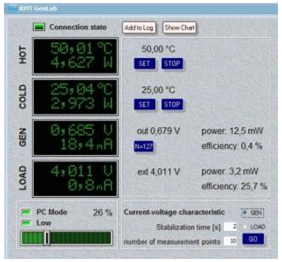
The RMT concept

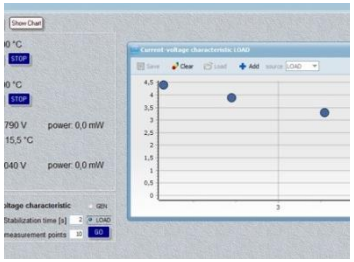
DEVICES for TESTS and DEVELOPMENTS

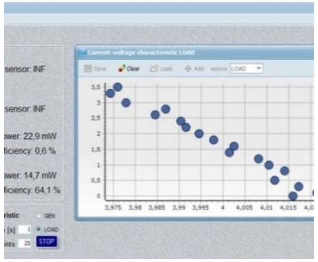
TE GENERATORS DEVELOPMENT KIT

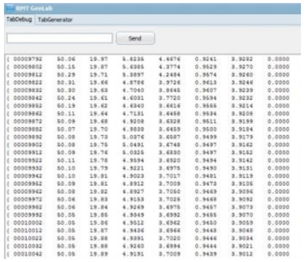
- All-in-one solution for TEG analysis
- Optimal for TEGs energy harvesting analysis
- Detailed TEG output and data logging
- Precise temperature setup for experiments
- Ability to connect different DC-DC converters
- Compact design (A4 size)
- Works with PC and in stand-alone mode



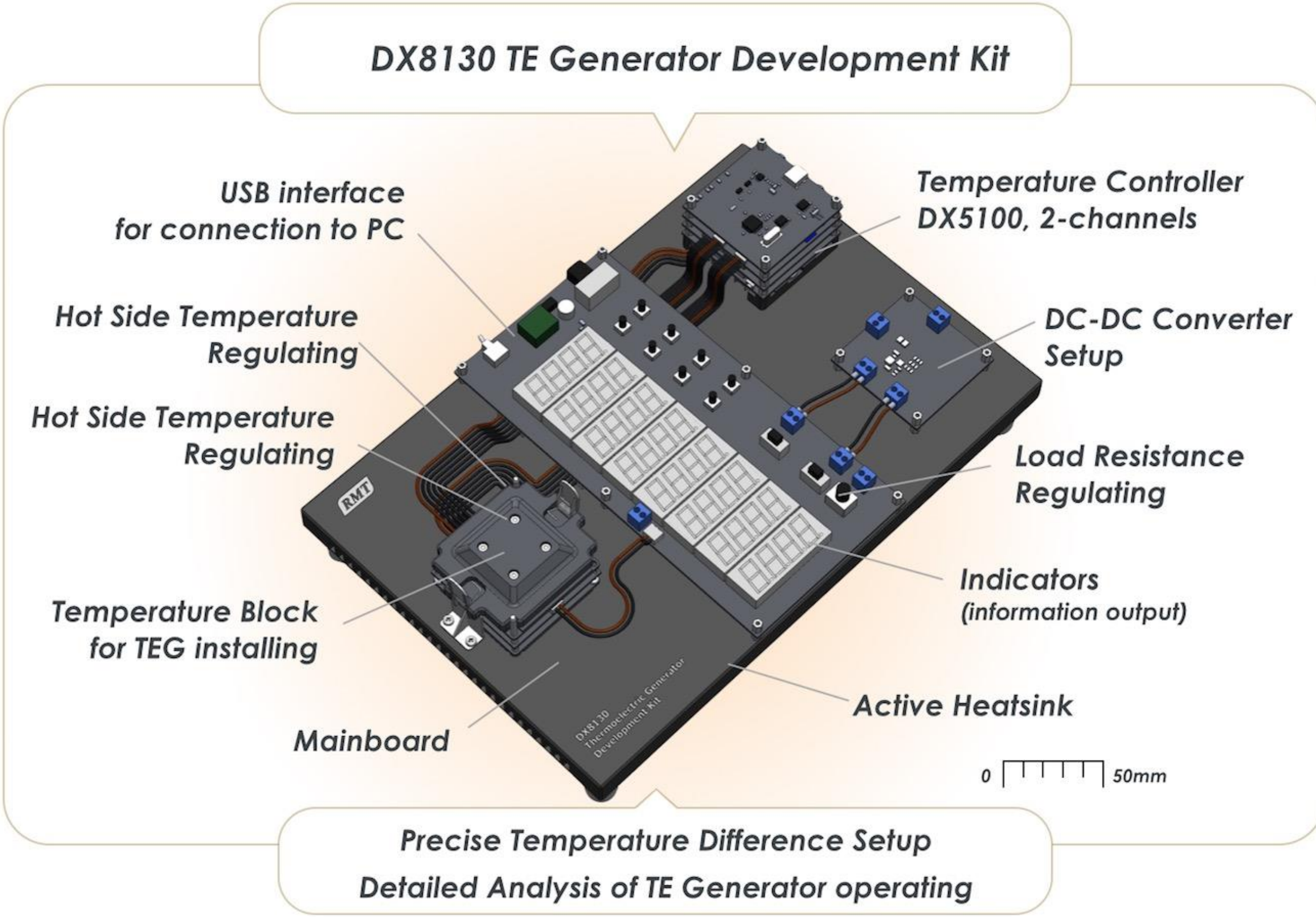




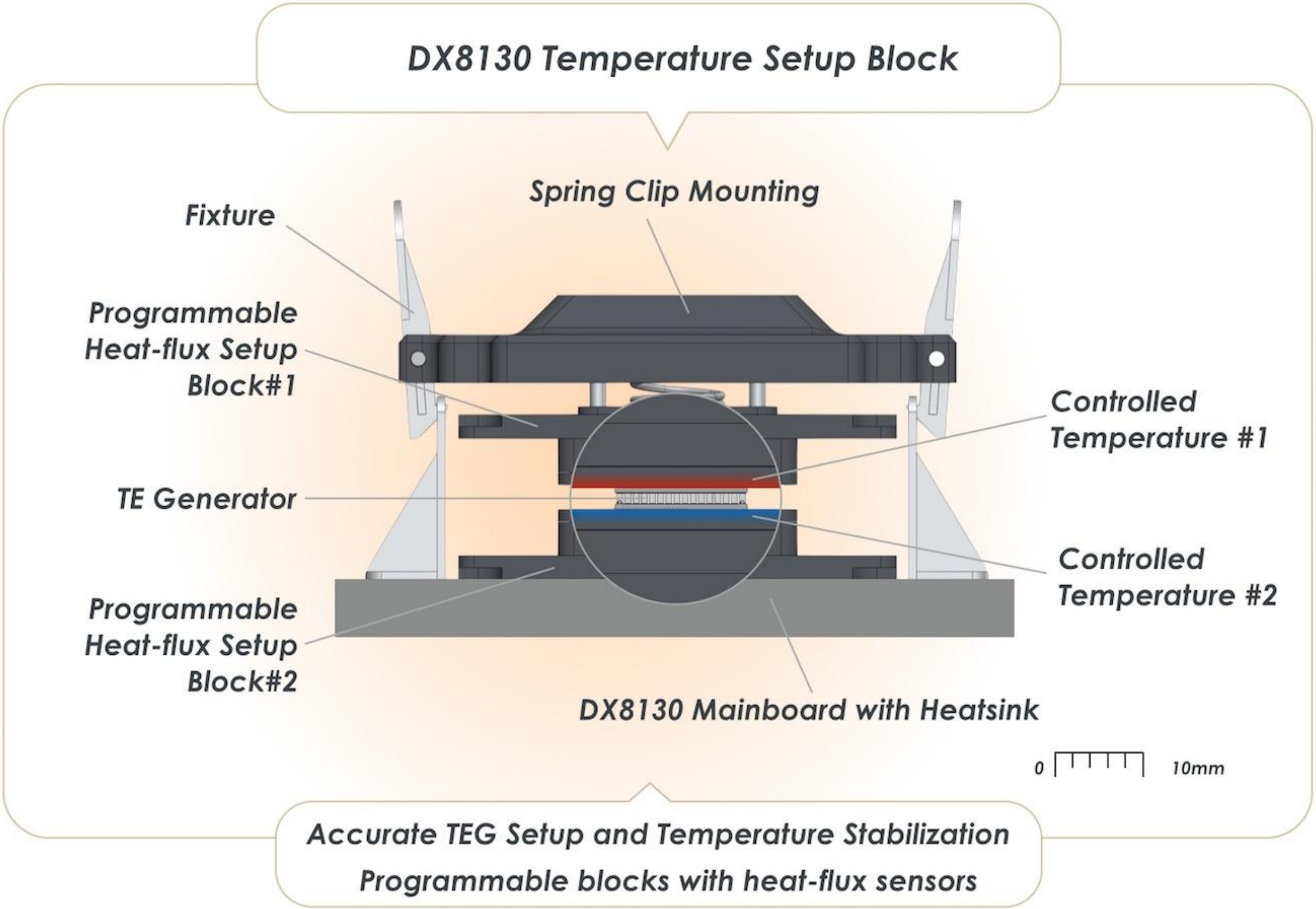




TE GENERATORS DEVELOPMENT KIT



TE GENERATORS DEVELOPMENT KIT



APPENDIX. TE GENERATORS DEVELOPMENT KIT

SPECIFICATIONS

Parameters	Units	Value
Temperature stabilizing range	°C	+10 … +100
Max temperature difference to set	°C	50
Output voltage range of TEG	V	0 … 9.999
Electric current range of the TEG	A	0 … 1.000
Heat flux range	W	0 … 9.999
Output voltage of DC-DC converter	V	0 … 9.999
Load current		
High current mode	A	0 … 0.100
Low current mode	mA	0 … 5.0
Computer interface		USB
TEGs Dimensions Supported		
Length x Width, A x B	mm^2	2x2 … 30x30
Height, H	mm	0.5 … 5.0
Power Supply of the Kit	V	110 … 240
Maximal power consumption	W	60
Overall dimensions of Kit AxBxH, max	mm	200 x 300 x 80
Weight	kg	3.0
Dimensions of main Modules		
Mounting table	mm	200 x 300 x 20
Electronic plate	mm	100 x 200 x 25
Controller unit	mm	55 x 55 x 35
Programmable heat flux unit	mm	55 x 55 x 8
DC/DC converter unit	mm	55 x 55 x 10

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