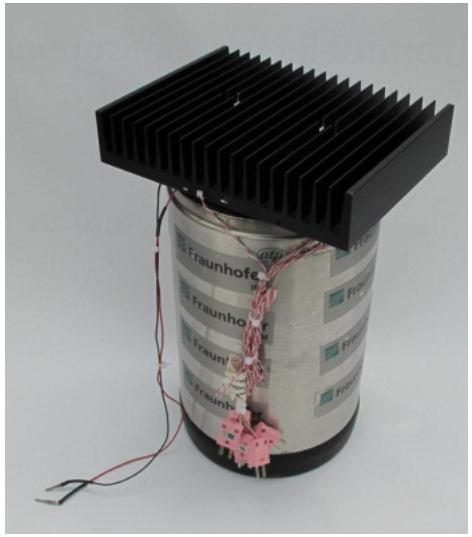
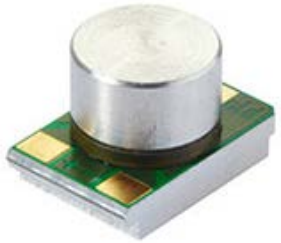
FRAUNHOFER INSTITUTE FOR PHYSICAL MEASUREMENT TECHNIQUES (IPM)

Jan König, K. Tarantik, A. Jacquot, J. Heuer, M. Winkler, M. Jägle, K. Bartholomé
EMRS Spring Meeting 2016, 04.05.2016

Survey on thermoelectric energy harvesters





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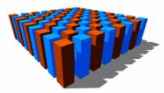

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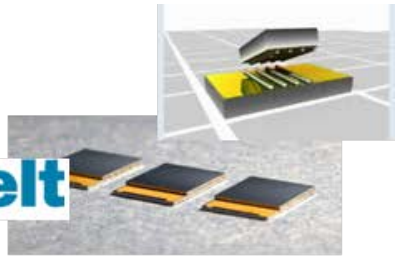
Energy Harvesting

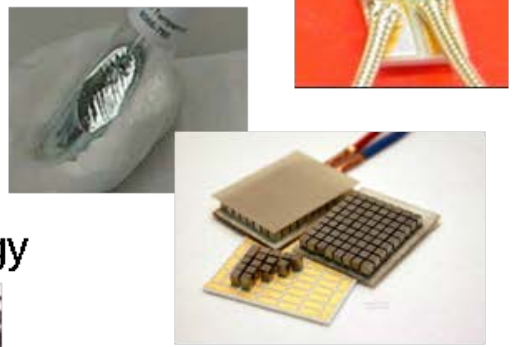
>25 years of experience in thermoelectrics

R&D for micropelt



Nanoscale materials
Nanocomposites

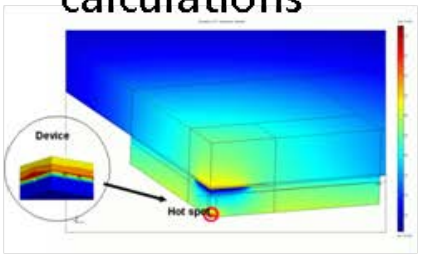
Bulk Materials
Modules
>200 °C



Thermoelectric metrology

Customer-specific
applications

Simulations/
calculations



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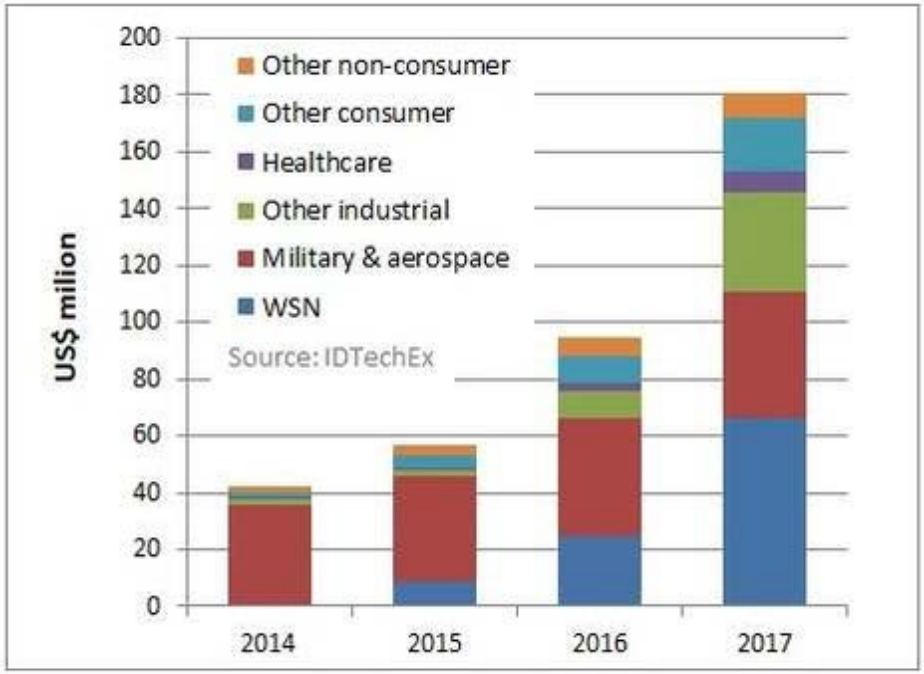
Market forecast for thermoelectric energy harvesting

"The market for thermoelectric energy harvesters will reach over $950 million by 2024"



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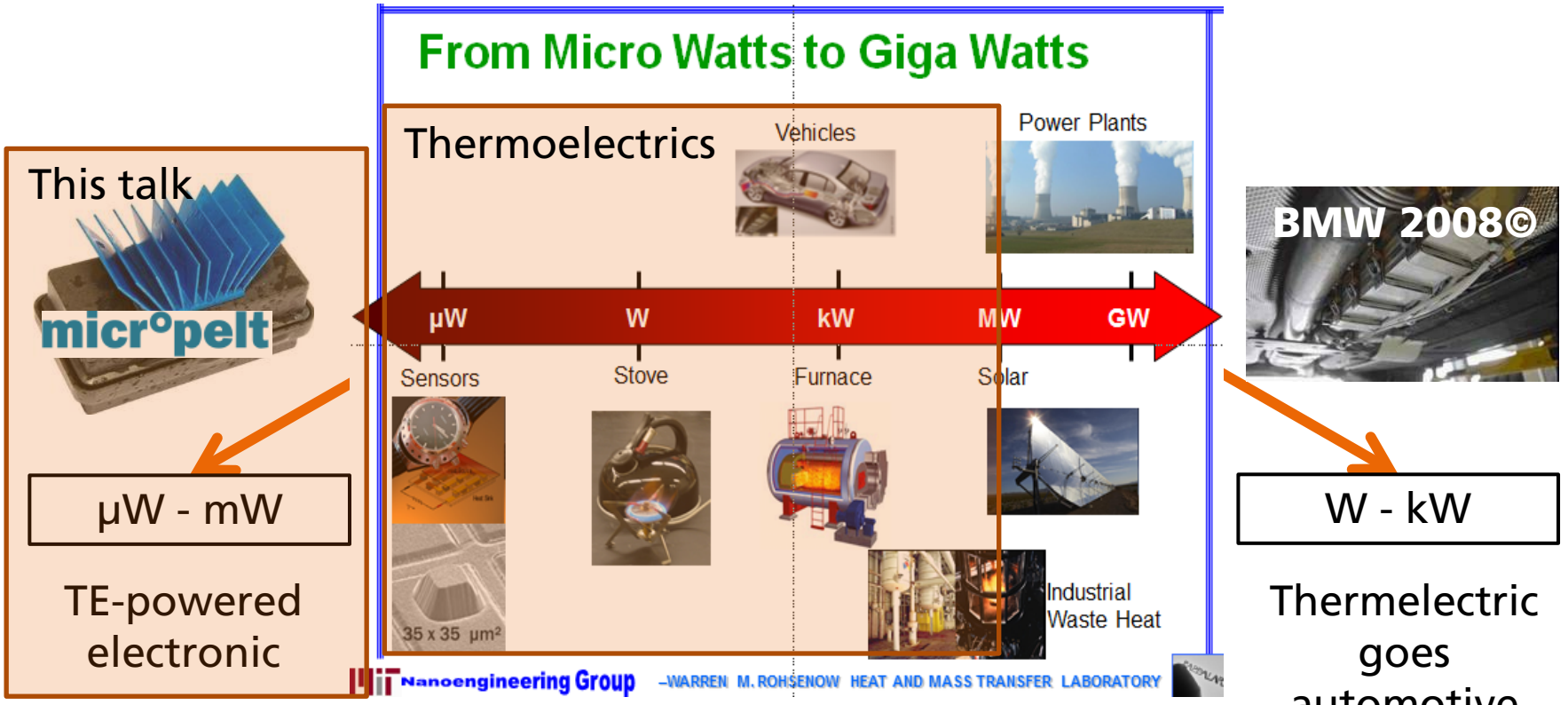
Power ranges for thermoelectric energy harvesting



G. Chen, MIT, USA; CIMTEC;
Montecatini Terme Juni 2010

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Powers provided by energy harvesting sources

Ambient micro Energy Harvesting sources



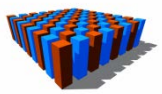



Source	Technology	Energy	Remarks
Acoustic (100dB)	Piezo	950 nW/cm^3	Little research done
RF-waves	Antennas	< 1 µW/cm^2	Near field only
Light	Solar cell	100 mW/cm^2	Sunlight
	Solar cell	100 µW/cm^2	Light
Switching operation	Electrodynamic	50 µJ/N	50µW EnOcean PTM-200-module
Temperature	Seebeck	60 µW/cm^2	Standard elements
	Seebeck	710 µW/cm^2	Micropelt @ 3K differential
Vibration	Piezo	4 µW/cm^3	Human motion (Hz)
	Piezo	800 µW/cm^3	Machine motion (kHz)

May 2011 -University of Hamburg Harburg

micropelt

micropelt



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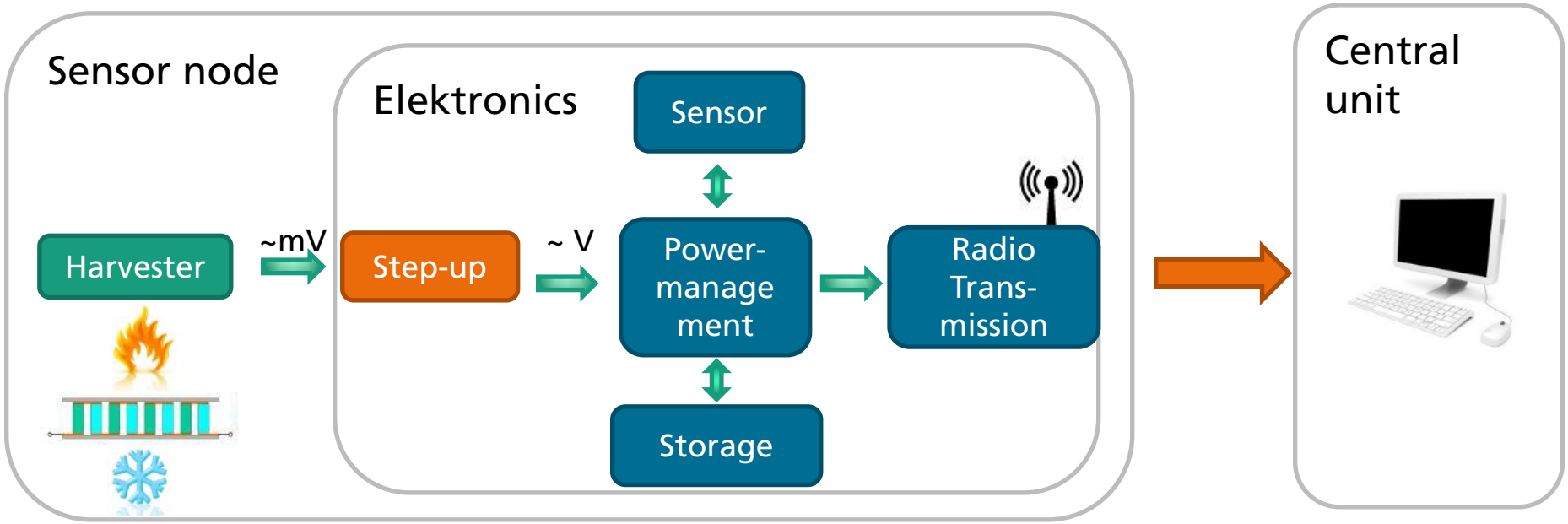
Self-powered sensor systems: Typical setup



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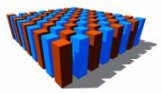

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Self powered sensor systems at Fraunhofer-IPM

Applications:

- ‚Hands-on'-demonstrator:
  use body heat to generate power and transmit temperature to computer
- Roast temperature sensor:
  thermoelectric skewer to measure temperature of roast and transmit it to oven
- Coffee pot demonstrator:
  use water/coffee heat and report filling level and temperature
- Aircrafts:
  monitor aircraft skin with energy-autarkic sensors
- Environmental monitoring:
  Exploit day/night temperature cycle

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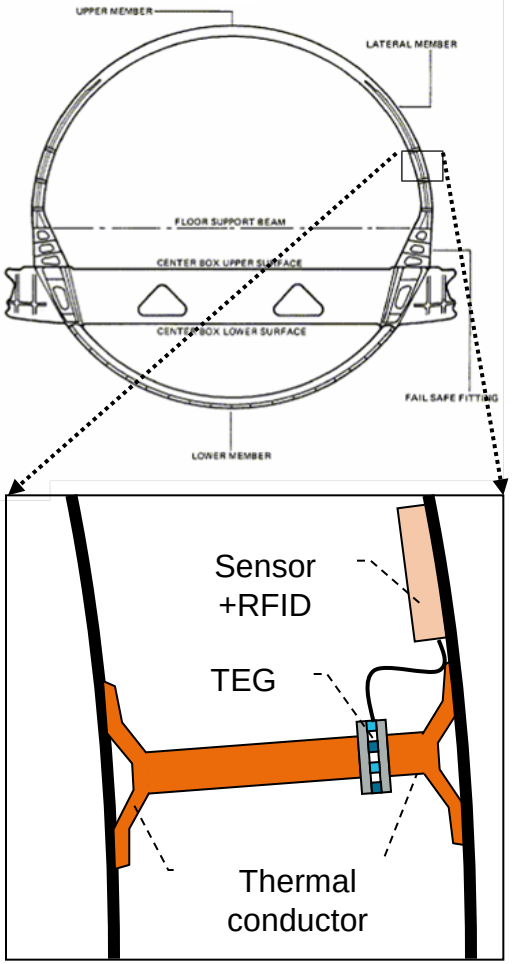
Aircraft monitoring

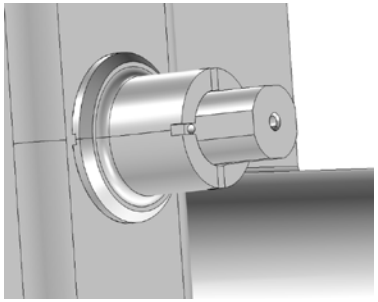
Condition-based maintenance

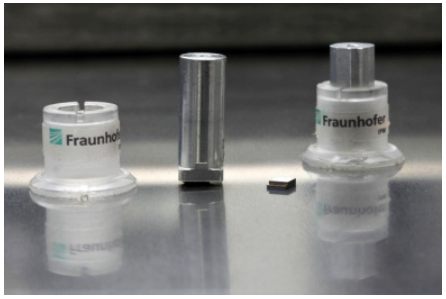


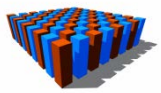
Exploitation of the temperature gradient between airplane body shell (~ -50°C) and passenger cabin(~ 20°C)

Thermal integration

Generation of sufficient power (**> 10mW**) while limiting the weight (**< 10g**)







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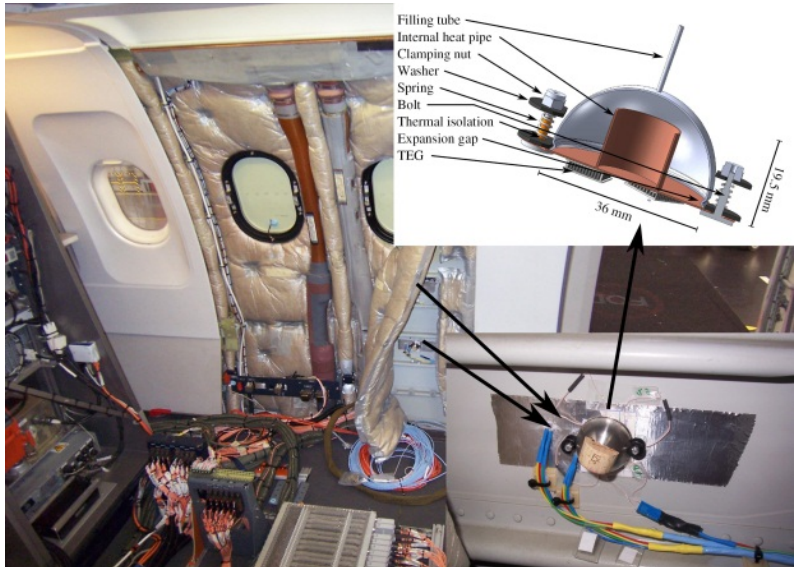
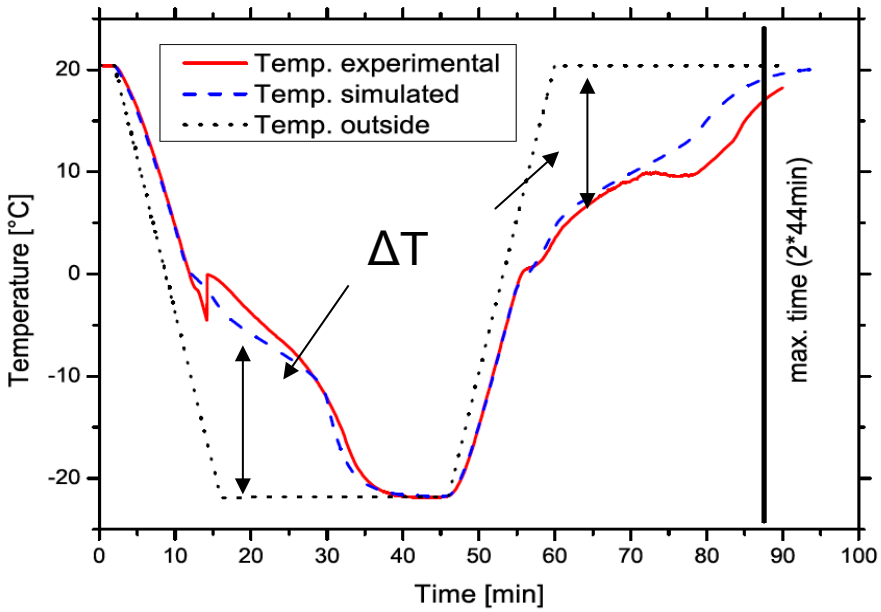
Aircraft monitoring

Exploiting temporal changes – Aircraft

B3_1: A. Elefsiniotis, EADS:
Harvester exploiting temporal temperature changes in aircrafts:

- generate ΔT with heat reservoir
- up to 17mW of electrical power
- average energy collected during one typical flight: ~23 J
- Sufficient for powering a sensor node >6h





Samson, D., et al., Journal of Electronic Materials, 2012. **41**(6)

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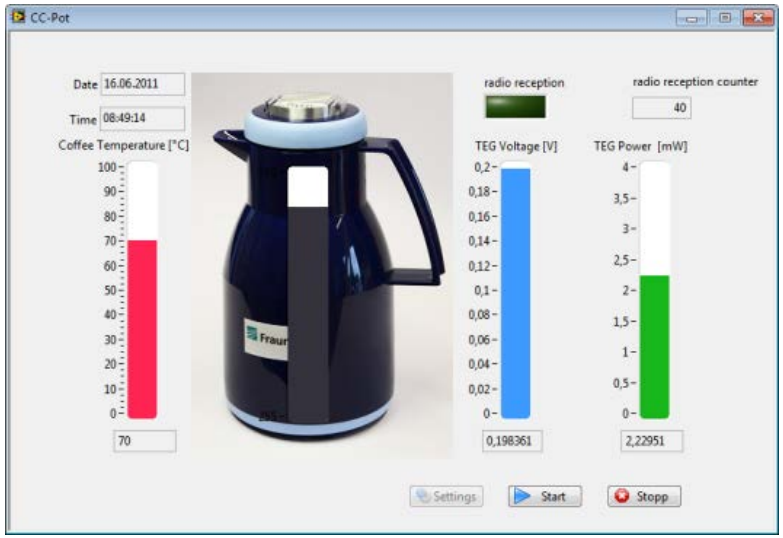
The communicating coffee pot

A smart home application



See it live at the exhibition - booth 39

What it does:

- Monitors coffee filling level and temperature
- Alerts secretary if coffee is empty or cold

Electrical data:

- maximum voltage of generator: 400 mV
- average voltage of generator: 150 mV
- maximum power: 85 mW
- average power: 12 mW

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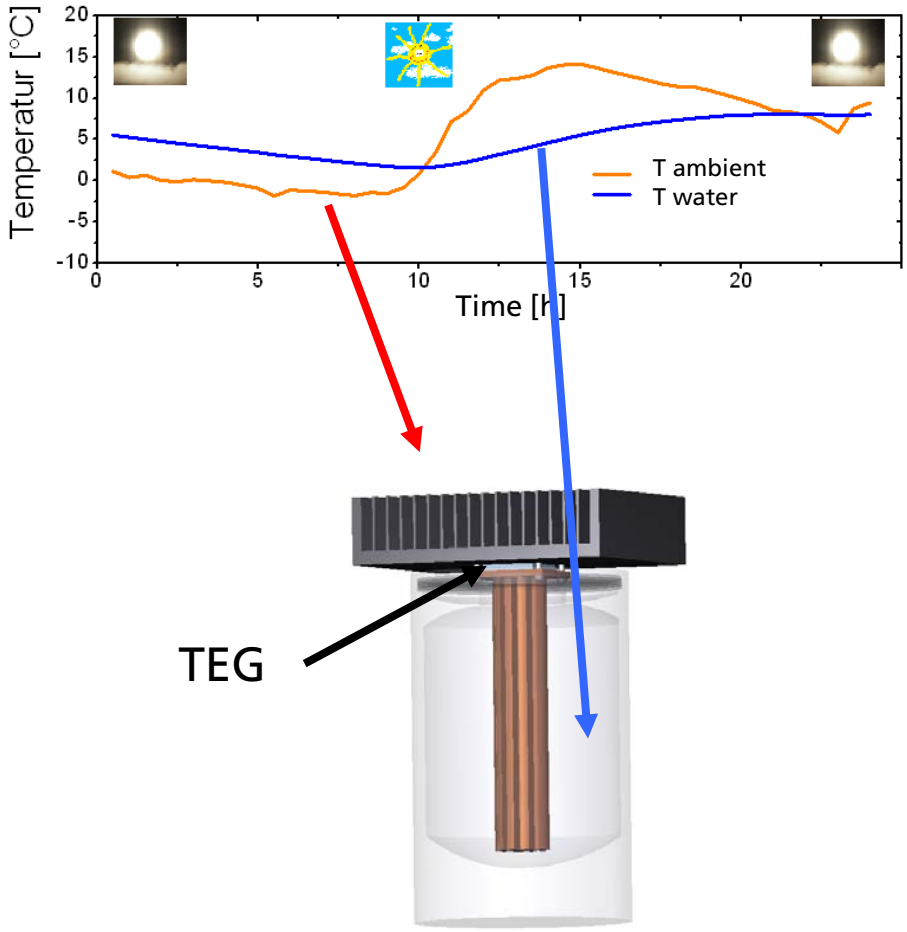
Environmental monitoring

Exploiting temporal changes with freestanding harvester

- Exploit temporal in contrast to spatial changes in temperature
- Fixed temperature at heat reservoir
- Temporal changing temperature at heat sink

→ Resulting ΔT at TEG

→ Generate sufficient ΔT for step-up converter, power management, sensors and radio transmission

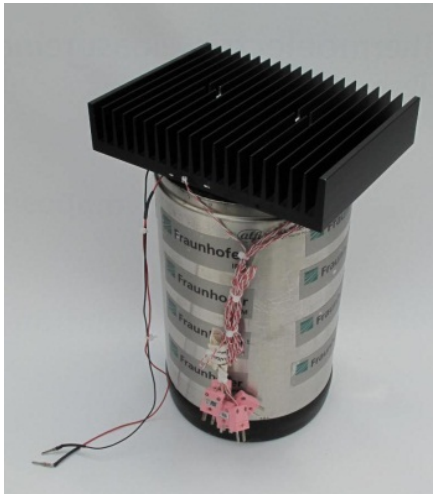


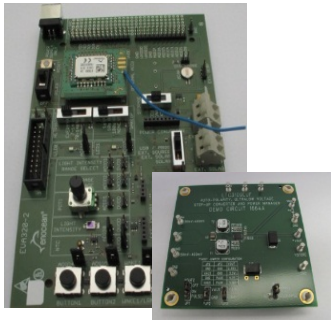
Bartel, Master Thesis Fraunhofer IPM, 2011

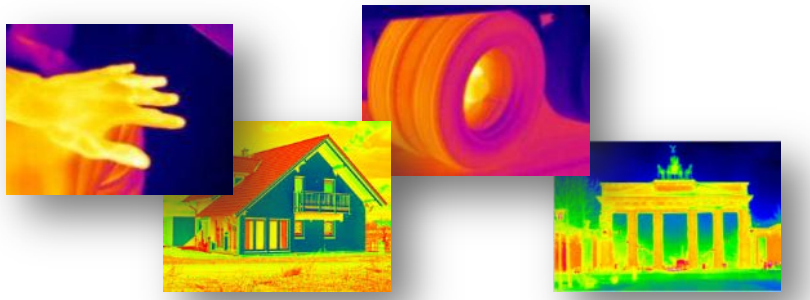
Fraunhofer IPM

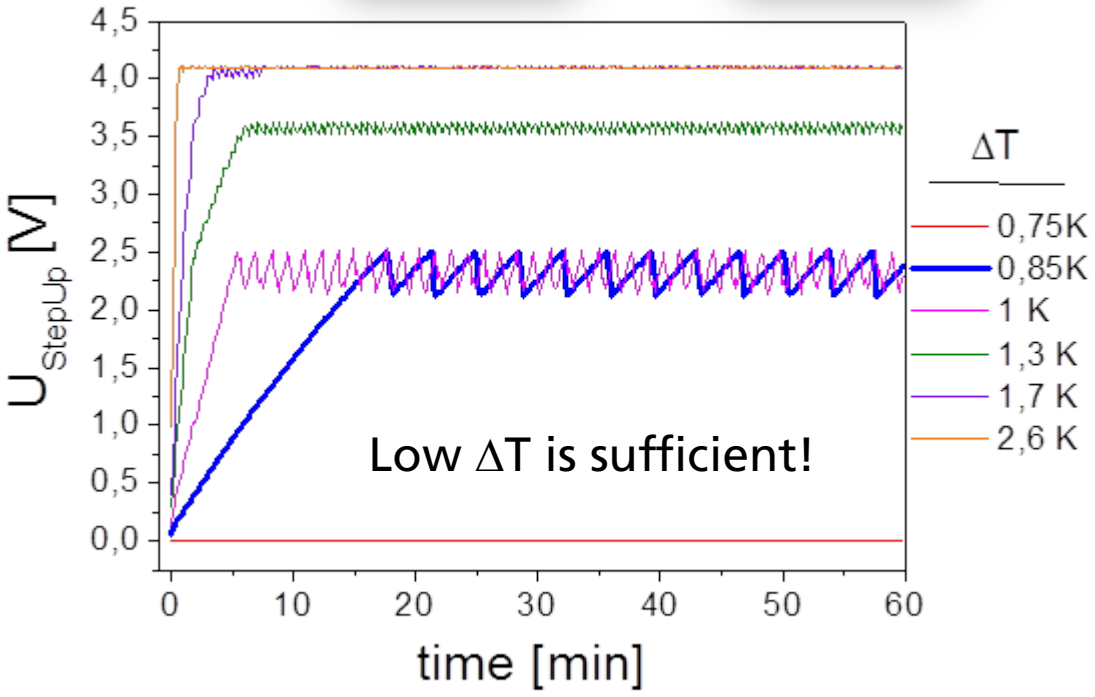
Freestanding harvester

Voltage and ΔT









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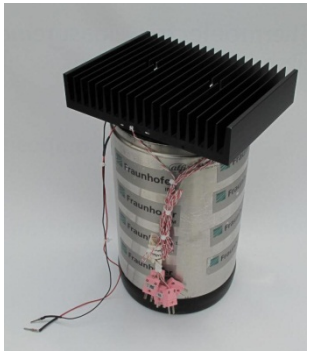
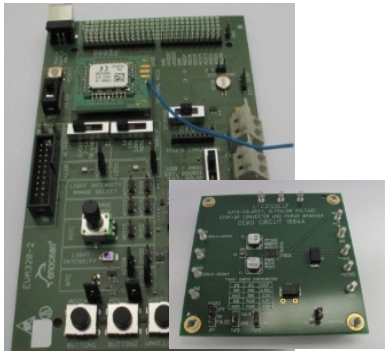
Freestanding harvester

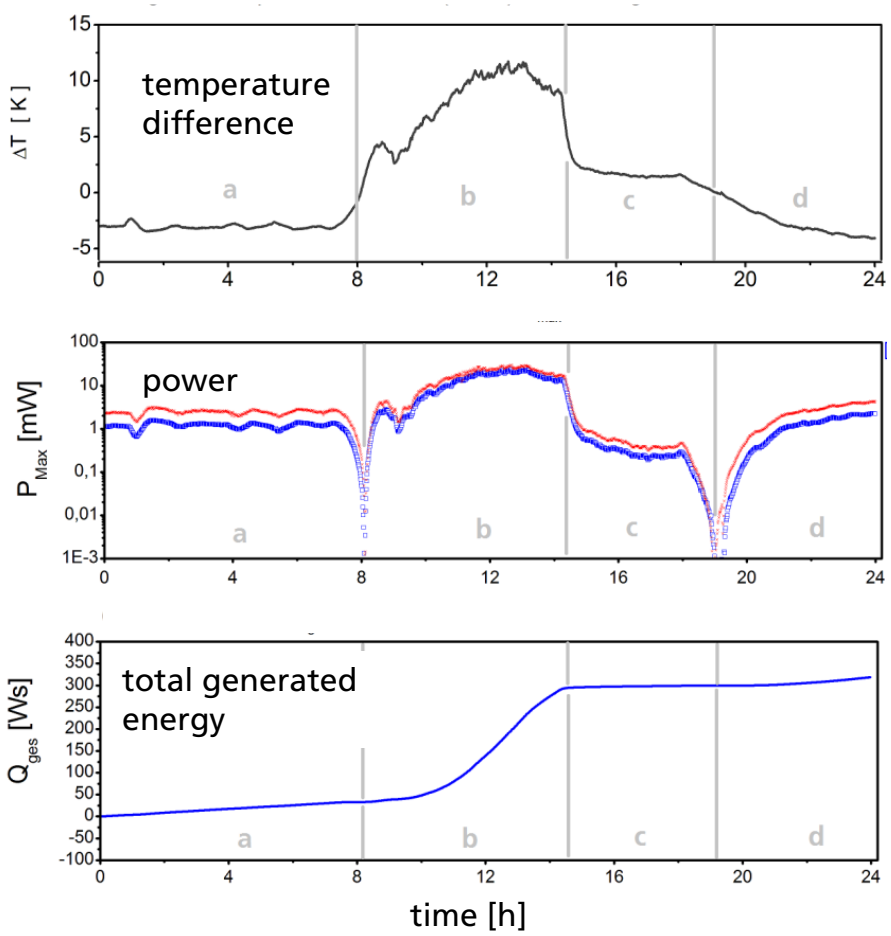
Exploiting temporal changes with freestanding harvester

experimental results:
system on IPM roof:

- system starts at ΔT~1K
- signal transmission each second
- ~300 – 350 J per day







Bartel, Masterthesis Fraunhofer IPM, 2011

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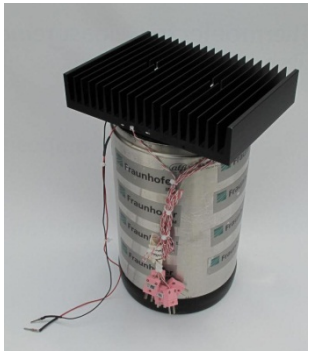
Freestanding harvester

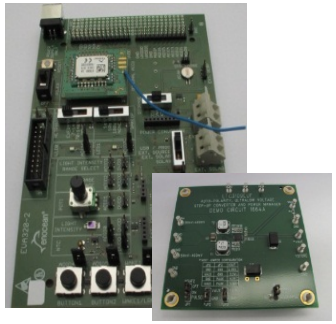
Exploiting temporal changes with freestanding harvester

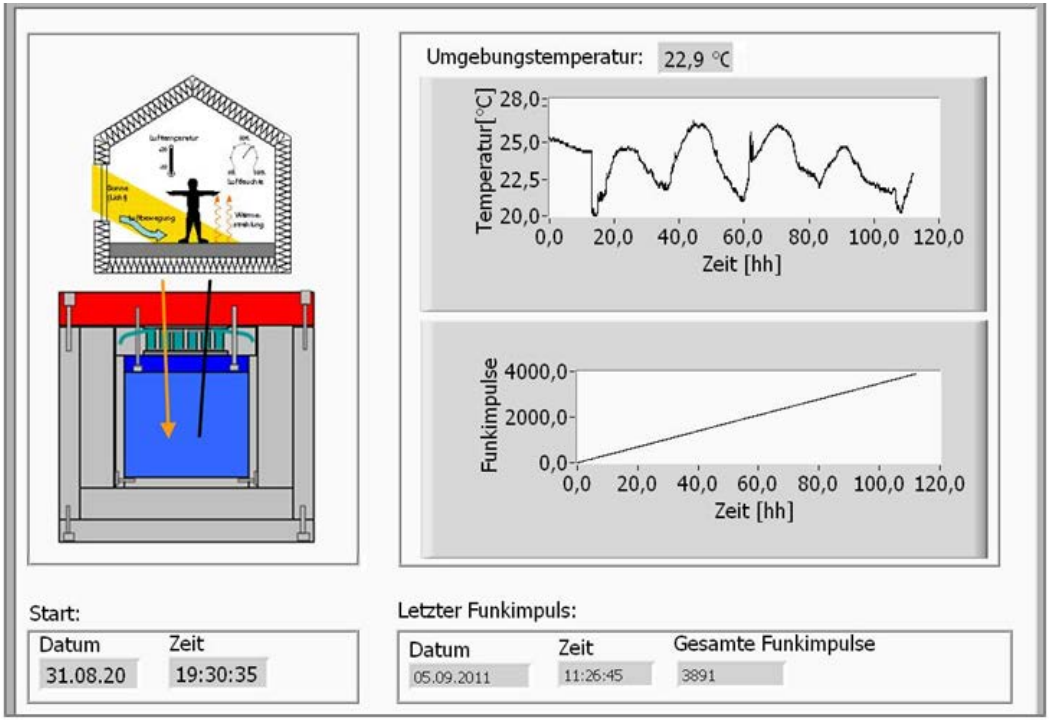
experimental results:

system in the lab:

- system starts at $\Delta T \sim 1K$
- signal transmission every 100 seconds
- ~50 J per day







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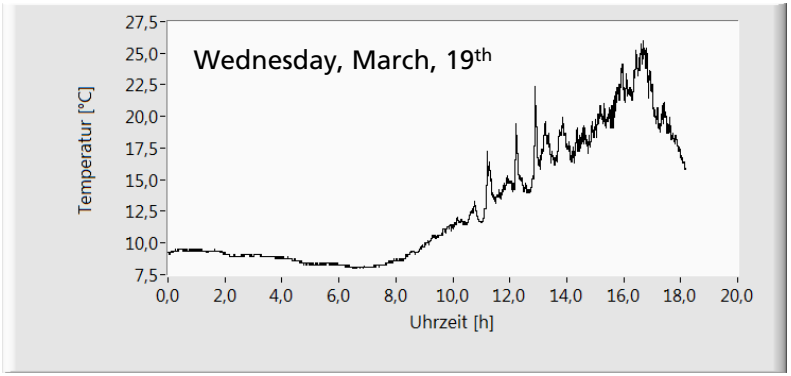
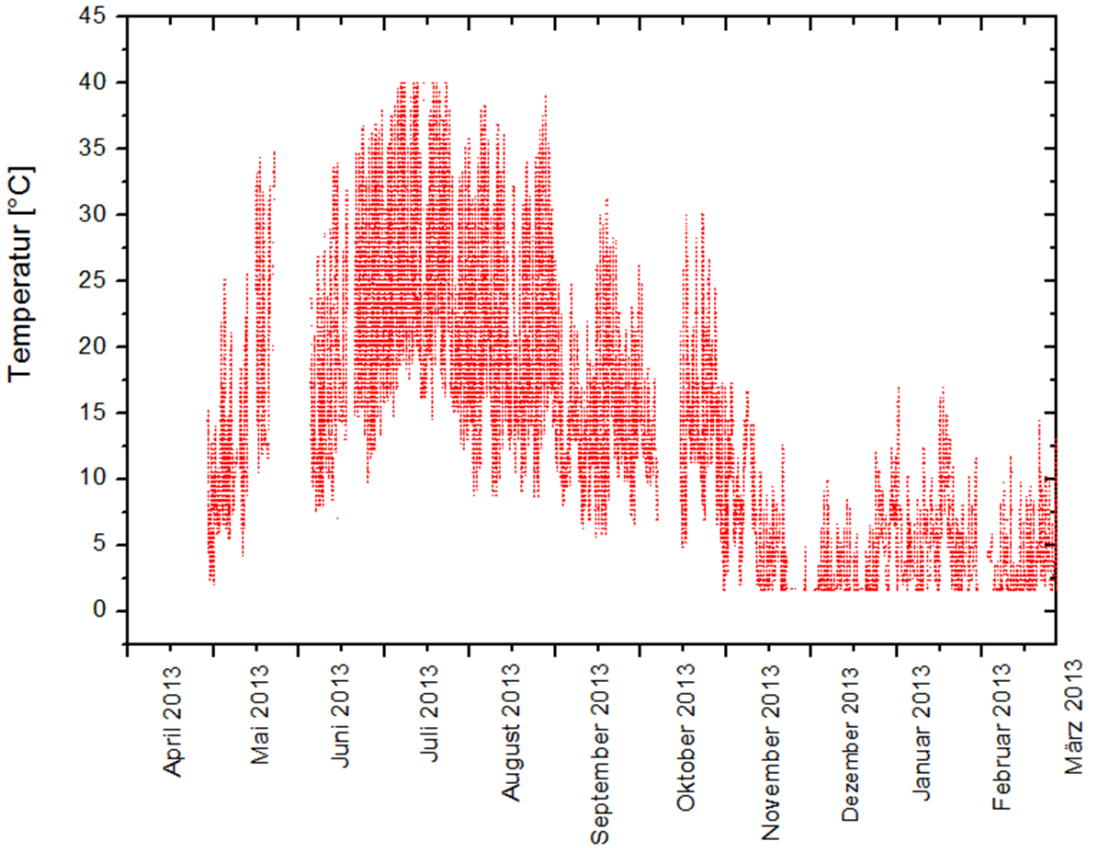
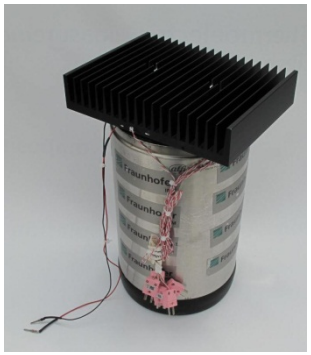
Freestanding harvester

Exploiting temporal changes

More than 1 million data points transmitted by self powered system







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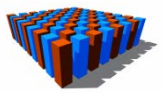

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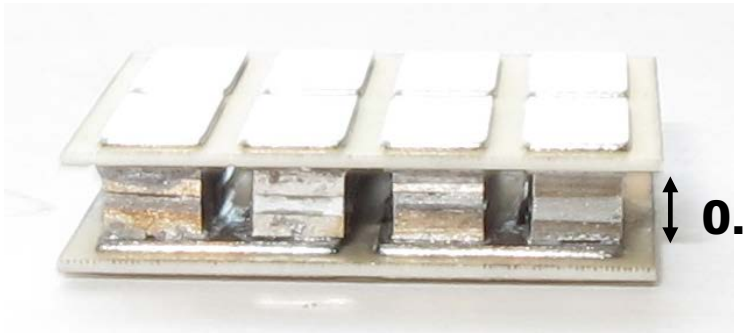
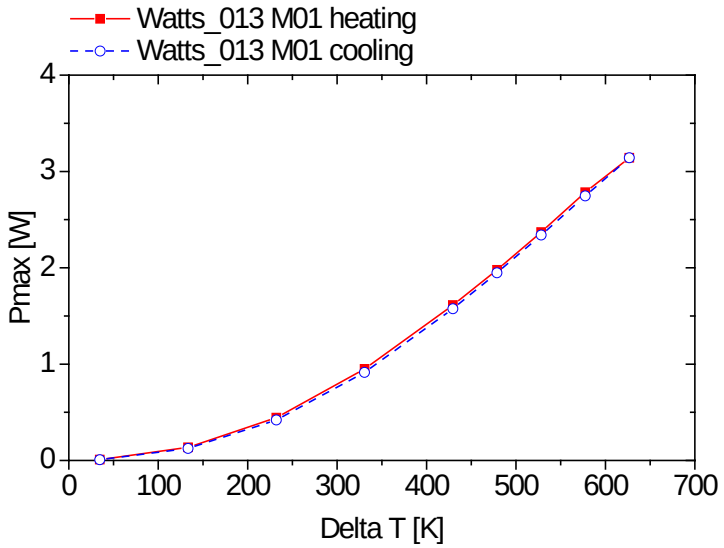
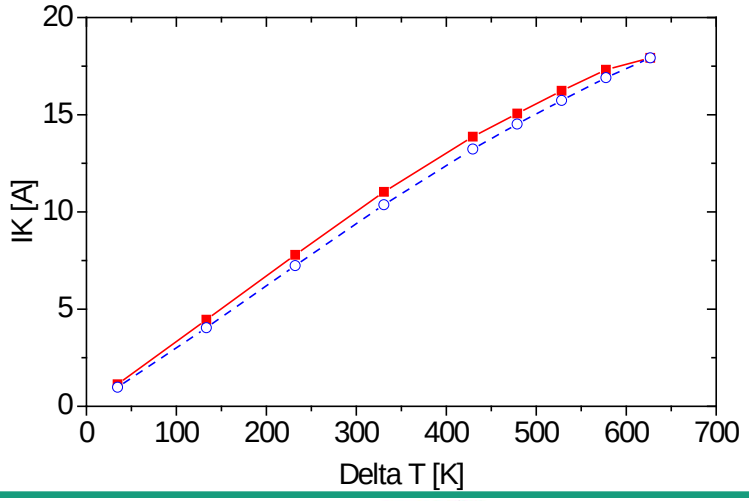
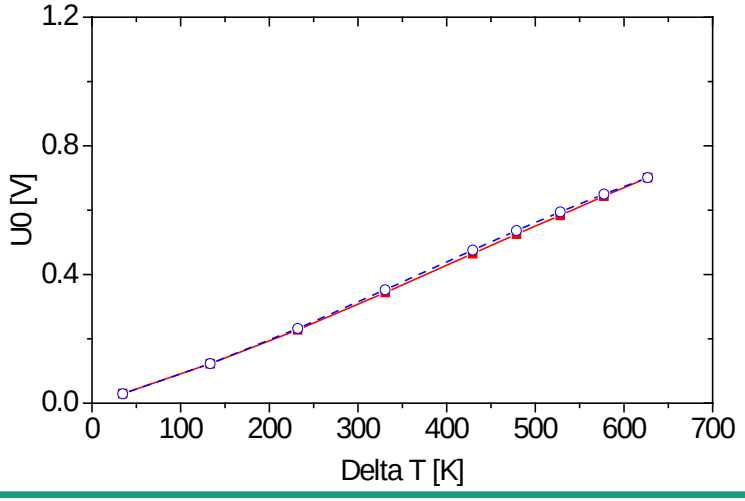
Module development for high (intermediate) temperature harvesting



Skutterudite module: Thin legs, high power, high current, low voltage







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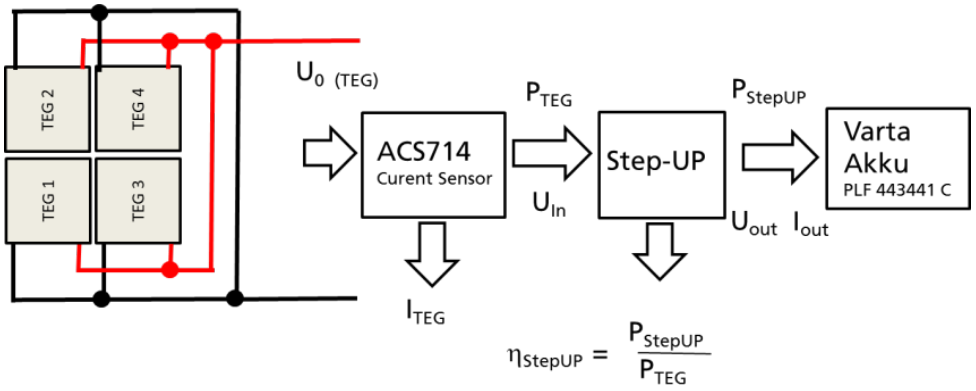
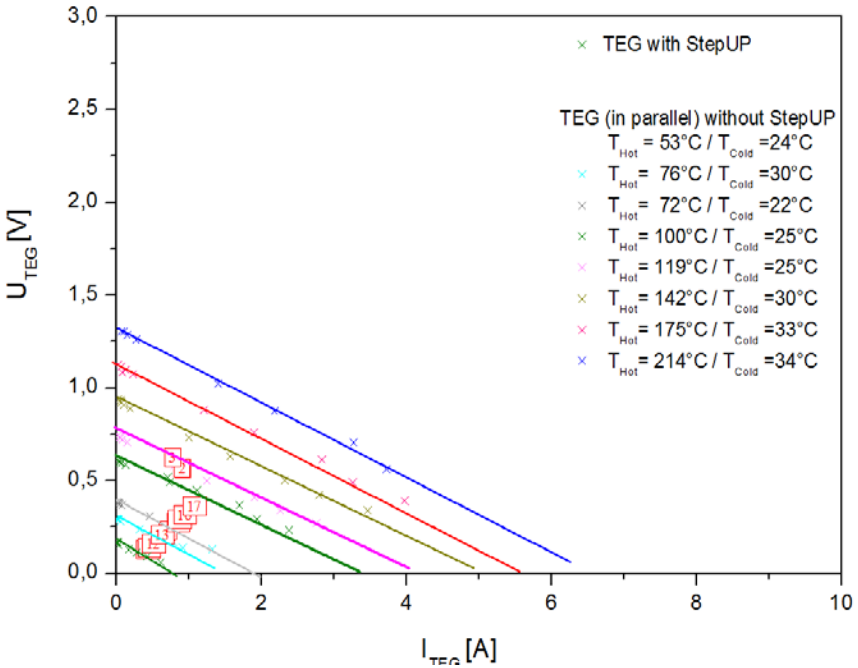
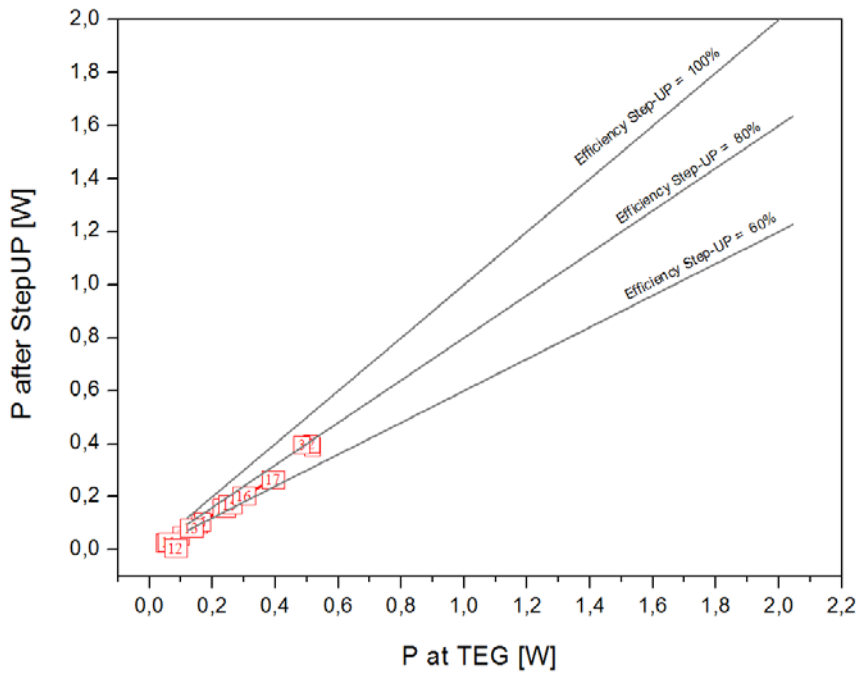
Harvesting system

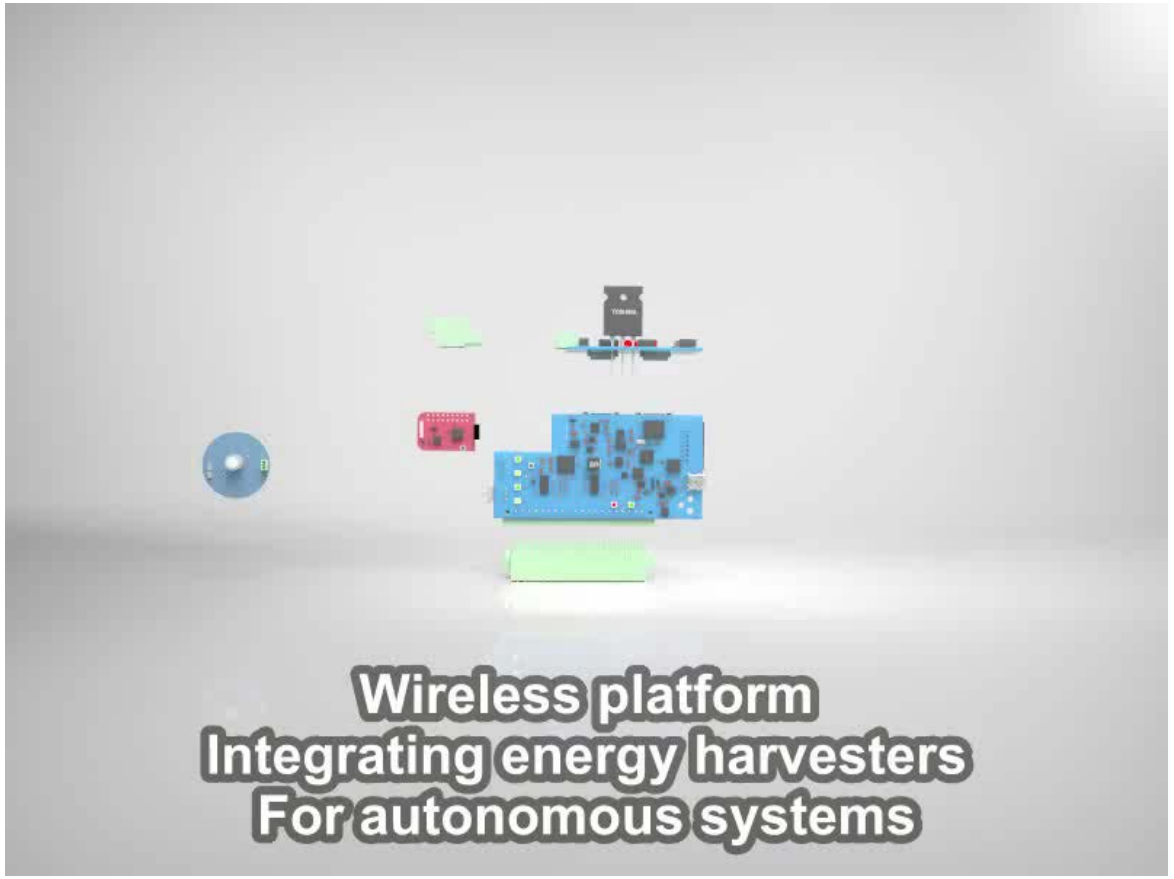






Flexible platform for integrating energy harvesters

Harvester demonstrator
3 TEG (15x15mm^2)
75 W_{th}
380 mW_e
T_{hot} =160°C
B_2Te_3 based TEG



Integration of harvester in system:
In progress..

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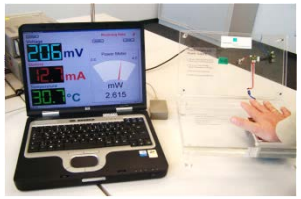
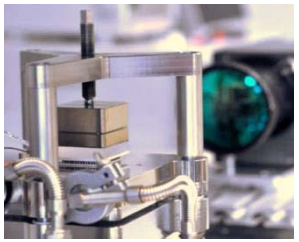
Thermoelectrics @ Fraunhofer IPM

Thermoelectric Expertise



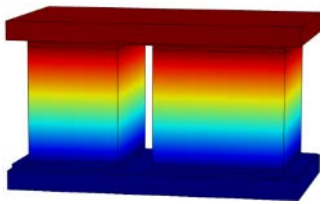


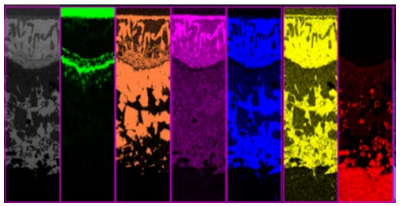
Simulation

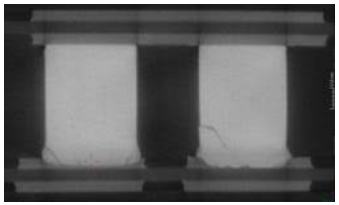
Characterisation

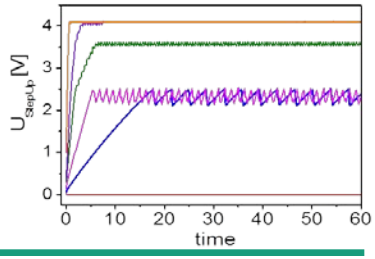
- TE-Material
- Elect. & therm. Connections
- TE-Modul
- TE-System

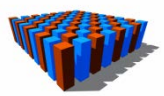
FMEA and Predictions











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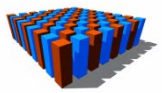
FRAUNHOFER INSTITUTE FOR PHYSICAL MEASUREMENT TECHNIQUES (IPM)

Jan König, K. Tarantik, A. Jacquot, J. Heuer, M. Winkler, M. Jägle, K. Bartholomé
EMRS Spring Meeting 2016, 04.05.2016

Survey on thermoelectric energy harvesters

1. Introduction
2. Self powered sensor systems (IPM)
3. Energy harvesting and self powering at high temperatures (IPM)
4. **Self powered sensor systems (IPM / Micropelt / other)**



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Thermoelectrics @ Fraunhofer IPM

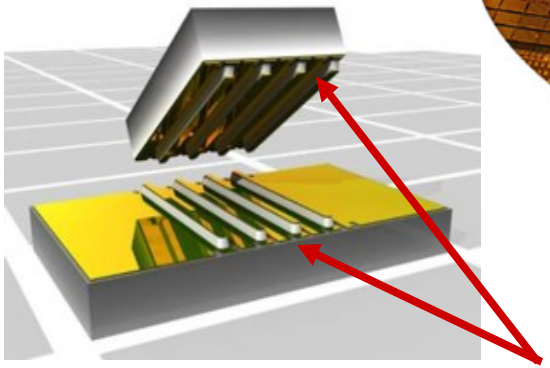
Thin film thermoelectric generators

First Si-wafer based module fabrication based on Bi_2Te_3

1998 - 2006

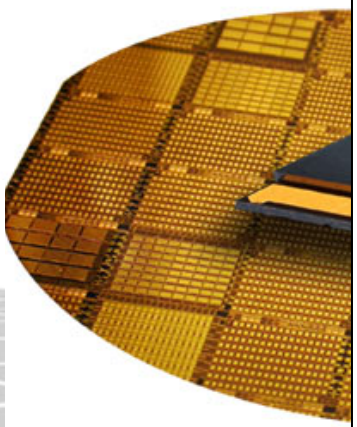
Now:
Spin-off Company:

micropelt
Thin film thermoelectrics.

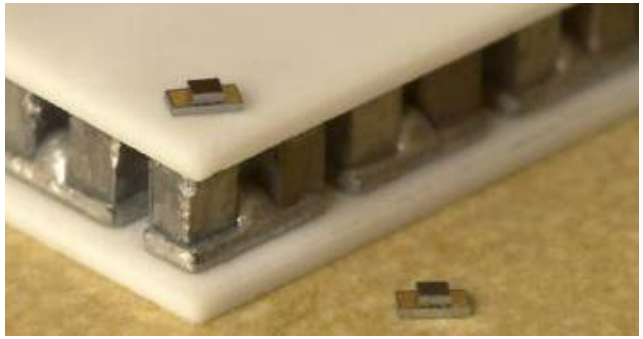


Micropelt device before soldering

Thermoelectric legs structured on wafer



- device height ~440µm
- leg height ~20µm
- 80 leg pairs/mm²
- Output power: ~1 mW @ΔT ~10-15K
- output voltage: ~0,5-1 Volt
- ΔTmax @85°C ~60K



micropelt

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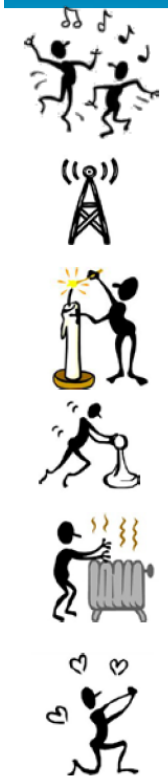
Energy harvesting basics

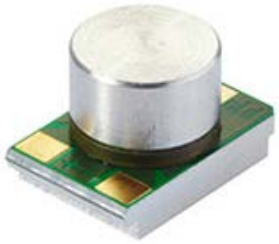
Ambient micro Energy Harvesting sources



Source	Technology	Energy	Remarks
Acoustic (100dB)	Piezo	950 nW/cm³	Little research done
RF-waves	Antennas	< 1 µW/cm²	Near field only
Light	Solar cell	100 mW/cm²	Sunlight
	Solar cell	100 µW/cm²	Light
Switching operation	Electrodynamic	50 µJ/N	50µW EnOcean PTM-200-module
Temperature	Seebeck	60 µW/cm²	Standard elements
	Seebeck	710 µW/cm²	Micropelt @ 3K differential
Vibration	Piezo	4 µW/cm³	Human motion (Hz)
	Piezo	800 µW/cm³	Machine motion (kHz)

May 2011 -University of Hamburg Harburg

micropelt



Basic harvesting element

TGP-755
MPG-D755 (~ 14 sqmm)
110 mV / K
300 Ω
18 K/W
15 x 10 x 9.3 mm

micropelt

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Examples
Thermoelectrically-driven sensors in domestic homes

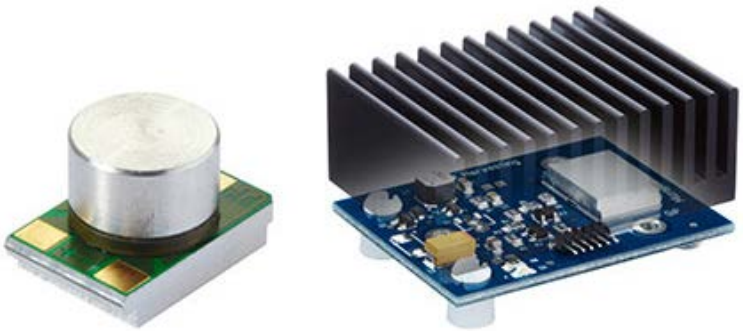
Thermoelectrically powered CO_2-sensor

Combination of:

- SST CO_2-sensor:
  CO_2-sensor with 3.5mW power consumption

- Micropelts TE-Core/RF
  harvesting module with RF-module

- Energy-autarkic CO_2-sensor for monitoring air quality

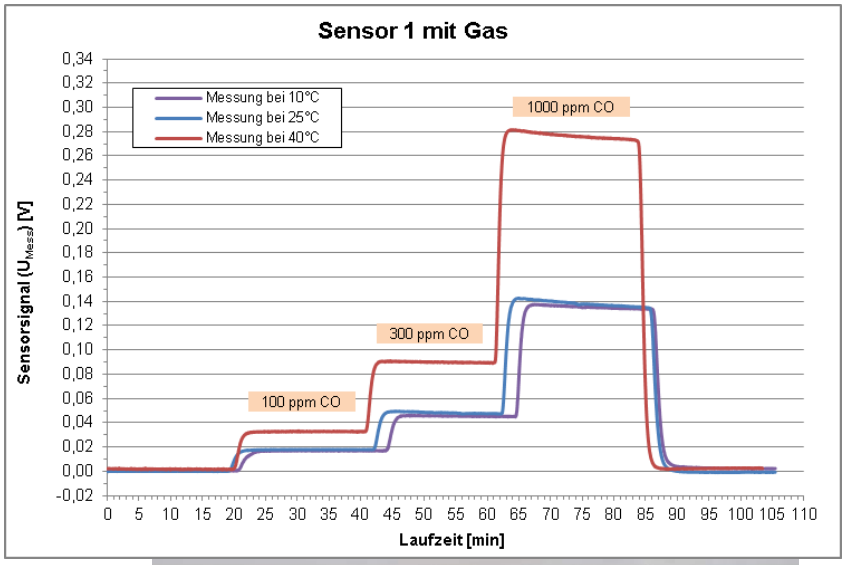


Fraunhofer IPM + micropelt

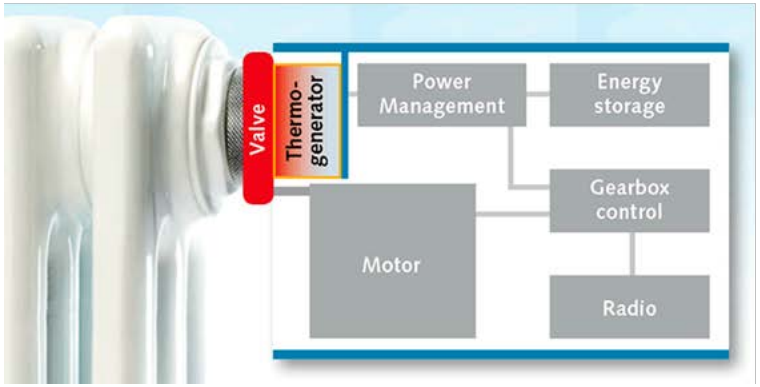
micropelt Fraunhofer IPM

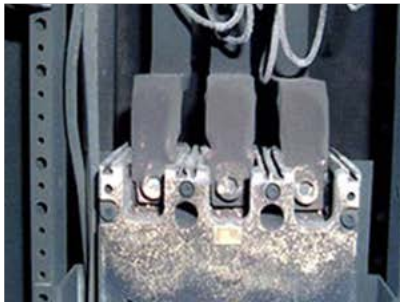
Self-powered gas sensors

- Steel slag transport train: Monitor CO concentration and train position
- SensRFID-System with integrated thermogenerator, two gas sensors and RFID-transponder



Some more application examples (Micropelt)





- iTRV: Intelligent thermostat saves heating costs
- mNODE: Temperature monitoring for busbars

micropelt

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Wireless PA sensor

ISA100Wireless

Article PROZESSAUTOMATION & MESSTECHNIK | ENERGY HARVESTING
http://www.pua24.net/pi/index.php?StoryID=41&articleID=211898 May 2012

Maintenance-free PA sensor

- Temperature, pressure, flow, …….
- WirelessHART, ISA100, Zigbee based
- No battery change over lifetime sensor

micropelt

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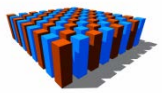
Summary

- **Introduction**
- **Self powered sensor systems (IPM)**
  - Hands-on demonstrator
  - Roast temperature sensor
  - Coffee pot demonstrator
  - Aircraft structural monitoring
  - Environmental monitoring with temporal ΔT
- **Energy harvesting and self powering at high temperatures (IPM)**
  - Adapted Skutterudite modules
  - Harvesting / voltage conversion / storage system
- **Self powered sensor systems (IPM / Micropelt / other)**
  - Self-powered gas sensors, temperature sensors, RFID systems, heating valves etc.



Good ideas for better solutions

Visit us on the Internet at
www.ipm.fraunhofer.de/en

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jan.koenig@ipm.fraunhofer.de

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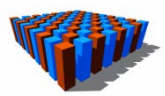

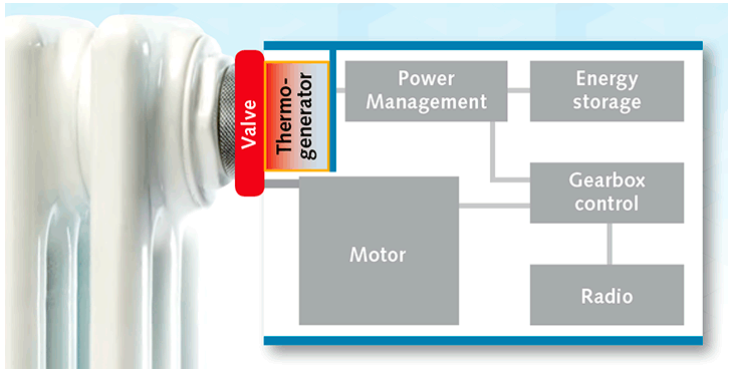

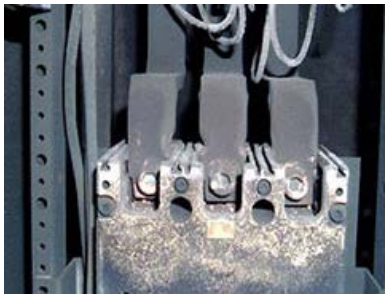

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