
Micro-Energy Management for Broadband Energy Harvesting Devices

EnerHarv 2018



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Micro-Energy Management for Broadband Energy Harvesting Devices

1. Applications and requirements
2. Bipolar input stage
3. Maximum power point tracking
4. Tunable vibration harvester
5. Application examples

Broadband Energy Harvesting Devices

Introduction

- Applications of energy harvesting differ strongly
 - Broad range of thermal gradients, sometimes bipolar
 - Broad range of accelerations, distributed over a certain frequency range
- First niche applications have only small sales quantity
- Most designs are “single use-case systems”
- Challenge: Universal, broadband components, which can be used in different applications
- Refund of development time with wider application range



Broadband Energy Harvesting Devices

Typical Application Areas

Condition Monitoring

- Monitoring of large machineries, engines, plants and structures with wireless sensors
- Save costs for wires by wireless connection
- Save maintenance cost by energy harvesting

Logistics and Transport

- Tracking goods and assets by GPS modules
- No maintenance through energy harvesting

Wearables

- Supply of smart watches, fitness trackers
- Maintenance free, limitless mobility



Broadband Energy Harvesting Devices Requirements

Condition Monitoring

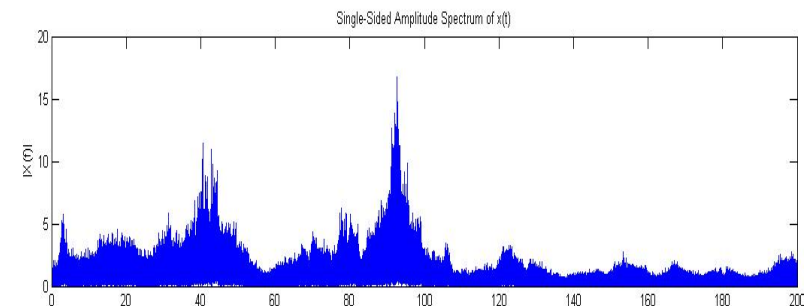
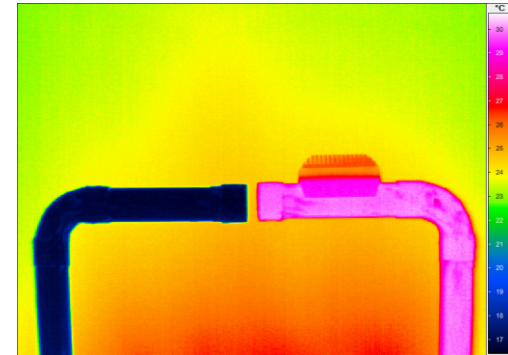
- Large thermal gradients, but strongly dynamic und bipolar (cold spots, hot spots)
- Size is not an issue

Logistics and Transport

- Vibrations with varying frequencies and amplitudes
- Size is not an issue

Wearables

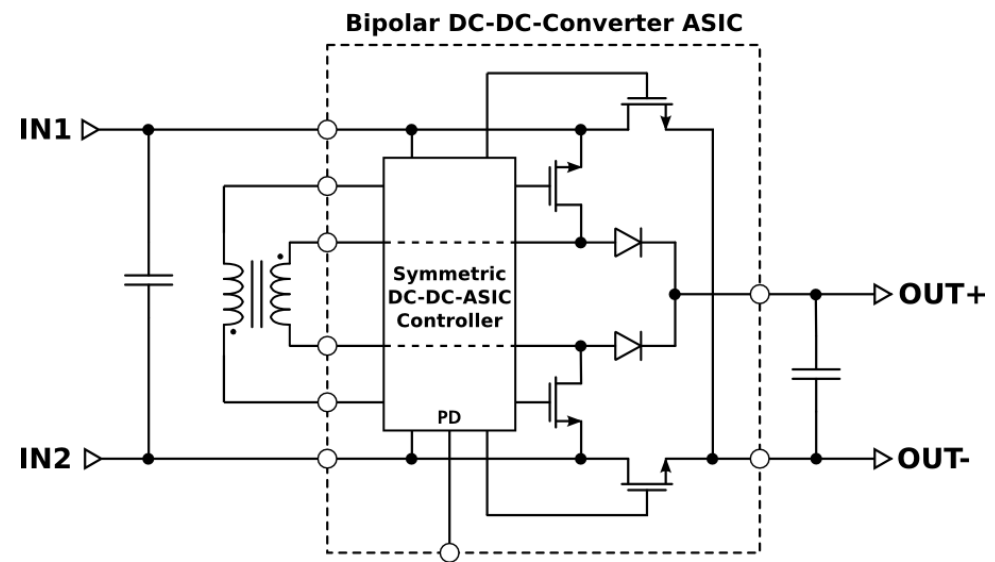
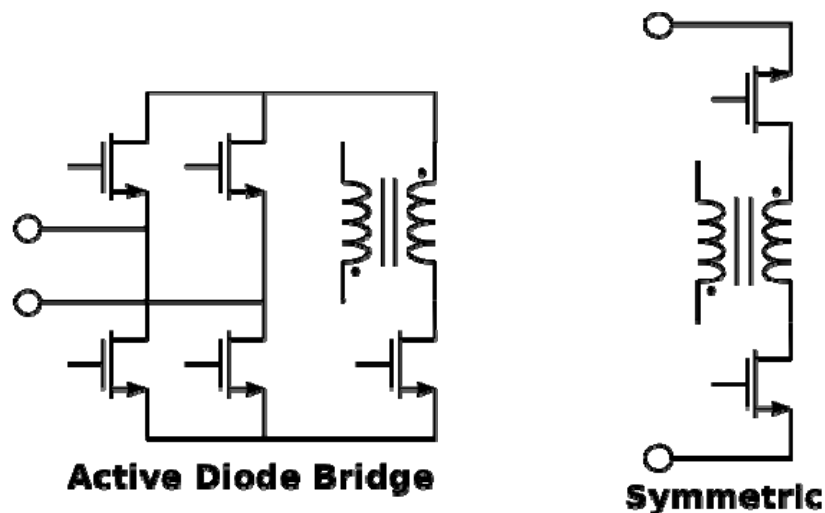
- Very small thermal gradients
- Large mechanical forces, low frequencies, sometimes shocks
- Size is an issue



Broadband Energy Harvesting Devices

Bipolar Input Stage

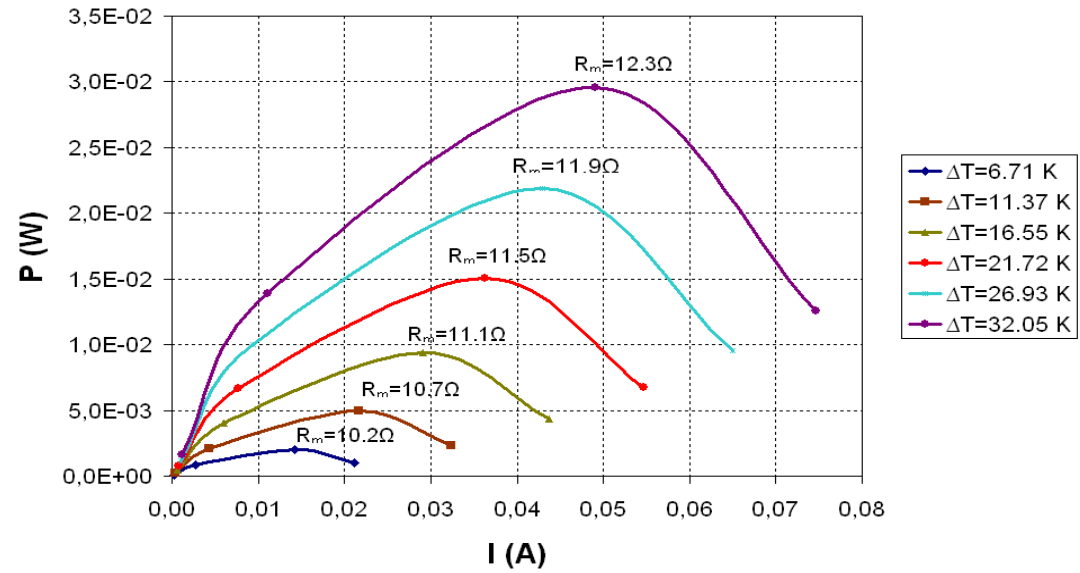
- Use hot and cold surfaces (water ducts, HVACs, windows): voltage converter with bipolar input stage
- Symmetric input stage: beneficial regarding start-up voltage, current and efficiency



Broadband Energy Harvesting Devices

Maximum Power Point Tracking

- Thermoelectric generators have a MPP
- MPP is a function of temperature
- With dynamic thermal conditions, power matching has to be adapted: MPPT

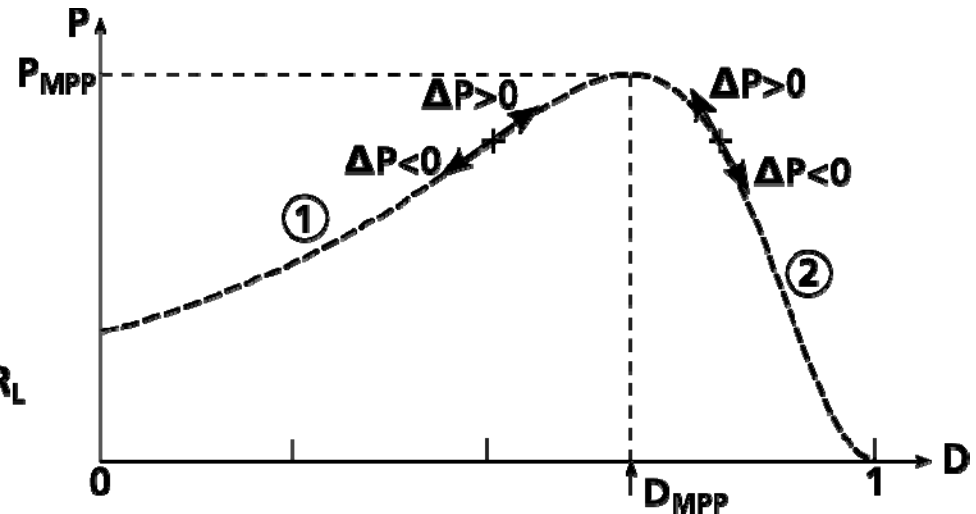
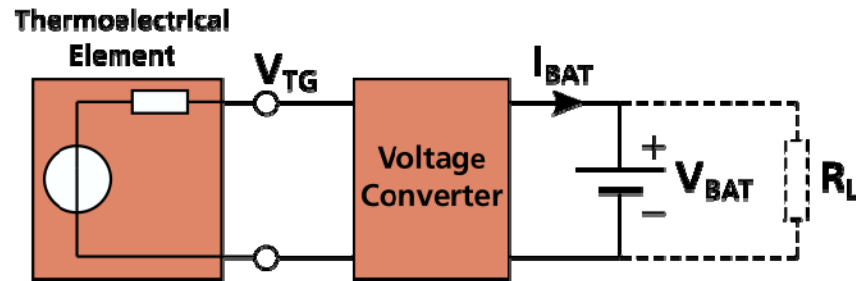


Broadband Energy Harvesting Devices

Maximum Power Point Tracking

“Perturb-and-Observe” Algorithm

- Duty cycle of dc-dc converter is changed in a certain direction
- If current I_{BAT} (as a measure of the power) increases, direction of change is kept

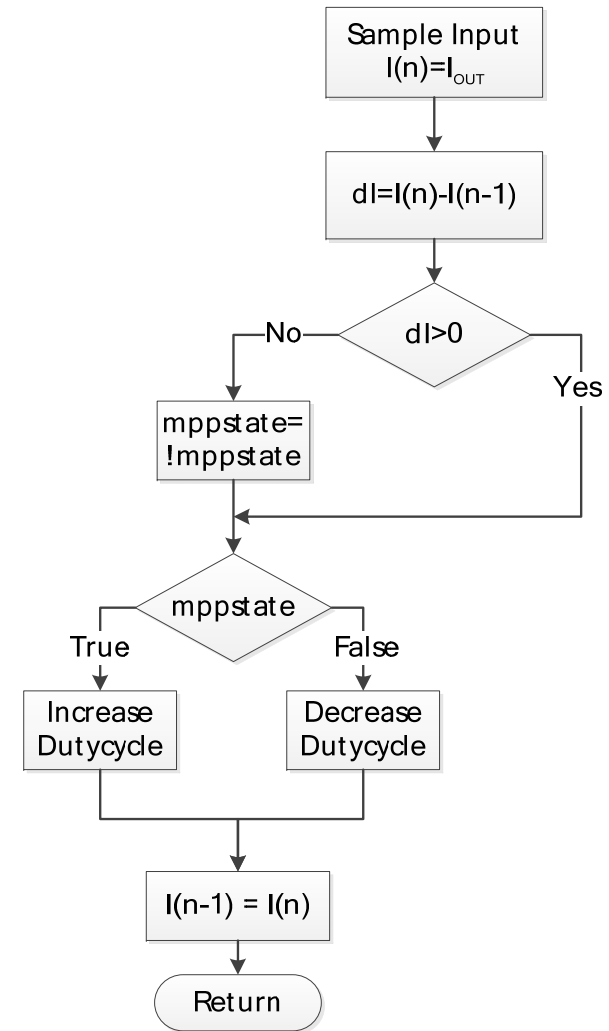
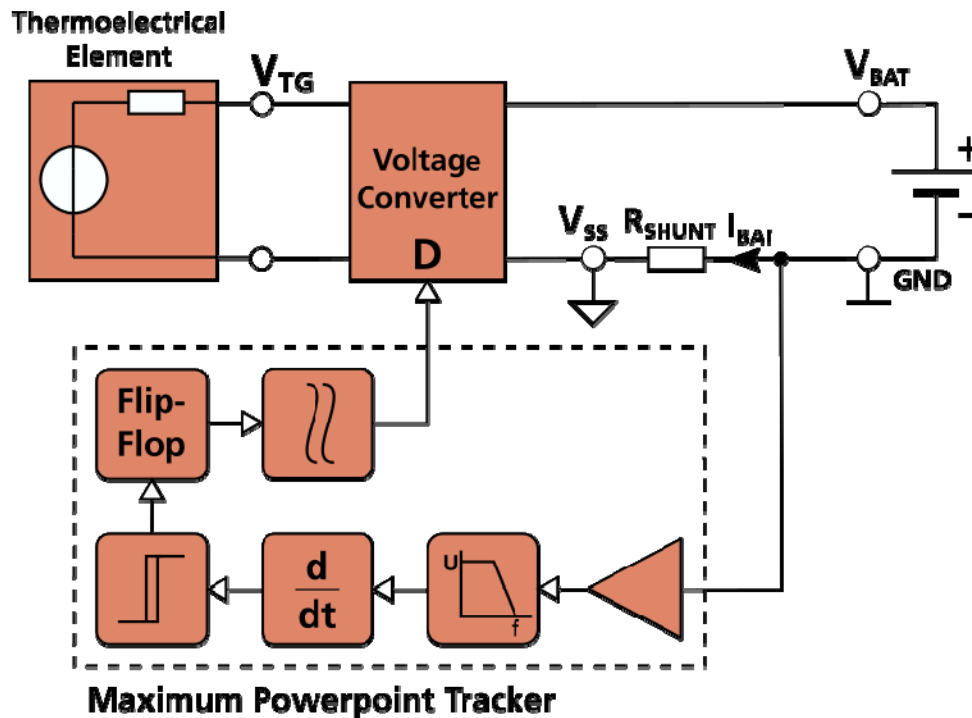


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Maximum Power Point Tracking

“Perturb-and-Observe” Algorithm

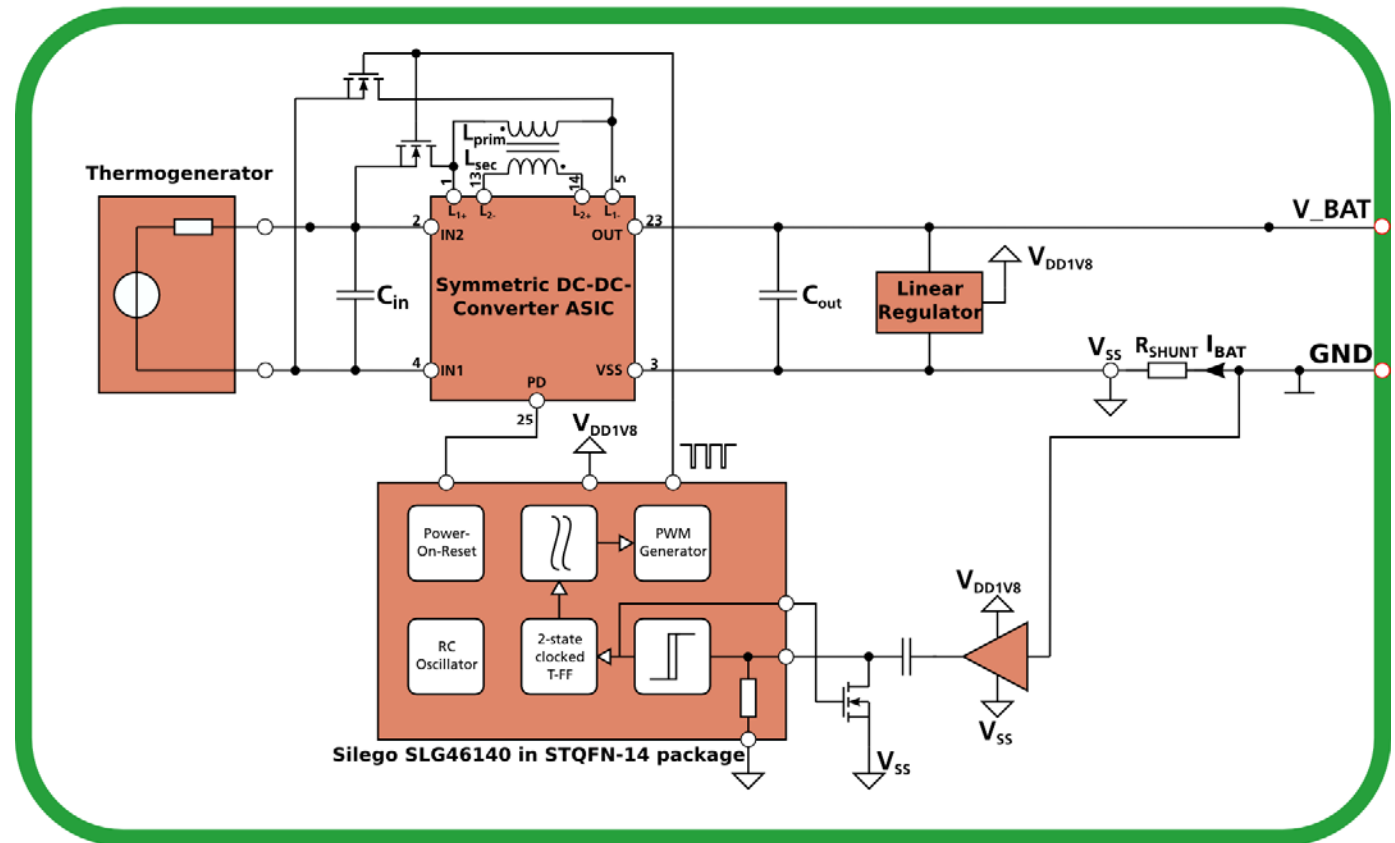
- Electrical implementation: amplification, filtering, differentiation, signature determination



Broadband Energy Harvesting Devices

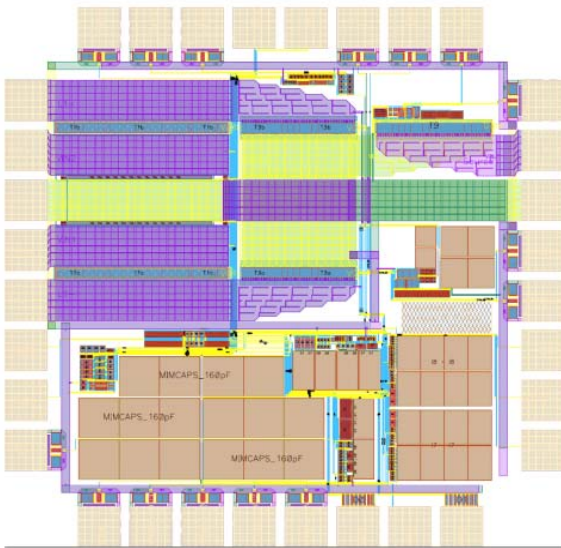
System

- Transformer 1:3
- Zero-threshold MOS, JFET or Depletion Mode
- MPPT: programmable Mixed-Signal IC Silego
- Consumption: 80 $\mu\text{A}@1,8\text{V}$



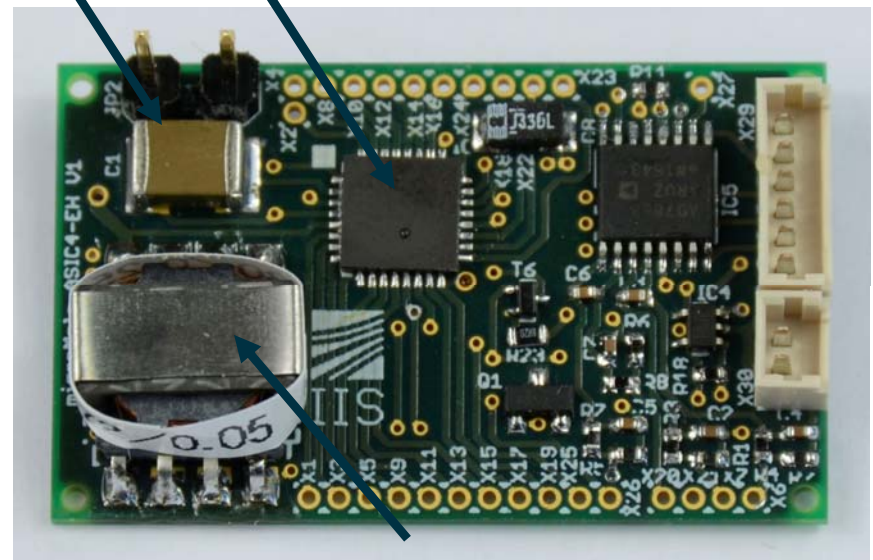
Broadband Energy Harvesting Devices System

ASIC-Layout (1,2*1,2 mm)



Output capacitor

DC-DC IC

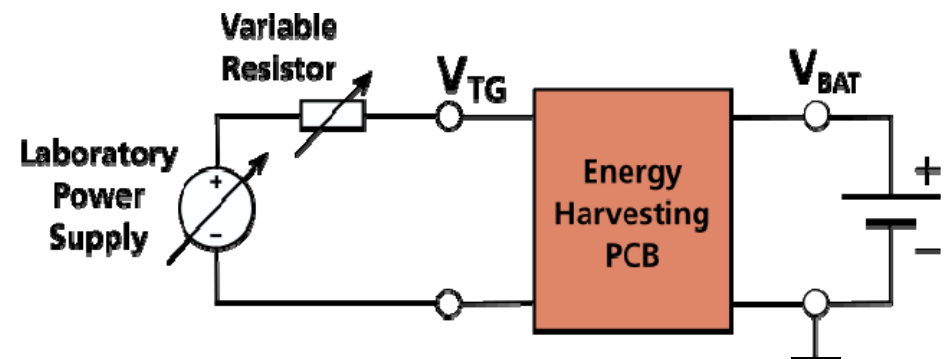
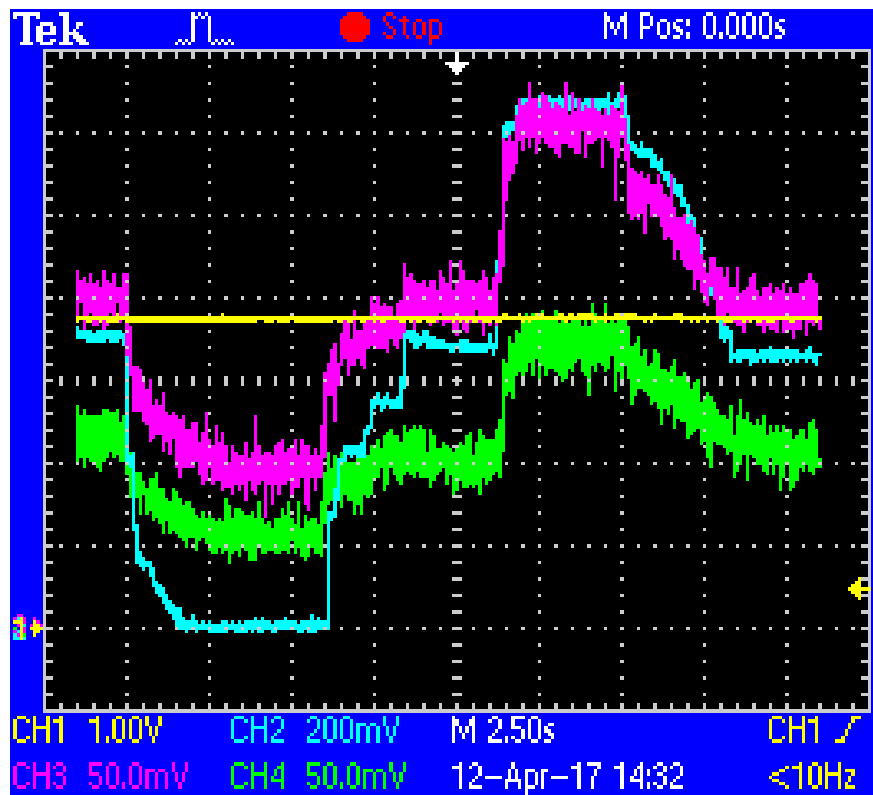


Transformer

Broadband Energy Harvesting Devices

Maximum Power Point Tracking

- Power transfer matching (MPP): 0.5 of open circuit voltage provided to the load

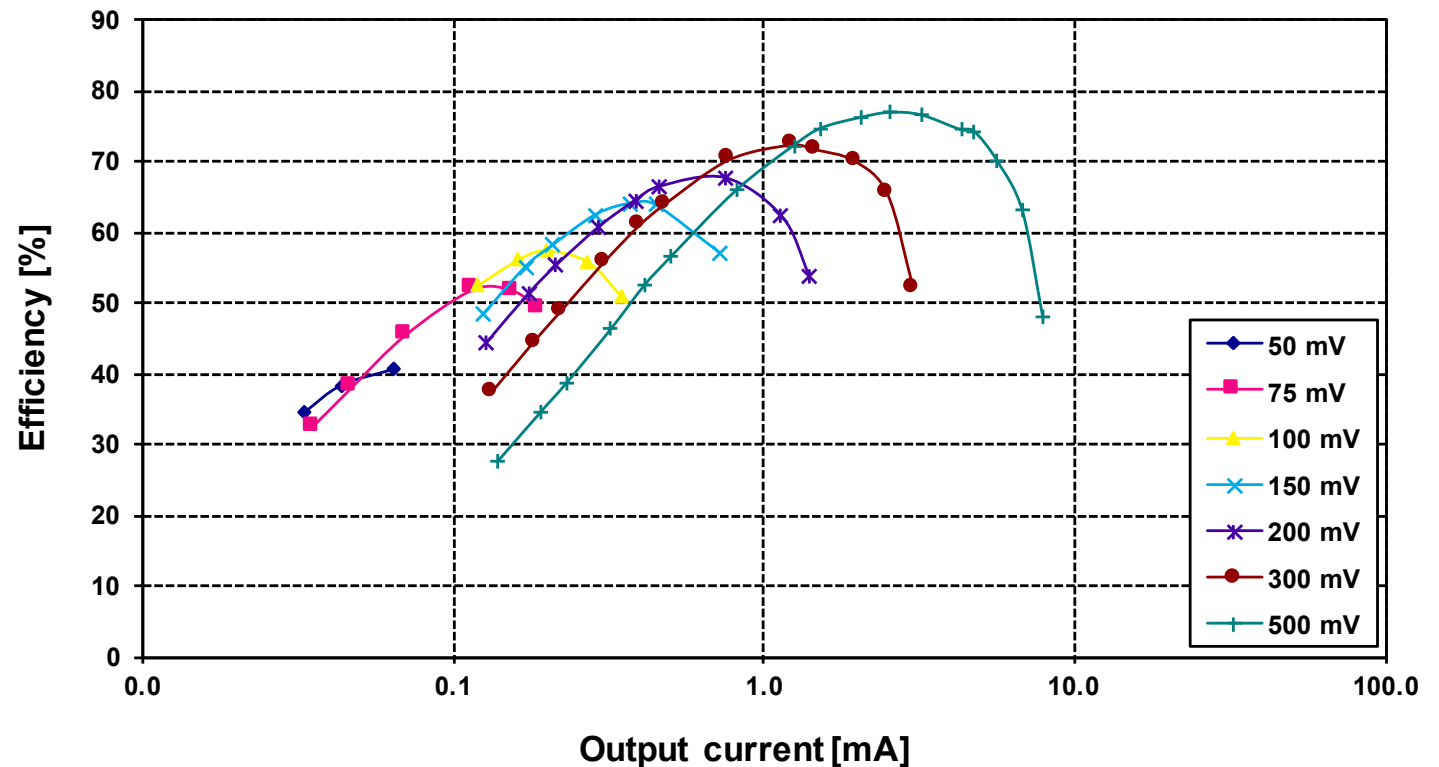


- CH1: V_{BAT} , battery voltage
- CH2: output current into battery
- CH3: voltage source at input, simulates open circuit voltage of TEG
- CH4: V_{TG} , simulates voltage of TEG

Broadband Energy Harvesting Devices

DC-DC Converter

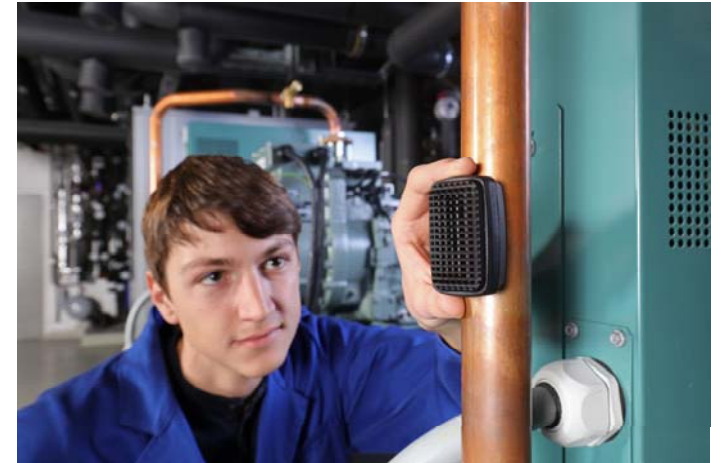
■ Start-up with 34 mV (Cold-Start)



Broadband Energy Harvesting Devices

Application Examples – Industrial Sensors

- Thermal gradients to power industrial wireless sensors
- Applications sensors measure temperature, humidity, vibration, gas etc.
- Bipolar gradients due to hot or cold surfaces
- 200 μW in 36 cm^3 with 2 K thermal gradient due to optimized power management
- Self-powered operation of Bluetooth LE with one transmission per second



Broadband Energy Harvesting Devices

Application Examples – Water Management

- Autonomous water sensor with wireless interface
- Thermoelectric generator and optimized power management
- in cooperation with Fraunhofer IZM in the Micromole-Project
- 2K thermal gradient produces typical output power of 200 μW
- Sensors: pH and conductivity (application specific customization possible)



Broadband Energy Harvesting Devices

Application Examples - Wristband with Thermoelectric Power Supply

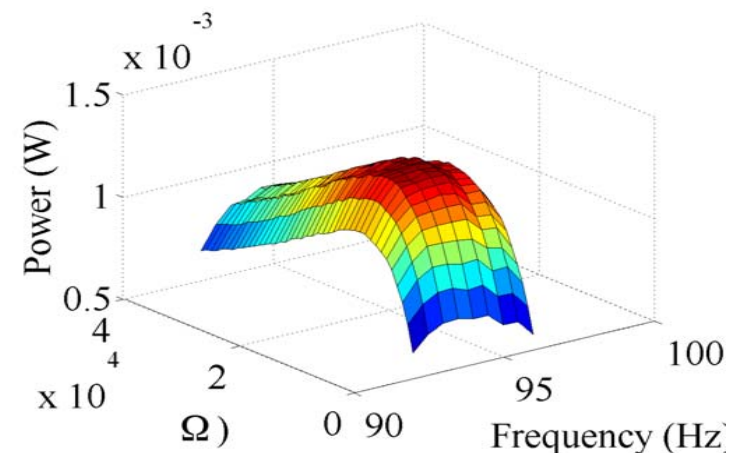
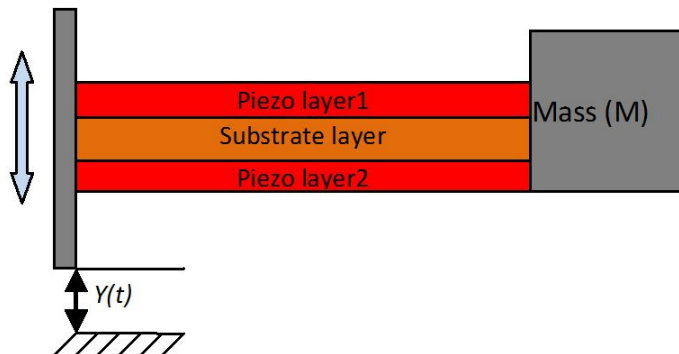
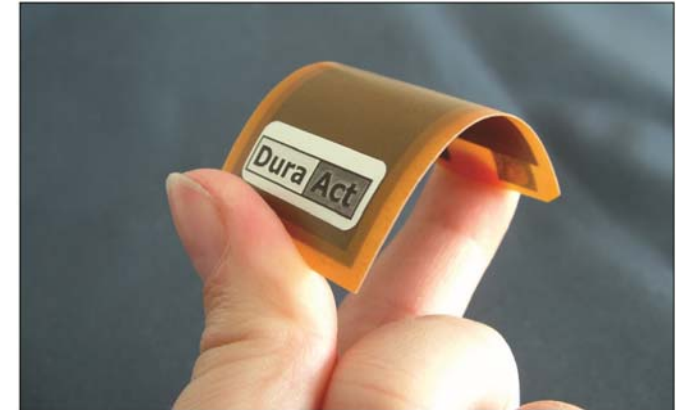
- Wristband with Bluetooth Low Energy connection
- Power supply covered with thermogenerator and Fraunhofer dc-dc converter
- Ca. 150 μW from 2-3 K thermal gradient
- BLE duty cycle: 1/s
- Sensor data: Temperature and acceleration, others possible
- Areas of application: Watches, medical sensors, wireless sensors
- Customization to different requirements (power output, size, integration) possible



Broadband Energy Harvesting Devices

Tunable Vibration Harvester

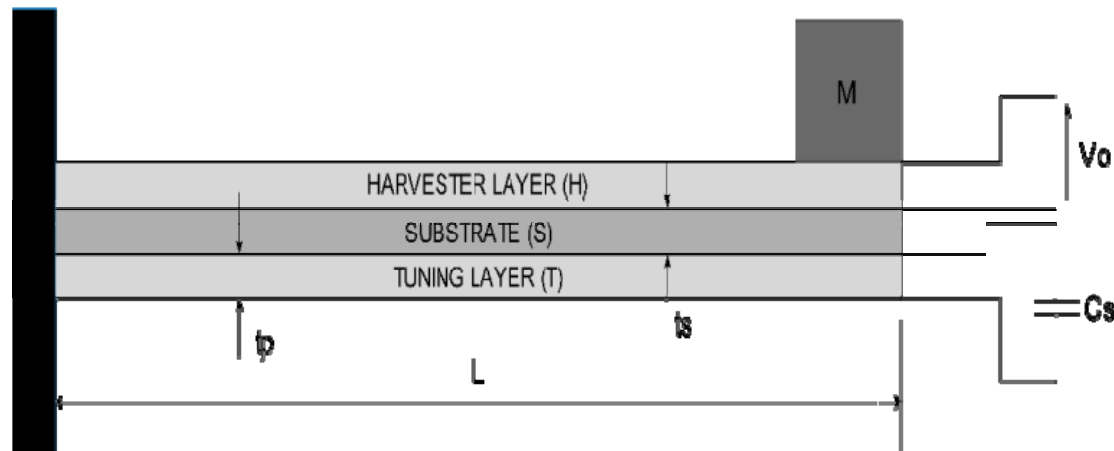
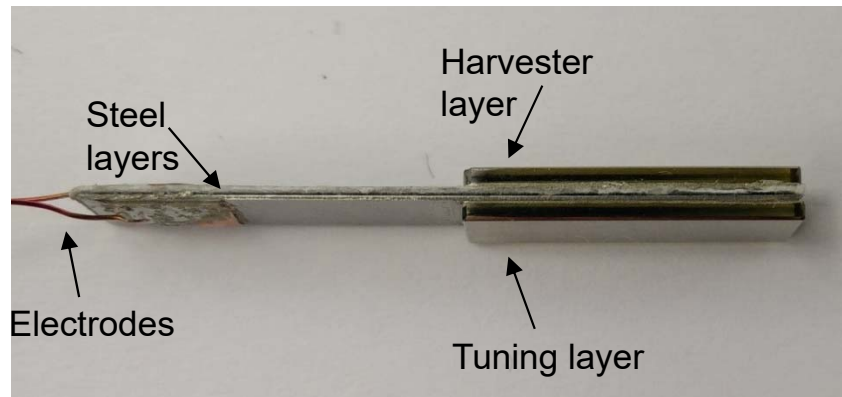
- Piezoelectric materials off-the-shelf like PVDF or PZT
- Resonant oscillators with fixed resonance frequency



Broadband Energy Harvesting Devices

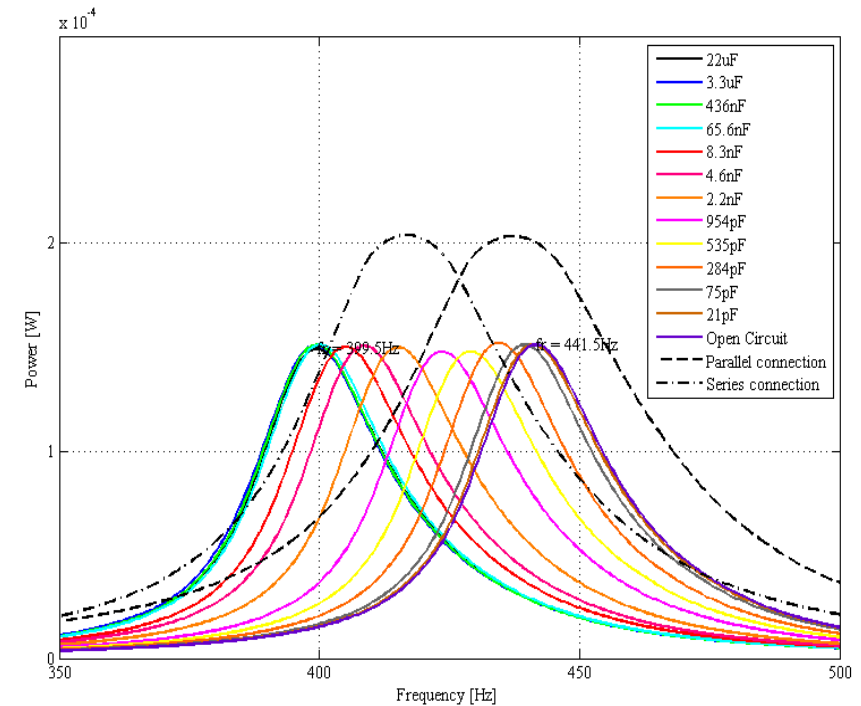
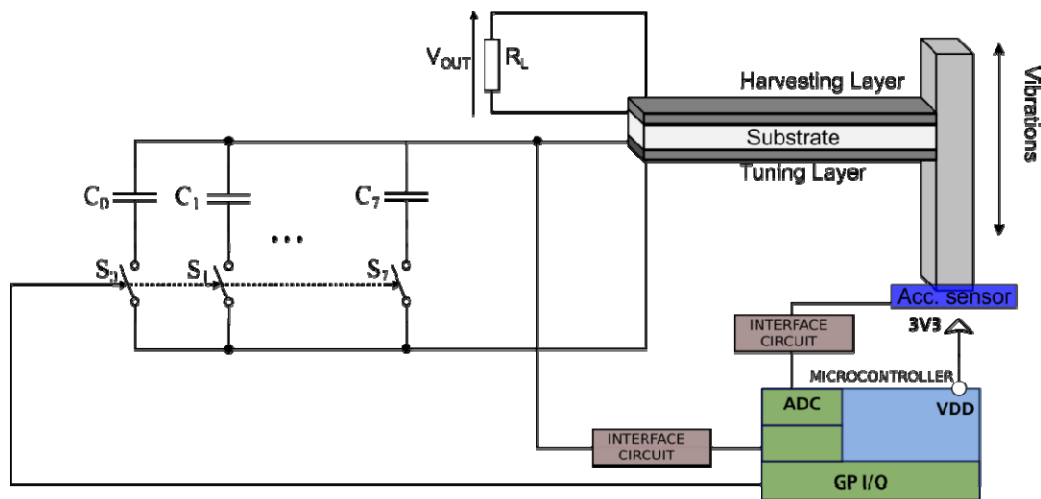
Tunable Vibration Harvester

- Piezoelectric material can be tuned by external capacitors



Broadband Energy Harvesting Devices

Tunable Vibration Harvester



Acceleration : 0.5 g, Frequency sweep: 350 - 500 Hz, Tip mass : 15 g, Harvester layer : 270 K Ω (load), Tuning layer: Shunt capacitance (C_s), $\Delta f = 73.5$ Hz, Tuning ratio = 10.5 %

Broadband Energy Harvesting Devices

Application Examples - Self-powered Tracking Tag

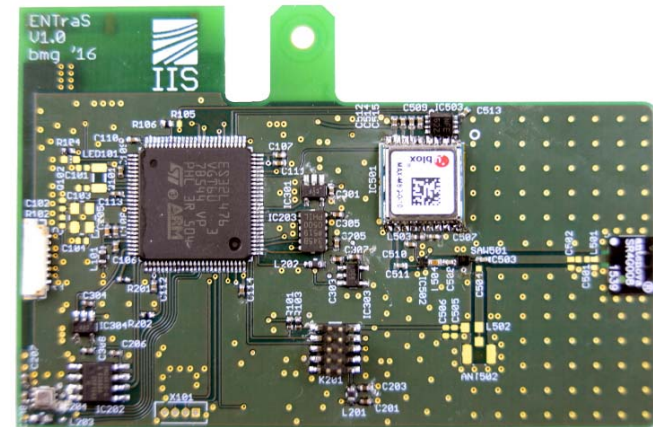
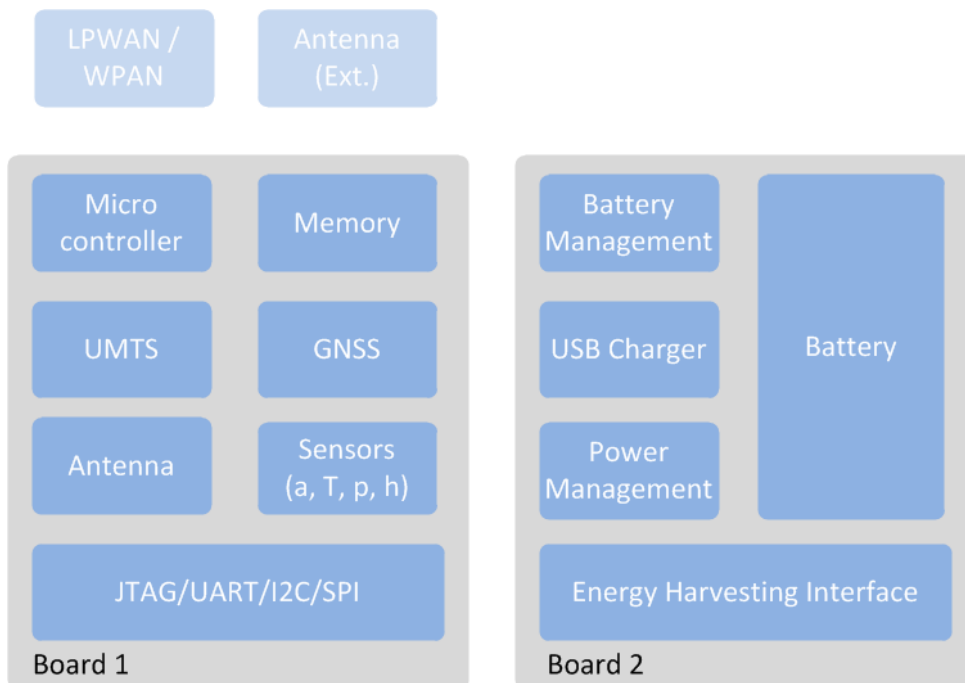
- Tracking systems for localizing expensive goods, assets, vehicles
- Measure and transmit position and other data
- Power supply is bottleneck for long-life applications (months, years)
- Vibrations are available in all moving objects, solar and thermal harvesters are optional



Broadband Energy Harvesting Devices

Application Examples - Self-powered Tracking Tag

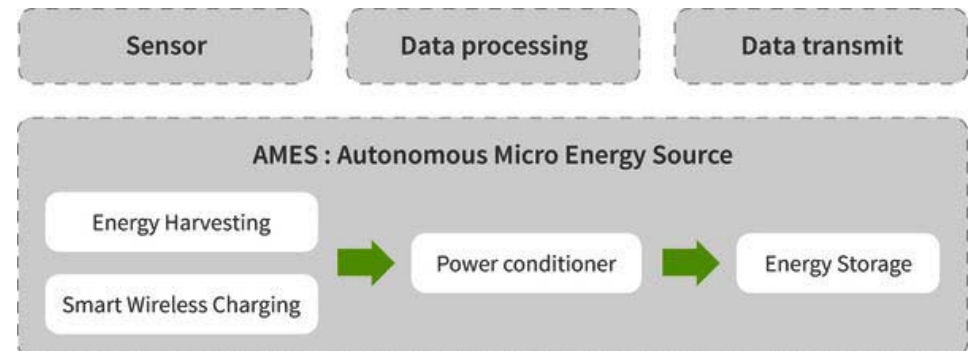
■ Hardware, power consumption



| Mode | Positions / Day | UMTS / Day | Power [mW] | Area Solar [cm*cm] |
|------|-----------------|------------|------------|--------------------|
| 1 | 2 | 1 | 2,5 | 7 [e.g. 3*3] |
| 2 | 6 | 2 | 3,5 | 10 [e.g. 3*4] |
| 3 | 12 | 12 | 9 | 26 [e.g. 5*6] |
| 4 | 24 | 24 | 17 | 47 [e.g. 6*8] |

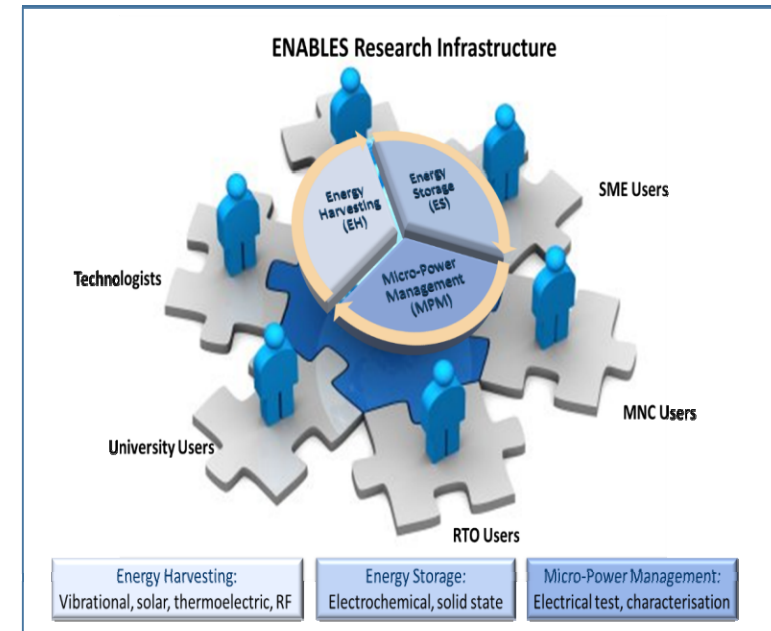
EnSO “Energy for Smart Objects” (ECSEL H2020 project, 2016-2020)

- EnSO “Energy for Smart Objects” project is focusing on an essential generic need within IoT, providing Autonomous Micro Energy Sources (AMES)
- Develop and demonstrate high capacity (> 20 mAh) and high density (> 300 Wh/l), low profile, shapeable, micro battery supported by efficient and reliable energy harvesters as well as easy charging
- Disseminate and standardize EnSO energy solutions with easy to use demonstration kits for a large number of use cases
- Consortium: CEA Leti, FhG, TNO, CSIC, SKF, Cairdac, Valotec, Gemalto, Gas Natural, Mahle, Solems, Enerbee, etc.
- <http://enso-ecsel.eu/>



EnABLES „European Infrastructure Powering the Internet of Things” (H2020 project, 2018 – 2022)

- Building an ecosystem for collaboration starting with EnABLES
- Joint research activities
- Providing external fast track access to expertise and laboratories (TA) – over 130 researchers
- Transnational Access (TA) offer launched in Juli 2018
- www.enables-project.eu
- *Partners:*



Broadband Energy Harvesting Devices

Summary

- Large range of promising applications:
 - Industrial
 - Automation
 - Transport
 - Wearables
- Ambient conditions differ strongly
- >> Tunable or broadband harvesters and electronics increase application range
- >> Refund of development costs by more use-cases



Broadband Energy Harvesting Devices

Summary

- The authors gratefully acknowledge the financial support of the following projects:
 - MicroMole: This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 653626
 - EnSO: This project has been accepted for funding within the Electronic Components and Systems For European Leadership Joint Undertaking in collaboration with the European Union's H2020 Framework Program (H2020/2014-2020) and National Authorities under grant agreement No 692482.
 - Daedalus: This project has received funding from the German Federal Ministry for Economic Affairs and Energy BMWi under grant agreement No 50NA1311.



Thank you for listening!

Any questions.....?

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