CoolSensorNet – Wireless Sensing using Energy Harvesting Technologies

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- Part I - CoolSensornet
    - Cluster of Excellence “Cool Silicon”, Project “CoolSensornet”
    - Condition Monitoring Principles
    - Block Diagram and Demonstrator
- Part II – Energy Harvesting
    - Motivation
    - Applications
    - System Approach
    - Current Activities
- Summary and Outlook

Overview

1) CoolComputing: Energy preserving computing platforms
2) CoolReader: Energy autonomous E-Paper with broadband wireless connection
3) **CoolSensornet:** Energy autonomous wireless sensors for structural health monitoring (SHM)
    - reduction of CO_2 emissions until 2020 by factor of 2
    - next generation airplanes with new materials (e.g. CFK/CFRP)
    - new SHM principles required

Cluster of Excellence "Cool Silicon" – Technical Lead-Projects

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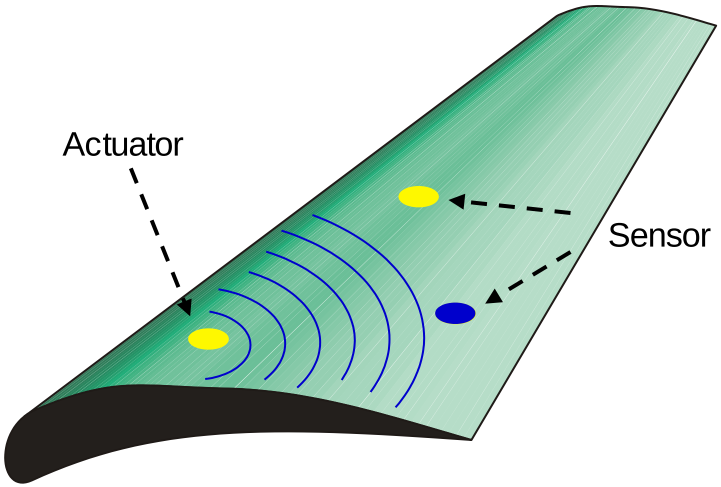
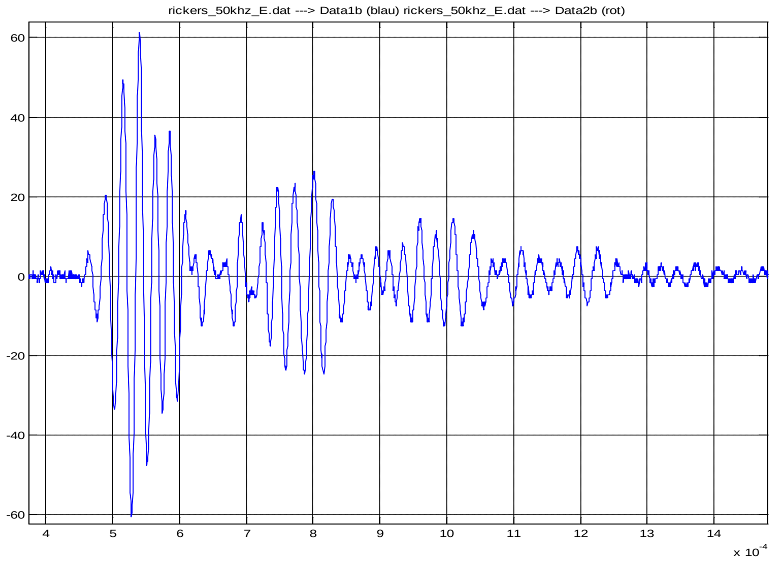
- Acousto ultrasonic (AU) structural health monitoring (SHM)
  - actuator stimulates lamb waves
  - sensor receives these waves





Fraunhofer IZFP

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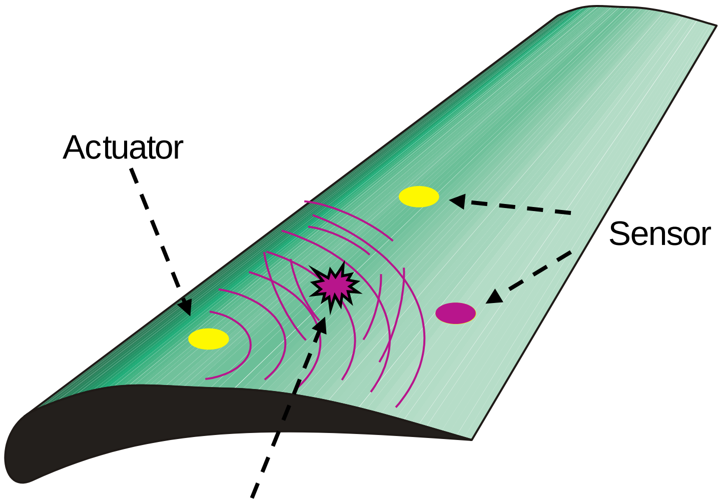
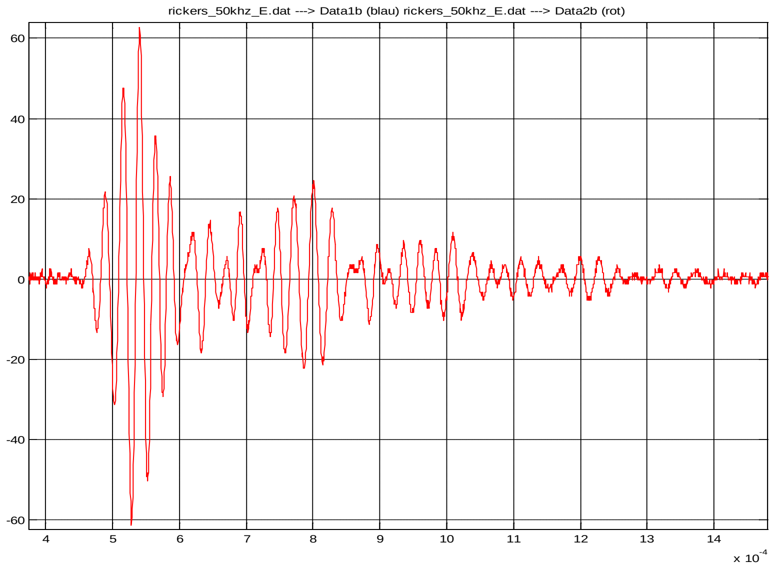
- ultrasonic wave interacts with structural flaw
- sensor signal changes amplitude and phase
- local monitoring of structure





AU SHM – Impact

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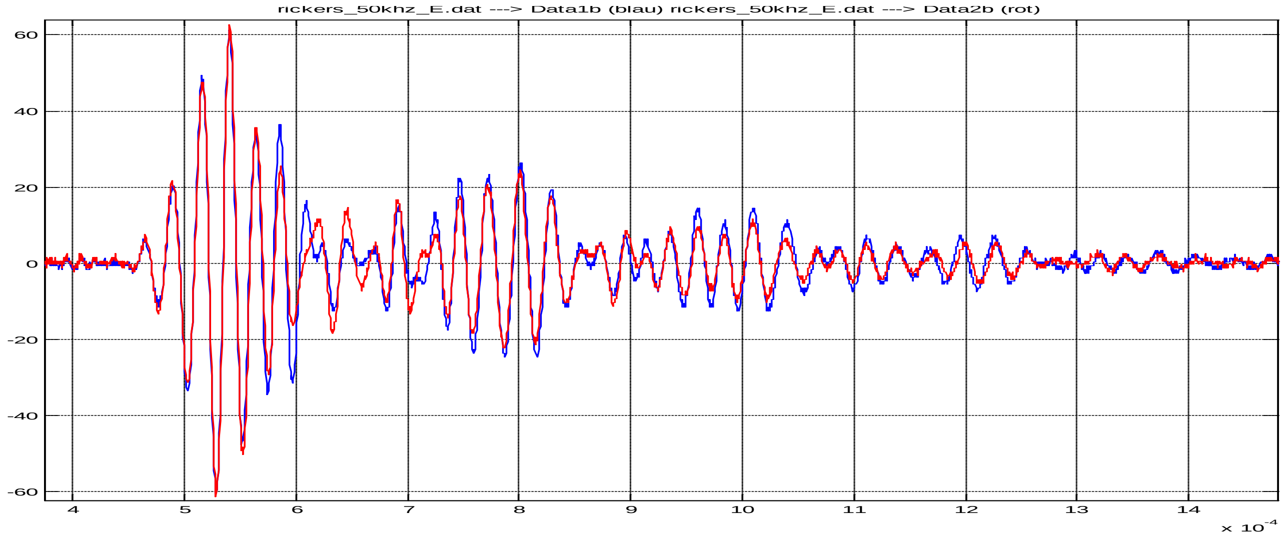
- Comparison between measured signal and reference signal
- Challenges - existing algorithms are resource demanding
  - high signal amplitude resolution
  - timing accuracy (timing synchronization required among sensor nodes)
  - memory requirement
- Currently investigation and optimization of algorithms for power consumption and chip area



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AU SHM – Detection

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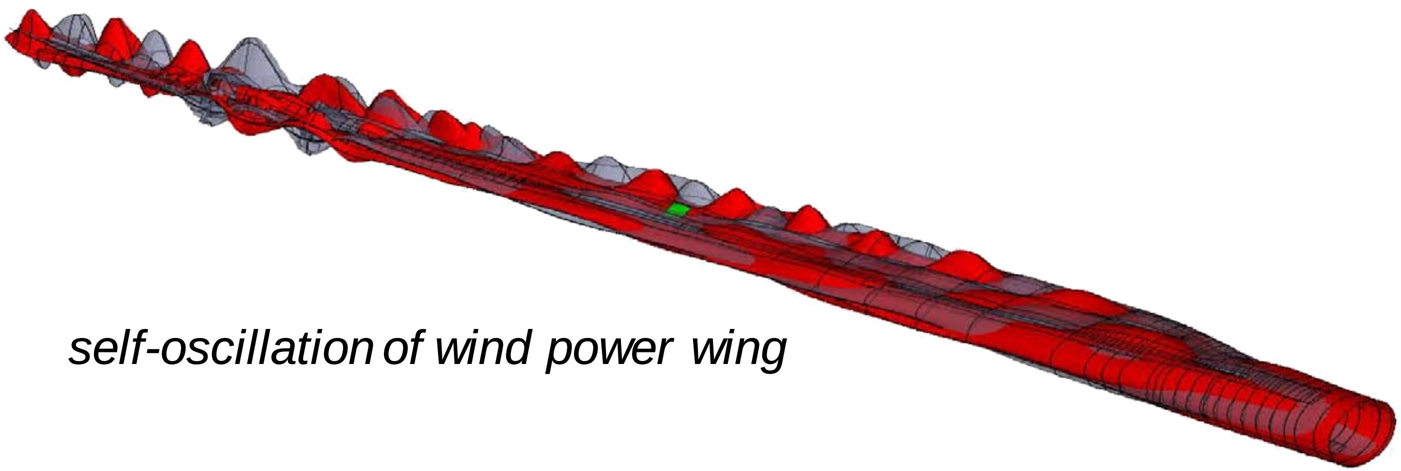
- Low frequency sensing
- Global monitoring of structure
- Comparison between reference state and actual state
  - red: Eigenform (undamaged state)
  - grey: Eigenform with delamination
- Challenge
  - long measurement time
  - → energy and memory requirement



self-oscillation of wind power wing

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Passive Structural Health Monitoring (SHM)

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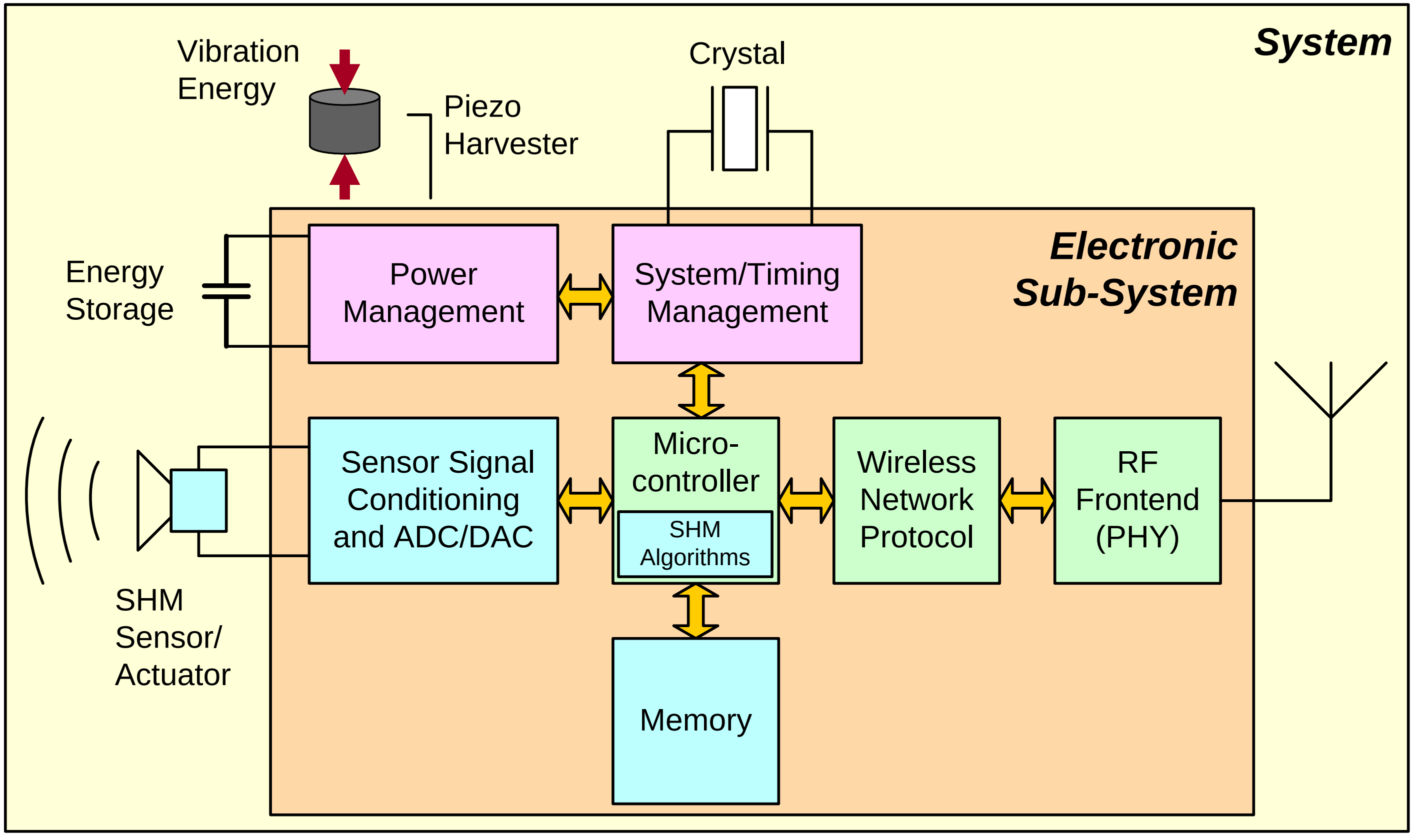
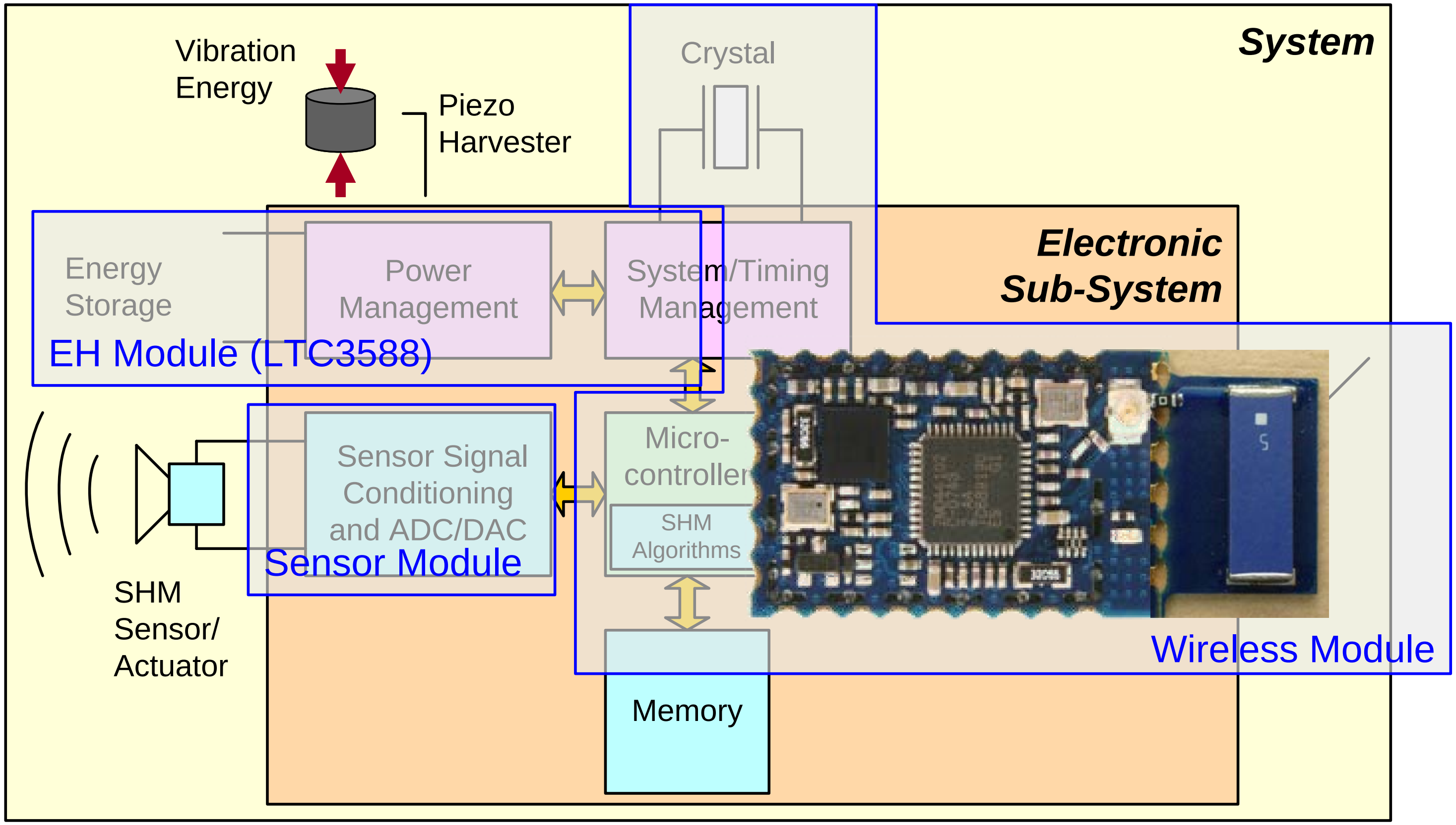


energy autarkic wireless sensor node

Block Diagram



first demonstrator (Dec/2010)

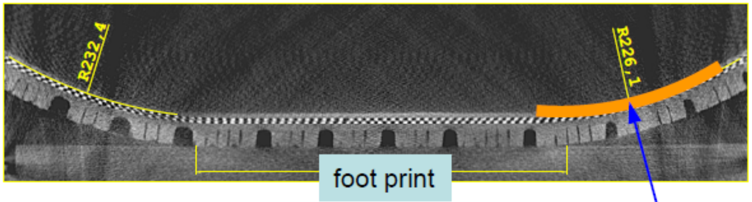
Block Diagram - Demonstrator

Part II – Energy Harvesting

Applications

- Energy autarkic wireless sensing applications, e.g.
  - structural health monitoring of
    - wind power wings / rotor blades
    - bridges
  - tire pressure measurement systems
  - metering
    - thermostats are a driving application
- Building automation (sensors & actuators with wireless interface)

Energy converter: Piezo - deformation bender

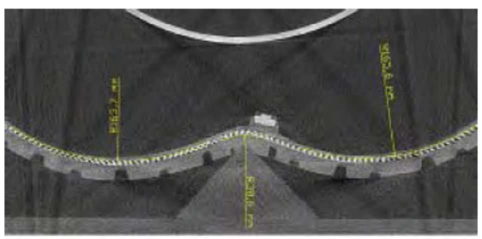


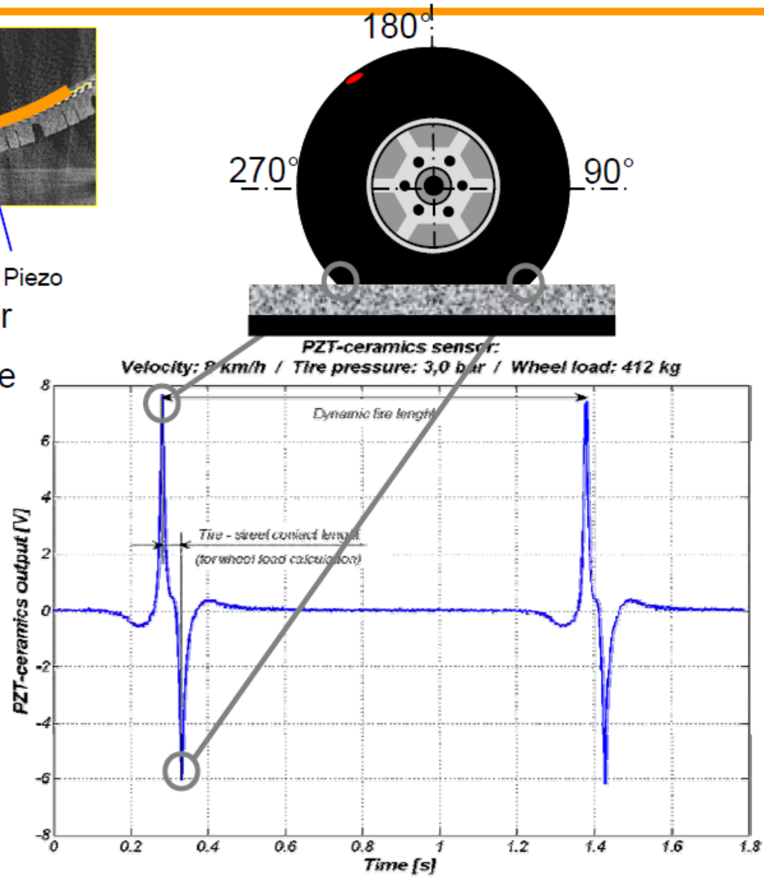
Pro:

- *deformation* offers acceptable power
- no add. seismic mass / package size
- realization of system functionality
- high speed survival

Con:

- overload protection difficult





Continental

BU Body & Security / Thomas Haas © Continental Automotive GmbH 2008

Example: Tire Pressure Monitoring System (TPMS) of Continental

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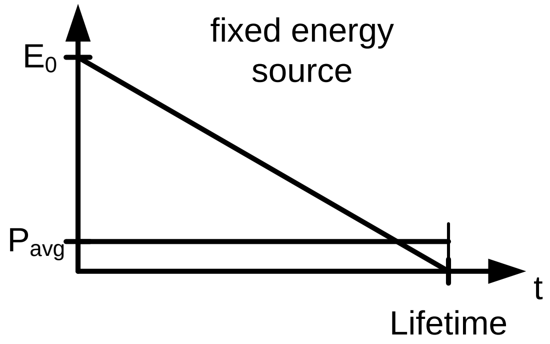
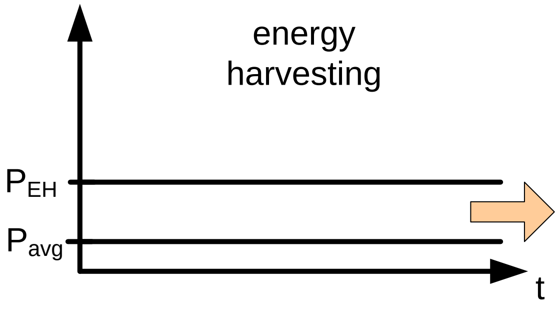
- Wireless applications today are mostly using fixed-energy sources – batteries
  - lifetime is fixed, or
  - battery has to be replaced (or recharged) → non-autarkic node
- If an energy harvesting system was got to work ….
  - potential for unlimited lifetime with respect to energy source
  - lifetime is limited by hardware components (reliability, aging)





Example for illustration: 100mAh battery vs. 100uW piezo vibration harvester

- 1uA sleep current with timer function active
- transaction every 2min for 50ms (e.g. beacon tracking, RX, TX) at 20mA → average current of 8.3uA
- average current consumption ~10uA
- battery life time 1.14 years
- energy harvesting application works if overall efficiency is larger than 10% (assuming “1V” for the moment)

Energy Harvesting – System Perspective

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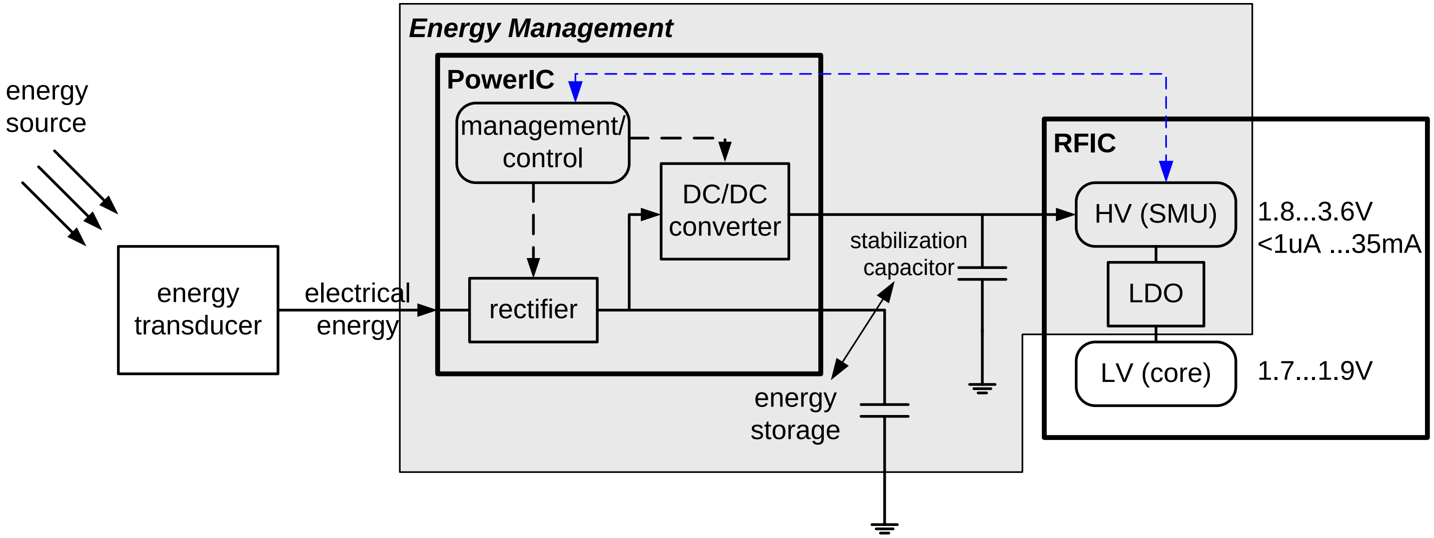
- Requirements
  - low power electronic components (same as for battery application)
  - energy harvesting power management (PM)
- Key parameters of power management
  - power consumption under light load (sleep mode)
  - efficiency
  - input voltage range
  - energy storage type and properties



How to get energy harvesting system to work?

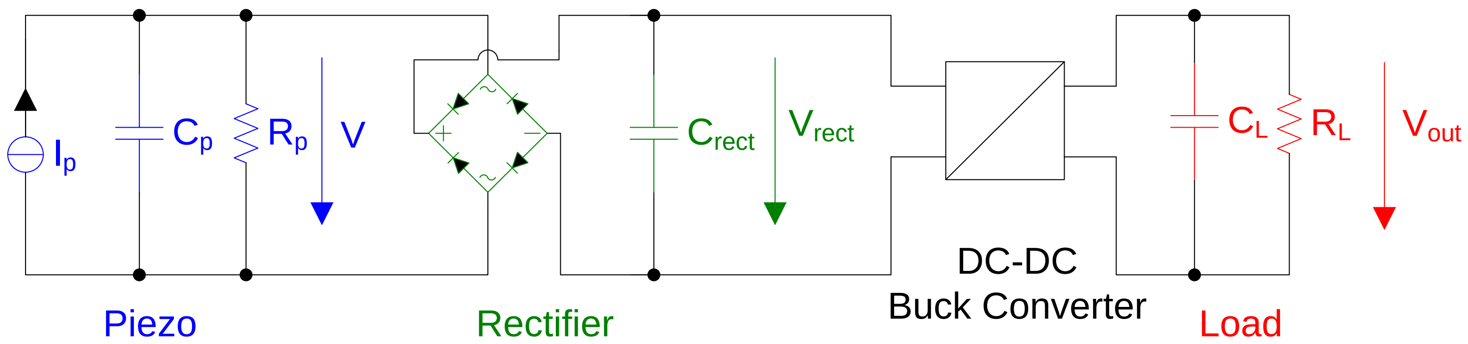
Block diagram based on simplified equivalent circuits:

- High-level parameters:

- AC Piezo generator:
  frequency fp
  open-circuit voltage Vp
  short-circuit current Ip
  impedance Cp, Rp

- Full-wave bridge Rectifier:
  diode voltage drop Vd
  storage capacitor Crect

- Load:
  capacitor CL
  output power Pout



- DC-DC Converter: quiescent current Iq
  efficiency **η**
  threshold voltages Vfall, Vrise
  maximum input voltage

Energy Harvesting System Model: Block Diagram

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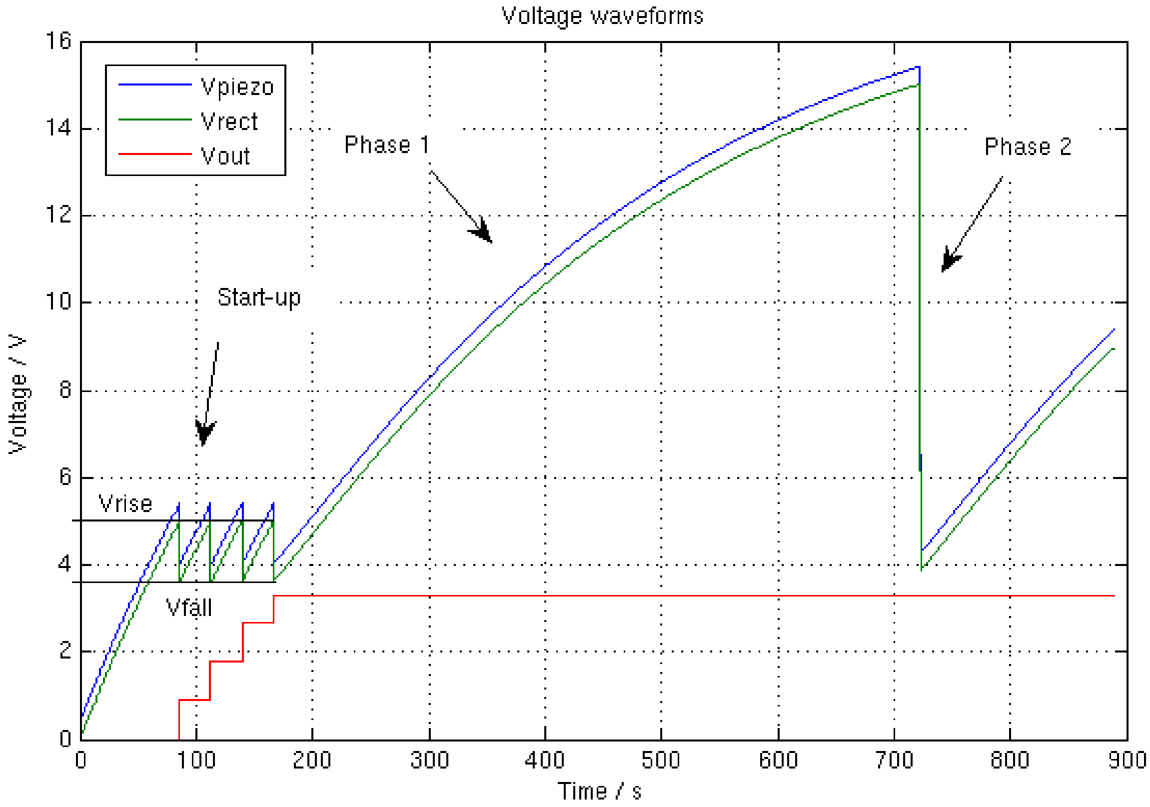
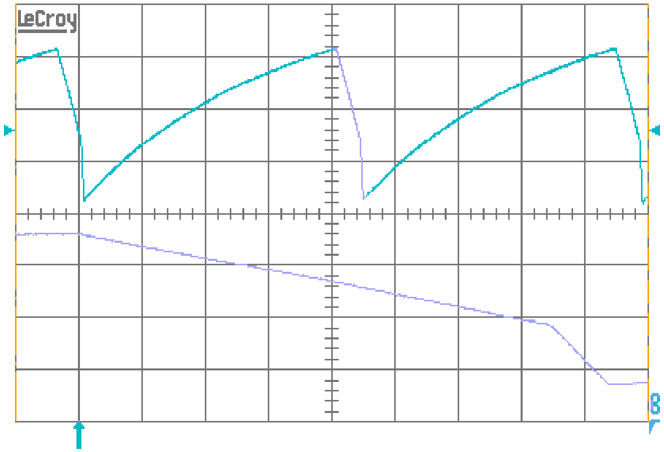
Energy harvesting operation cycle:

- Phase 0: start-up
- Phase 1: minimum power operation (IC in sleep mode) and energy accumulation
- Phase 2: maximum power operation (IC in active mode) for short time



Wireless Module with Energy Harvesting (duty-cycling)



Energy Harvesting System Model: Operation Cycle

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- CoolSensornet project overview
- Energy harvesting introduction

- Energy Harvesting is one way to enable energy efficient systems
  - Take the energy and use it - it is available anyway!

- Wireless & Energy Harvesting = Autarkic Sensor Nodes

Summary