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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
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 CO2 emissions until 2020 by factor of 2
   • next generation airplanes with new materials (e.g. CFK/CFRP)
   • new SHM principles required
- Acousto ultrasonic (AU) structural health monitoring (SHM)
  - actuator stimulates lamb waves
  - sensor receives these waves

![Diagram of actuator and sensor stimulating and receiving lamb waves](image)

Graph: 

```
 x 10^-5

 rickers_50khz_E.dat ---> Data1b (blau) rickers_50khz_E.dat ---> Data2b (rot)
```

Acousto Ultrasonic (AU) Structural Health Monitoring (SHM)
- ultrasonic wave interacts with structural flaw
- sensor signal changes amplitude and phase
- local monitoring of structure

AU SHM – Impact
• 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
• 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
energy autarkic wireless sensor node
first demonstrator (Dec/2010)
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

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Example: Tire Pressure Monitoring System (TPMS) of Continental
• 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)
• 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 $f_p$
    - open-circuit voltage $V_p$
    - short-circuit current $I_p$
    - impedance $C_p, R_p$
  - Full-wave bridge Rectifier:
    - diode voltage drop $V_d$
    - storage capacitor $C_{rect}$
  - Load:
    - capacitor $C_L$
    - output power $P_{out}$

- DC-DC Converter:
  - quiescent current $I_q$
  - efficiency $\eta$
  - threshold voltages $V_{fall}, V_{rise}$
  - maximum input voltage

Energy Harvesting System Model: Block Diagram
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
• 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