
CTS | Ferroperm. This document and the information in it is proprietary and is the property of CTS | Ferroperm. It may not be copied or disclosed to a third party or used for any purpose other than that for which it is supplied without the express written consent of CTS | Ferroperm.

Information contained in this document is subject to certain Export Control regulations, specifically of the (choose as appropriate) United Kingdom, European Union, other national jurisdiction and / or the United States International Traffic in Arms Regulations and / or Export Administration Regulations. Each recipient of this document is responsible for ensuring that transfer or use of any information contained in this document complies with all relevant Export Control Regulations.



Energy harvesting based sensor network for industrial monitoring

Presented by: Tomasz Zawada

CTS | Ferroperm, Denmark

21st November 2013, Energy Harvesting and Storage USA 2013, Santa Clara, USA

Outline

- 1 | **Company introduction**
- 2 | **System architecture**
- 3 | **Piezoelectric technology for energy harvesting (EH)**
- 4 | **Sensor nodes and Wireless Sensor Network (WSN)**
- 5 | **Climatic chamber and real industrial environment tests**

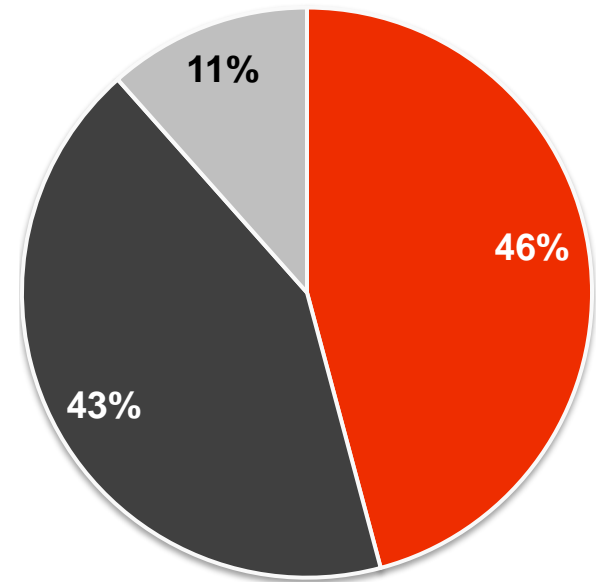
1

Company introduction



Overview

- » Provides high technology products and systems for the aerospace, defence and other specialist markets, including: medical, industrial, energy, test and automotive
- » 60 years experience in extreme environment engineering
- » Annual sales (2012), £1,605.8 million, 10% growth in comparison to 2011
- » Listed on London Stock Exchange (MGGT)
- » FTSE100 company



OE 52% / Aftermarket 48%

- Civil aerospace
- Military
- Energy and other

CTS | Ferroperm Denmark

- » We are a manufacturer of piezoelectric materials, components, devices
- » 2-3 million units produced annually
- » Major markets
 - Medical ultrasound
 - Underwater acoustics
 - Acceleration sensors
 - Flow meters
 - Energy Harvesting



2

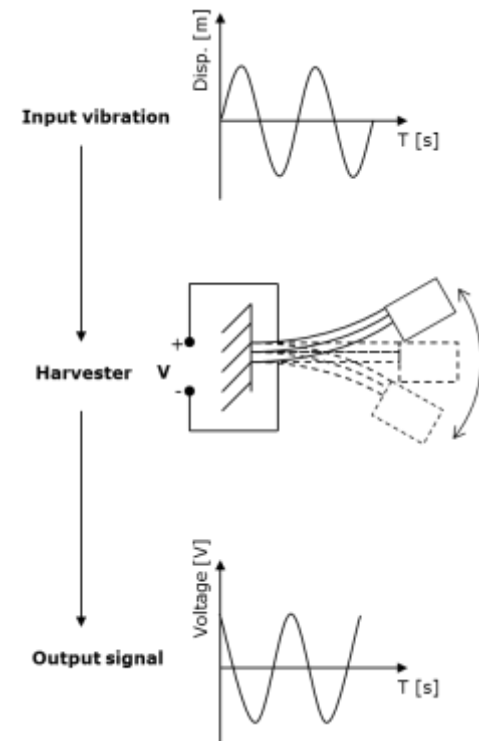
System architecture



Kinetic energy harvesting – basic principle

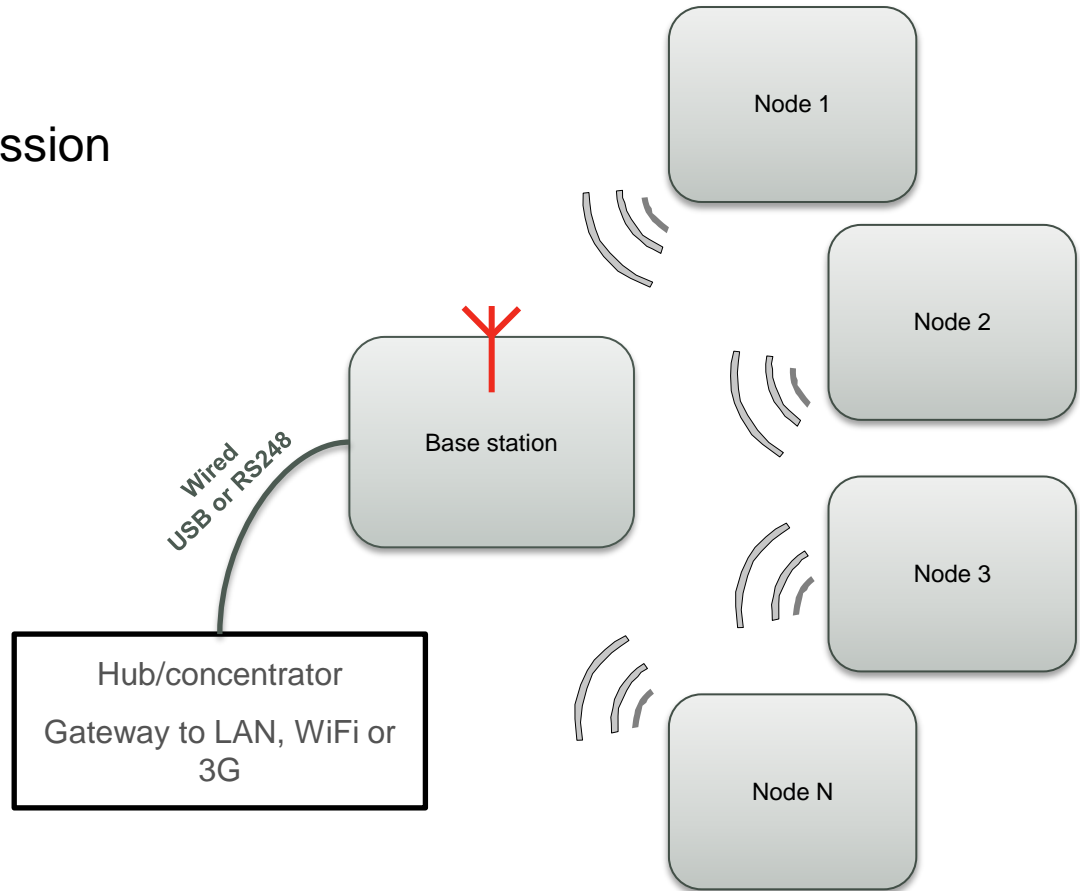
Energy Harvesting - transforming low grade energy into usable electrical energy enabling an autonomous, wireless operation of electronic devices

- » The kinetic energy is transformed into electrical energy
- » The kinetic energy can be in the form of the following:
 - Harmonic vibration
 - Non-harmonic vibration
 - Rotation
 - Displacement
 - Torque
 - Acoustic wave
 - Etc.



Energy harvesting based wireless sensor network

- » Star topology
- » Unidirectional transmission
- » 16 sensor nodes
- » 2.4 GHz radio link
- » Proprietary protocol
- » Distance (3-10 m)



General features of the system

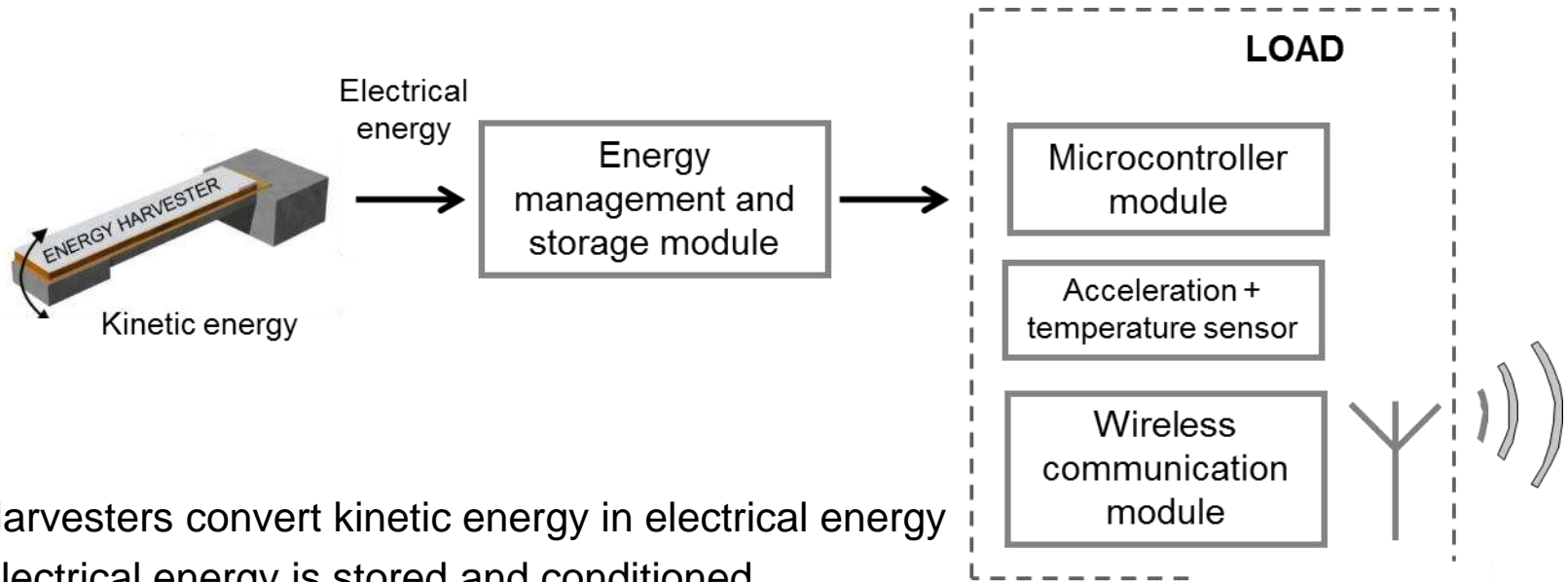
» Micro generator level

- Highly integrated
- Small (millimeter scale)
- Sourcing energy from vibrations

» System level

- Low weight
 - Energy autonomous
 - Wireless
 - Long life
 - Wide range of working temperatures
-

Sensor node architecture



- » Harvesters convert kinetic energy in electrical energy
- » Electrical energy is stored and conditioned
- » When electrical energy is sufficient the load is powered
- » Microcontroller repeats acceleration measurement and data transmission at fixed time intervals

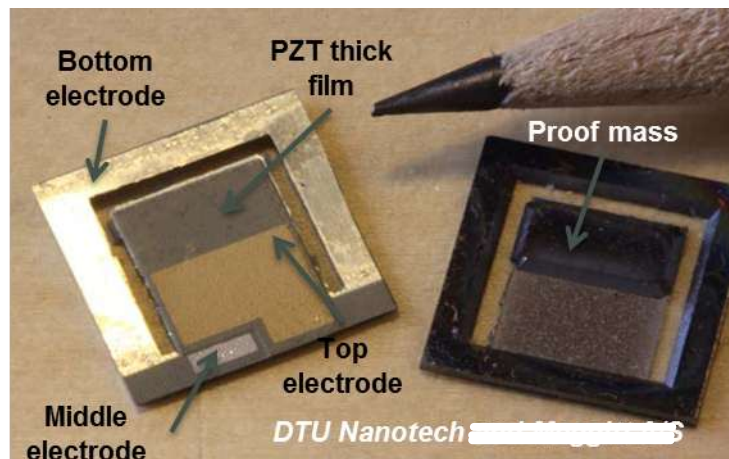
3

Piezoelectric technology for energy harvesting



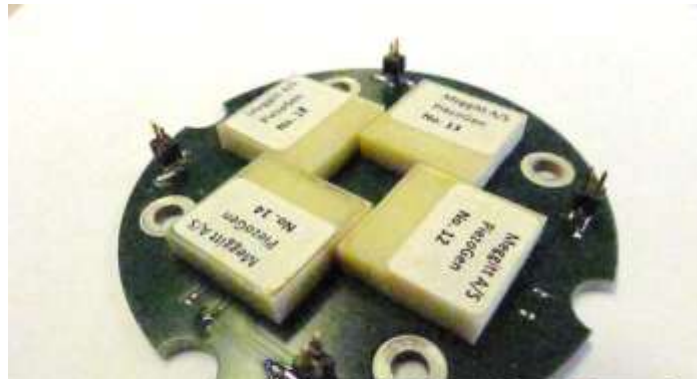
Energy Harvesting micro-generators – thick film based bimorph

- » Realized with silicon micromachining technology and PZT thick films deposited by screen-printing technique
- » Single clamped cantilevers with a silicon proof mass at the free end
- » Bimorph configuration
- » 10x10 mm² lateral dimensions
- » Higher voltage and power compared to unimorph
- » Si/PZT fabrication + middle electrode + 2nd PZT layer + Si membrane removal



Fully assembled generator board

- » Four EH devices are combined in order to assure the proper power level/bandwidth
- » Fully assembled board delivers approx. 100 μ W of continuous power at 0.3 g RMS, resonance (e.g. 300 Hz)



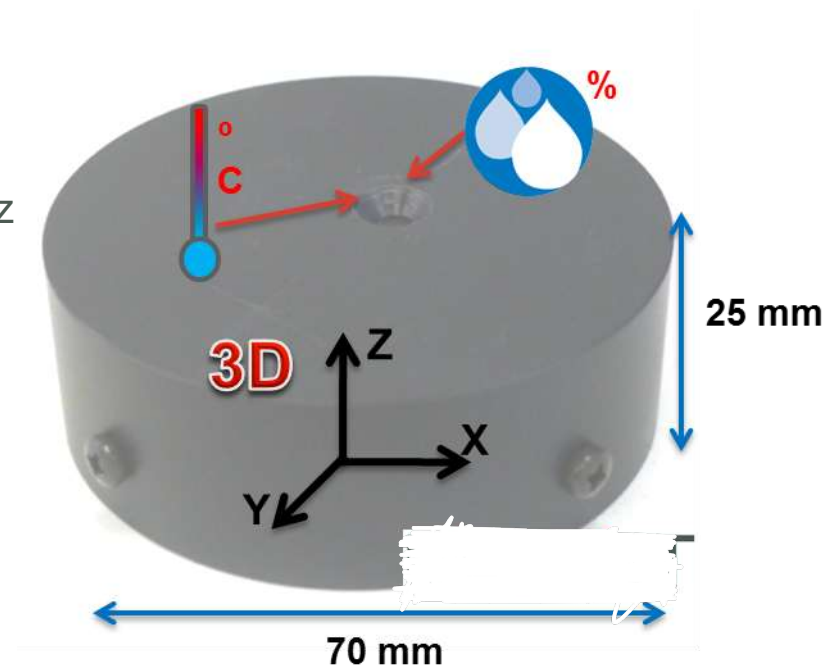
4

Sensor nodes and Wireless Sensors Networks



Sensor Node

- » Operation temperature
 - Range: -40 – 70 °C
- » Acceleration measurement
 - 3D acceleration measurement
 - Sampling frequency = up to 3200 Hz
 - Resolution = 13 bits
- » Ambient temperature
 - Accuracy ± 0.4 °C (10 °C - 60°C)
- » Relative humidity
 - Accuracy ± 3.0 %RH (20% - 80%)
- » Sensor nodes are linked using 2.4 GHz wireless communication forming star-like network architecture

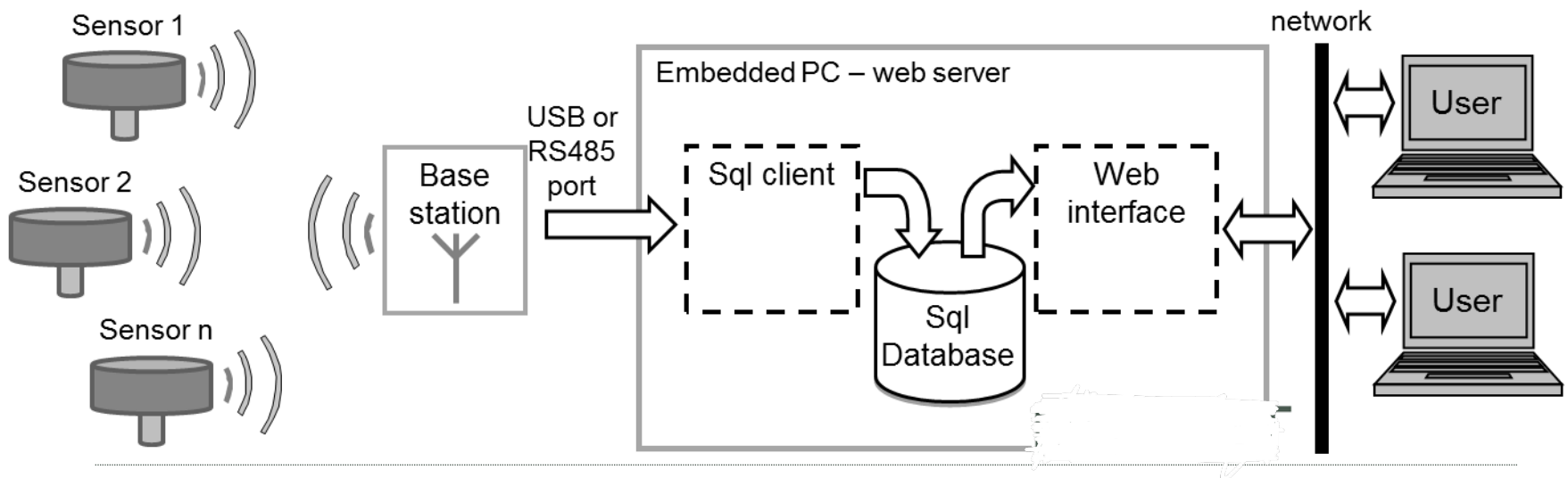


Operation principle of the sensor node

- » Due to low energy level the nodes operate with low duty cycle
- » The microcontroller alternates acceleration and temperature measurement and data transmission with sleep intervals
- » The minimal acceleration level is approx. 0.3 g RMS, working frequency is tunable in a broad range

Working network of wireless and battery-less sensor nodes

- » Several wireless sensor can operate at the same time
- » Base station receives and forwards the incoming packets to the web server
- » Sql client collects the incoming data and stores them in the database
- » Web database interface shows the stored data to the users
- » Intercompatibility of the different EH sensor nodes

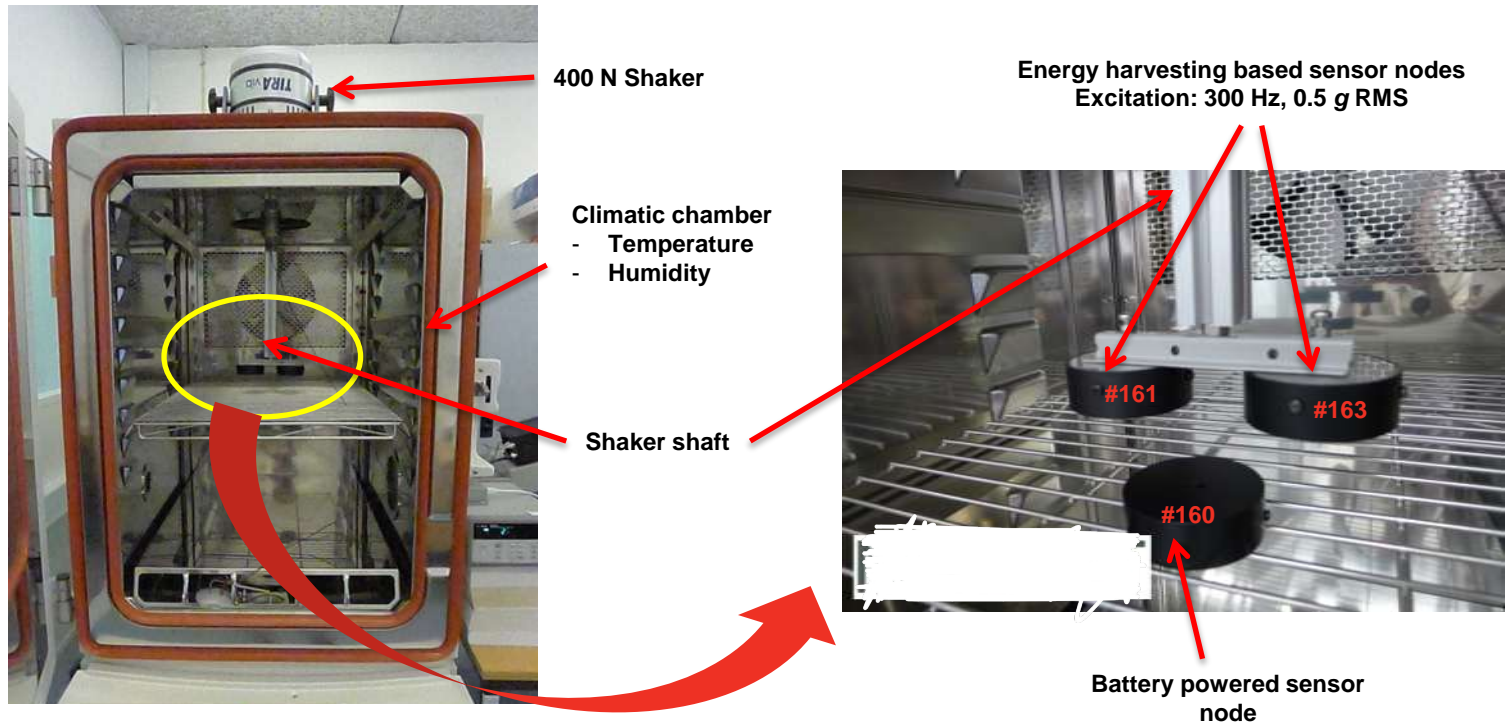


5

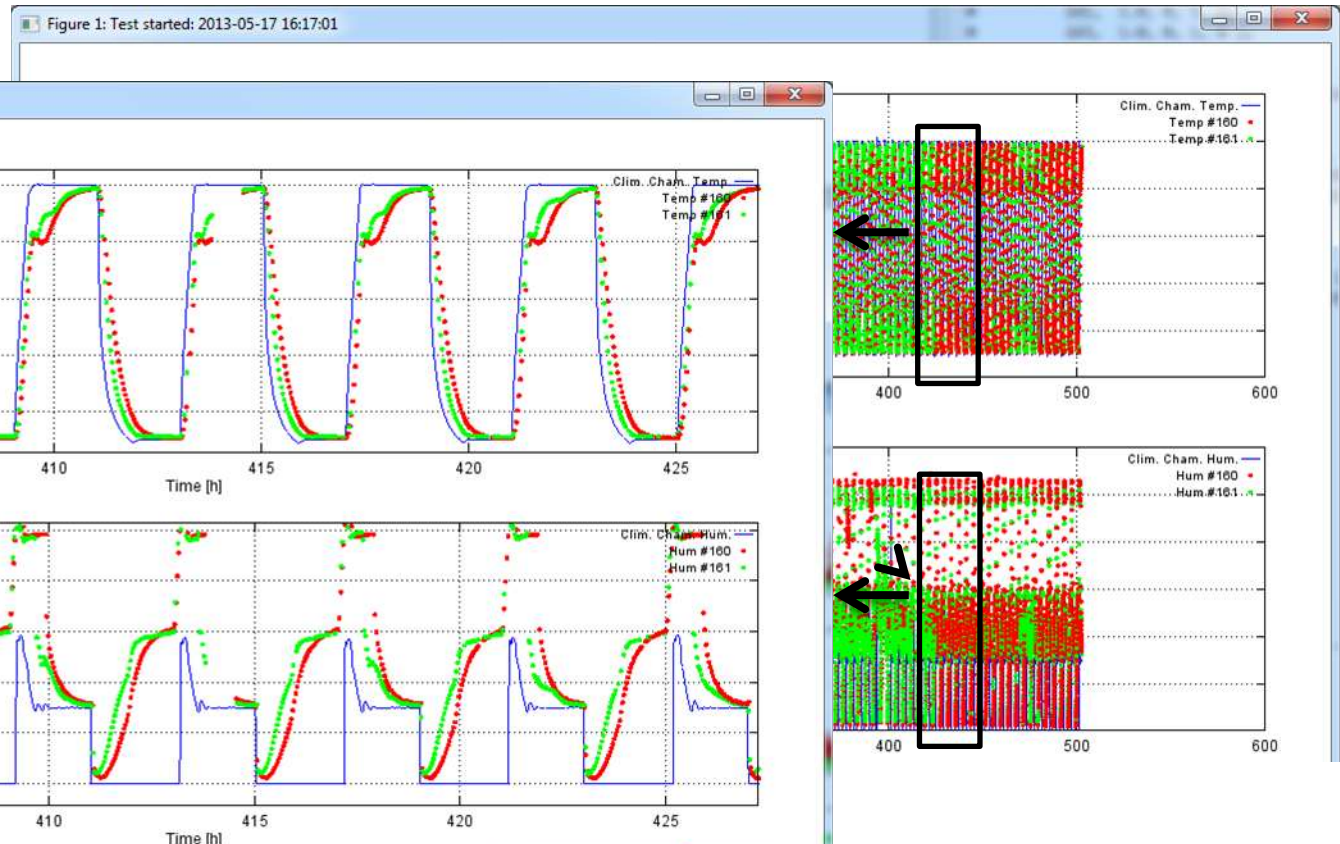
Climatic chamber and real environment testing results



Climatic testing



500 hours test

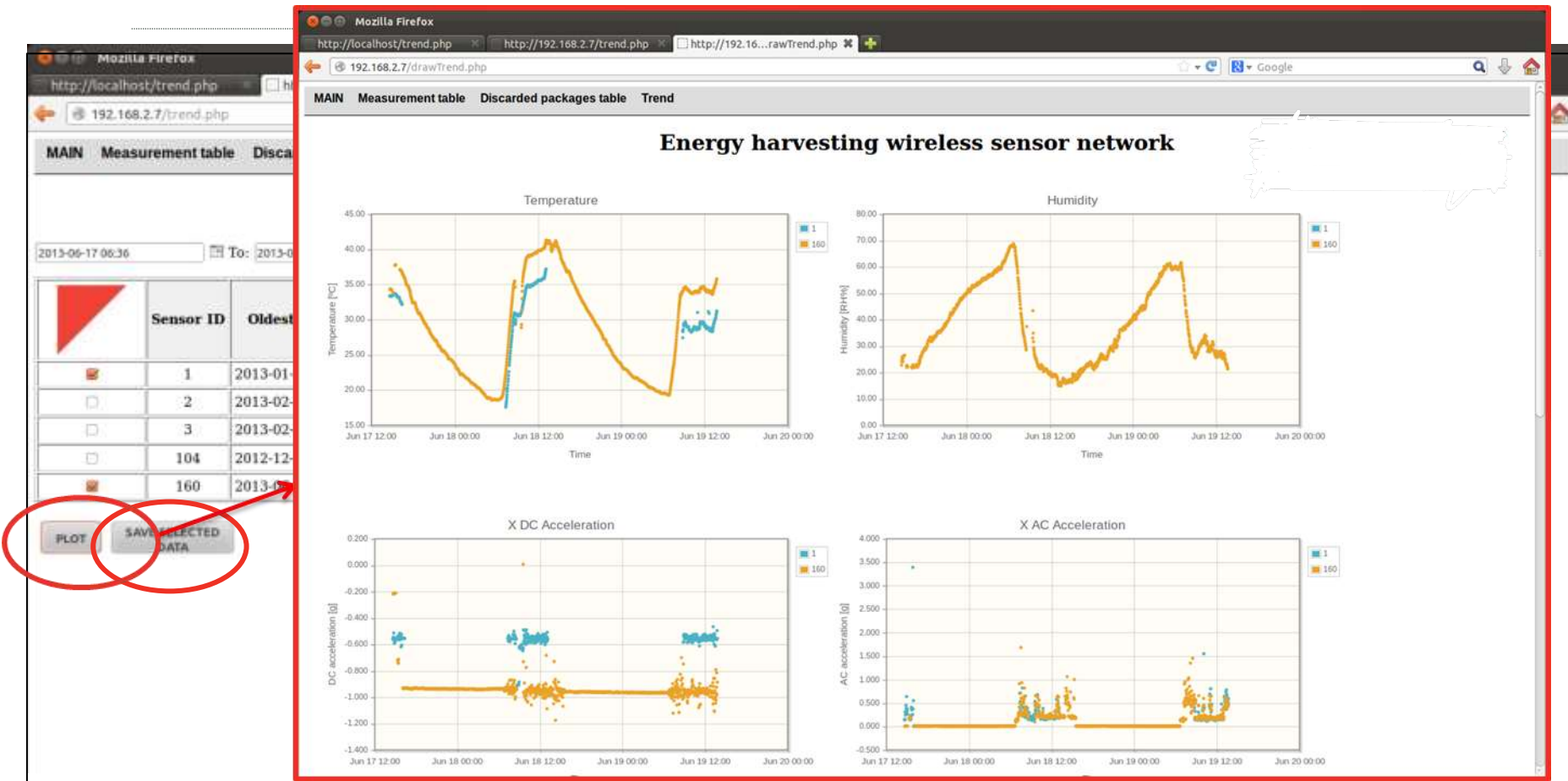


Industrial environment setup – an example

- » Energy harvesting powered sensors have been placed on hydraulic pumps located outside of the factory building
- » The base station together with the data server was placed inside the factory building
- » Operating harvesting frequency was 220 Hz
- » Battery powered sensor node was used as the reference



Results – example of data trends



Conclusions

- » The EH devices are capable of generation of 15 to 20 μW of power at moderate accelerations of about $\sim 0.3 \text{ g RMS}$
 - » The PZT thick film micro generators can successfully power sensor nodes, enabling energy autonomous, wireless measurement of acceleration, temperature and humidity at low levels of vibration e.g. 0.25 g RMS
 - » The data is easily accessible through number of standard network interfaces: LAN, WiFi, 3G
 - » The climatic testing indicated good performance in real environment conditions
 - » The wireless and battery-less sensor systems have been successfully applied in monitoring of industrial equipment
 - » The presented network of sensors can be applied in permanent as well as temporary monitoring in e.g. difficult to access locations
 - » Energy harvesting based sensor nodes enable systems that are:
 - Energy autonomous
 - Maintenance-free
 - Very easy to deploy
-

Special thanks

» CTS | Ferroperm Denmark Team

- Dr Konstantin Astafiev
- Louise Borregaard
- Karl Elkjaer
- Dr Michele Guizzetti
- Dr Erling Ringgaard
- Dr Ruichao Xu

» DTU Nanotech Team

- Prof. Erik V. Thomsen
 - Ruichao Xu
 - Anders Lei
-

Acknowledgments

Danish National Advanced Technology Foundation through the ELBA project [**EL**iminating **BA**tteries – energy harvesters for integrated systems]
contract no. 036-2009-1

The logo consists of the letters "ELBA" in a bold, white, sans-serif font, centered within a dark gray rectangular box.

ELBA

Thank you



The information contained in this document is the property of CTS | Ferroperm and is proprietary and/or copyright material. This information and this document may not be used or disclosed without the express authorization of CTS | Ferroperm. Any unauthorized use or disclosure may be unlawful.

The information contained in this document may be subject to the provisions of the trade compliance regulations (including those regulations governing transfer to a dual national or third country national, export and re-export) of various countries; see the first page for specific requirements. The recipient acknowledges that licences from the applicable regulatory agency or agencies may be required before the recipient may further disclose such information to others, and that such licences may impose restrictions on further disclosure of such information. The recipient agrees to comply with all applicable governmental regulations as they relate to the transfer, export and re-export of information disclosed in this document.
