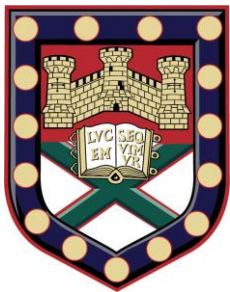




smarter?

in response to 2nd (2011) call

Jean-Marie Dilhac, Marise Bafleur



Outline

- *Scientific background, potential impact & key challenges*
- *Presentation of consortium*
- *Structure of the project, work plan and deviation*
- *Project management:*
 - *internal project meetings*
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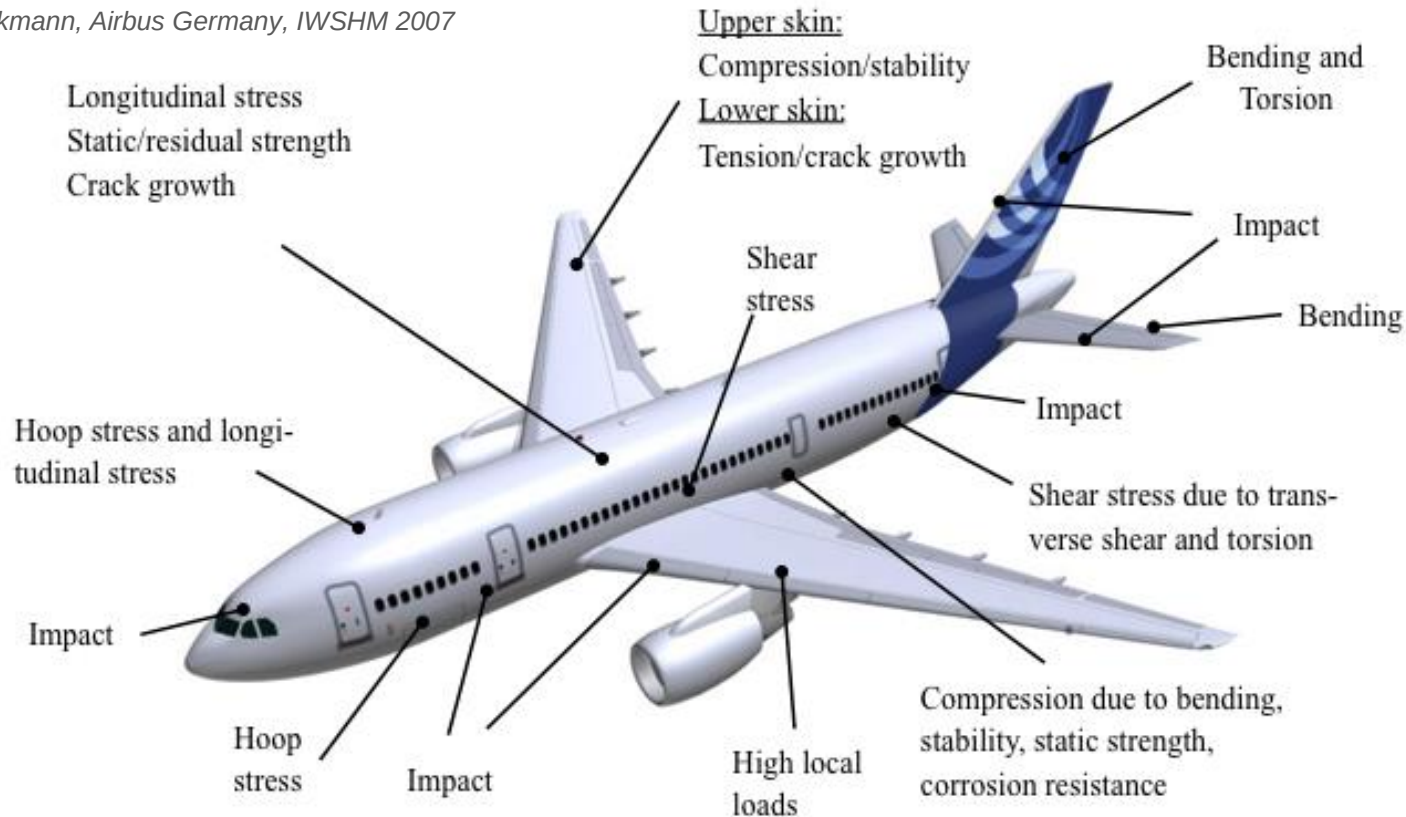
SMARTER

*Smart Multifunctional Architecture & Technology
for Energy-aware wireless sensoRs*

Structural Health Monitoring

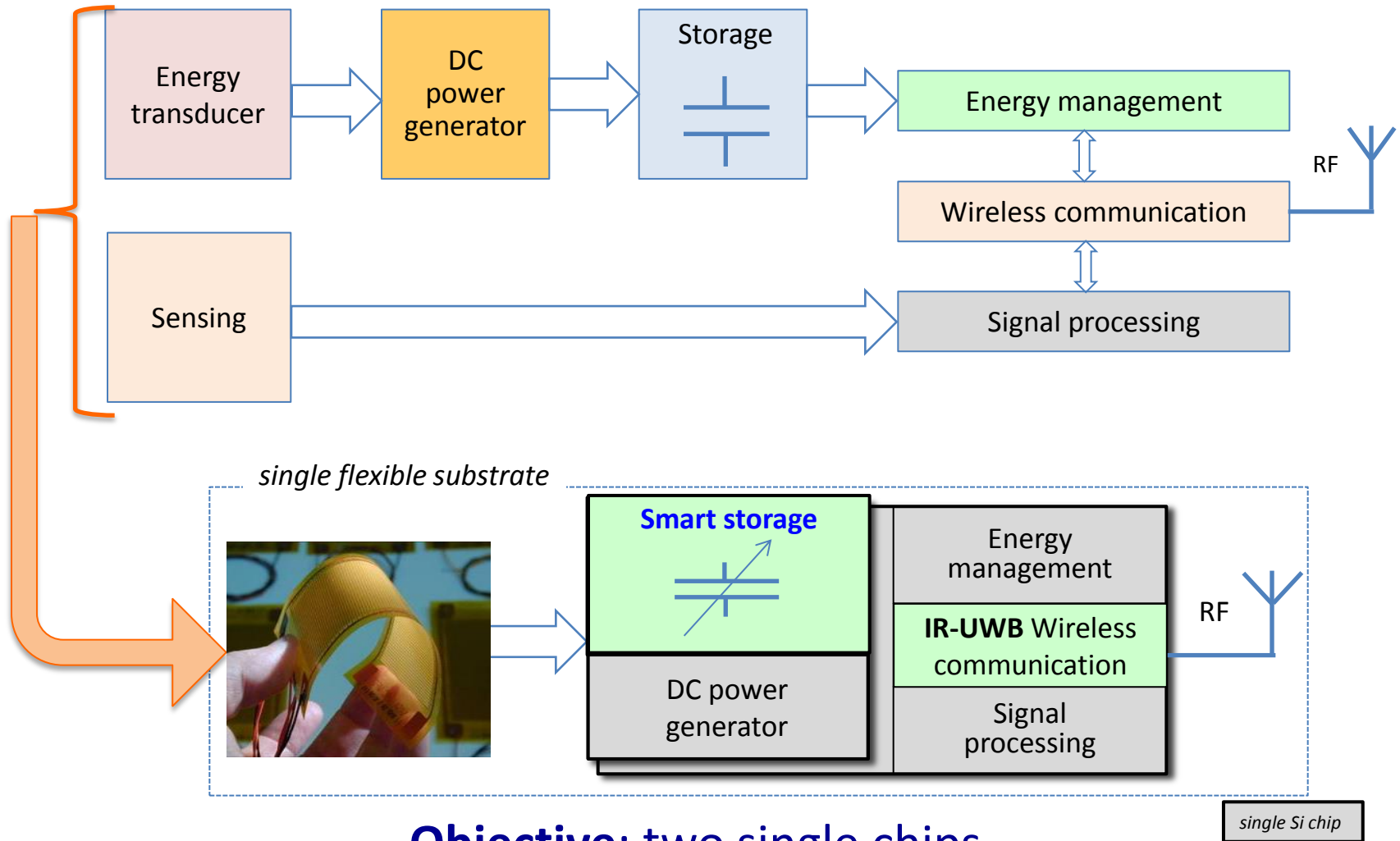
*through deployment of wireless
and battery-free sensor network*

© Holger Speckmann, Airbus Germany, IWSHM 2007



Potential impact: *predictive maintenance is a major challenge and is linked to Clean Sky, a Public Private Partnership between the European Commission and the Aeronautical Industry. It was set up to bring significant step changes regarding the environmental impact of aviation.*

Scientific background & key challenges





Sensor / harvester location: wing root

Sensor / harvester target performance:

- *1.2-15mW at 1-10 Hz*
- *230-570 micro strain for 20 cm²*

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Presentation of consortium

Participant	Main activities / skill	availability of chist-era funding
Cranfield University + Exeter University <i>(as of November 2013)</i>	harvesting and sensing device, simulation, tests	1 st of October 2012
University of Barcelona	full-custom integrated circuit	not yet
LAAS-CNRS	management, adaptive storage, communication	15 th of March 2013

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LAAS

WPO – Project management

LAAS

WP1

Specifications
& architecture

Specifications

Device & architecture
optimization

Spec.

Device & architecture
optimization

Specifications

Technology

Models

WP4

Integration

U
B

Technology

Models

WP3

Smart adaptive
storage

Prototypes

Device & architecture
optimization

Prototypes

Prototypes

WP5

Demonstrator

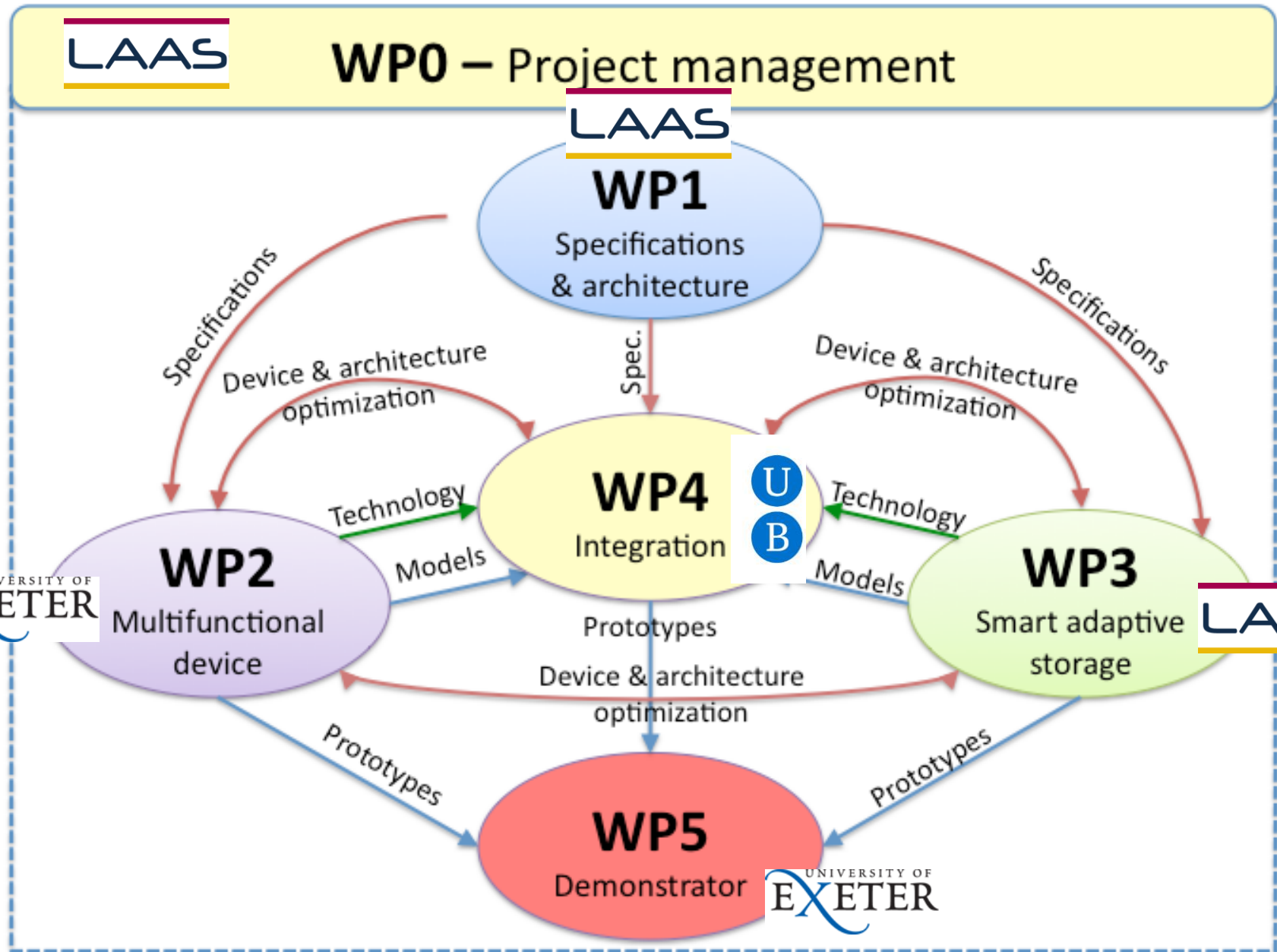
UNIVERSITY OF
EXETER

WP2

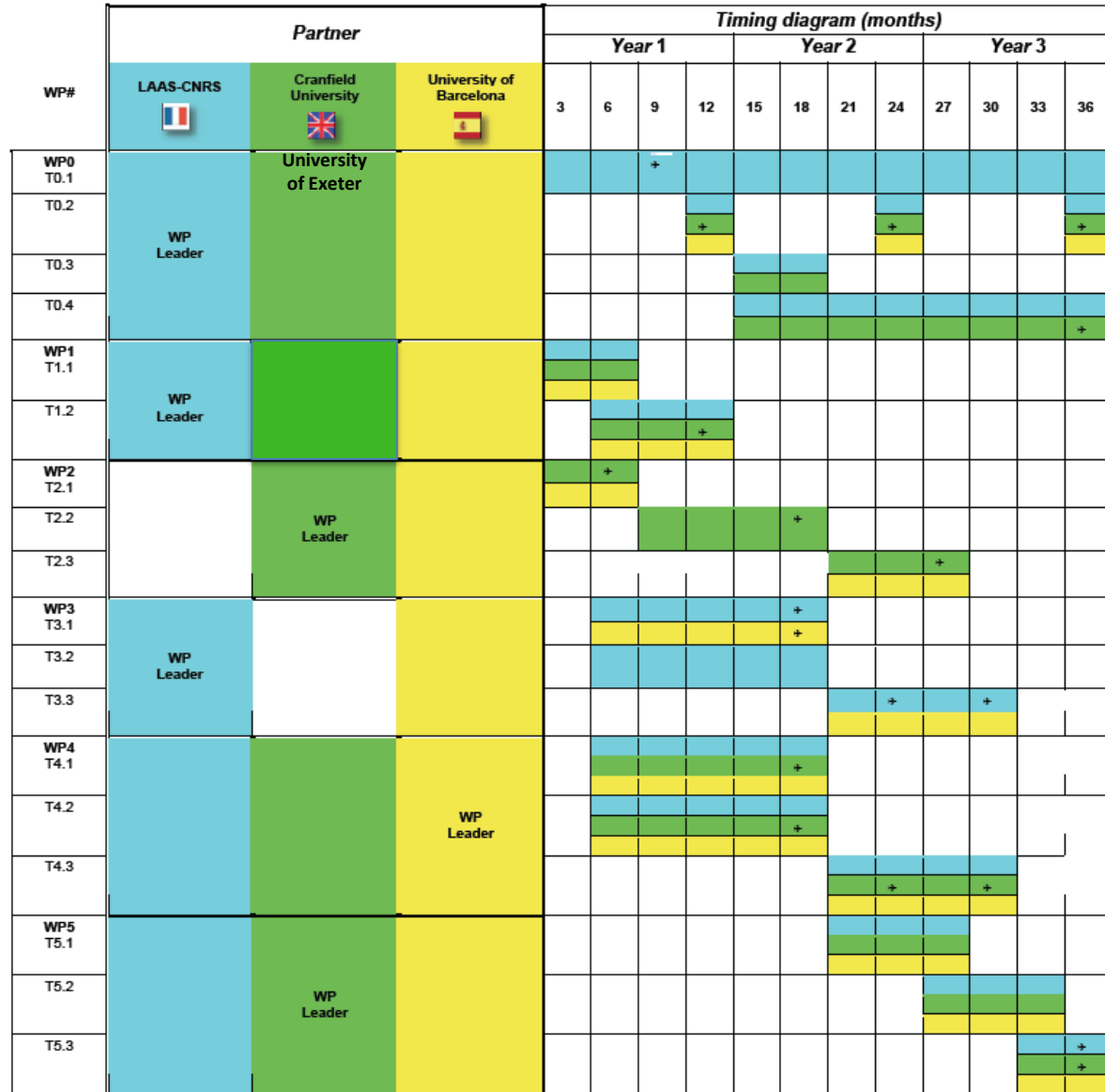
Multifunctional
device

LAAS

UNIVERSITY OF
EXETER



Smarter: structure of the project



Deliverables 													
Milestones 													
	1	1	2		5		3	1	1	2		4	1
					4								
go no-go	Only alternative paths to be chosen after each milestone												
Progress report  /expenses 													
													
Consortium agreement  /final report 													

Project synchronisation issues

2012	2013	2014	2015	2016
10			09	
11				04
	06*			05

** provisional starting date*

Request for an extension of the project

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Internal meetings



Date	Location	Attending partners	Purpose
10/07/12	Cranfield	LAAS, Cranfield	Visit of Cranfield facilities
08/12/12	Barcelona	all	Tentative kick-off meeting
27/03/13	Brussels	LAAS, Cranfield	CHIST-ERA Projects Seminar Mutual information
20/06/13	Barcelona	all (Cranfield via webex)	Application and technology issues, preliminary discussions on SHM scenario and wireless sensor node architecture
03/12/13	Exeter	LAAS, Exeter (Barcelona via webex)	Application and technology issues Management of Exeter/ Cranfield participation Discussions on SHM scenario

Exchanges

Jordi Colomer (University of Barcelona) stay at LAAS-CNRS scheduled for July-August 2014.

Financial Reporting

N°	Partner	Person.months	Total costs	Percentage of requested budget
1	LAAS-CNRS*	9	112 k€	11%
2	Cranfield University/the University of Exeter**	14.6	£116k	25%
3	University of Barcelona***	0	0€	NA

** Due to the funding issues of our Spanish partner, LAAS did not hire yet the PhD student who was supposed to start working in tight cooperation with them on the design of the UWB communication chip.*

*** Please note that Meiling Zhu previously working at Cranfield University has relocated her job to the University of Exeter since 01/11/2013 and she has requested to transfer the funding to the University of Exeter (an on-going process).*

**** Funding not arrived at University of Barcelona at the date of this presentation.*

Industrial Advisory Board

LEONI
BAE SYSTEMS

Advisory Board Members		
Julien Féau	Airbus Operations SAS	julien.feau@airbus.com
Bruno Foucher	EADS Innovation Work	bruno.foucher@eads.net
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Chris Bagley	TWI	chris.bagley@twi.co.uk

- . Diffusion of a first newsletter
- . First feedbacks received

AIRBUS
GROUP

THALES
TWI


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POWER HARVESTER

Power harvester characterization

Harvester:

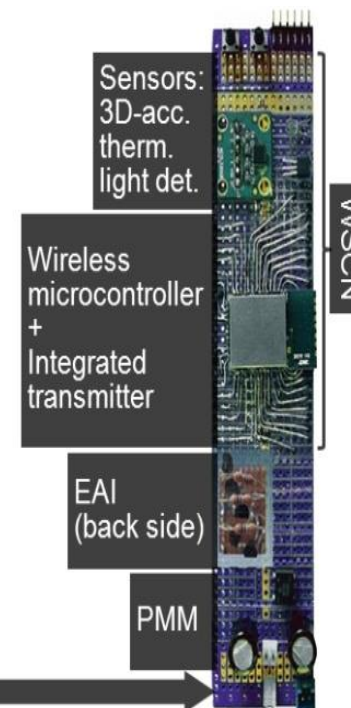
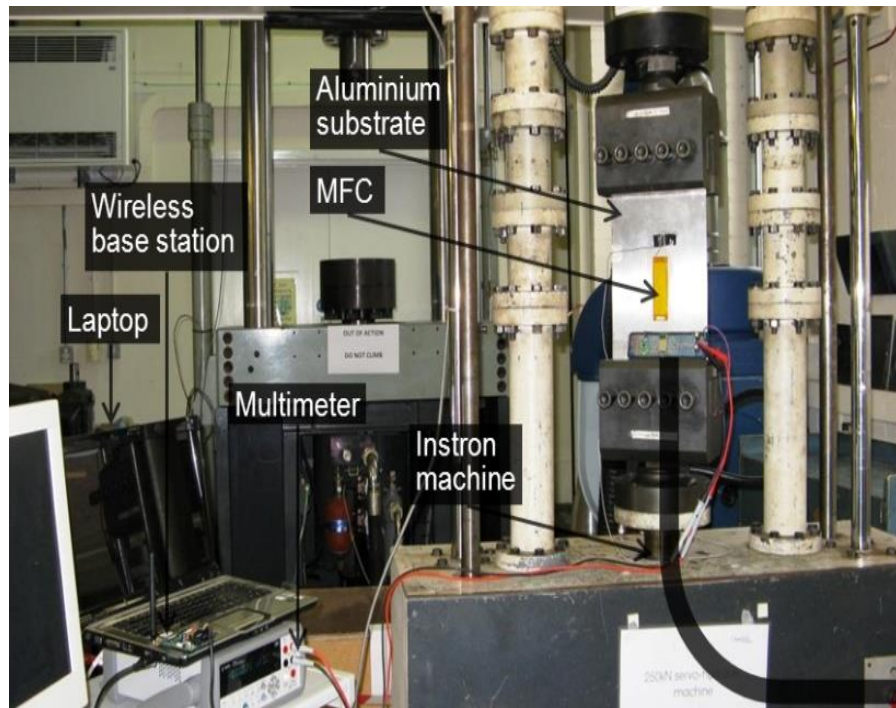
Macro Fiber Composite MFC M8528-P2

PZT piezoelectric element operating in d_{31} mode

Size: $105 \times 34 \text{ mm}^2$ - Active area: $85 \times 28 \text{ mm}^2$

Thickness: $300 \mu\text{m}$

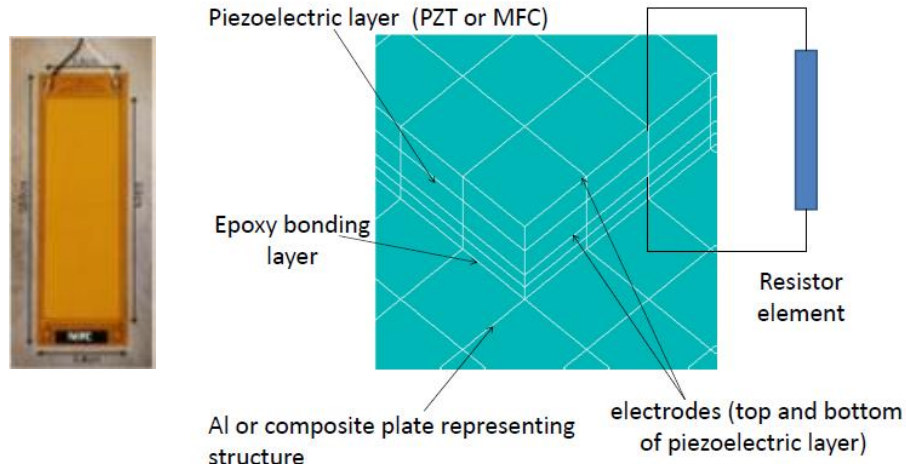
Testing Set-up



Testing set-up is using Instron machine is used to produce vibration, where the MFC (macro fibre composite material) is the piezoelectric energy harvesting element.

Power harvester modelling

Modelling of Power Output based on Finite Element Analysis



Coupled Piezoelectric Circuit-Finite Element Model , which is able to connect to a resistor element to calculate the power output.

Model used to study how the epoxy layer thickness affects the power output (see below).

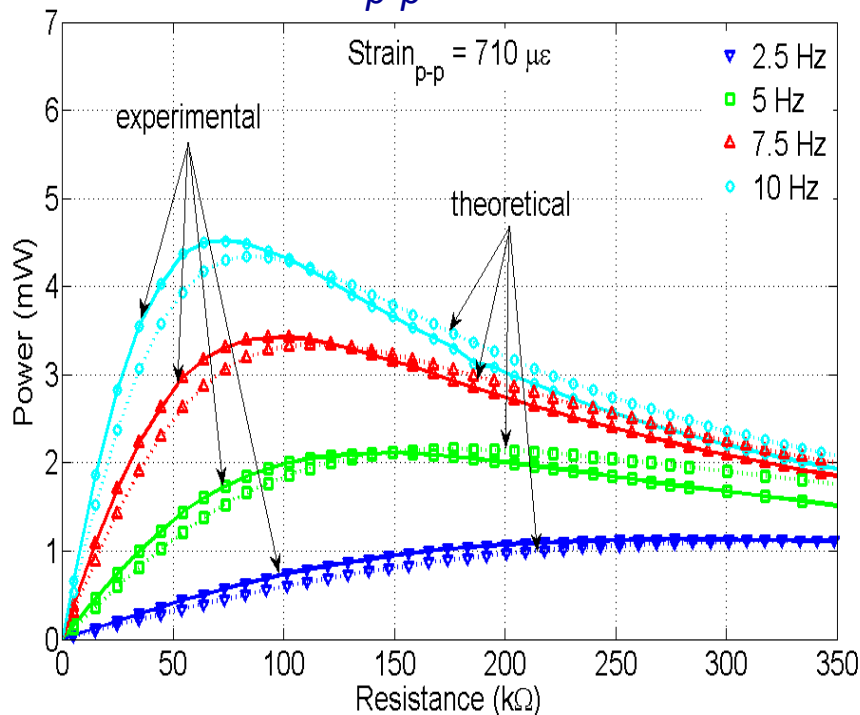
	Epoxy Layer Thickness (mm)			
Frequency (Hz)	0	50	100	200
	Percentage Power Loss			
2.5	0	35.4	51.5	69.8
5.0	0	35.4	51.5	69.8
7.5	0	35.4	51.5	69.8
10.0	0	35.4	51.5	69.9

Percentage of Power loss with Epoxy Layer Thickness vs Frequency

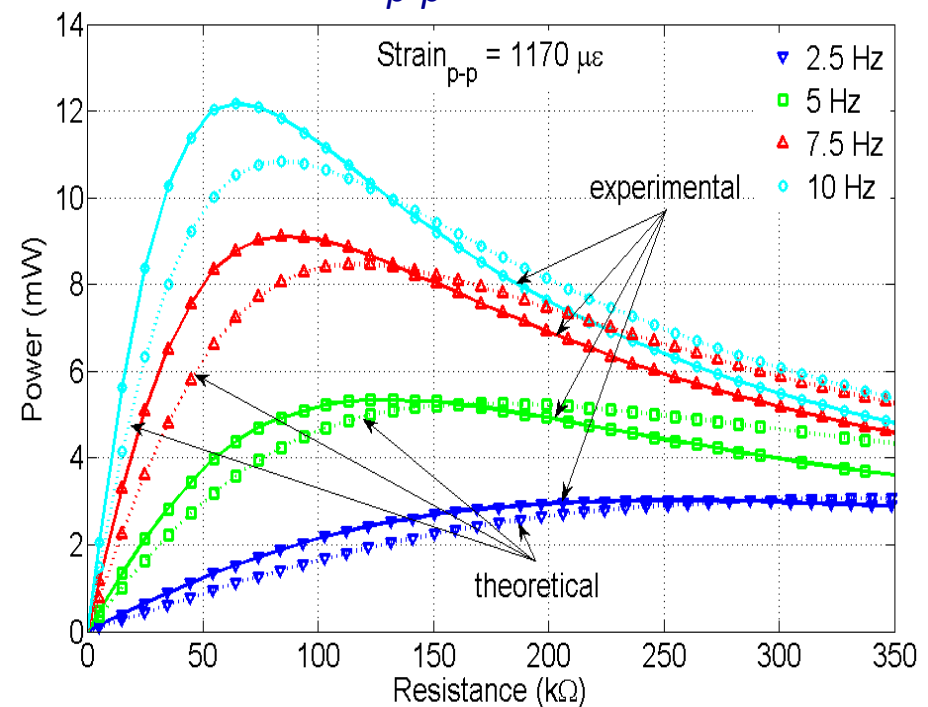
MFC Power harvester results

Theoretical and experimental average harvested power as a function of resistive load for different frequencies and strain levels

$\text{Strain}_{p-p} = 710 \mu\epsilon$



$\text{Strain}_{p-p} = 1170 \mu\epsilon$



MFC harvester allows powering a wireless sensor node performing data acquisitions and wireless transmissions at intervals of 4.9–0.4 s

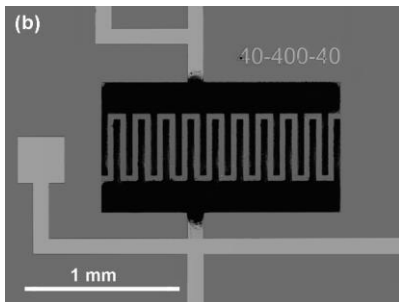
MICRO-SUPERCAPACITOR TECHNOLOGY

LAAS-CNRS

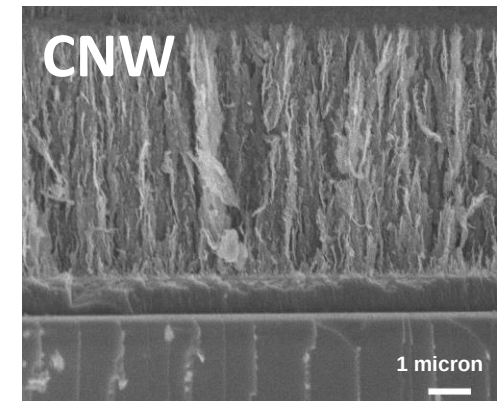
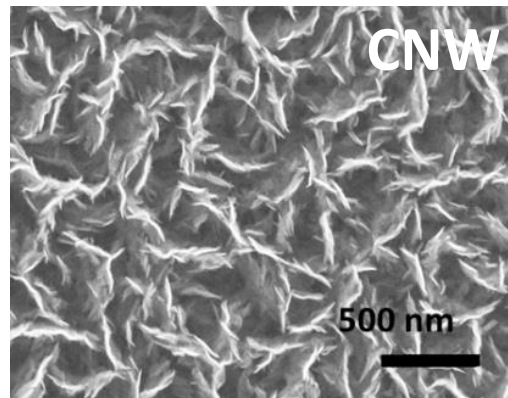
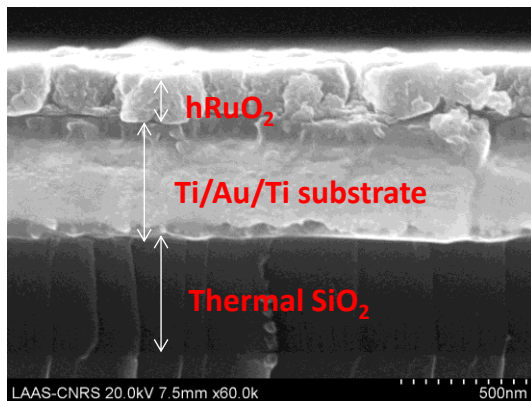
Micro-supercapacitor Technology Challenges

- Silicon integration:
 - *Co-integration with control circuitry for adaptive storage*
 - *Expected improved performance regarding self-discharge*
- Targeted specific energy: **1J/cm²**
- **Electrode material** is key
- Need for innovative **solid** electrolyte
- Need for wafer-level **airtight sealing**

Micro-supercapacitor Technology



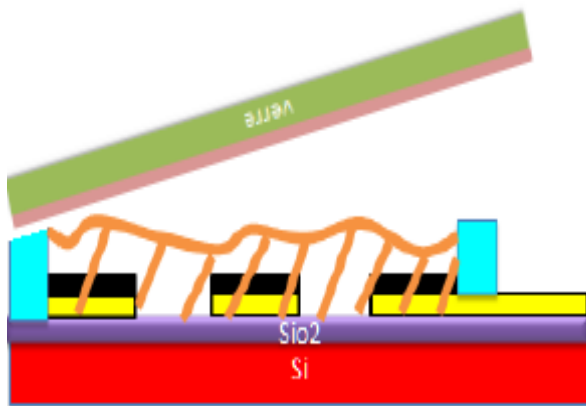
Electrode	Electrolyte (liquid / solid)	Potential Window	Capacitance	Specific Energy	Further developments
Activated Carbon	Liquid	2.3 V	2 mF/cm ² (cell)	5 mJ/cm ² (cell)	Encapsulation
hRuO ₂	Liquid or solid	0.9 V	5 mF/cm ² (cell)	2 mJ/cm ² (cell)	Encapsulation
hRuO ₂ /CNW	Liquid or solid	0.9 V	> 1000 mF/cm ² (electrode)	405 mJ/cm ² (electrode)	- Integration in a micro-device - Encapsulation



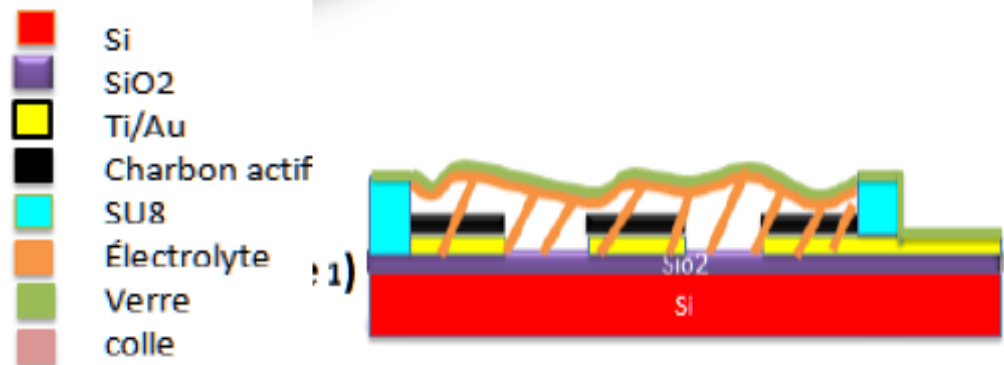
Micro-supercapacitor Encapsulation

- Two alternative wafer-level technologies:

Glass sealing



Parylene passivation



Encapsulation Technologies

Electrode material
deposition



SU8 cavities for
electrolyte
deposition



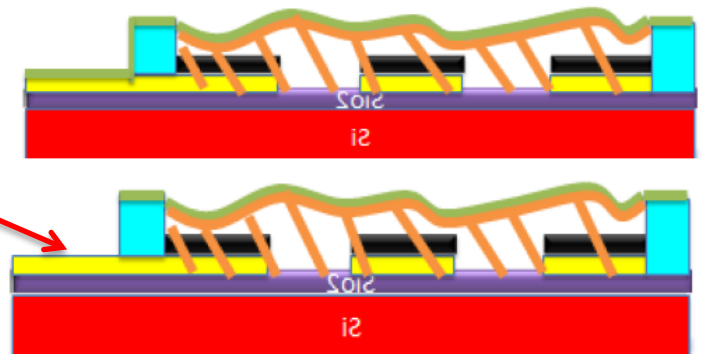
Glass sealing



Critical step:
contact opening



Parylene passivation

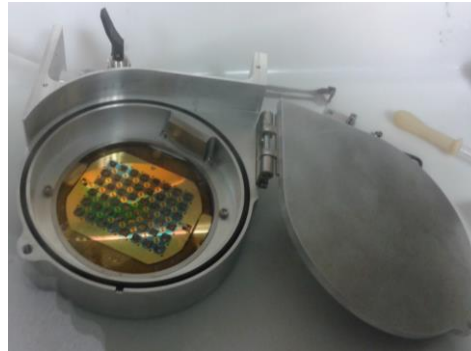


Microsupercapacitors: encapsulation

- Constraints in fabrication: use of sensitive electrolytes < 1 ppm H₂O required
- ***Realization of sample transfer system*** from Glove Box (Jacomex) to parylene deposition system (Comelec)



Transportable glove box

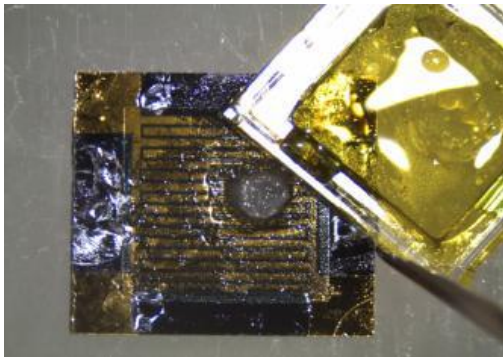
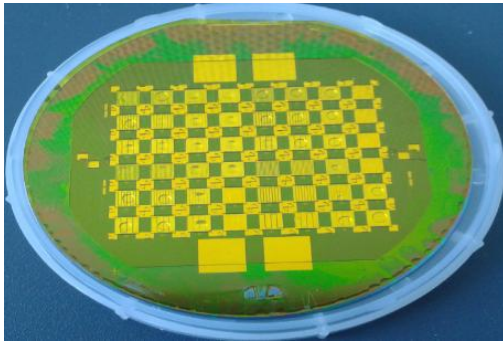


MACHINE C30S



Micro-supercapacitor Encapsulation Results

Glass sealing

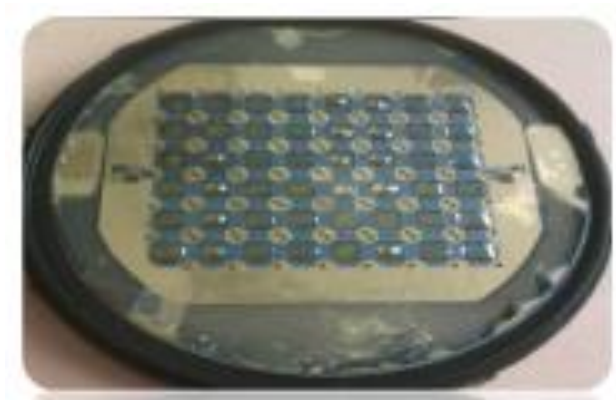


Successful wafer-level glass sealing

Delamination of glass sealing upon dicing

Solution: appropriate hard-baking of SU8 to improve adherence

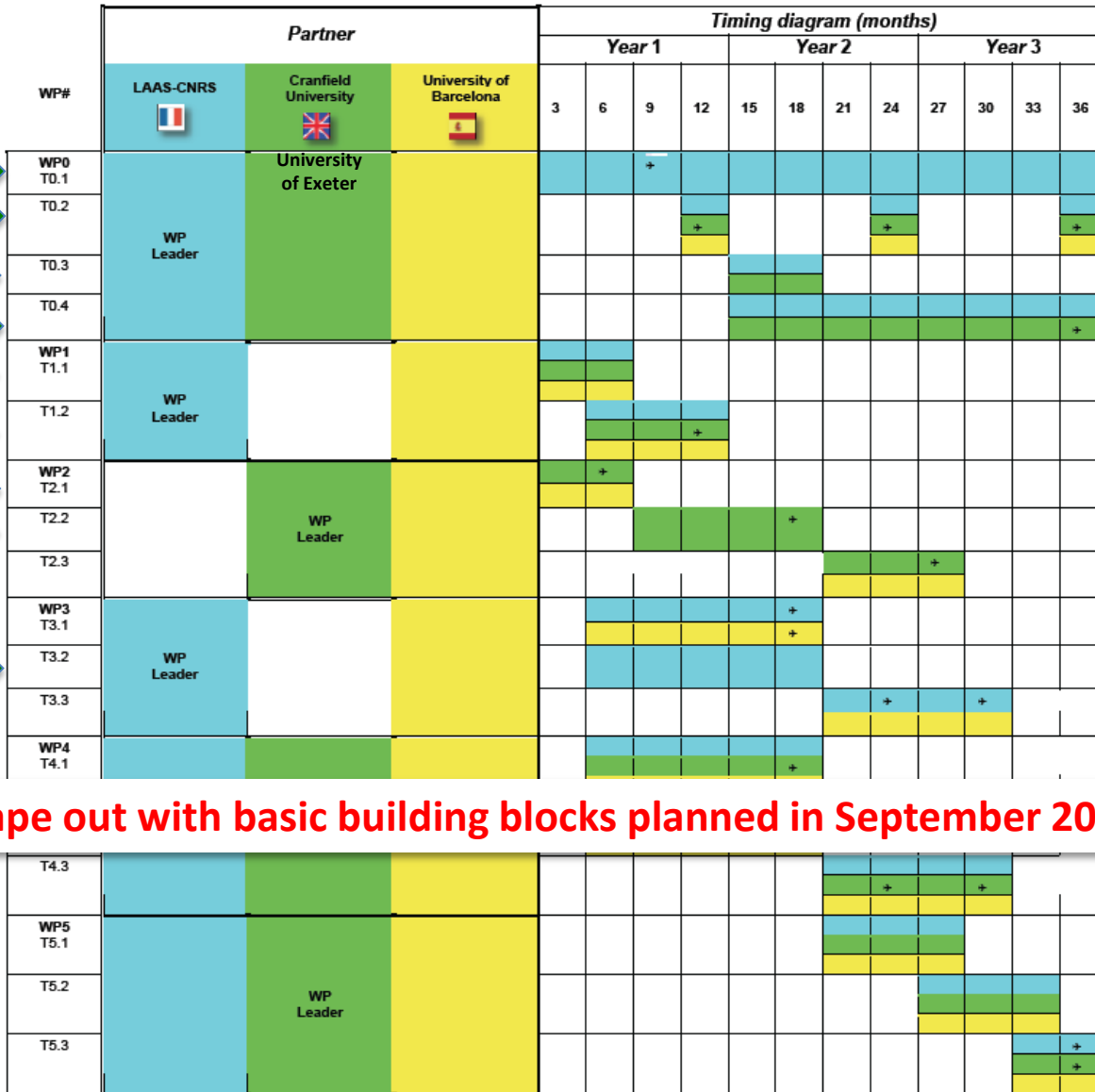
Parylene passivation



Deposition of a uniform layer of parylene

Issue upon subsequent photolithography for contact opening

Solution: Increase SU8 cavities height



First silicon tape out with basic building blocks planned in September 2014

[illegible]

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SMARTER

Smart Multifunctional Architecture & Technology for Energy-aware wireless sensoRs (SMARTER)

Technological progress over the last 20 years has lead to an explosion in the application of Information and Communication Sciences and technologies (ICST). Although in general greatly beneficial to mankind the ubiquitous use of electronic systems increases global energy consumption and it is within this context that this project will contribute by achieving breakthroughs in the design, construction and performance of an autonomous system harvesting its own energy from the environment. A particular envisioned application of ICT, that becomes a more pressing societal demand, concerns Structural Health Monitoring (SHM) in various fields (industrial, aeronautics, buildings, roads. However, up to the present time, there has been no efficient large deployment of such systems, the main roadblocks being their energy autonomy and size.

Accordingly, a project is proposed whose overall aim is to demonstrate the feasibility of a self-powered, battery-free wireless sensor node (WSN) for applications to structural health monitoring (SHM). In many SHM applications, the use of a battery is prohibited by factors such as: low/high-temperature operation, safety, requirement for an extended lifetime specification, replacement cost and for environmental considerations. One significant innovative concept is to make use of the SHM sensing device (strain gauge) itself to implement a single multifunctional device providing both structural health data and electrical energy from mechanical vibrations. The other proposed novelty is for the system to be able to store the harvested energy in a fully integrated smart storage device, which adapts its capacitance value according to the available energy in the environment and to the power consumption of the load. This adaptability will allow on the one hand, maximizing the transfer of harvested energy from the transducer to the storage device and on the other, maximizing the usability of the stored energy.

Published/Submitted Journal Papers supported by the project:

1. A Giuliano and M. Zhu (2014) *Characterization of a Low-frequency Strain Energy Harvesting Powered Wireless Sensor System with an Energy-aware Interface*, IEEE Sensors, Revised in Jan. 2014.
2. Giuliano and M. Zhu (2014) *A Passive Impedance Matching Interface Using a PC Permalloy Coil for Practically Enhanced Piezoelectric Energy Harvester Performance at Low Frequency*, IEEE Sensors, Revised in Feb. 2014.
3. Daniels A, Zhu M. & Tiwari A. (2013). "Evaluation of Piezoelectric Material Properties for a Higher Power Output from Energy Harvesters with Insight into Material Selection Using a Coupled Piezoelectric-Circuit Finite Element Analyses", *IEEE Transactions on Ultrasonics Ferroelectrics and Frequency Control*, vol.6, no.12, 2626 - 2633.

Published international conference papers supported by the project:

4. Marsic V, Zhu M. (2013) *Duty-cycle passive time characterisation for input power and energy storage variation of an energy harvesting tailored wireless sensing system*, *Journal of Physics: Conference Series* 476 (2013) 012102 doi:10.1088/1742-6596/476/1/012102.
5. Giuliano A & Zhu M (2013). *Experimental study of a passive impedance matching interface based on a centimeter-size high inductance coil for practically enhanced piezoelectric energy harvester performance at low frequency*, 2013 IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber,Physical and Social Computing, 20-23 Aug. 2013, Beijing, China, 1659 - 1661.
6. Daniels A, Alessandro Giuliano, Zhu M. & Tiwari A. (2013), *Modeling, Validation and Design Analyses of a Piezoelectric Cymbal Transducer for Non-Resonant Energy Harvesting*, 2013 IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing, 20-23 Aug. 2013, Beijing, China, 1665 - 1667.
7. M.Bafleur, J.M.Dilhac, *Towards energy autonomy of wireless sensors in aeronautics applications: SMARTER collaborative project*, 2013 IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing, 20-23 Aug. 2013, Beijing, China, 1668 - 1672.

Thank you