

*CHIST-ERA Project Seminar 2015
Madrid, March 20, 2015*

Impossible d'afficher l'image.

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*
 - *student/scientist exchange*
 - *financial reporting*
 - *Industrial advisory board*
- *Main results*
- *Dissemination*

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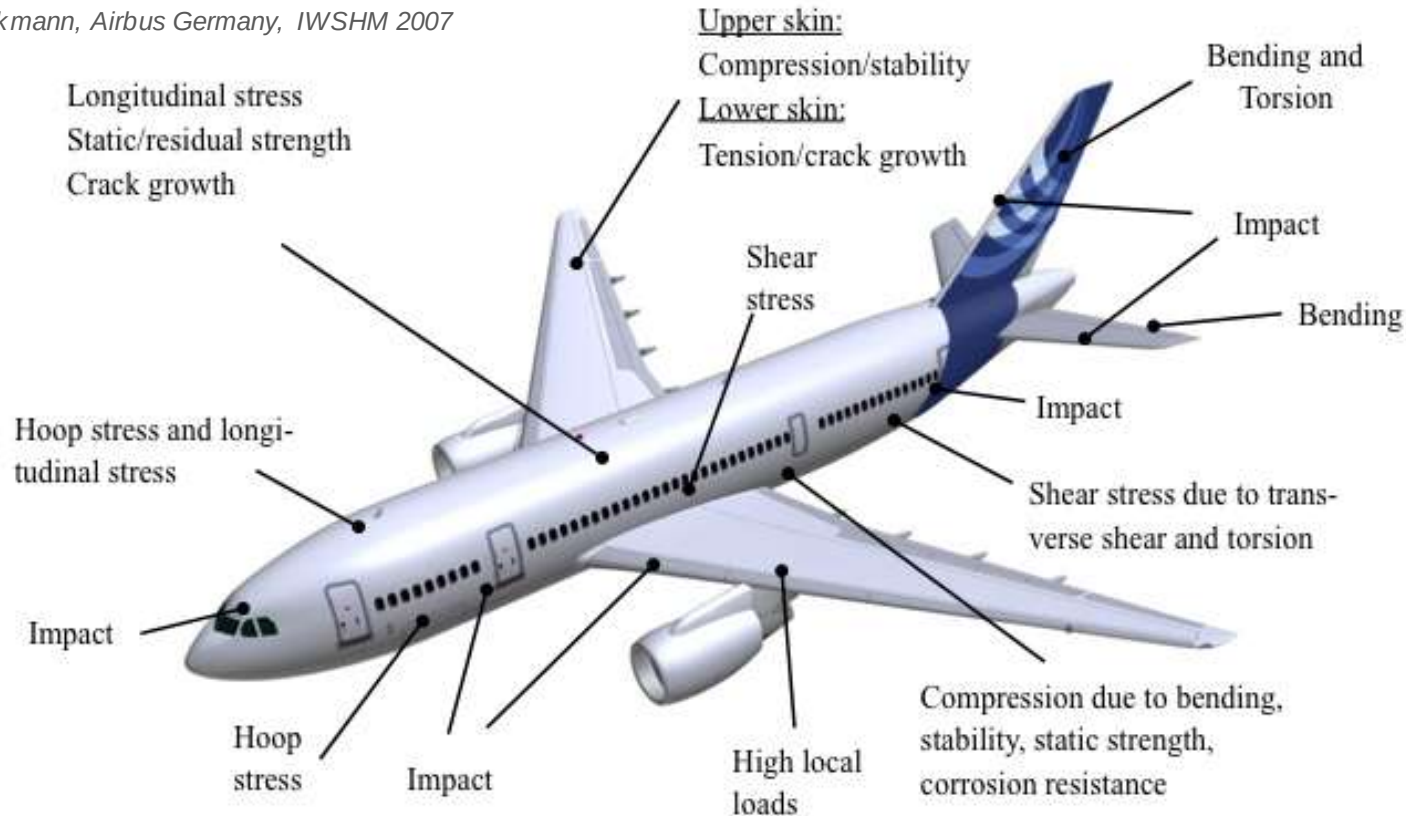
SMARTER

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

Structural Health Monitoring

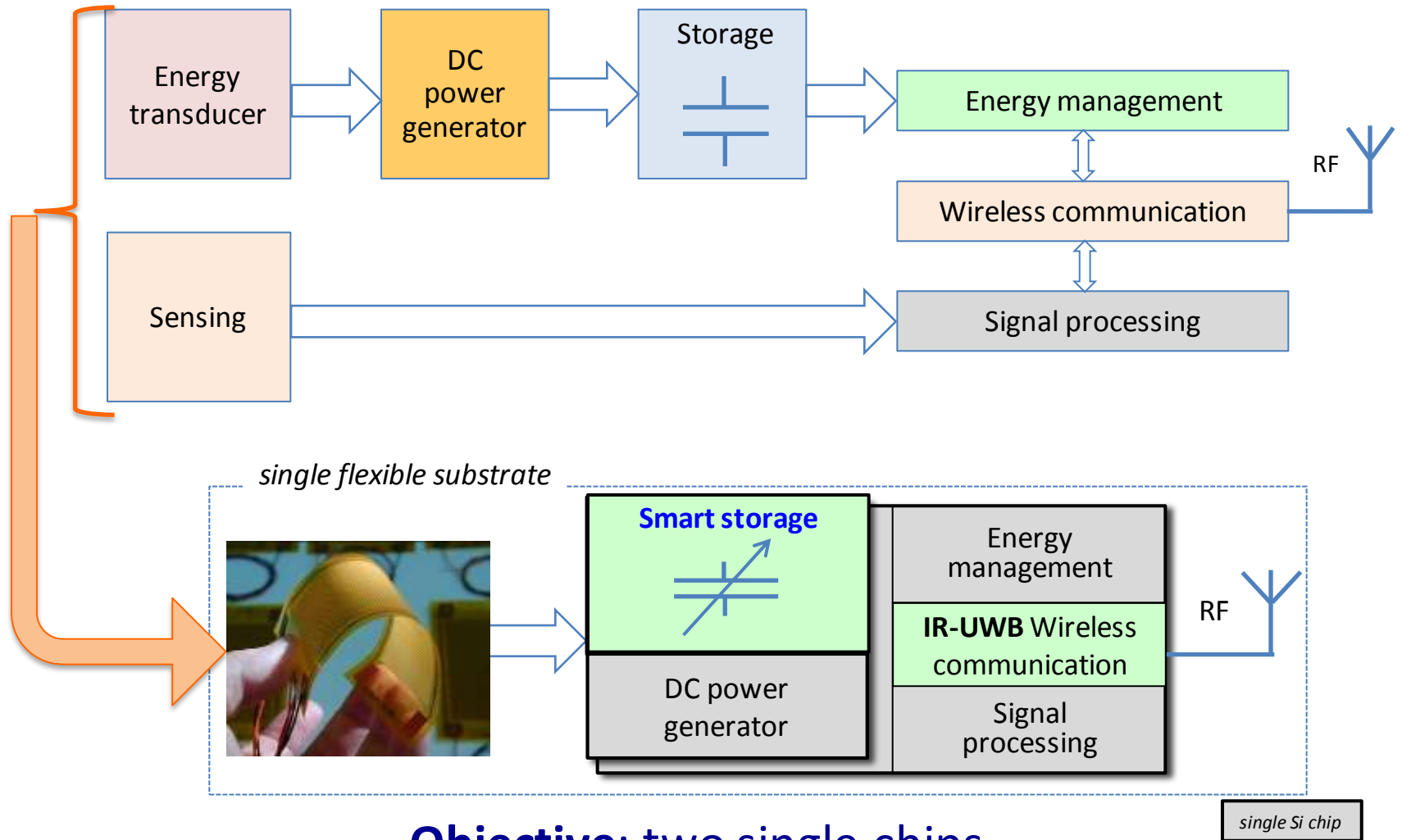
*through deployment of wireless
and battery-free sensor network*

© 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
Exeter University <i>(formerly Cranfield University before November 2013)</i>	harvesting and sensing device, simulation, tests	1 st of October 2012
University of Barcelona	full-custom integrated circuit	1 st of January 2014
LAAS-CNRS	management, adaptive storage, communication	15 th of March 2013 <i>(eligible expenditure since Nov 2012)</i>

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Project synchronisation issues

2012	2013	2014	2015	2016
10				30/04
11				
				•

* on-going negotiation

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Internal meetings



6	03/02/2014	Webex	LAAS, Barcelona	Preparation of Jordi Colomer stay at LAAS
7	11/04/2014	Toulouse	LAAS, Barcelona	Preparation of Jordi Colomer stay at LAAS
8	03/06/2014	Exeter	Barcelona, Exeter	Discussion on application scenario
9	08/07/2014	Toulouse	ALL	General coordination
10	07-09/2014	Toulouse	Jordi Colomer stay	Design of integrated circuit

Financial Reporting

N°	Partner	<u>Person.months</u>	Total costs	Percentage of requested budget
1	LAAS-CNRS*	9	112 k€	11%
2	Cranfield University/the University of Exeter**	14.6	£116k	42%
3	University of Barcelona***	TBD	21 k€	18% approx

** Due to the funding issues of our Spanish partner, LAAS hired only in January 2015 the PhD student who is now working in tight cooperation with UB 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.*

Industrial Advisory Board

LEONI

BAE SYSTEMS

Advisory Board Members		
Julien Féau	Airbus Operations SAS	julien.feau@airbus.com
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Chris Bagley	TWI	chris.bagley@twi.co.uk

- . Diffusion of a second newsletter
- . Feedbacks and visits received

AIRBUS
GROUP

THALES

TWI

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WP2 MULTIFUNCTIONAL DEVICE WP5 DEMONSTRATOR

Power harvester characterization

Harvester:

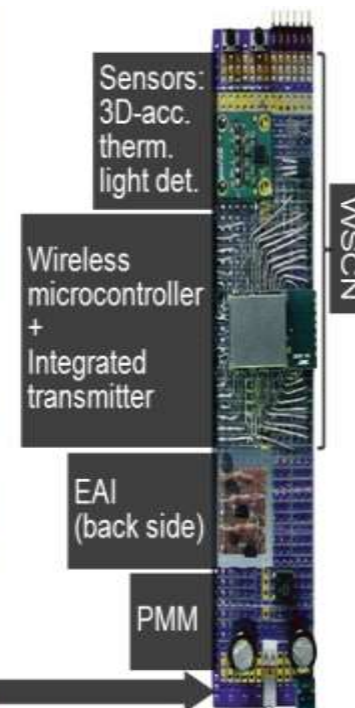
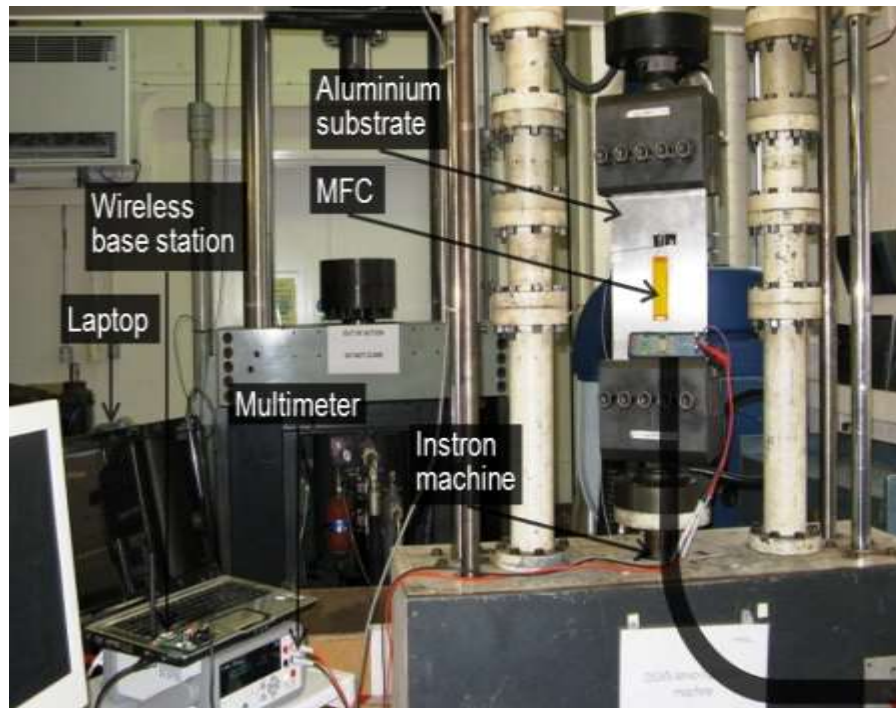
Macro Fiber Composite MFC M8528-P2

PZT piezoelectric element operating in d_{31} mode

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

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

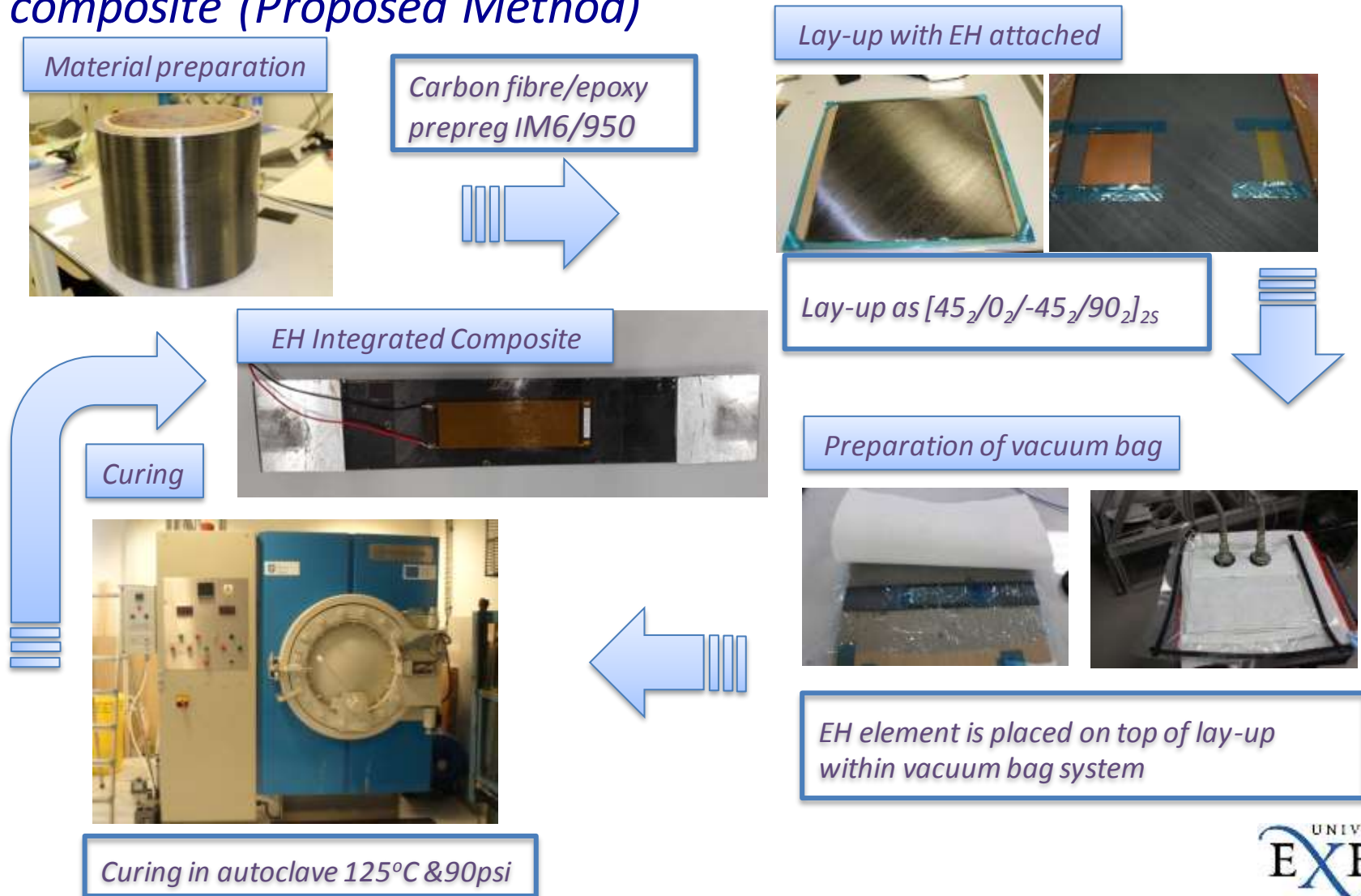
Testing Set-up



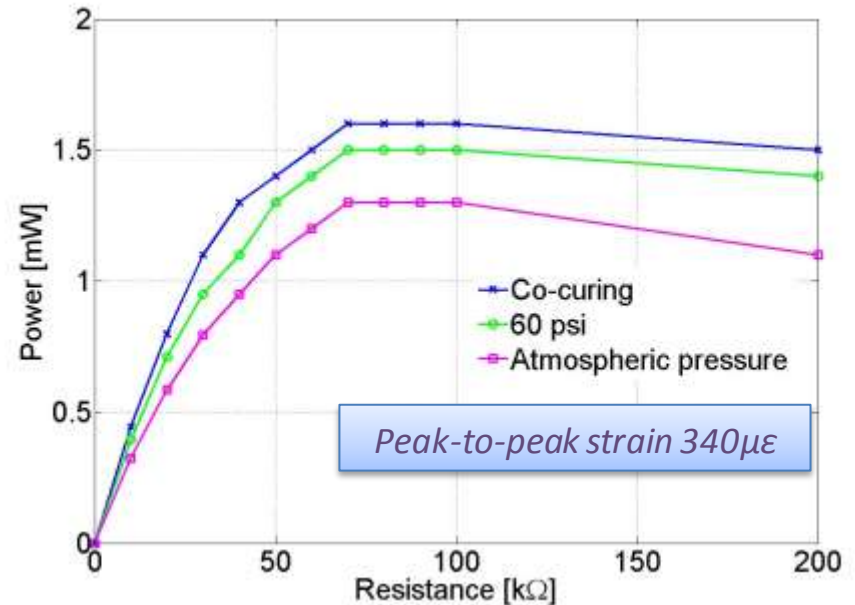
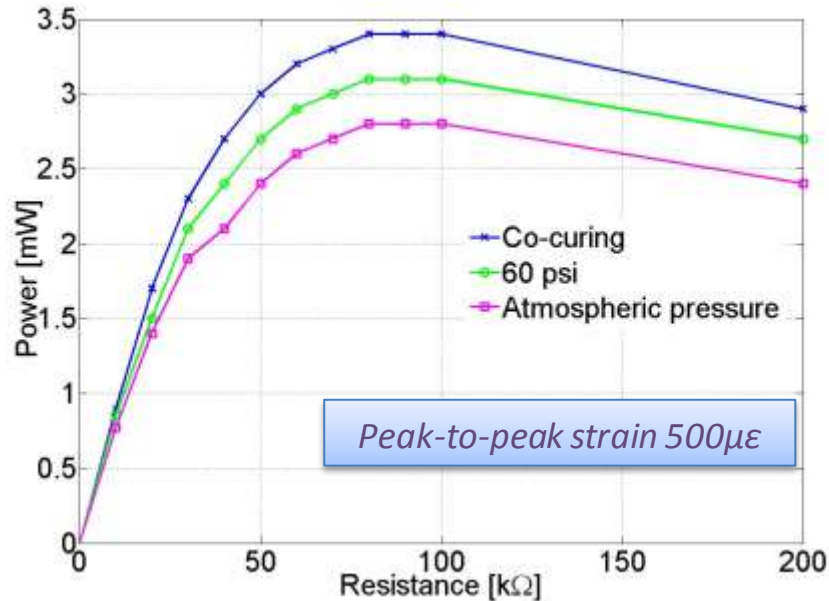
Testing set-up is using Instron machine is used to produce vibration, where the MFC (macro fibre composite material) is the piezoelectric energy harvesting element.

WP2: Energy Harvesting and Optimisation

Fabrication process to co-cure EH (energy harvesting) element onto composite (Proposed Method)

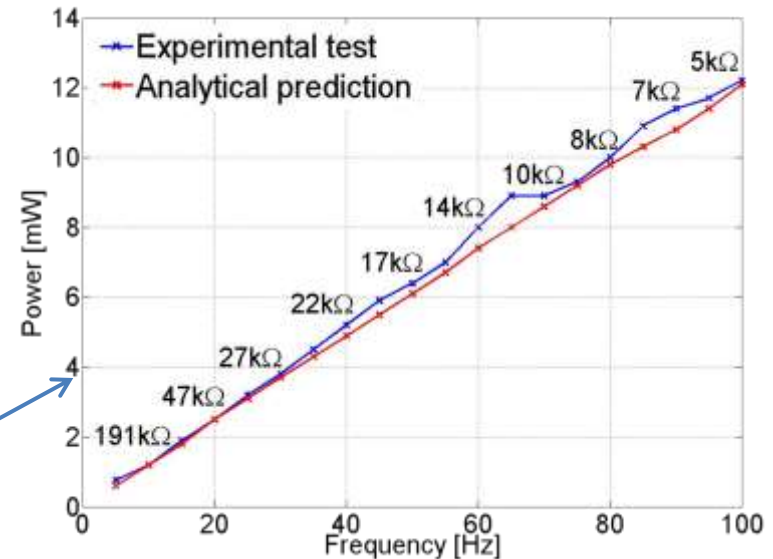
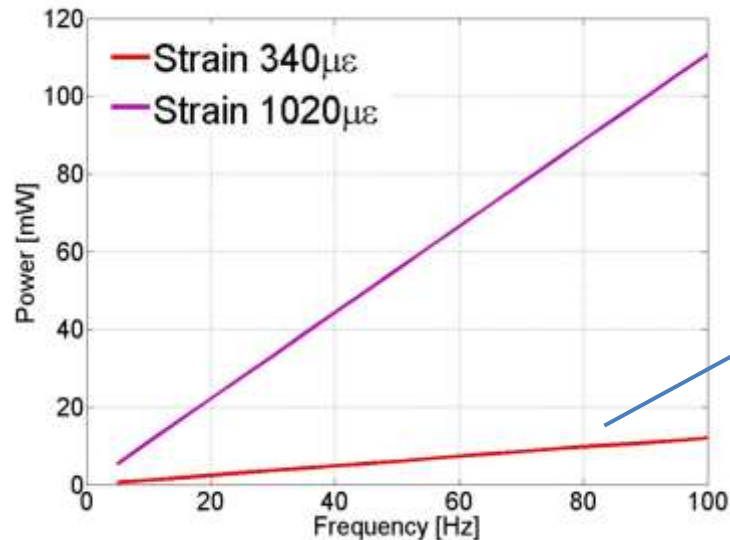


Comparison of integration methods and energy harvested at various strain levels



- Co-curing method offers the highest efficiency in power harvesting because there is no extra adhesive applied for the bonding which will dampen the strain.
- A high pressure of 60 psi applied during direct-bonding process also improves the power harvesting capability if compared with integration process under the atmospheric pressure (14.7 psi).

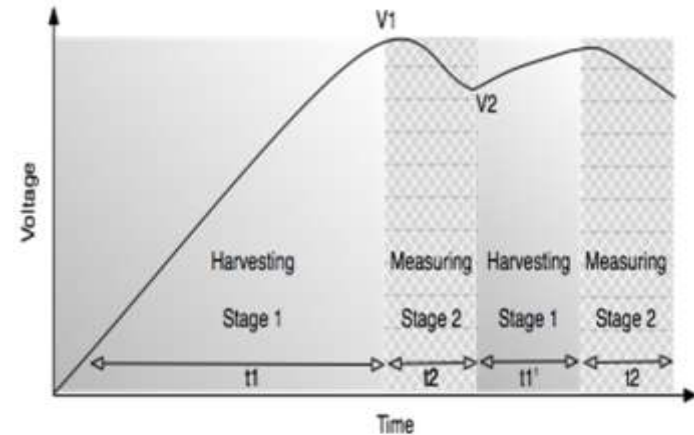
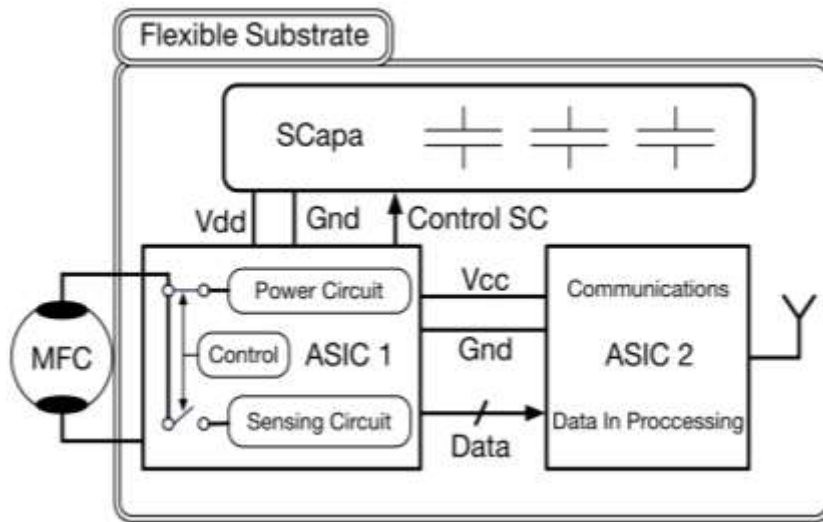
Analytical vs. experimental tests from frequency of 5-100Hz for EH integrated using co-curing method



- *Analytical prediction of maximum output power from frequency of 5 to 100 Hz was performed at peak-to-peak strain levels of 340 $\mu\epsilon$ and 1020 $\mu\epsilon$, which is the range of strain levels which could be experienced by an aircraft during a flight profile.*

WP4

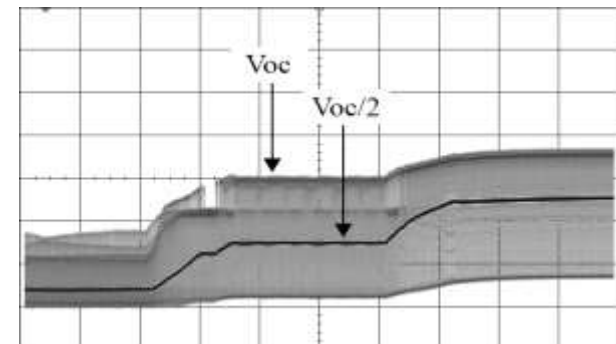
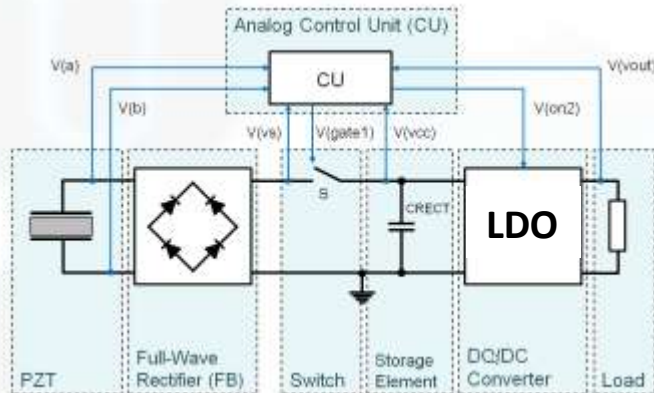
INTEGRATION



$t1 \rightarrow$ Time used to charge the capacitor for a first time till the operation voltage V_{op}

$t2 \rightarrow$ Time used to measure the MFC V_{oc} , process the data and transmit it

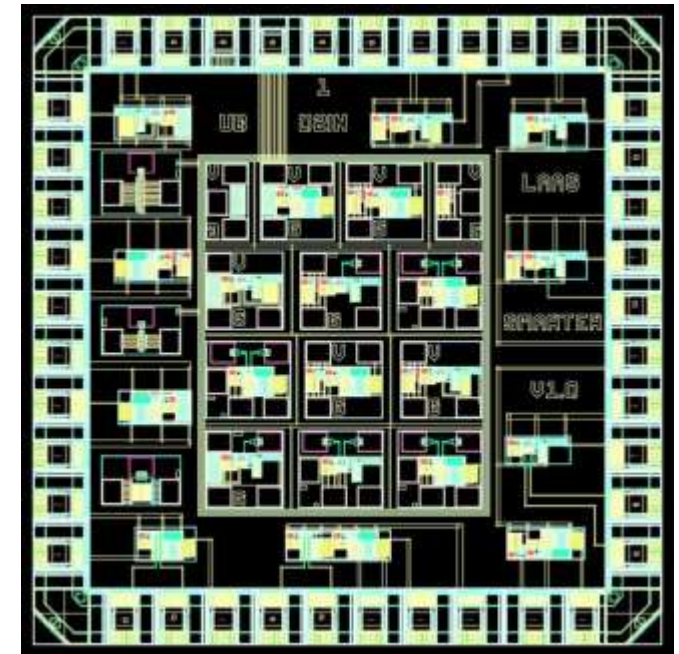
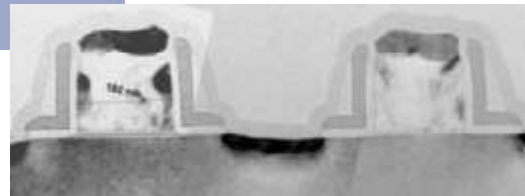
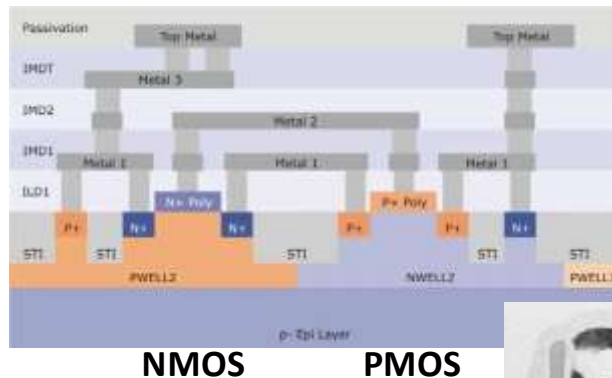
$t1' \rightarrow$ Time used to charge the capacitor again



P.Miribel-Català, J.Colomer-Fararons, J.Lafuente Brinquis, J.López-Sánchez, *Self-Powered Adaptive Circuit Sampling for a Piezoelectric Harvester*, 2014 DCIS Conference on Design of Circuits and Integrated Systems, 26-29 Nov. 2015, Madrid, Spain.

Technology

- XT018 – Smart Power SOC Platform
 - CMOS 1.8/5V
 - NVM Module
 - DMOS+HVMOS Modules
 - DEPL Module + Analog Devices



**Silicon to be received
April 12th, 2015**

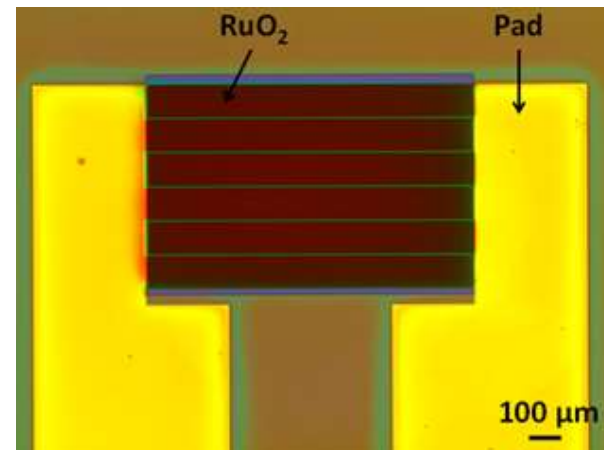
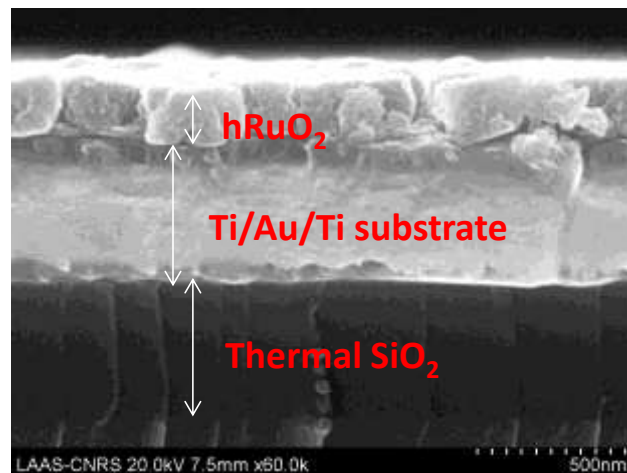
WP3 SMART ADAPTIVE STORAGE MICRO-SUPERCAPACITOR TECHNOLOGY

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
<u>hRuO₂</u>	Liquid or solid	0.9 V	5 mF/cm ² (cell)	2 mJ/cm ² (cell)	Encapsulation
Activated Carbon	Liquid	2.3 V	2 mF/cm ² (cell)	5 mJ/cm ² (cell)	Encapsulation
<u>hRuO₂/Porous Gold</u>	Liquid (H ₂ SO ₄) or solid (PVA-	0.9 V	> 3000 mF/cm ²	>1J/cm ² (electrode)	- Stack configuration



- Constraints in fabrication: use of sensitive electrolytes < 1 ppm H₂O required
- ***Parylene encapsulation chosen for the final realization***
- Deposition system (Comelec) acquisition under process

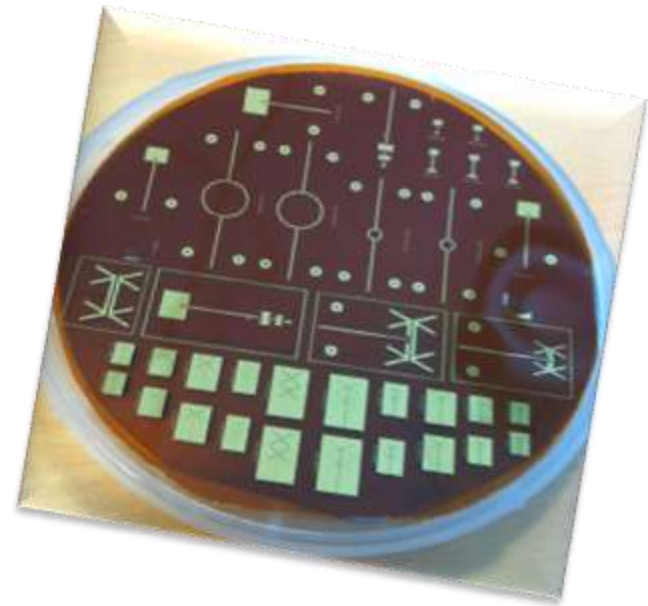
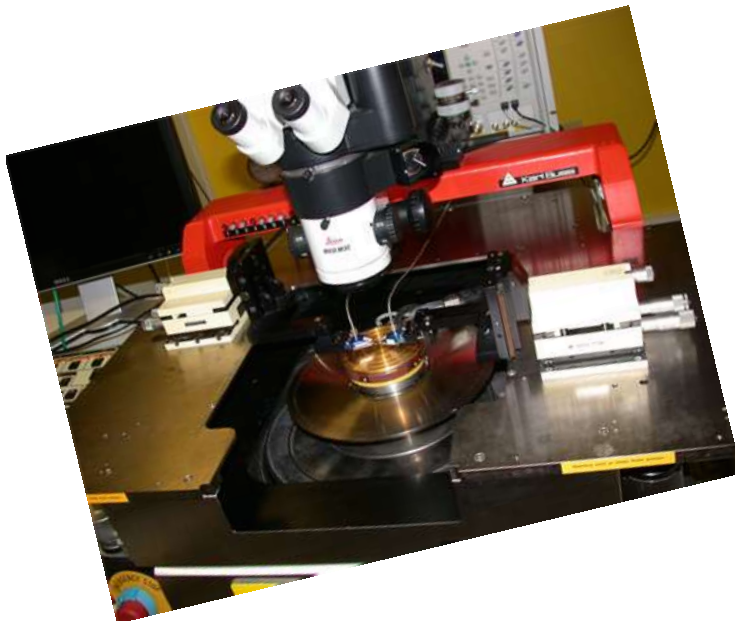


Transportable glove box



Heterogeneous integration on flexible substrate

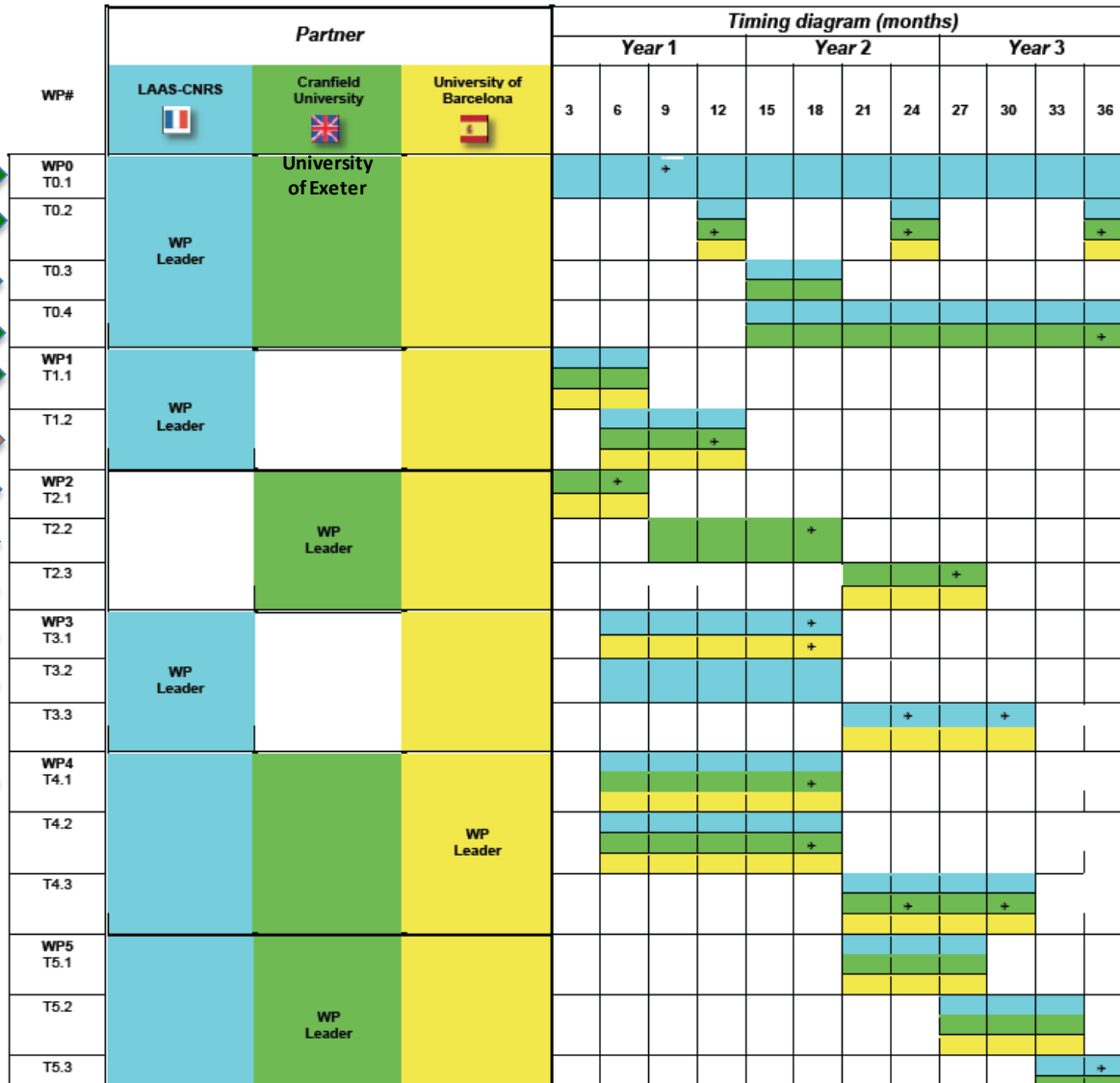
- *Flexible substrate choice : Kapton, for its very good RF properties.*
- *RF characterization of Kapton using ring resonator; choice of the best thickness for our application: 127 μm thickness*
- *Set-up of the technological process in our clean room*



Heterogeneous integration on flexible substrate

- *Antenna design*
- *Patch antenna – easy design*
 - *Bandwidth measured @60 GHz = 1.5 GHz*
 - *Gain ~ 4dB*
- *Cross slot dipole antenna*
 - *Bandwidth measured @ 60 GHz = 10 GHz*
 - *Gain ~ 2 dB*
- *Future work*
 - *Design and realisation of cross dipole antenna array – ultra wide band and high gain – optimal for our application*
 - *Flip-chip process set-up*



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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.

- 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.
- 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.
- 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.
- 4. T.M. Dinh, A. Achour, S. Vizireanu, G. Dinescu, L. Nistor, K.Armstrong, D. Guay, D. Pech, *Hydrous RuO₂/carbon nanowalls hierarchical structures for all-solid-state ultrahigh-energy-density micro-supercapacitors*, Nano Energy, vol. 10 (2014) p. 288-294.

Published international conference papers supported by the project:

- 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.
- 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.
- 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.
- 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.
- P.Miribel-Català, J.Colomer-Fararons, J.Lafuente Brinquis, J.López-Sánchez, *Self-Powered Adaptive Circuit Sampling for a Piezoelectric Harvester*, 2014 DCIS Conference on Design of Circuits and Integrated Systems, 26-29 Nov. 2015, Madrid, Spain.

Poster at national conference

- M.Bafleur et al, *ADREAM: An experimental platform for tackling the challenges of energy: from smart microsystems to smart grid*, Symposium Georges Giralt (www.laas.fr/1-32368-28-octobre-2013-Symposium-Georges-Giralt.php), Toulouse (France), 28 octobre 2013.

Thank you