Piezoelectric Energy Harvesting Powered Wireless Sensing System for Vibration Measurement

Battery-free
Wireless sensors

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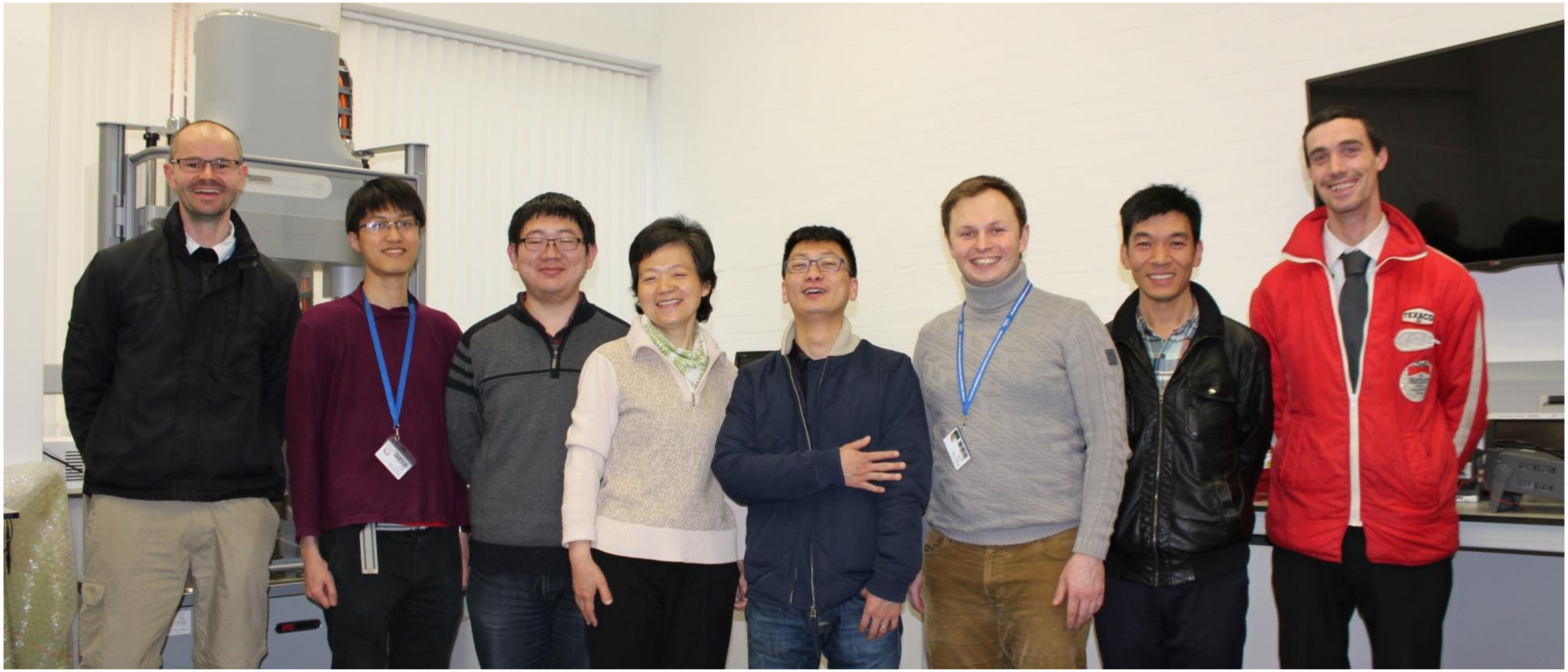
EH Research Group at Exeter

Critical mass:

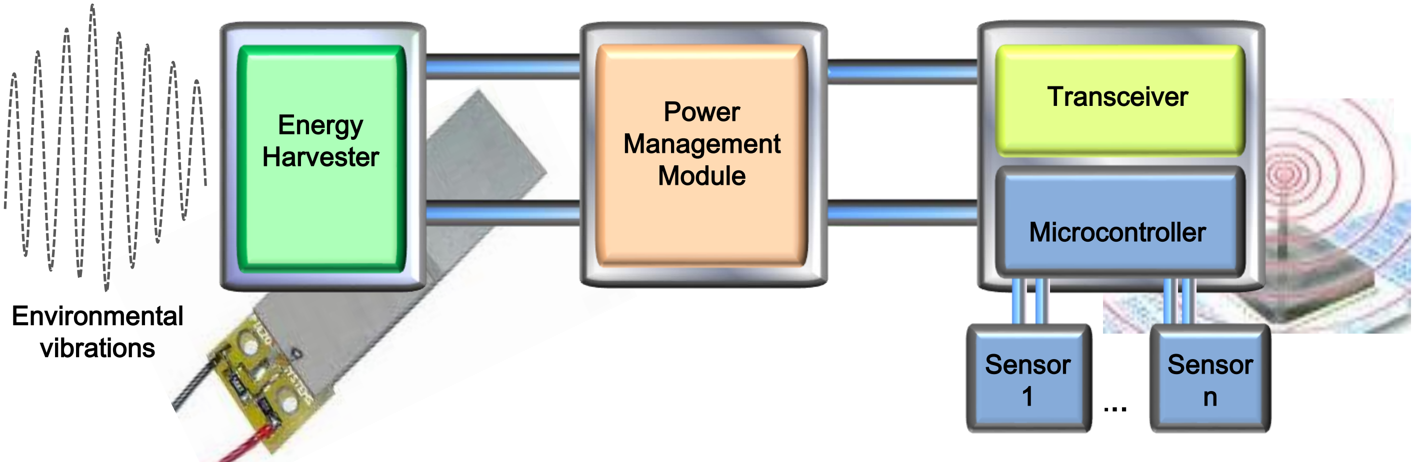
- 1 RF and 3 ARF
- 3 PhD students+1 recruited
- 1 Lecturer recruited

Research Areas:

- Energy harvesting
- Power management
- Wireless sensing
- Modelling and simulation
- Integration & characterisation

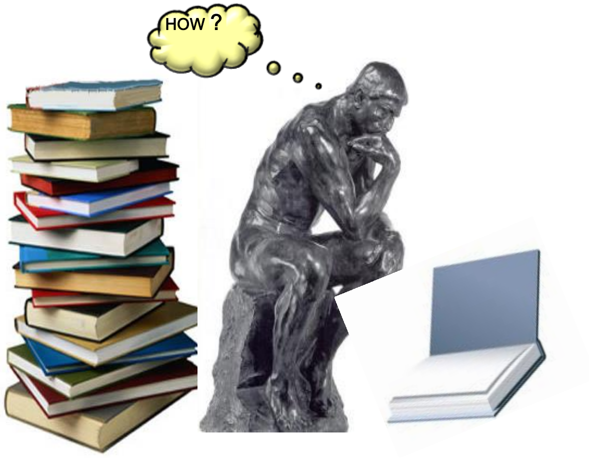


Research Challenges on Integration

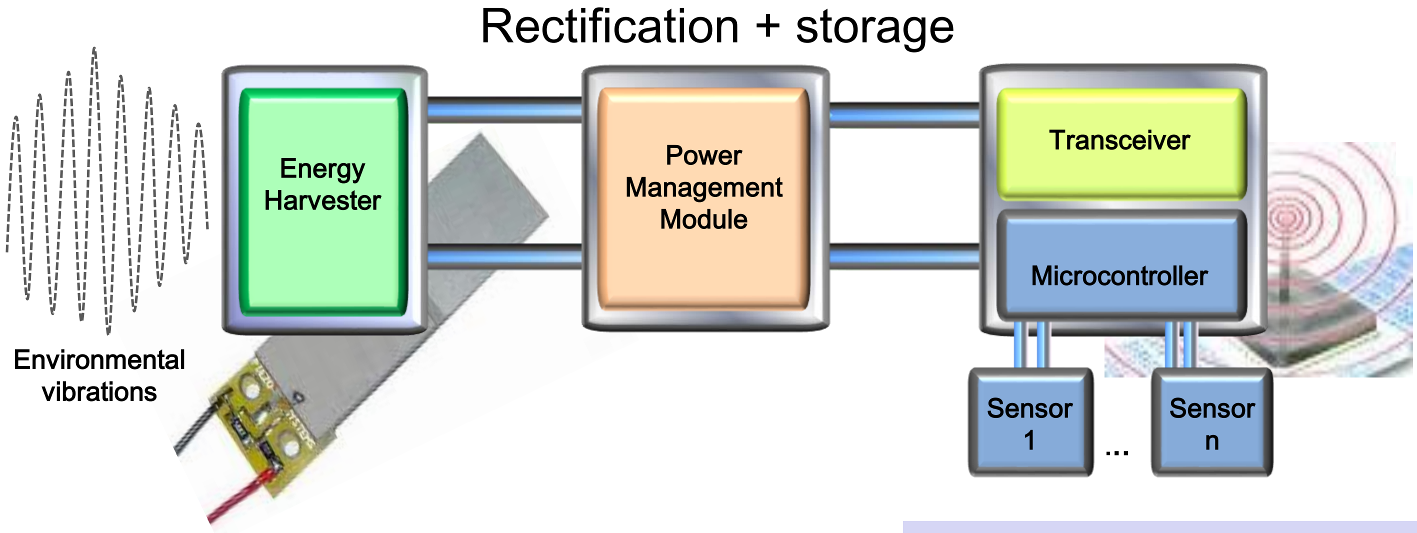


Challenges on integration for wireless sensing

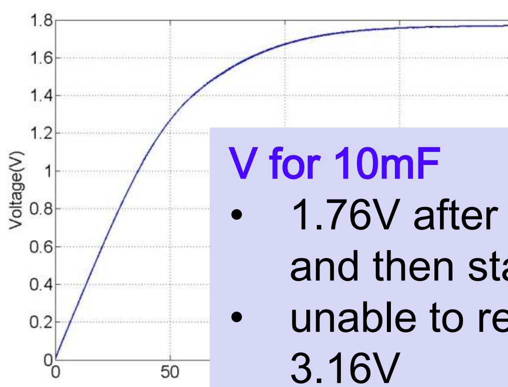
- Limited energy harvested (mW range)
- Mismatches between:
  - Energy harvested and energy demanded
  - Harvester electric load and WSN electric load connected
- High power consumption of WSN
- High power consumption of PM unit



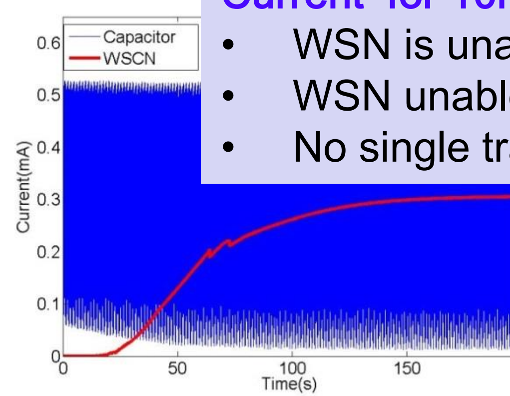
Initial Integration



For 600με at 10Hz, 3.44mW generated



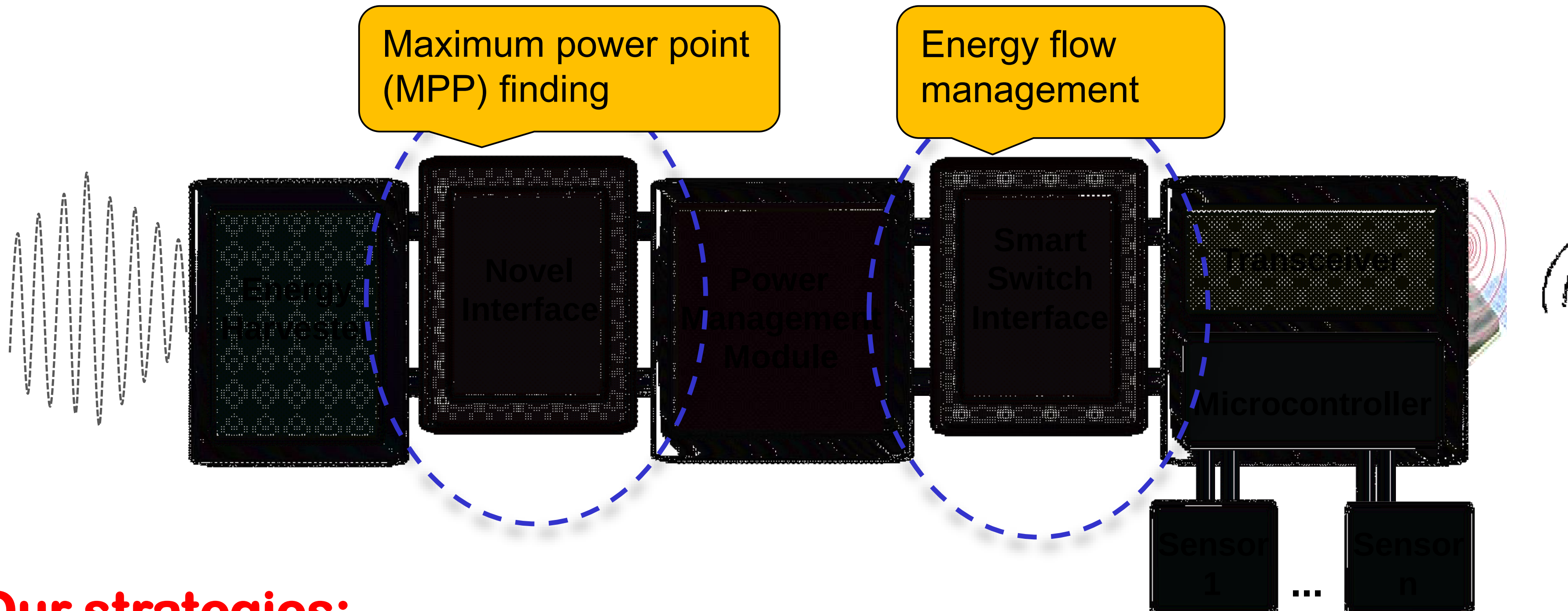
V for 10mF
- 1.76V after 158s and then stable
- unable to reach 3.16V



Current for 10mF
- WSN is unable to start
- WSN unable to work
- No single transmission

Using off-the-shelf commercially available products and “plug and play” method do not work for the EH integration

New System Architecture for Integration



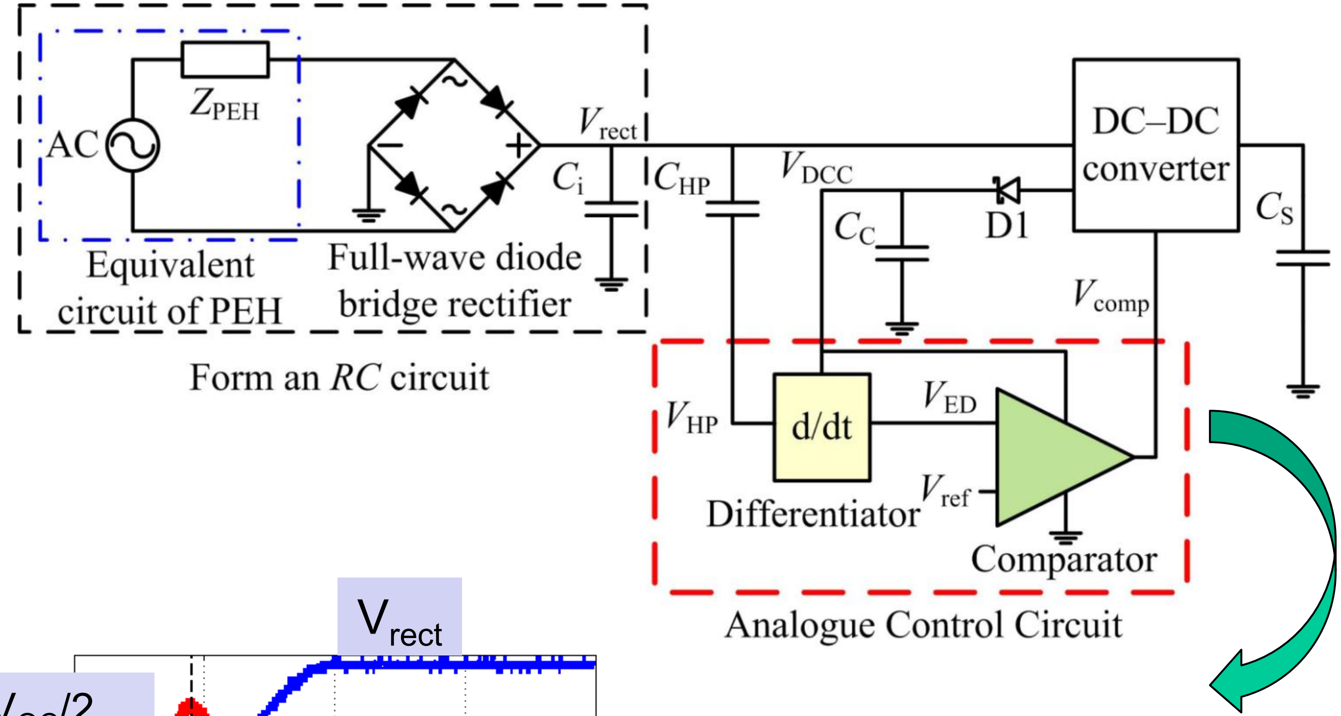
Our strategies:

To maximise power extracted from harvesters :
Adaptive maximum power point (MPP) finding analogue circuit

To manage energy flow:
Autonomous energy-aware circuit and software

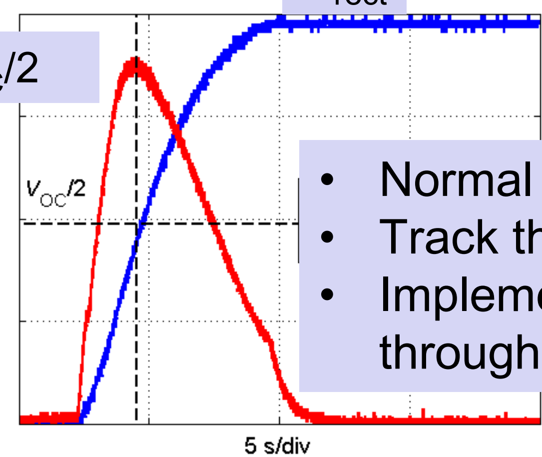
To reduce power consumptions
Introducing two interfaces and reducing complexity of circuits

Our Approach to MPP Finding



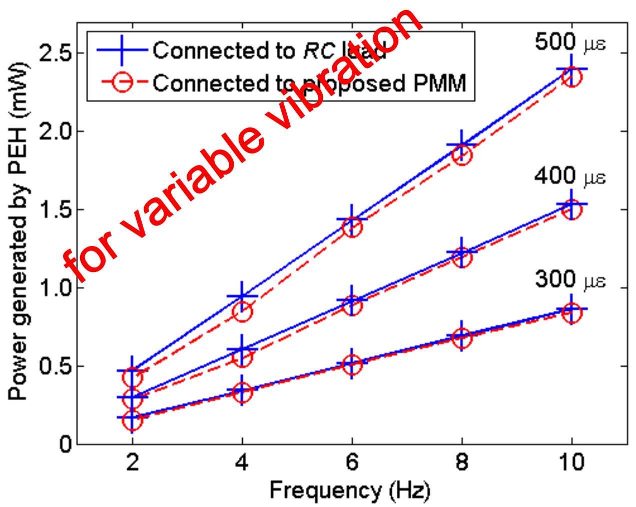
V_{rect}

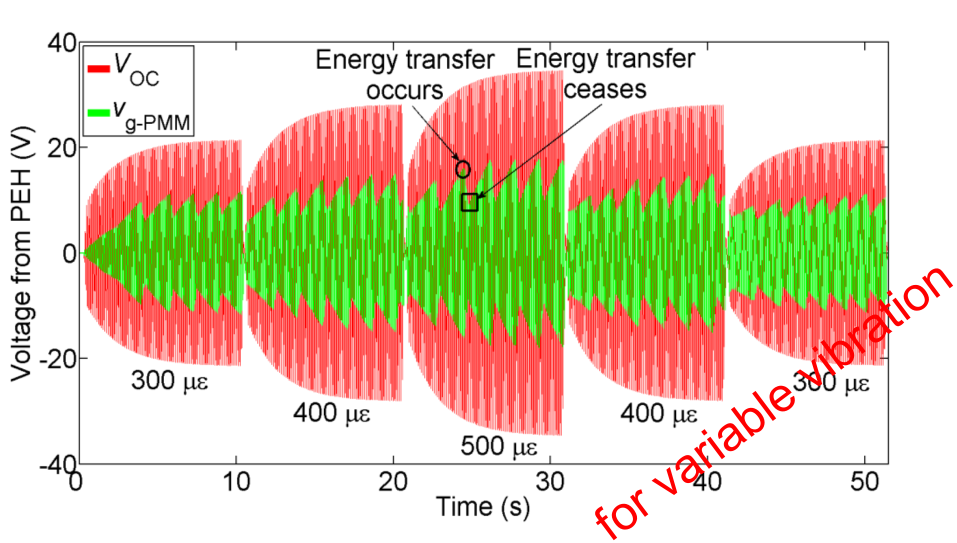
MPP in $V_{OC}/2$

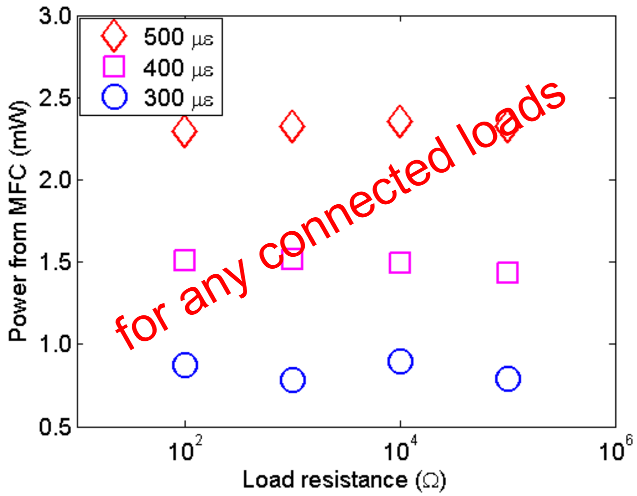


- Normal way is using sensing circuitry & μC
- Track the voltage charging profile of capacitor, V_{HP}
- Implemented by analogue control circuit (ACC) through d/dt without sensing circuitry & μC

MPP Performance of our Approach







Performance:

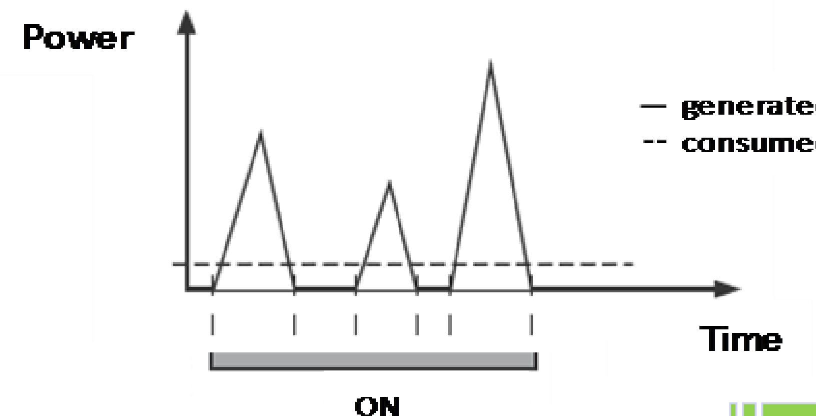
- Able to transfer MPP for variable vibrations and for any connected loads
- Tracking capability of up to 98.66%
- Consumes as little as 5.16 μW of power during operations
- Without start-up problem.

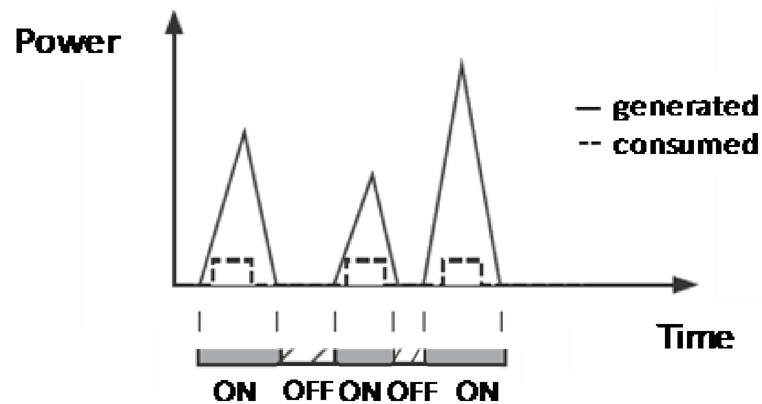
Our approach to energy flow management

Simple philosophy:

- There is vibration, we will harvest energy and storage it without waste.
- Once enough energy is stored, we will use the energy to power WSNs.

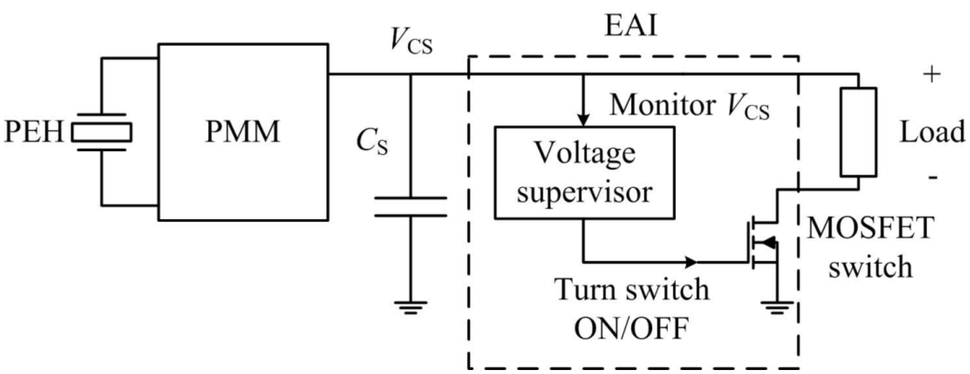
How to implement: smart switching through energy-aware interface (EAI).

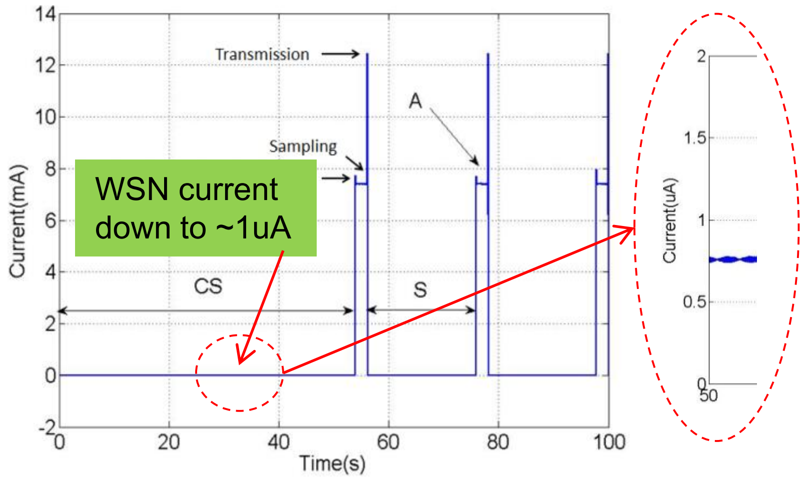




Pre-scheduled approach - time-based → Move to → **energy-aware based**

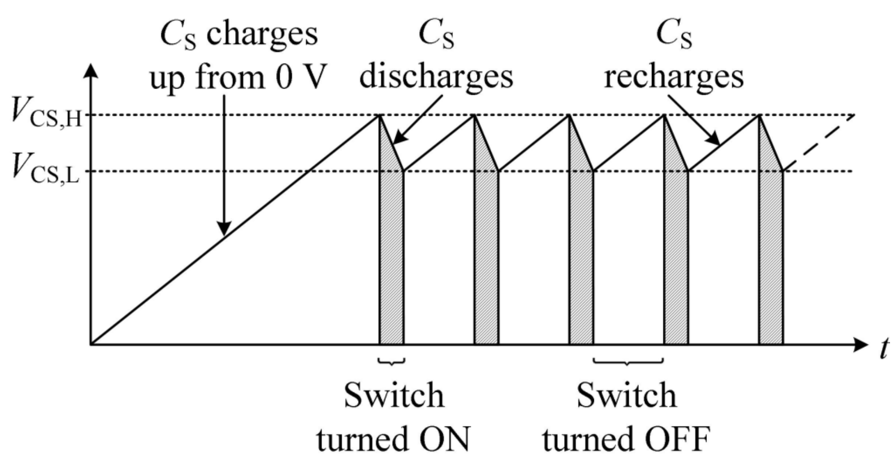
How we developed the EAI





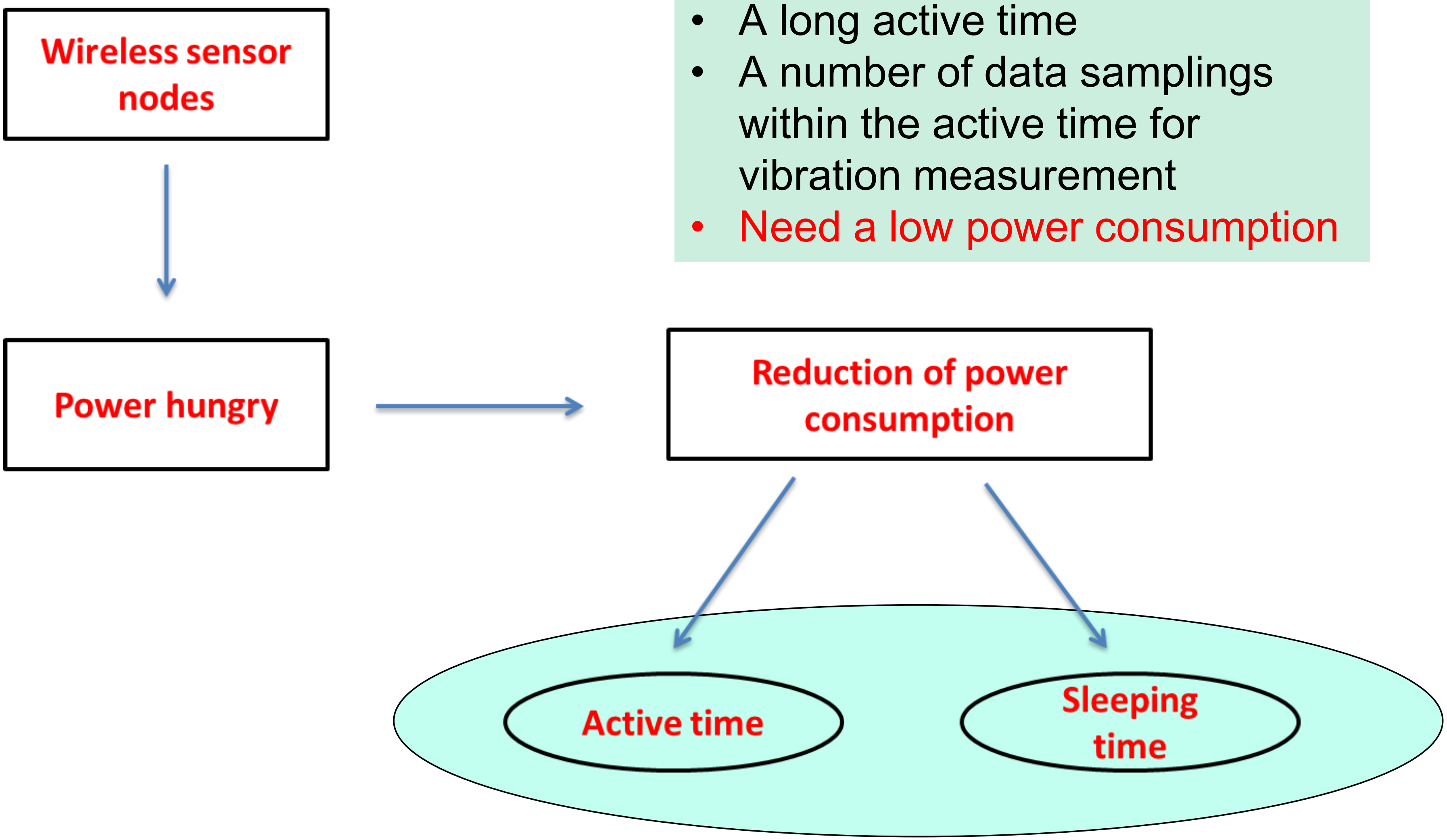
EAI benefits:

- Reduce the power consumption of WSNs during the sleep time down to about **1 μw**.
- Allow harvested energy to be accumulated in the energy storage
- Allow to deal with mismatch of energy harvested and energy demanded

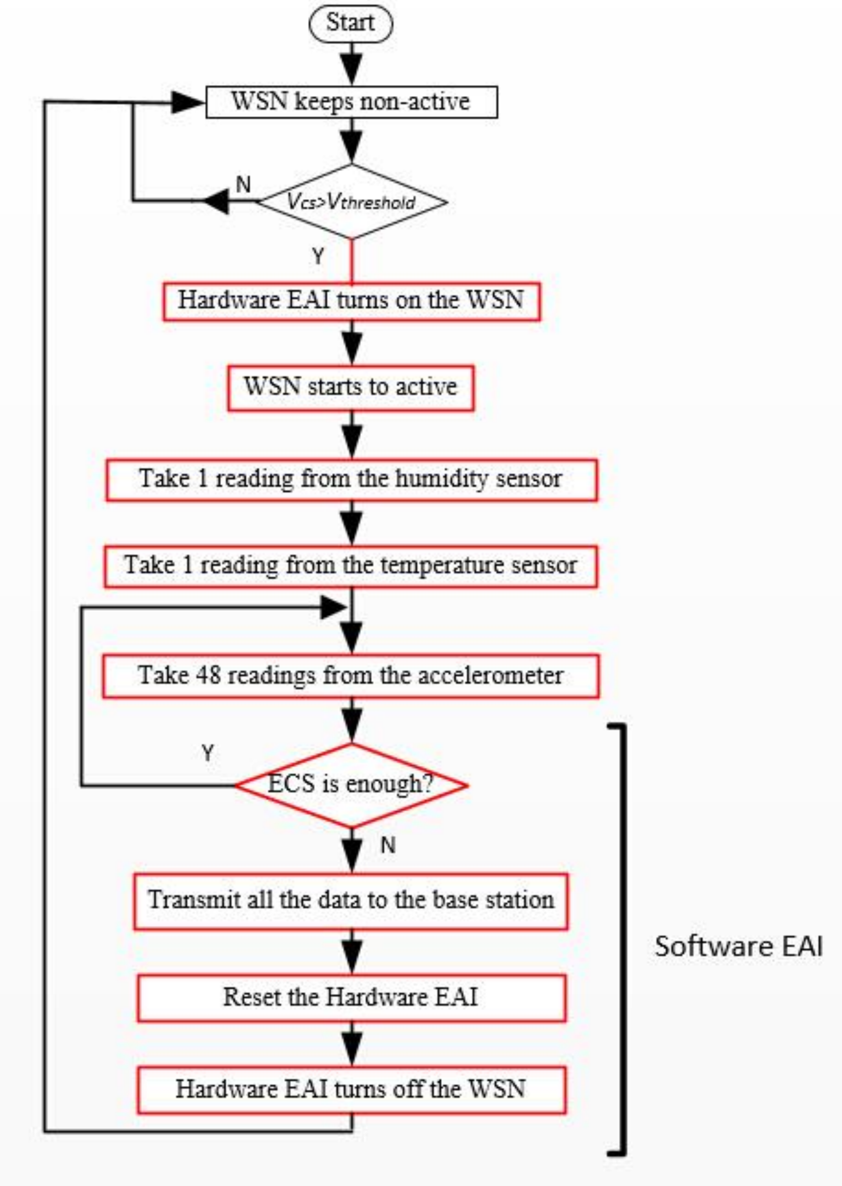


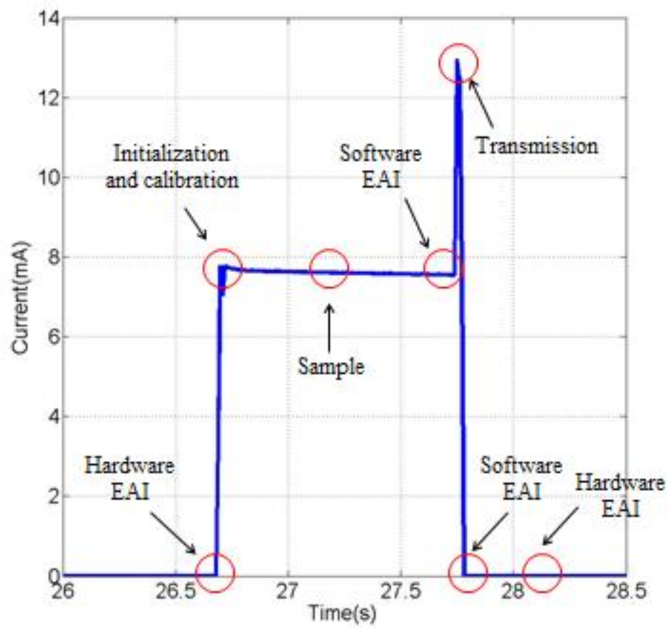
WSNs for Vibration Measurement

- A long active time
- A number of data samplings within the active time for vibration measurement
- Need a low power consumption



Software to Reduce the power consumption

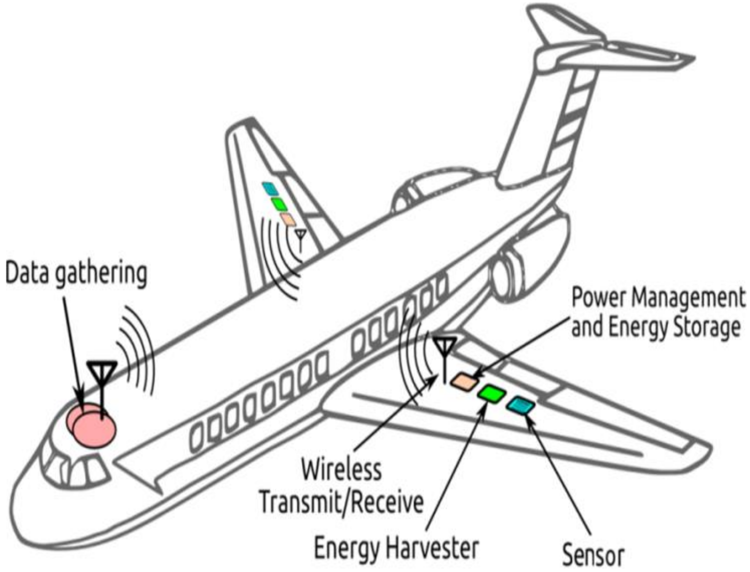




Strain Energy Harvester for Aircraft Wing

Piezoelectric transducer onto composite materials

Macro-Fibre Composite (MFC) [patented by NASA]

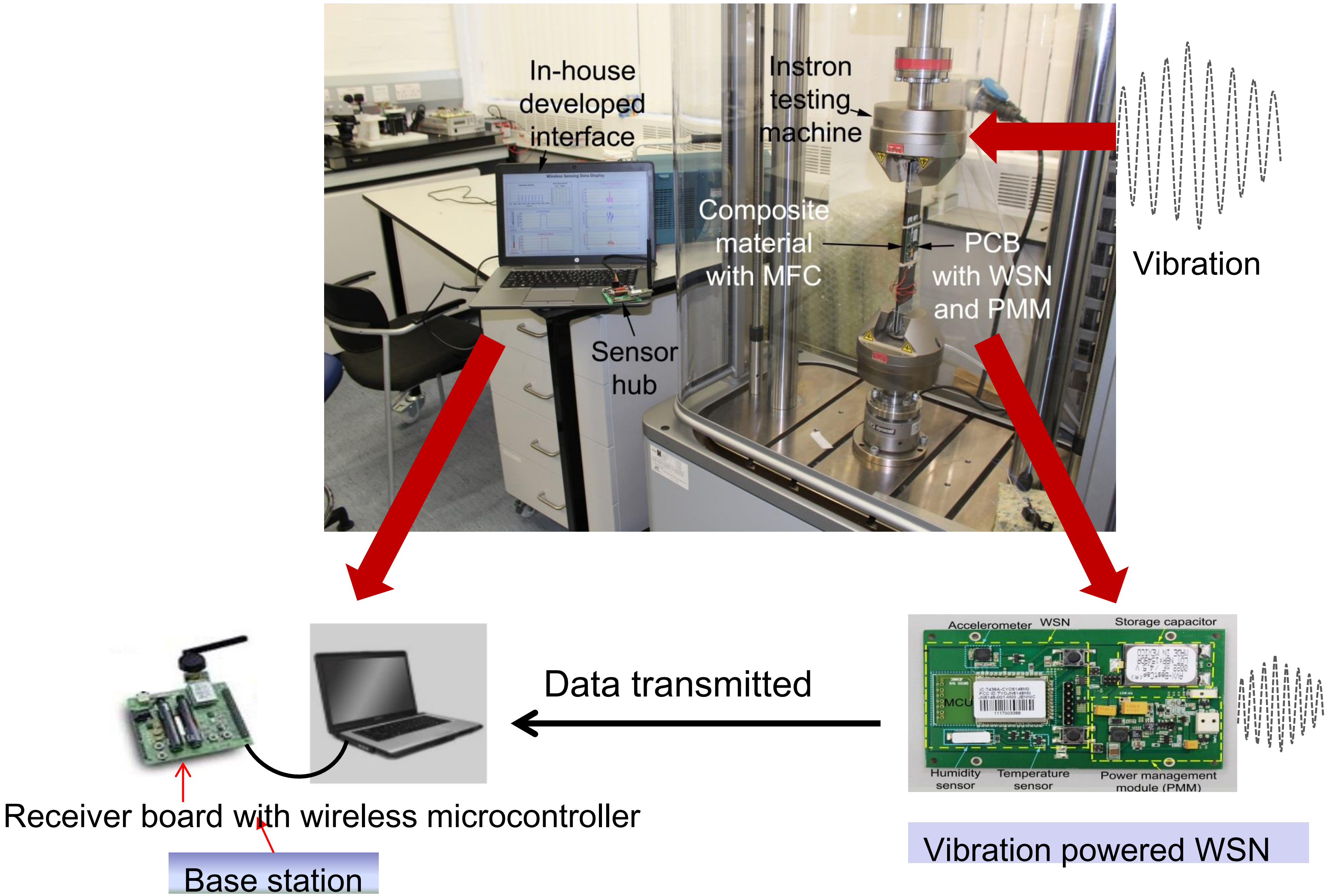


Advantages

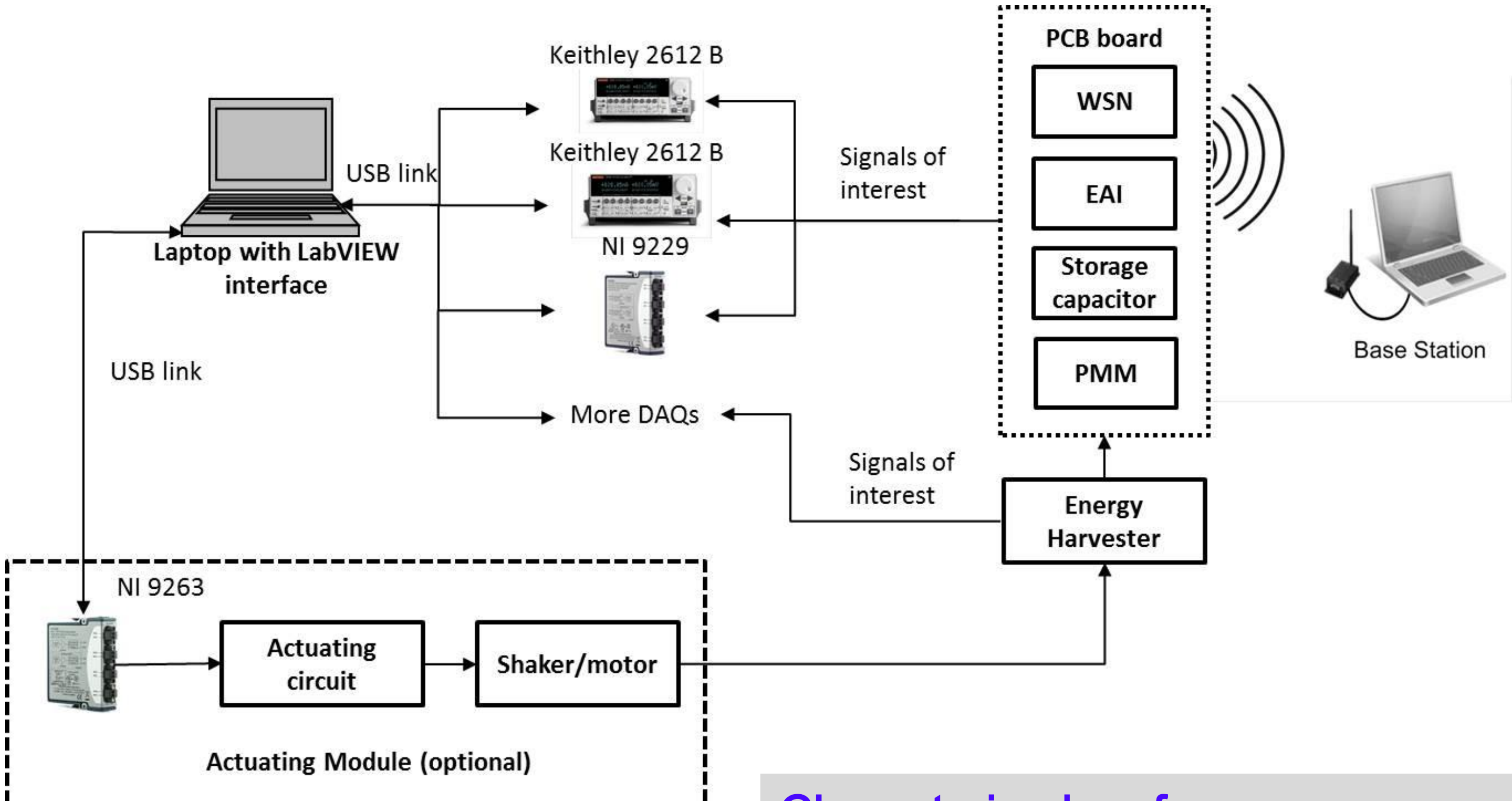
- Flexible and durable
- Multifunction: energy generation, actuation/sensing
- Crack tolerant
- Conforms to curved surfaces

For structural health monitoring

Energy Harvested Powered WSNs in Lab



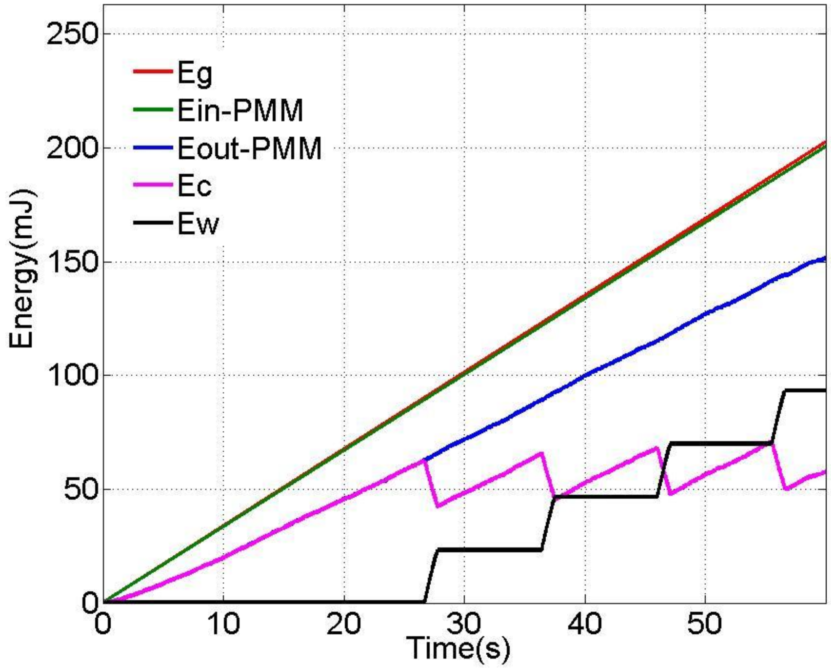
Multichannel and On-line Characterisation



Characterised performance:

- Energy generation from harvesters
- Energy consumption in the system
- Powering the WSN capability

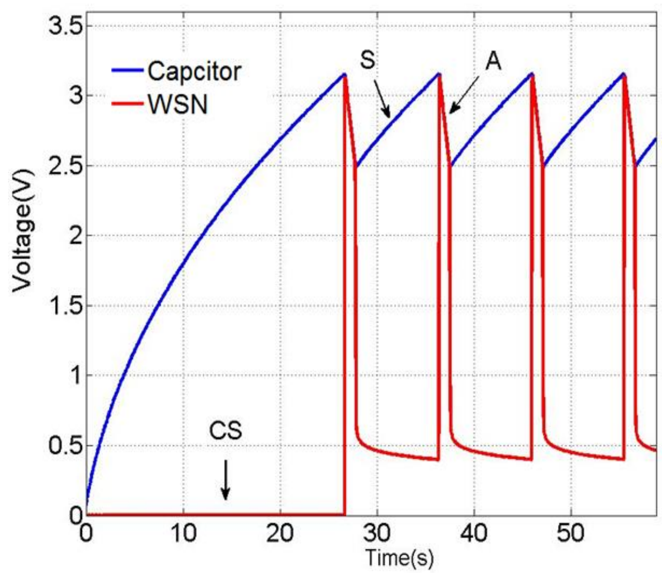
Energy Generation and Consumption



For peak-to-peak strain loading of 600με at 10Hz

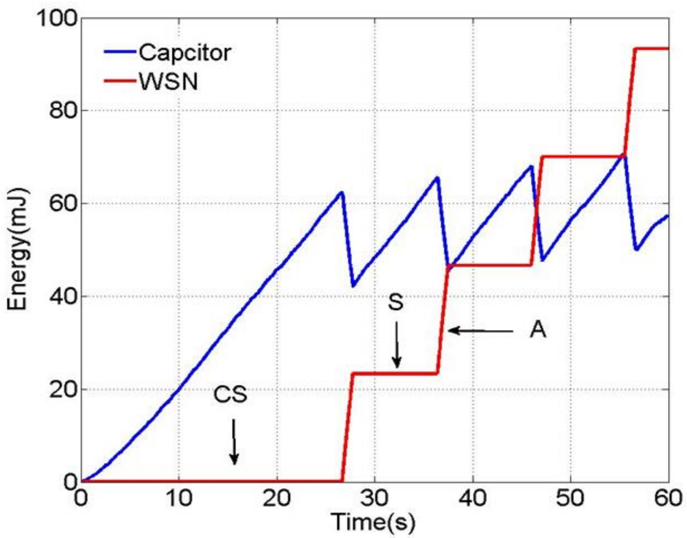
- An average power generated: 3.38 mW
- An average power delivered to WSN: 2.54 mW
- Sleep current → 1.26μA
- $\eta_{overall}$ =75%

Powering WSN Capability



For 10mF, peak-to-peak strain loading of 600με at 10 Hz

After 26.69s, V reaches 3.16V, able to power the WSN for 1.16s after every 8.53s, i.e., 13.6% of duty cycle.



- 20.06mJ/active time
- 48×6+2=290 samplings @ 580 bytes(96*6+4)
- 34μJ/byte, including wake up, sampling and transmission
- Sensor current consumptions: 7.83μA (T), 7.42μA (H) and 12.45μA (A)

Comparisons of power with different Conf.

Configurations	$\overline{P}_g$ (mW)	$\overline{P}_{rec}$ (mW)	$\overline{P}_c$ (mW)	η_{rect} (%)	η_{all} (%)
MFC+68.96kΩ	5.03	4.92		97.76	97.76
MFC+98 kΩ+22μF	3.44	3.34		97.15	97.15
10mF+MFC+EAI+WSN	0.50	0.35	0.35	70.00	70.00
10mF+MFC+PMM+EAI+WSN	3.38	3.34	2.53	99.00	75.00

Comparisons of currents with and without EAI

	Conf.	WSS software	Performance	Average sleep current (μA)
1	MFC+PMM+**EAI**	Microcontroller in any sleep mode	WSS able to work	0.95
2	MFC without EAI	Microcontroller in sleep mode	V_{CS} reaches ~1.2V WSS unable to work	
3	MFC+PMM without EAI	Microcontroller in sleep mode	V_{CS} reach ~ 2V, WSS unable to work	
4	DC Power Source + PMM+EAI	Microcontroller in **sleep** mode	WSS able to work	28.3
5	DC Power Source + PMM+EAI	Microcontroller in **deep sleep** mode	WSS able to work	17.3

Welcome to
Energy Harvesting Demonstration Event at Exeter

Monday, 13th Jun 2016

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Wireless sensors

Acknowledgments

EPSRC Engineering and Physical Sciences Research Council

Technology Strategy Board

SEVENTH FRAMEWORK PROGRAMME