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Next-Generation Energy-Harvesting Electronics: Holistic Approach

Alex Weddell
8 June 2011

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Project Overview

- £1.6M, three-year, EPSRC-funded project
- Kicked off in Q4 2009
- Over 25 people at four UK institutions:

University of Southampton
Newcastle University
Imperial College London
University of Bristol

- Industrial advisory board:

DIODES INCORPORATED
ARM
dialog SEMICONDUCTOR
Mentor Graphics

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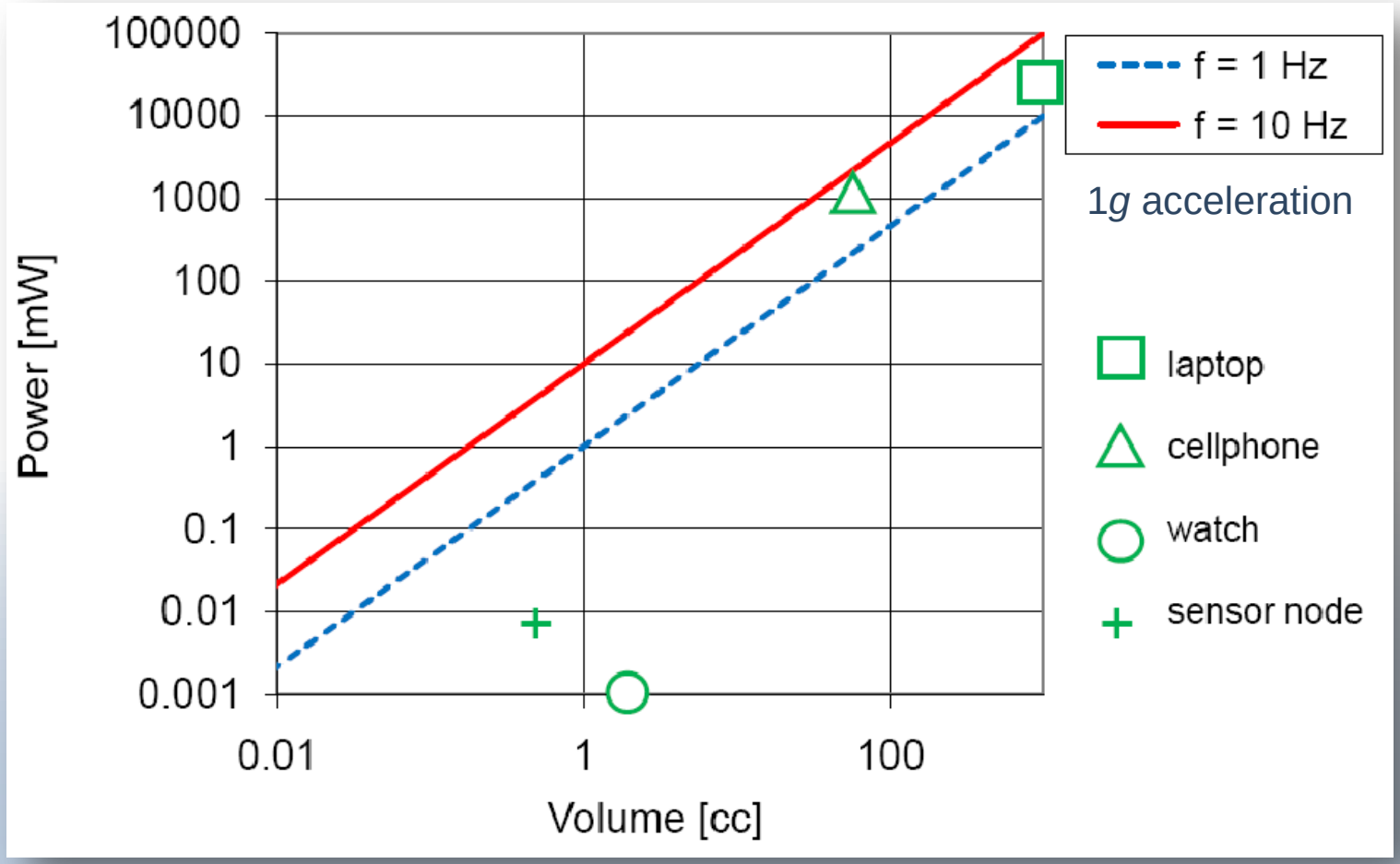
Applications of Vibration EH

- Typically condition monitoring, using wireless sensors
  - Sensors can be retro-fitted without electrician/batteries

- Also applications in asset tracking, monitoring of rotating machinery, even human health monitoring

Energy Harvesting used for Wireless Condition Monitoring, *GE* [Online]. Available: http://eh-network.org/events/dissemination2011/presentations/Tom%20Berry.pdf

Limitations of Vibration EH



P. Mitcheson, "Next Generation Energy-Harvesting Electronics " [Online], available: http://www.holistic.ecs.soton.ac.uk/presentations/mitcheson_npl.pdf

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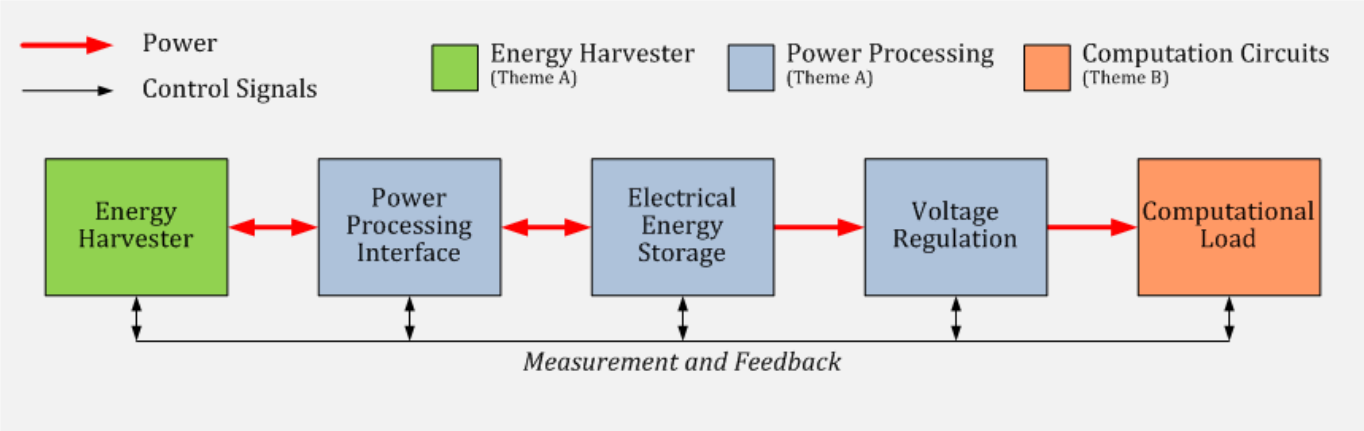
Taking a 'Holistic' Approach

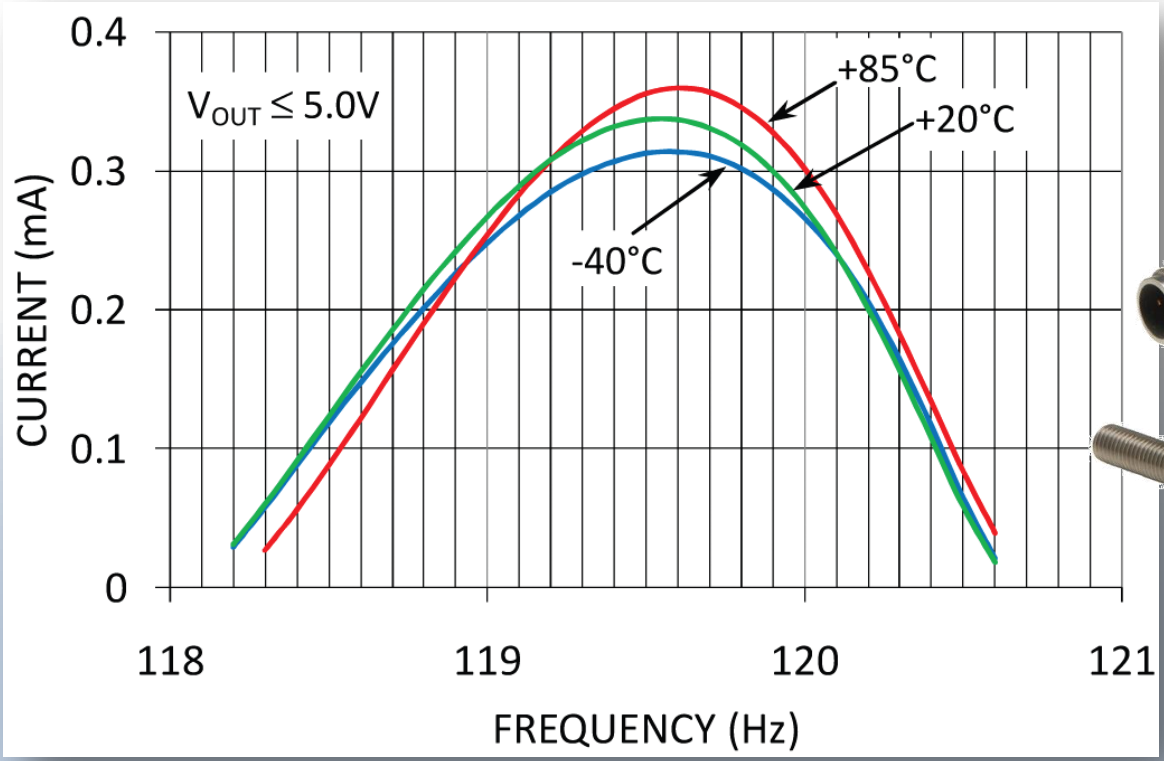
- Two-way interactions between each part



- To achieve good efficiency, simulate complete system
- Must adapt to changes to maintain efficiency

The First Problem...

- Vibration amplitude and dominant frequency vary
- Harvesters are tuned to fixed frequencies

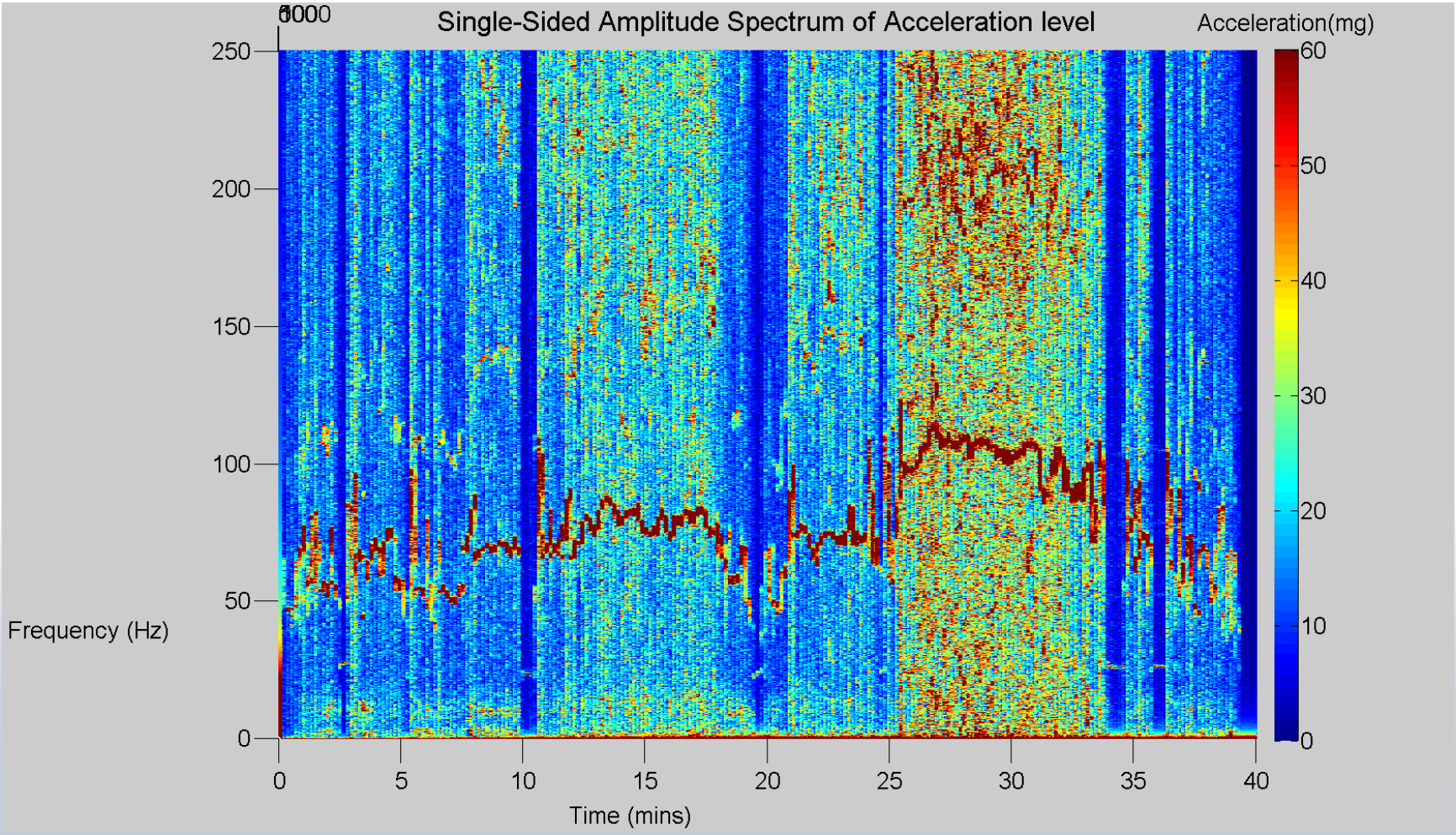


PMG FSH Free-standing vibration energy harvesters, *Perpetuum Ltd.* [Online]. Available: http://www.perpetuum.com/resources/PMG%20FSH%20Datasheet.pdf

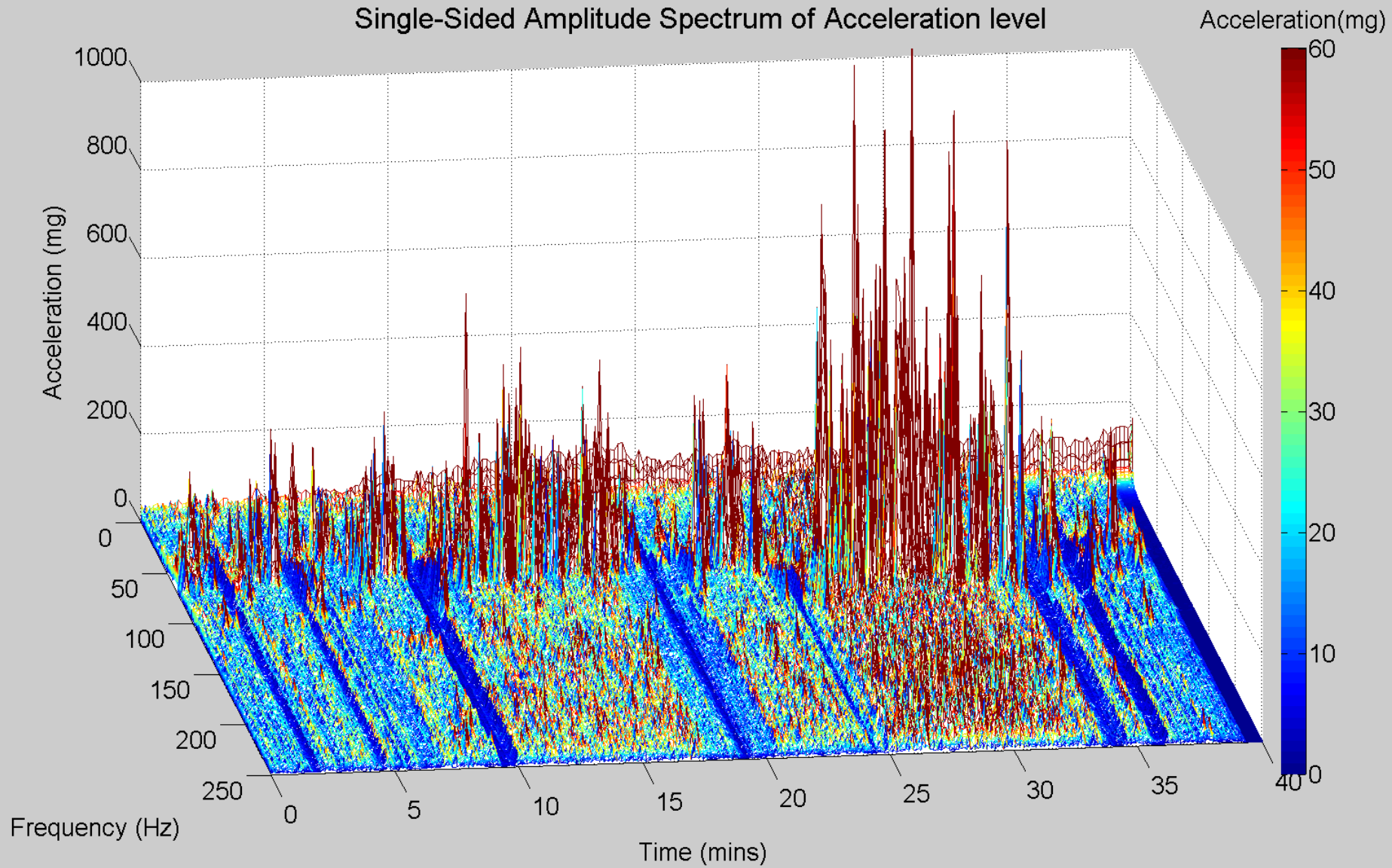
Car Engine

Monitored vibration on engine block, while driving on a variety of roads

Engine Test (0-250Hz)



Speed(mph)	30	60	20	60	70	30



Speed(mph)	30	60	20	60	70	30

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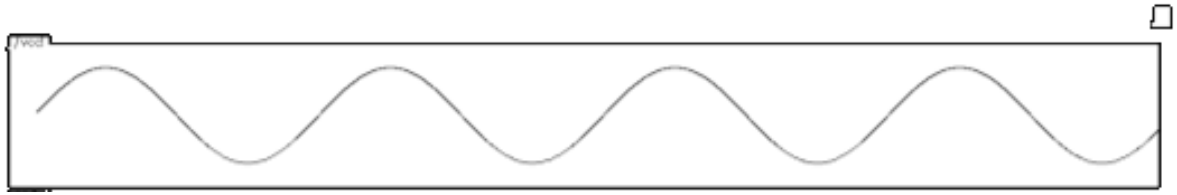
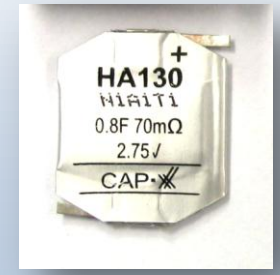
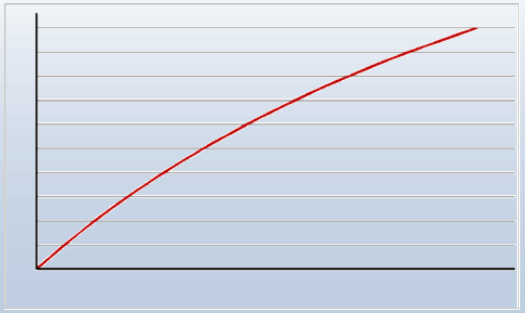
The Second Problem…

- Conventional electronics operate at a fixed voltage
- Takes a long time to charge, voltage varies
- How will systems work with varying input voltages?







←Time (hours)→

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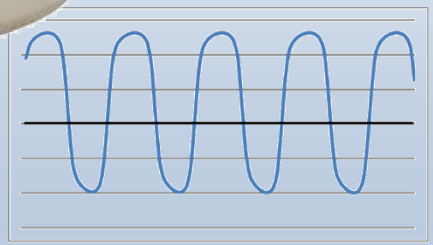
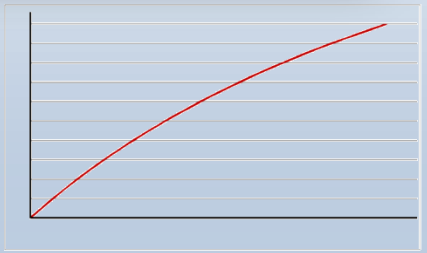
The Third (and final) Problem...

- Systems are complex and can't be simulated easily
  - Design in isolation results in poor efficiency (~2%)
- Mix of long and short times make simulation difficult



←Time (ms)→



←Time (hours)→

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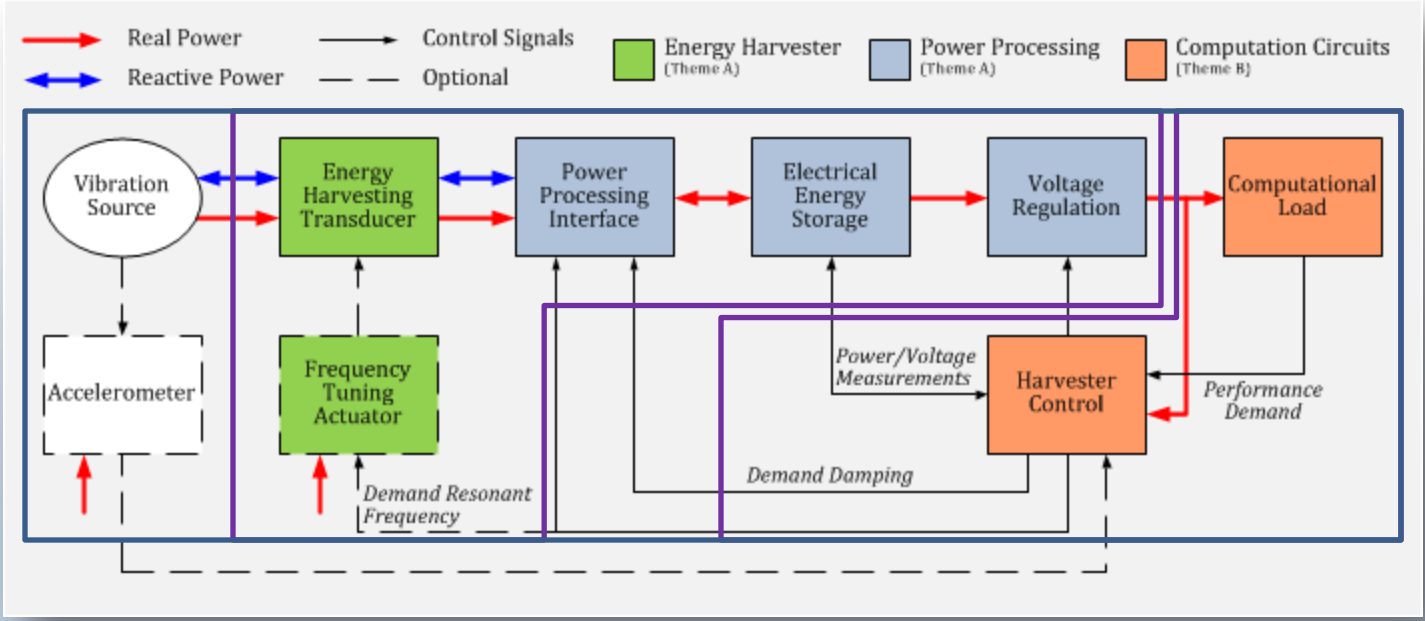
Project Themes

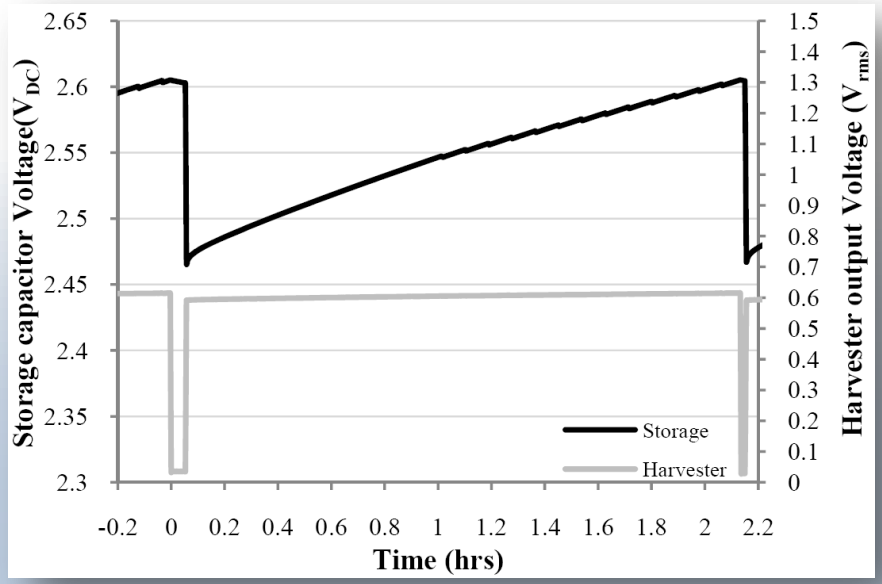
- A: Adaptive, High-Efficiency Micro Generators
- B: Energy Harvesting-Aware Computation Circuits
- C: Integrated Modelling & Performance Optimisation for Energy Harvesting Systems

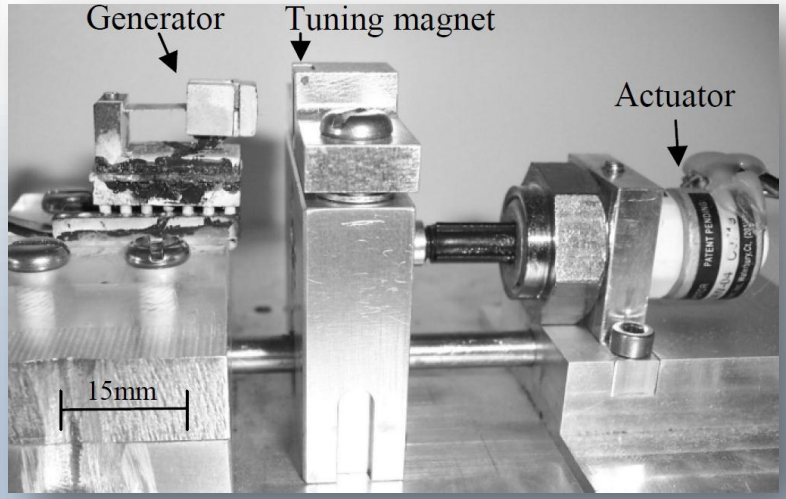


Energy Harvesting Systems: A Block Diagram (2010, July 16). *Holistic Energy Harvesting* [Online]. Available: http://www.holistic.ecs.soton.ac.uk/res/eh-system.php

Case Study

- Existing tuneable EM vibration energy harvester
- Tuning range 64-78Hz, and is energy-intensive
- Not designed in a 'Holistic' way





Ayala Garcia, I., Zhu, D., Tudor, J. and Beeby, S. (2009) *Autonomous Tunable Energy Harvester*. In: *PowerMEMS 2009*, 1-4 December 2009, Washington DC, pp. 49-52

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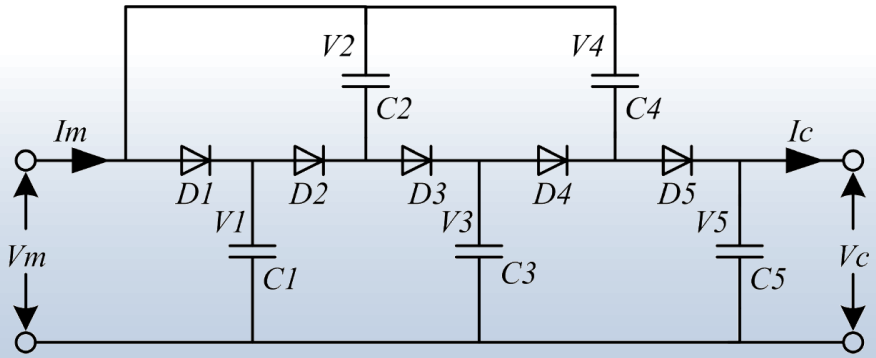
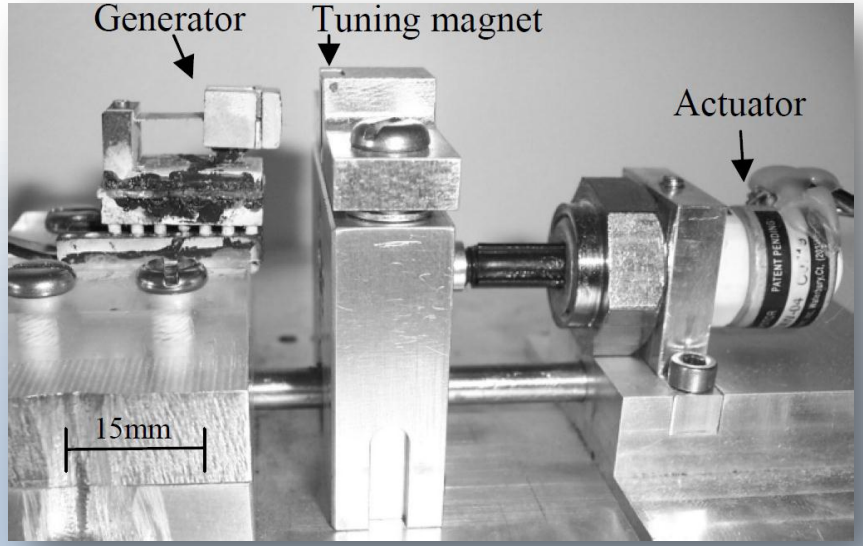
Theme A

- Novel tuning mechanisms for electromagnetic vibration EH – replacing large systems with MEMS
- Highly-efficient power conversion circuits (inc. boost converters) for tuneable EH





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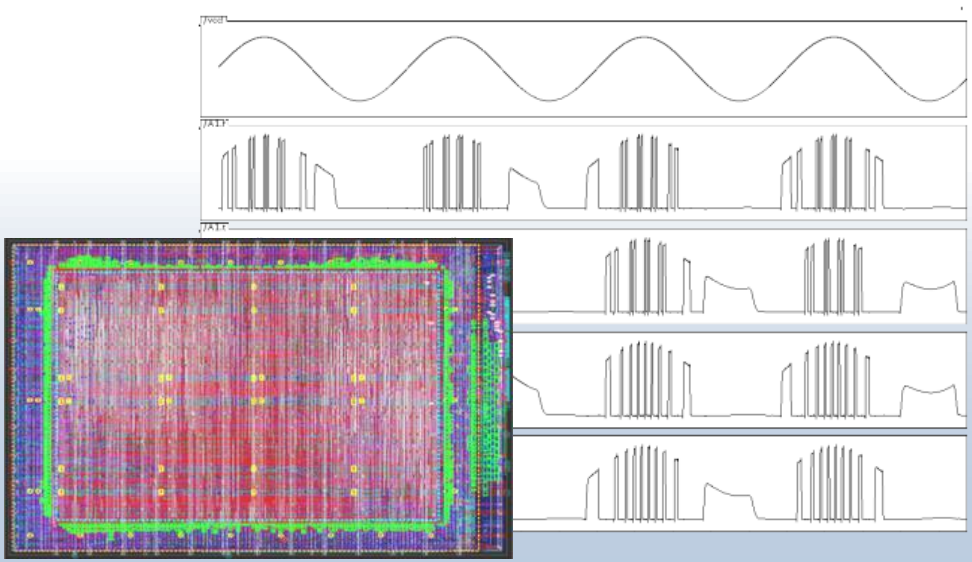
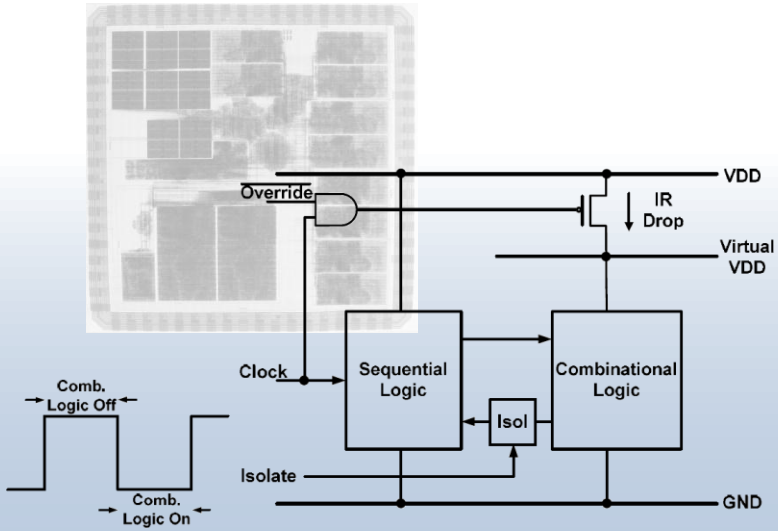
Wang, L., Kazmierski, T., Al-Hashimi, B., Weddell, A., Merrett, G. and Ayala Garcia, I. (2011) Accelerated simulation of tunable vibration energy harvesting systems using a linearised state-space technique. In: *Design, Test and Automation in Europe (DATE 2011)*, March 14-18, 2011, Grenoble, France.

Theme B

- "Energy-modulate", and reduce active power
  - Asynchronous digital circuits capable of operating from variable sources
  - An ultra-low-power synchronous digital processor





A. Yakovlev, "Energy-Modulated Computing", Design, Automation and Test in Europe 2011 (DATE 2011), Grenoble, France, 14-18 March 2011, pp. 1340-1345.
Mistry, J., Al-Hashimi, B., Flynn, D. and Hill, S. (2011) Sub-Clock Power-Gating Technique for Minimising Leakage Power During Active Mode. In: *Design, Automation and Test in Europe*, 14-18 March 2011, Grenoble, France.

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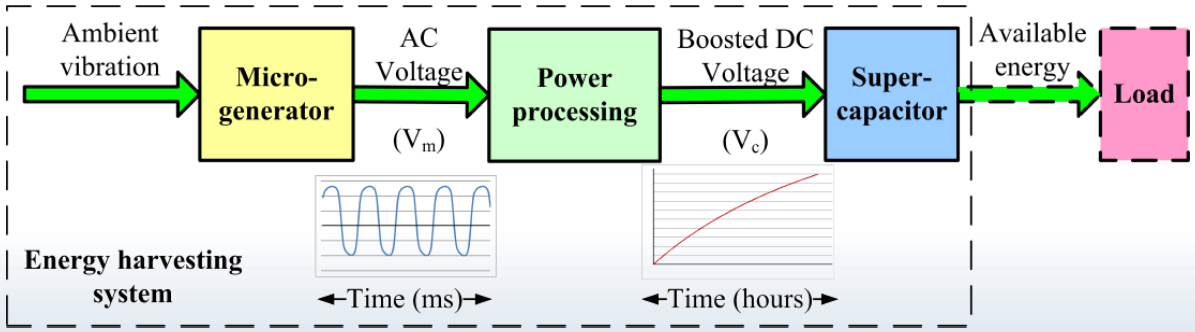
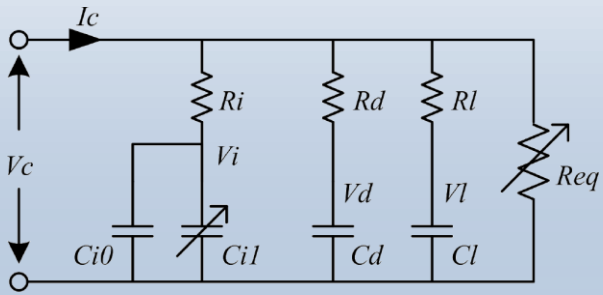
Theme C

- Simulation techniques for complete systems
- Modelling of system components (e.g. supercapacitor)
- Already 100x faster simulation, enabling optimisation





	Existing technique	Proposed technique
Simulator	SystemVision	MS Visual C++
HDL	VHDL-AMS	SystemC-A
Integration method	Newton-Raphson	Adams-Bashforth
CPU time for Scenario 1	2185 sec	20.3 sec
CPU time for Scenario 2	7 hours	228 sec

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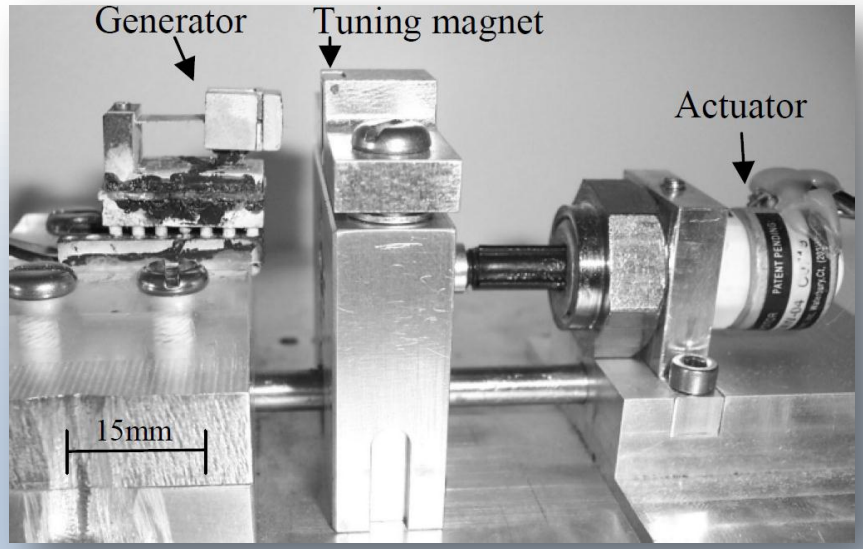
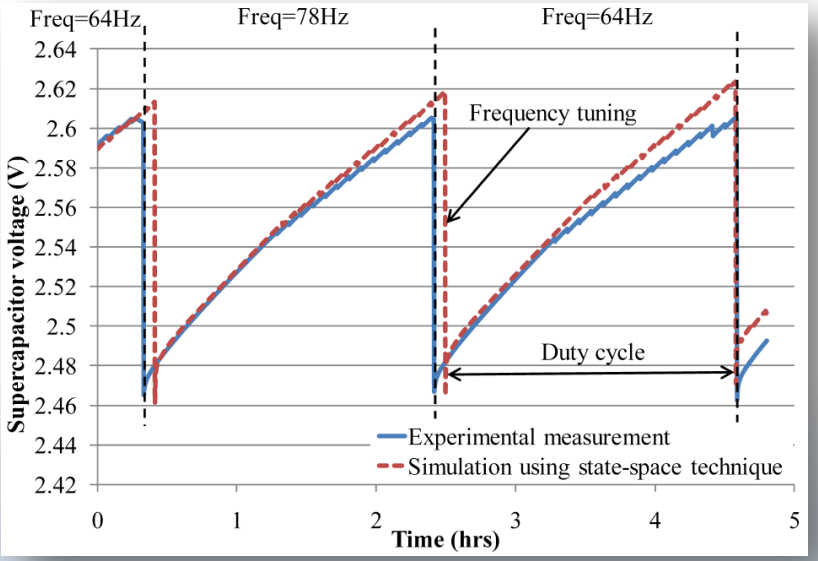
Complete System Simulation

- Able to simulate complete tuneable EH systems, including load
- Good levels of accuracy, and simulations complete much faster than previous methods





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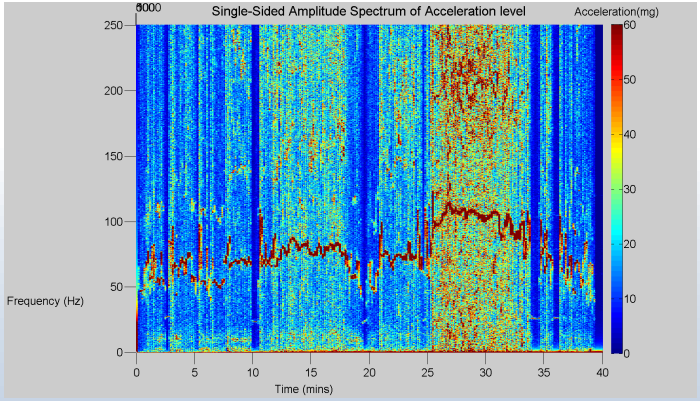
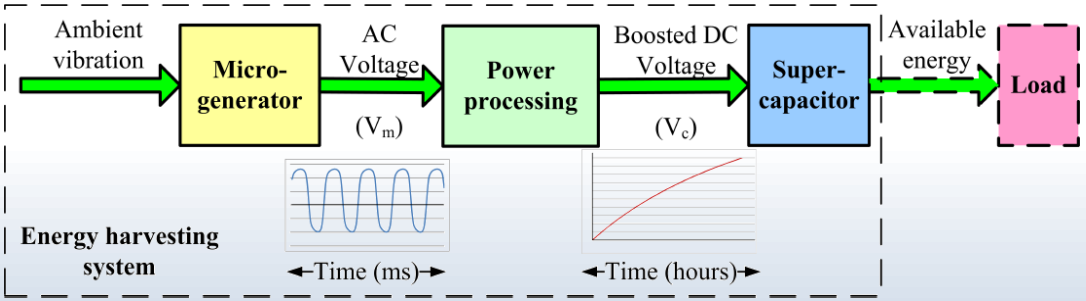
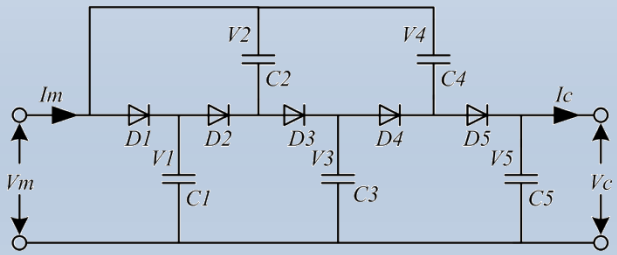
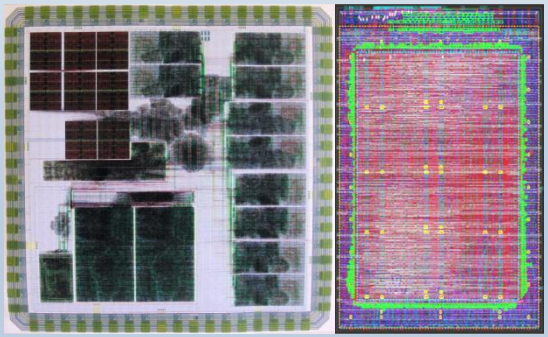
Next Steps

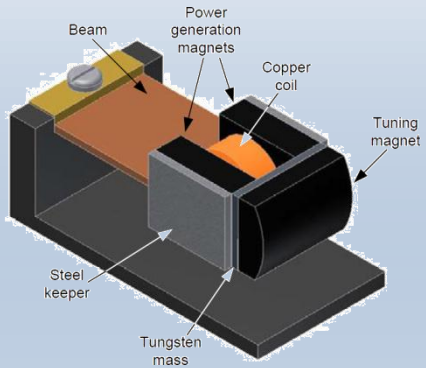
- Project ending in Q4 2012
  - System design targeted at real application
  - Complete system simulation
  - Deliver a real-world 'Holistic' demonstrator











To Learn More…

- Project Website – www.holistic.ecs.soton.ac.uk
  [or just search for "holistic energy harvesting"]

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Thank You

www.holistic.ecs.soton.ac.uk

EPSRC

Engineering and Physical Sciences Research Council (EPSRC) grant numbers EP/G067740/1 (Southampton), EP/G066728/1 (Newcastle), EP/G06881X/1 (Bristol), and EP/G070180/1 (Imperial) "Next Generation Energy-Harvesting Electronics: Holistic Approach"