Next Generation Energy-Harvesting Electronic Systems: Holistic Approach

Theme A: Adaptive, high efficiency micro generators

Task A1 – Automatic tuning of generator resonant frequency(imperial)
Task A2 – Interface circuitry for vibration-driven micro-generators (Bristol)

Showcase 11Feb 2013

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Overview

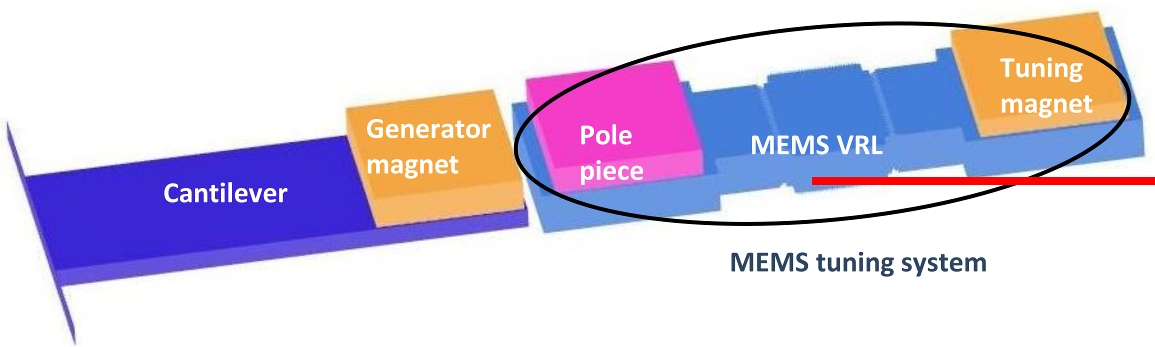
Task A1 – Automatic tuning of generator resonant frequency

- Resonant frequency tuning using MEMS Variable Reluctance Link (VRL)
- Resonant frequency tuning using Potential Well technique

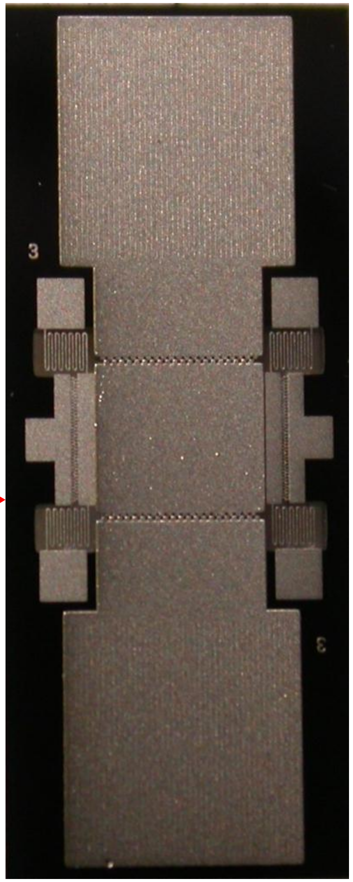
MEMS Variable Reluctance Link

Tuning concept of generator system:

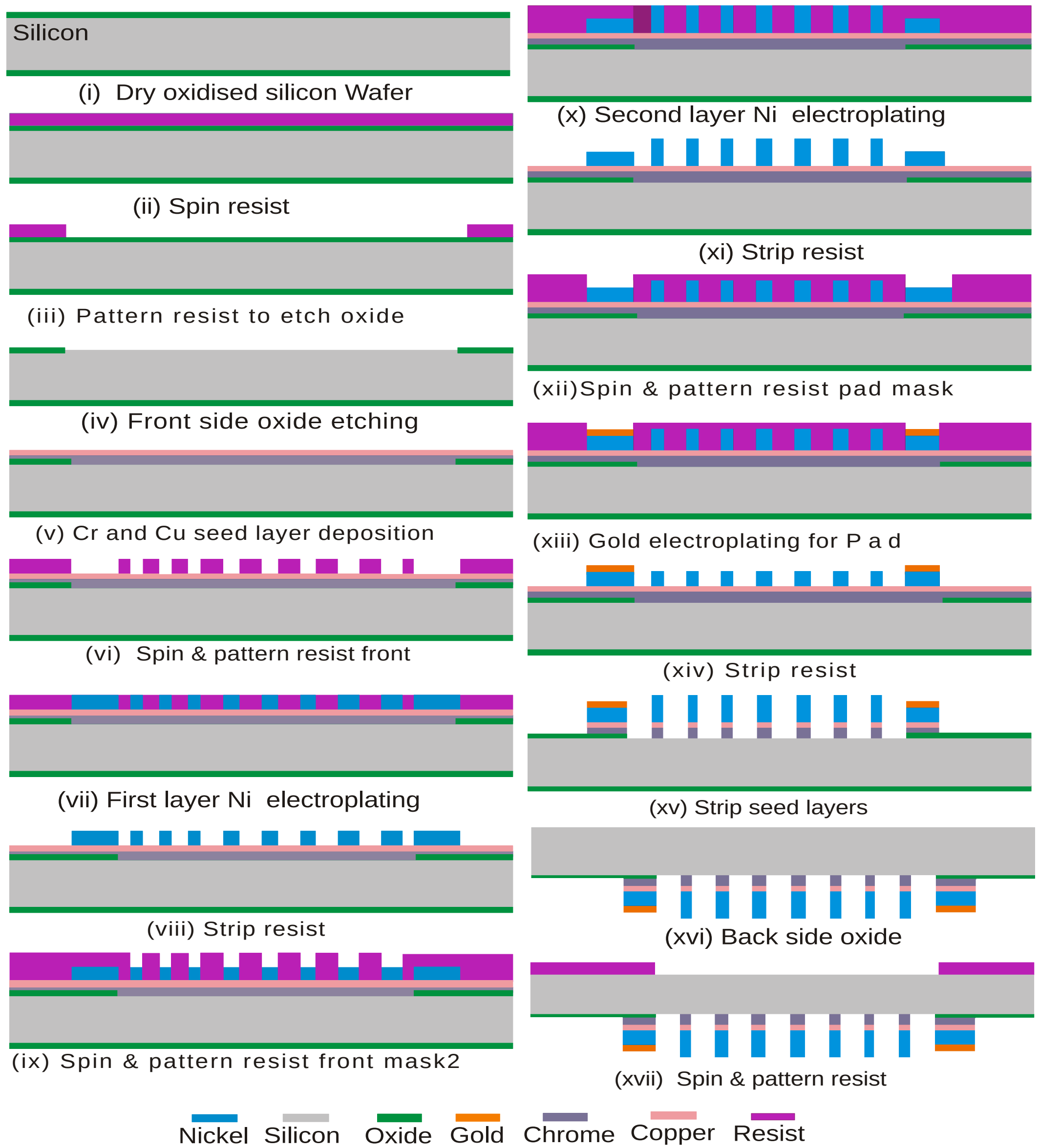
- Variable Reluctance Link(VRL)
- Use permanent magnet, linked to oscillating proof mass by low reluctance path to pole piece
- Vary reluctance of this path by introducing a variable air gap
- MEMS Comb drive actuator controls variable air gap of VRL



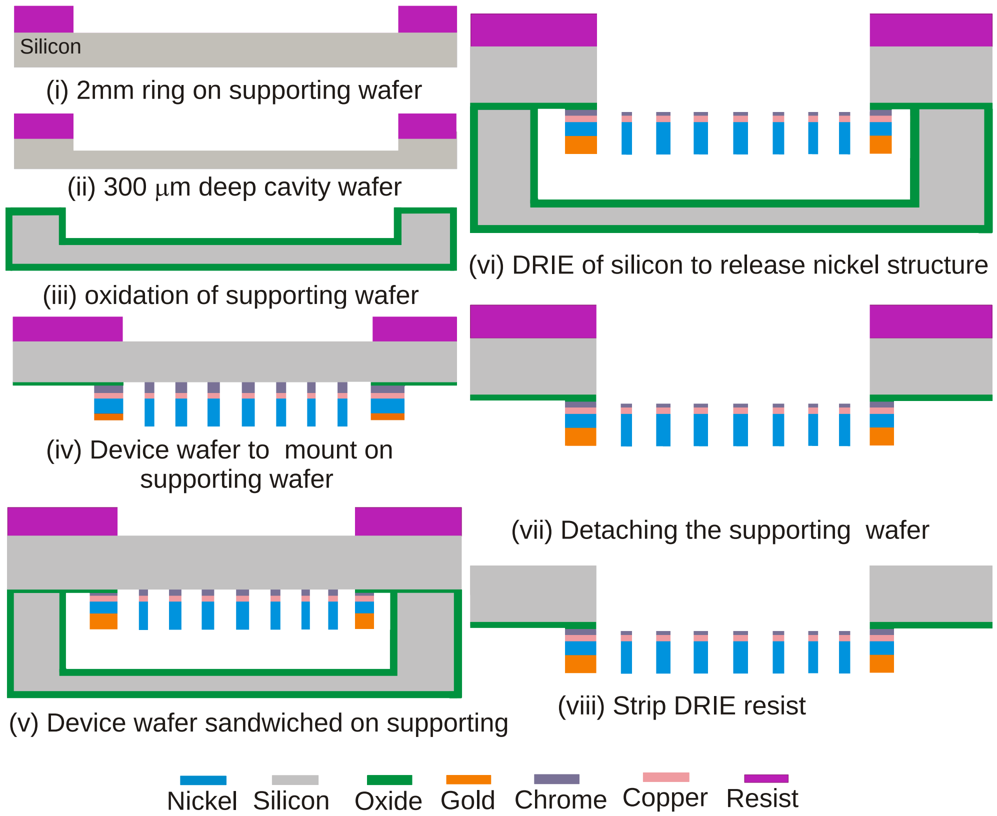
MEMS tuning system



Process flow for MEMS VRL



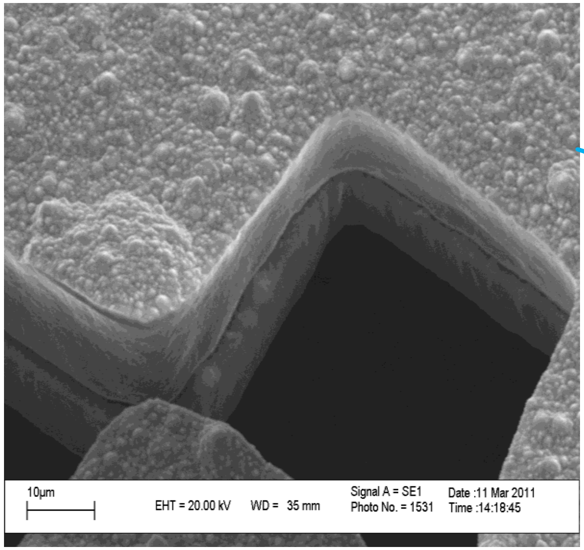
Process flow for MEMS VRL

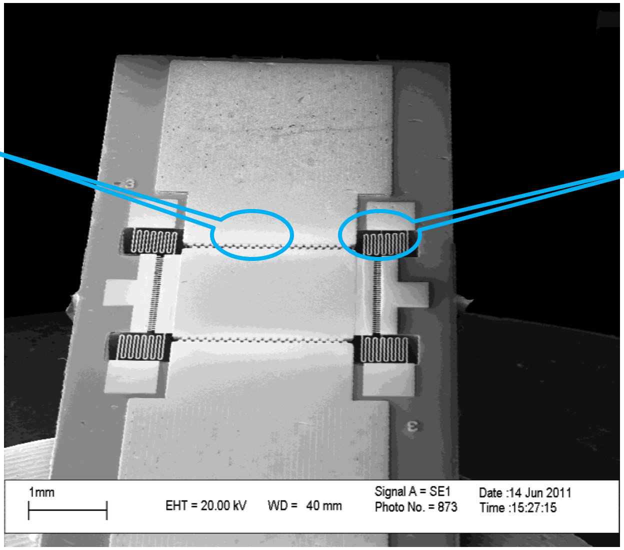


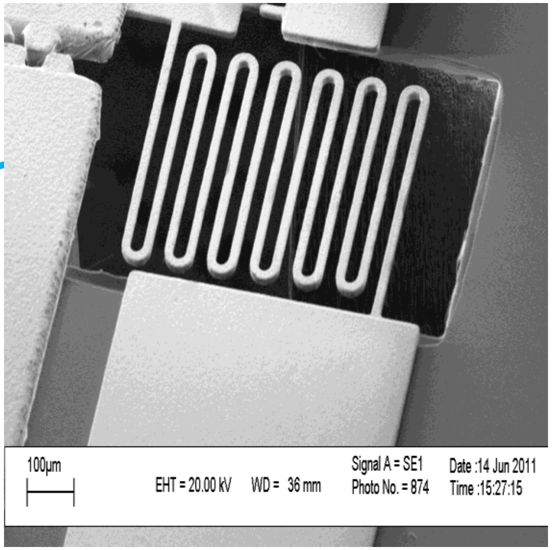
MEMS process to release the VRL structure from the back side wafer

Variable Reluctance Device, design:

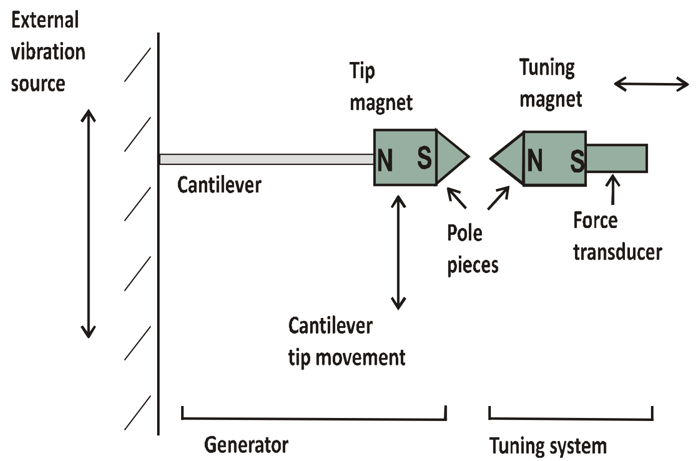
- Magnetic flux will pull link into low reluctance position with high force
- To reduce required actuation force, balance this magnetic effect against suspension stiffness of variable link
- Electrostatic comb drive to limit power consumption of actuator



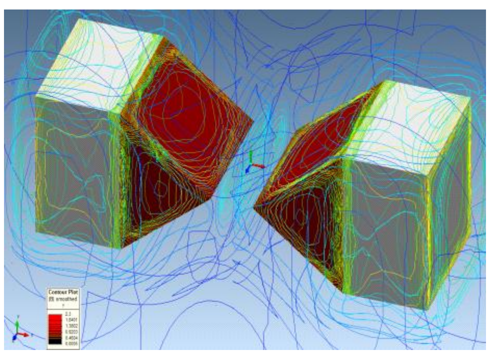




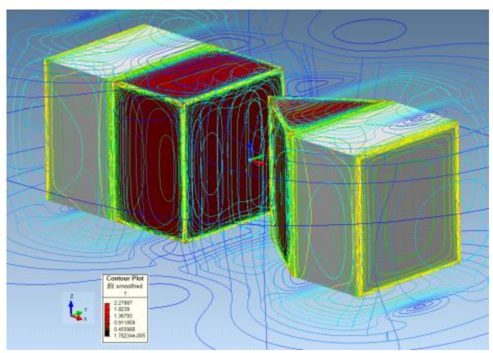
Resonant frequency tuning using Potential Well technique



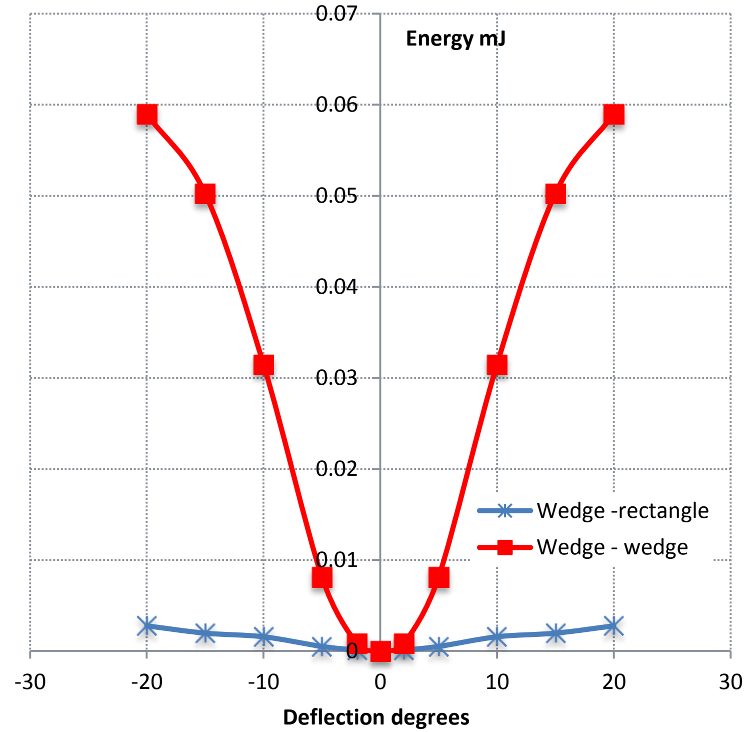
Potential well technique with sharp wedge shape pole piece on both generator and tuning system



Force: 146 mN

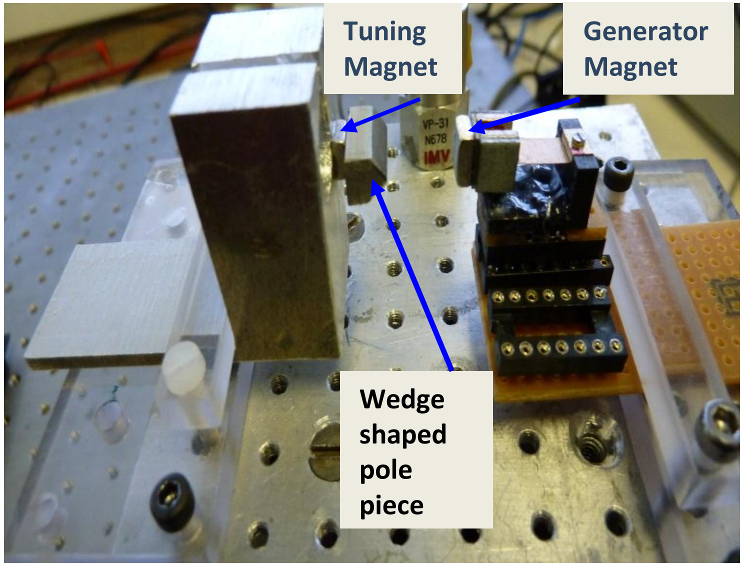


Force: 179 mN

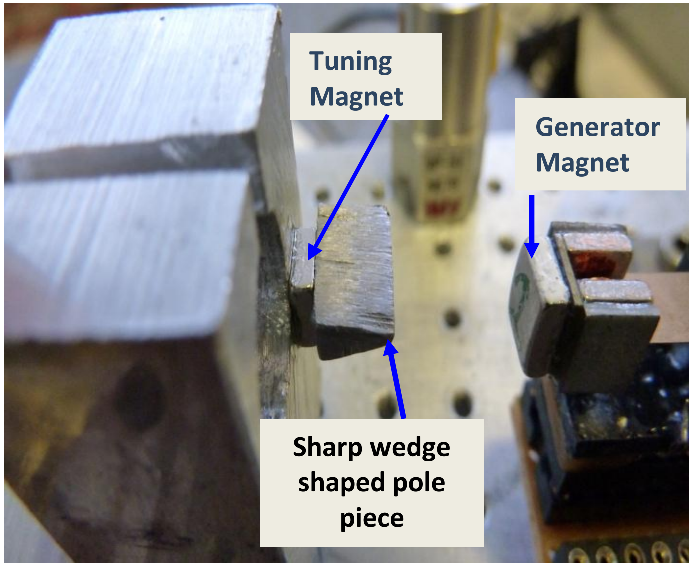


Potential wells for wedge-wedge and wedge-rectangle pole piece systems showing considerable difference in the depth of the wells when 1 mm pole-piece separation in each case.

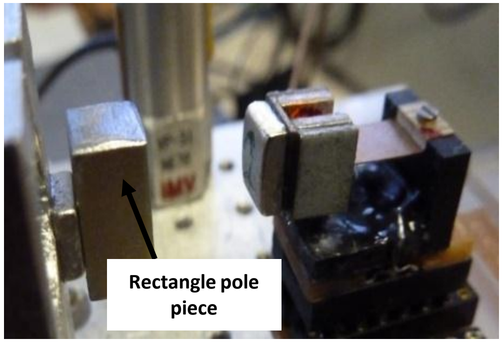
Resonant frequency tuning using Potential Well technique

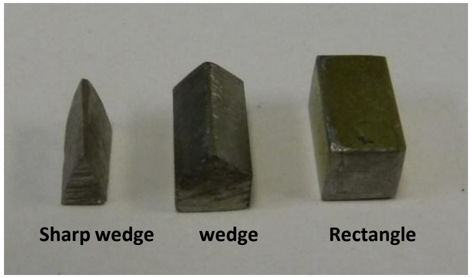


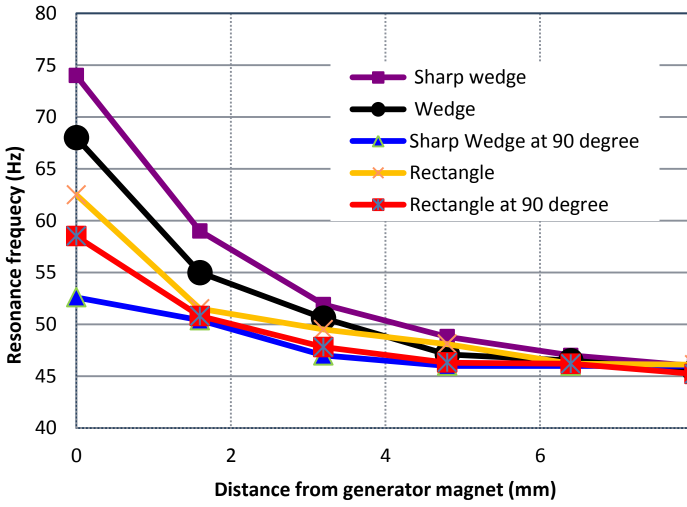
Test arrangement with shaped pole piece



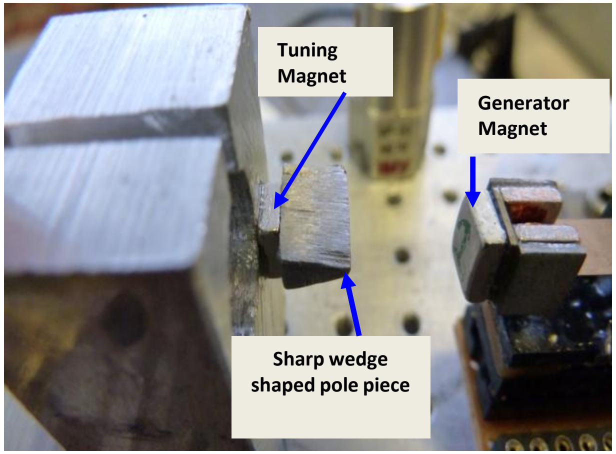
Test arrangement with sharp wedge shape pole piece



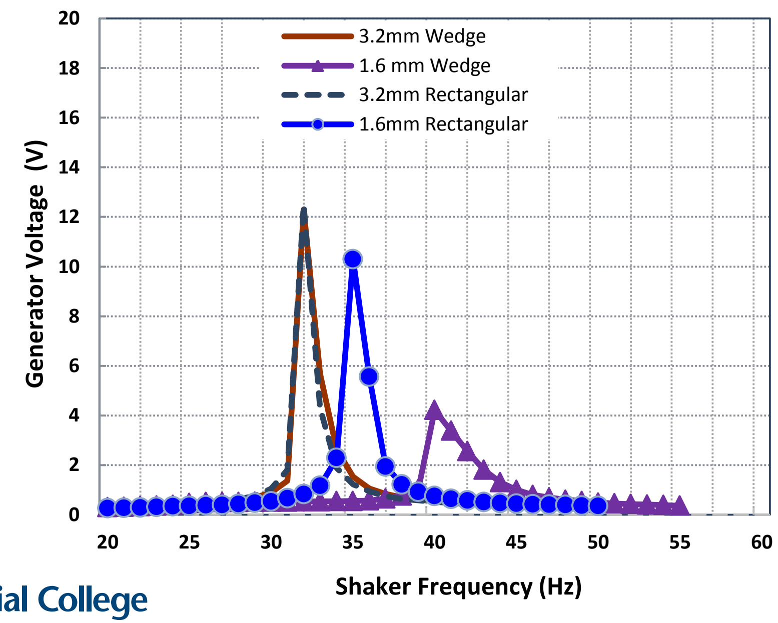


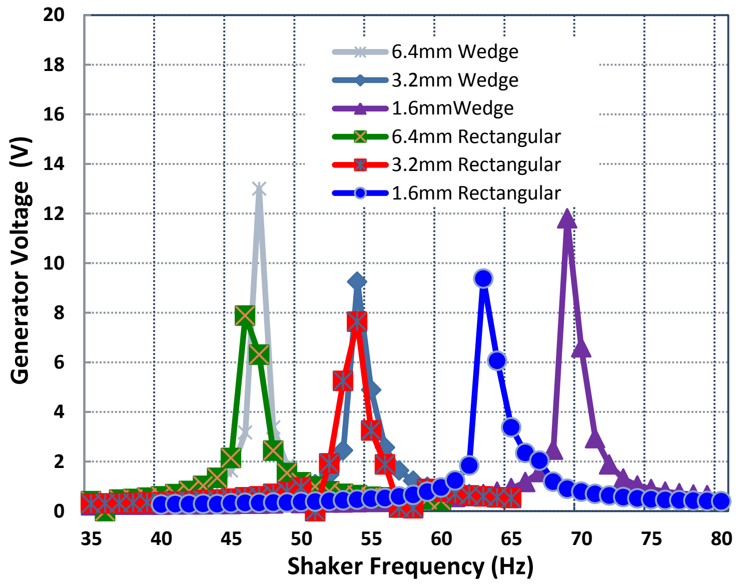


Resonant frequency tuning using Potential Well technique

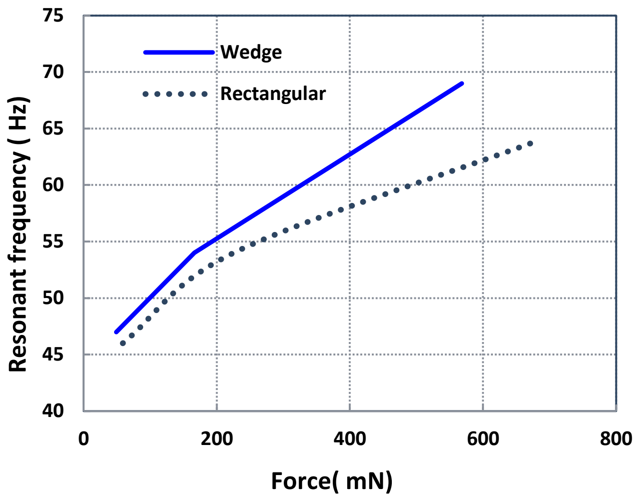


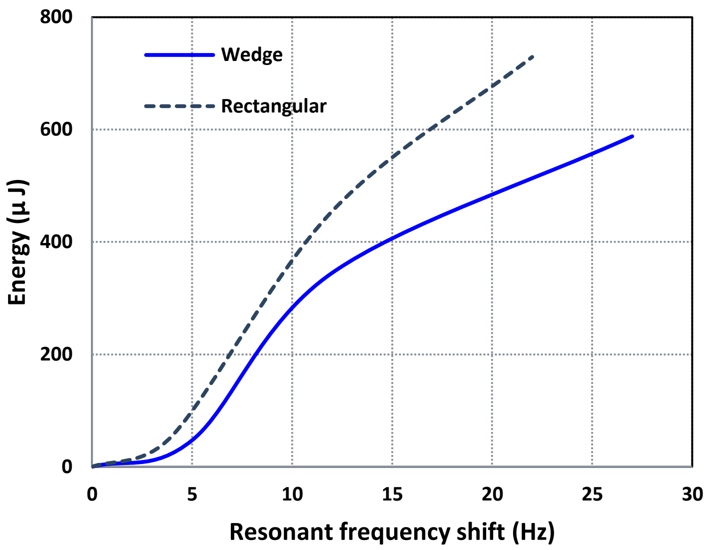
Test arrangement with sharp wedge shape pole piece only on tuning system





Resonant frequency tuning using Potential Well technique





A tuning range of 25% of the untuned resonant frequency (45Hz) is achieved with the wedge-shaped pole-pieces, approximately double that achieved with rectangular pole-pieces

Less energy is required to achieve the same tuning range using magnetic field shaping

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Task A2 – Interface circuitry for vibration-driven Energy Harvesters

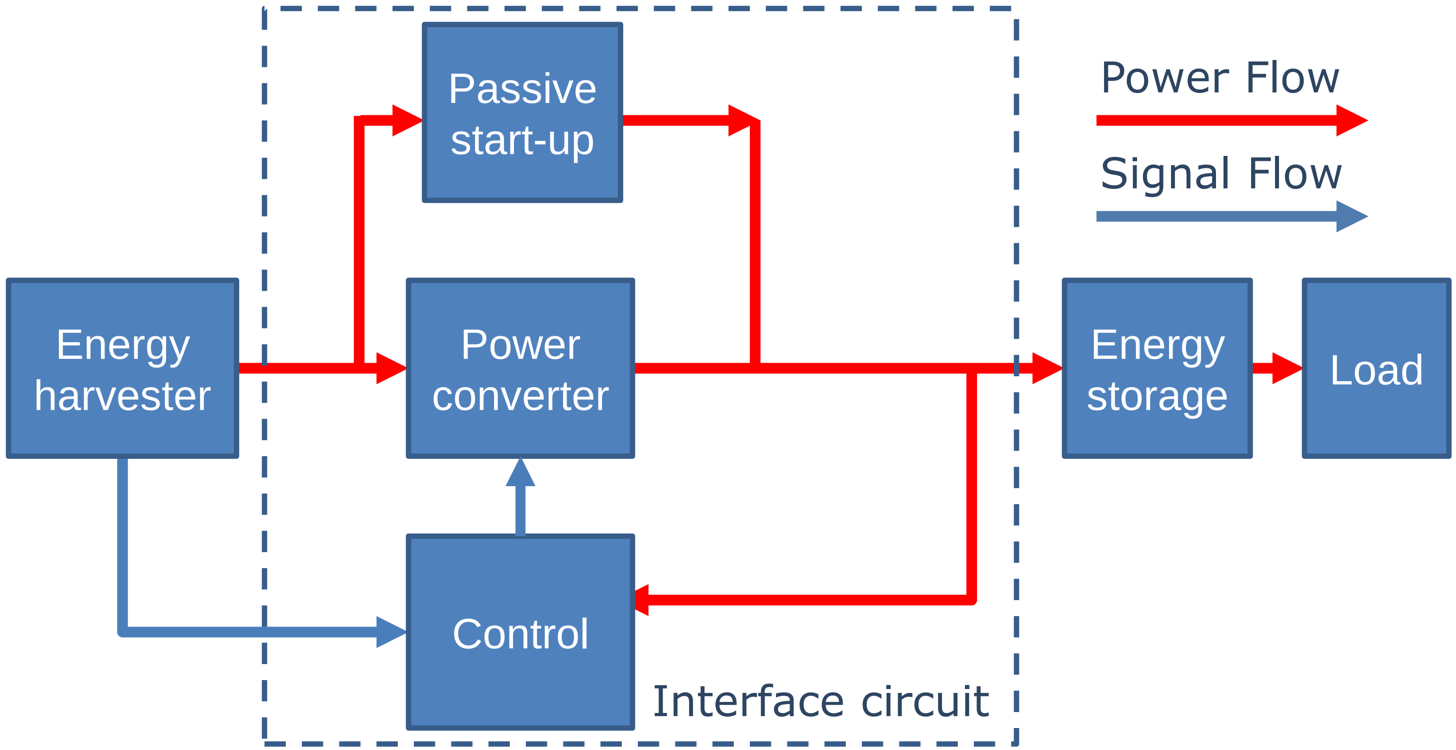
holistic energy harvesting

Main challenges

- Interface circuit design
- Matching circuit behaviour to harvester (impedances)
- Maximum power point tracking
- Tracking amplitude, frequency and load changes
- Very low power implementations

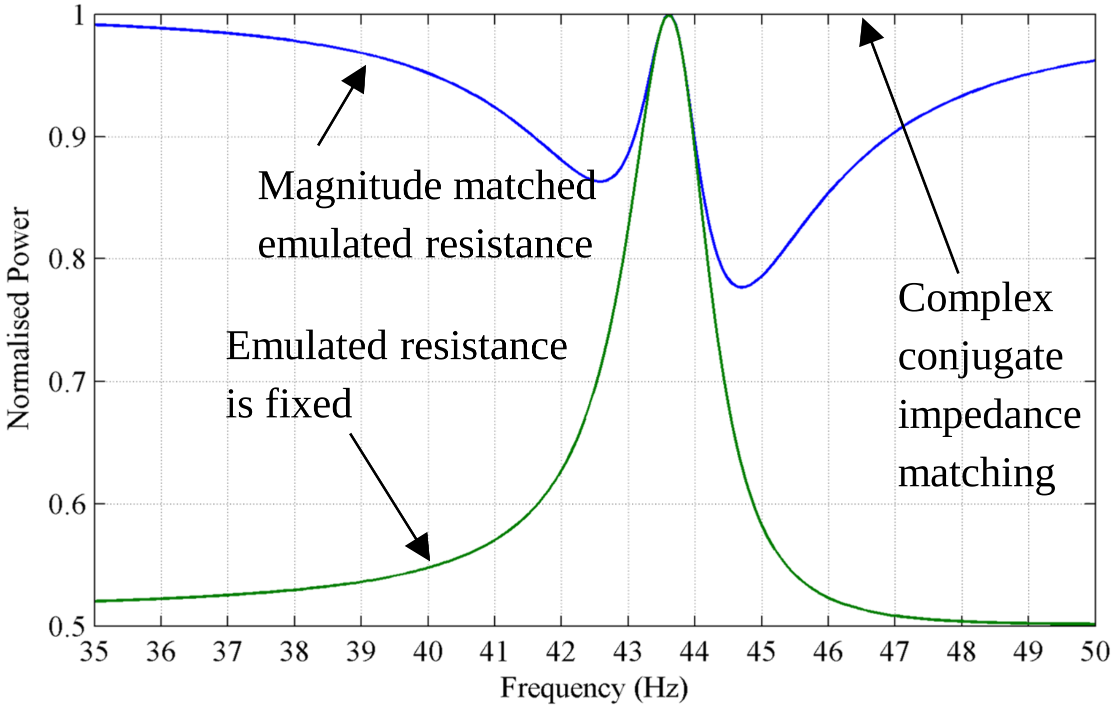
INTERFACE CIRCUIT DESIGN

- Rectification and Voltage Boosting
  - The harvester generates low-amplitude (<1V) AC voltage
  - The load requires 2V – 4.5V DC voltage
- Zero energy start-up



Matching circuit input impedance to harvester

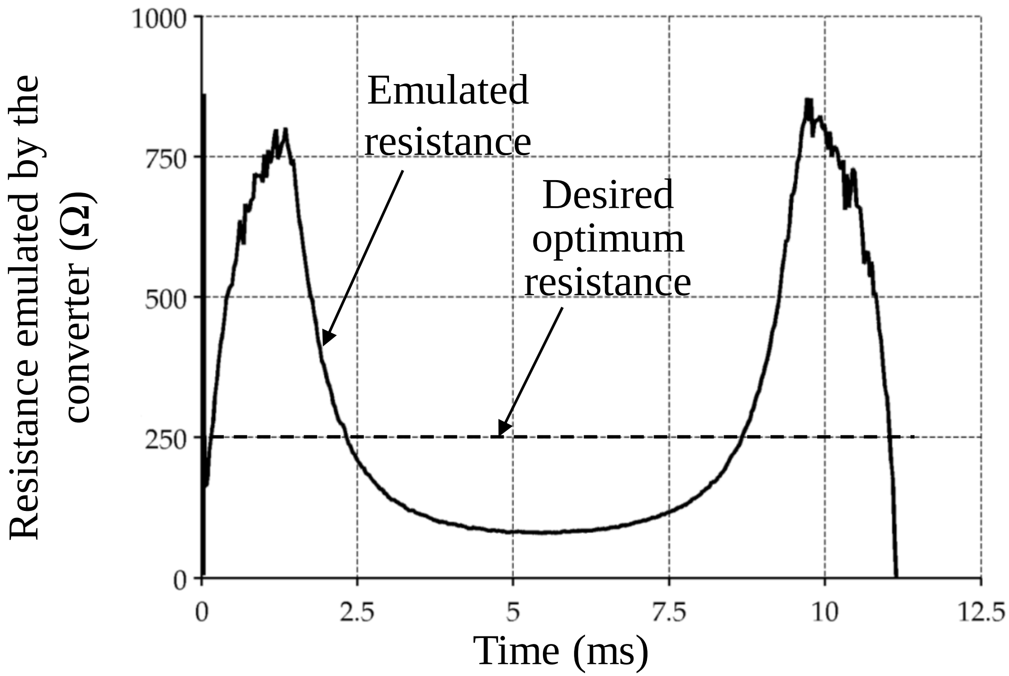
- Maximum power is extracted at matched impedances
- Harvester impedance is a function of the frequency
- Complex conjugate impedance matching requires high quiescent power for implementation
- Power close to the theoretical maximum can be extracted when the emulated resistance matches the magnitude of the source impedance



Power extracted with fixed load (green) and load adaptive to the frequency (blue)

Converter control

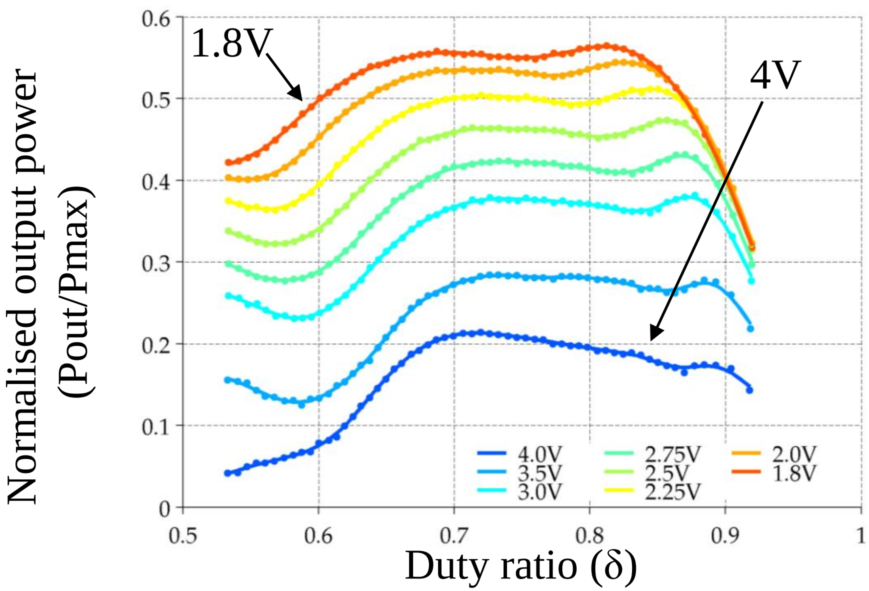
- The input impedance of the converter is a function of the instantaneous input and output voltages
- For maximum power extraction the impedance should be fixed during the harvester cycle and equal to the optimum



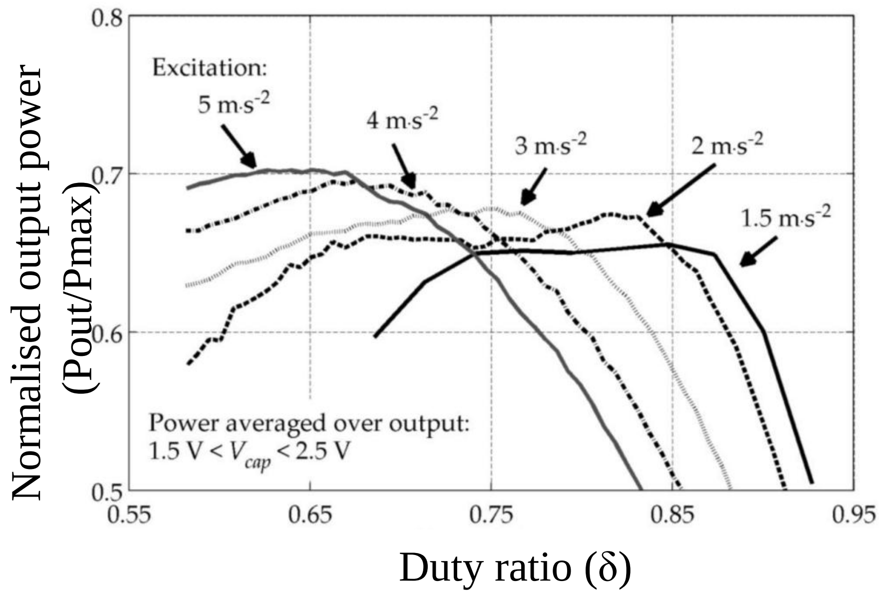
Emulated resistance during one harvester half-cycle at a constant duty ratio of the converter, the variation is caused by variation in the input voltage

Maximum power transfer tracking

- The power delivered to the load is a function of the extracted power and the conversion efficiency
- The optimum operating point is a function of the excitation magnitude and the output voltage



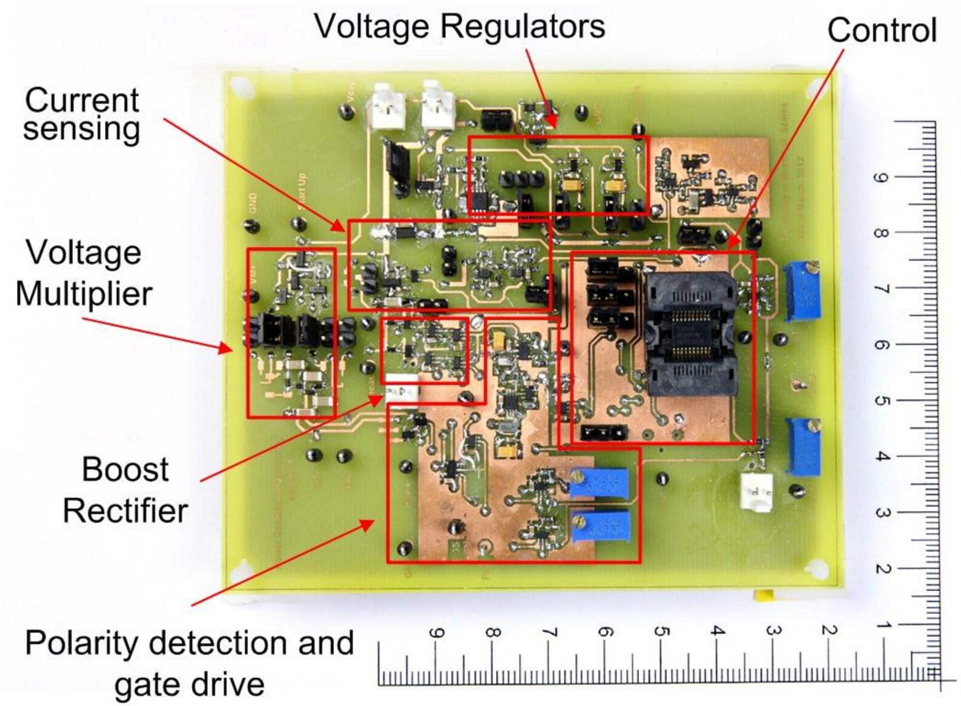
Output power as a function of the duty ratio at different output voltages, acceleration is constant (200 mg)



Output power as a function of the acceleration averaged over output voltage levels from 1.5 to 2.5 V

Low power implementation

- All functional requirements should be implemented at very low power which will allow for miniaturization of the harvester
- To achieve low-power operation:
    - The quiescent consumption should be as low as possible
    - The conversion efficiency should be maximised



Implementation of high-efficiency ultra-low-power adaptive interface circuitry for energy harvesting