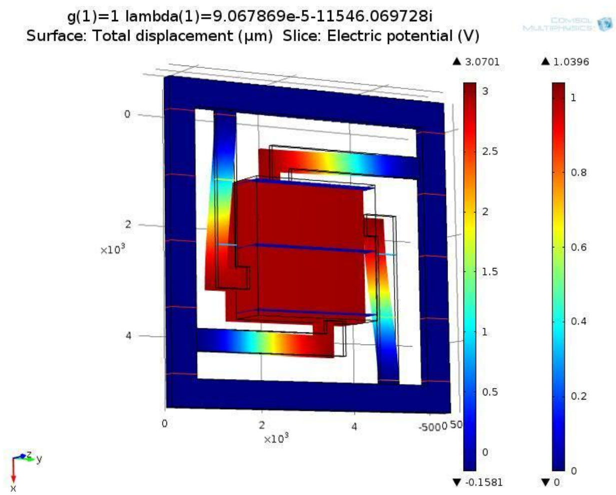
Design and Simulation of MEMS Based Piezoelectric Vibration Energy Harvesting System



Akila R.
Bharath Kumar M.C.
Deepa B. Prabhu
Anju Gupta
M. Alagappan
Dr. N. Meenakshisundaram
PSG College of Technology, Coimbatore

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The need for cleaner energy

- Mobile devices – independent of electric grid
- Periodic recharging of the batteries
- Disposal of the battery
- Convert existing renewable and waste energy into useful energy for devices
  - Solar radiation
  - Thermal differentials
  - Vibration
  - RF emissions
- The power from an industrial vibration source can be of the order of 100µW/cm^2 - sufficient for ultra-low power devices

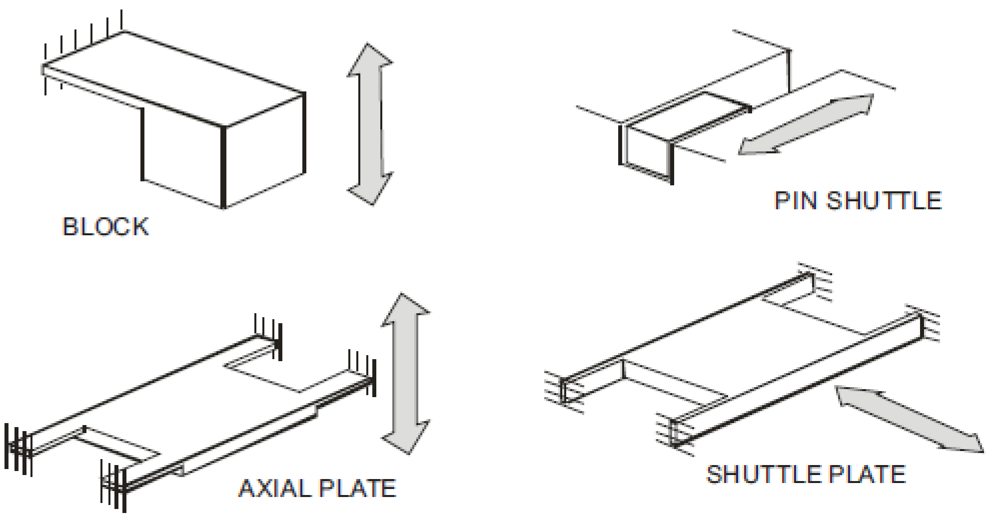
Heavy metals from battery harmful for environment
Picture: www.ehow.com

Solar panels for CCTV cameras
Picture: http://www.2mcctv.com

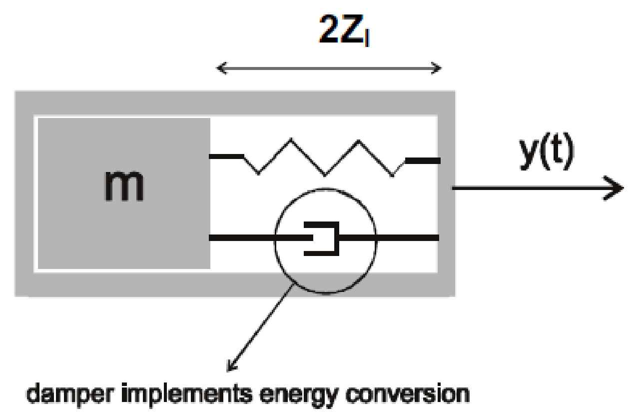
Vibration based energy harvesting

Design:

- Spring – mass- damper system
- Natural frequency of proof mass matches with the source vibration frequency
- Resonance - maximum coupling from the source to the transducing mechanism



Principal proof mass and suspension geometries for inertial energy harvesters
Image: E. P. Yeatman, "Micro -engineered devices for motion energy harvesting,"



A spring suspension supports a proof mass m within a frame, motion of the mass on its spring is excited by motion of the host structure y(t), and damping of this internal motion by the transducer generates electrical power
Image: E. P. Yeatman, "Micro -engineered devices for motion energy harvesting,"

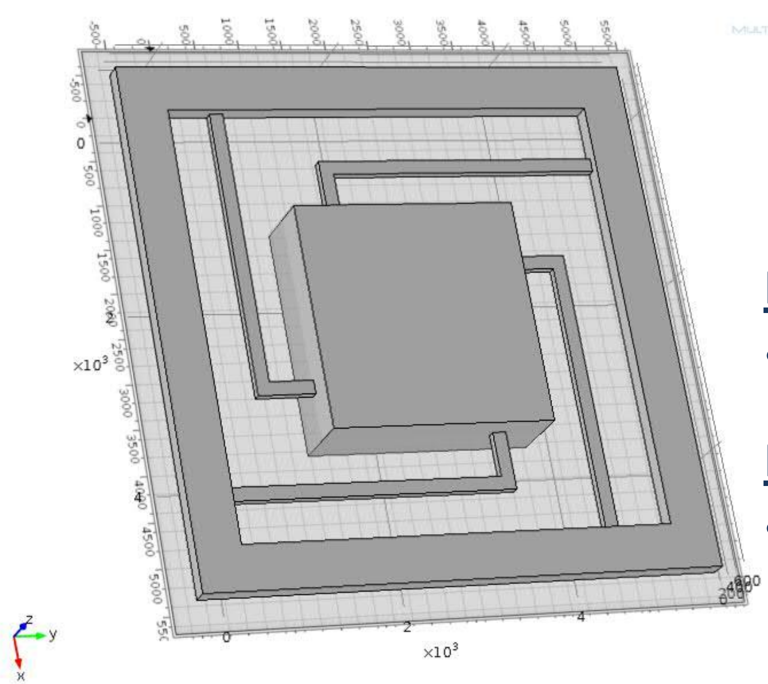
Transducing mechanisms

- Electrostatic
  - Plates of the capacitor move against each other by a mechanical force
  - Capacitor has to be charged initially with a battery for measuring the displacement
  - Not an ideal mechanism for energy harvesting
- Electromagnetic
  - Used at the macro scale mostly with the pin shuttle geometry
  - Integration in the micro scale is challenging due to the design of coils and micro scale magnets
- Piezoelectric
  - Produce output effectively even at low frequencies
  - Reasonably high voltage levels

Methodology

- Identify and select a source of vibration - machinery in industries
- Tune proof mass - spring system to the frequency of vibrations
- Develop a software model for simulation and optimization studies
- Test the transducer mechanism and design the converter and/or storage circuit
- Redesign to accommodate variations

Proposed geometry and parameters



Geometry:

- The proof mass is designed to be square prism of side length 2500 μm, and of variable height for tuning the device
- The suspension is spider leg geometry (150μm wide) with fixed constraints at one end and fixed to the proof mass at the other

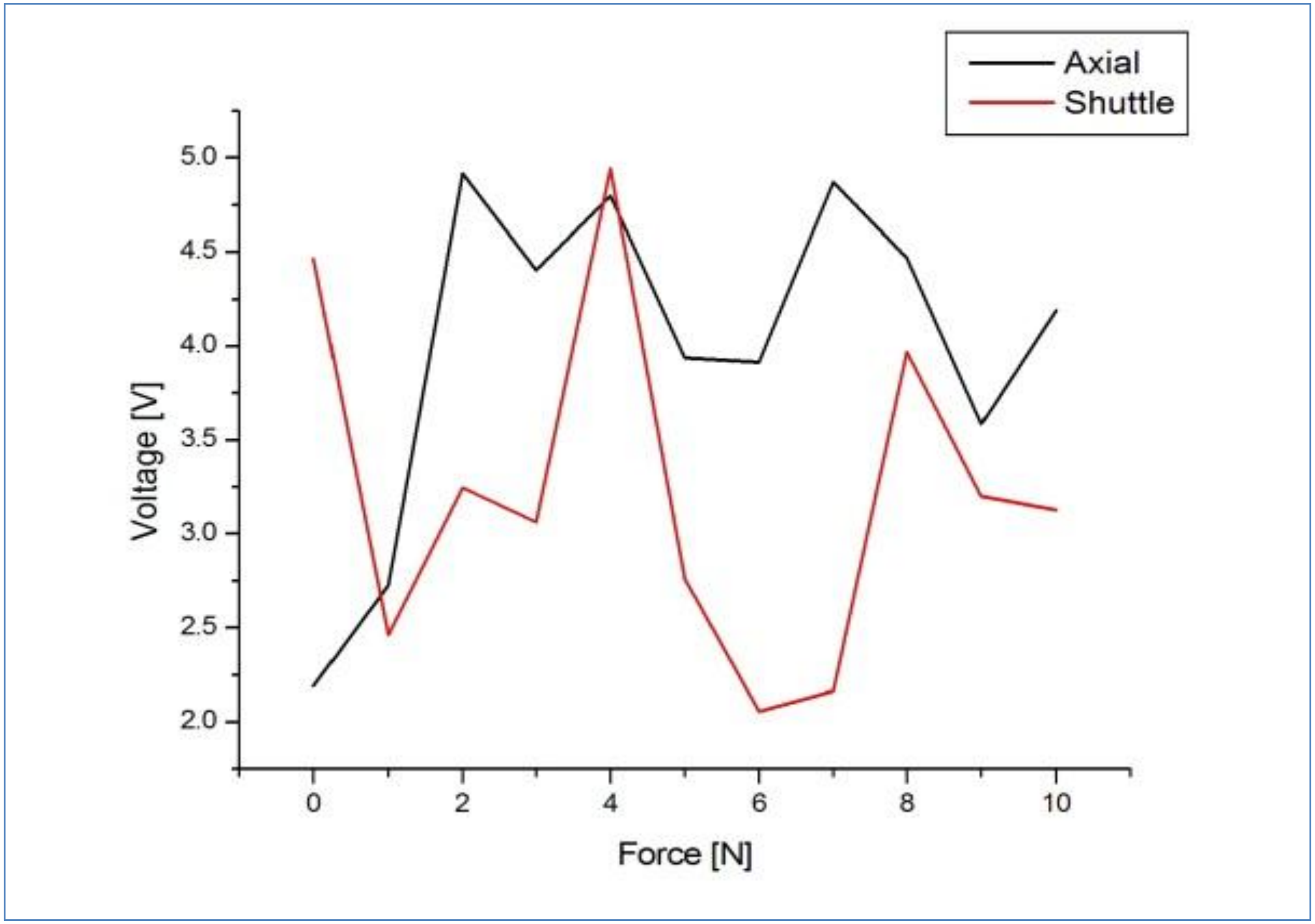
Physics used:

- Piezoelectric devices

Materials used:

- PZT-5H, Zinc oxide, $BaTiO_3$

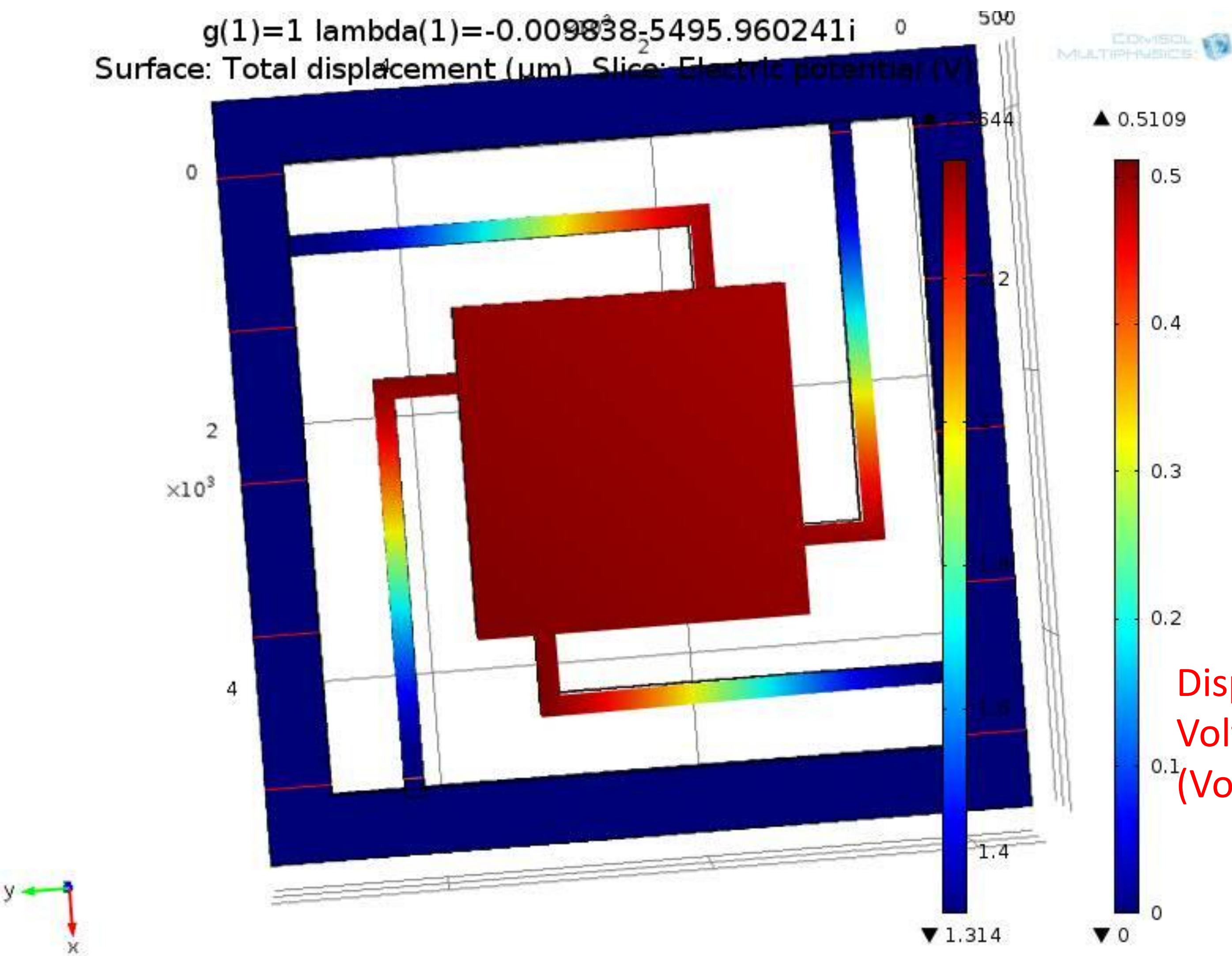
Effect of mode of operation



Effect of different piezoelectric materials

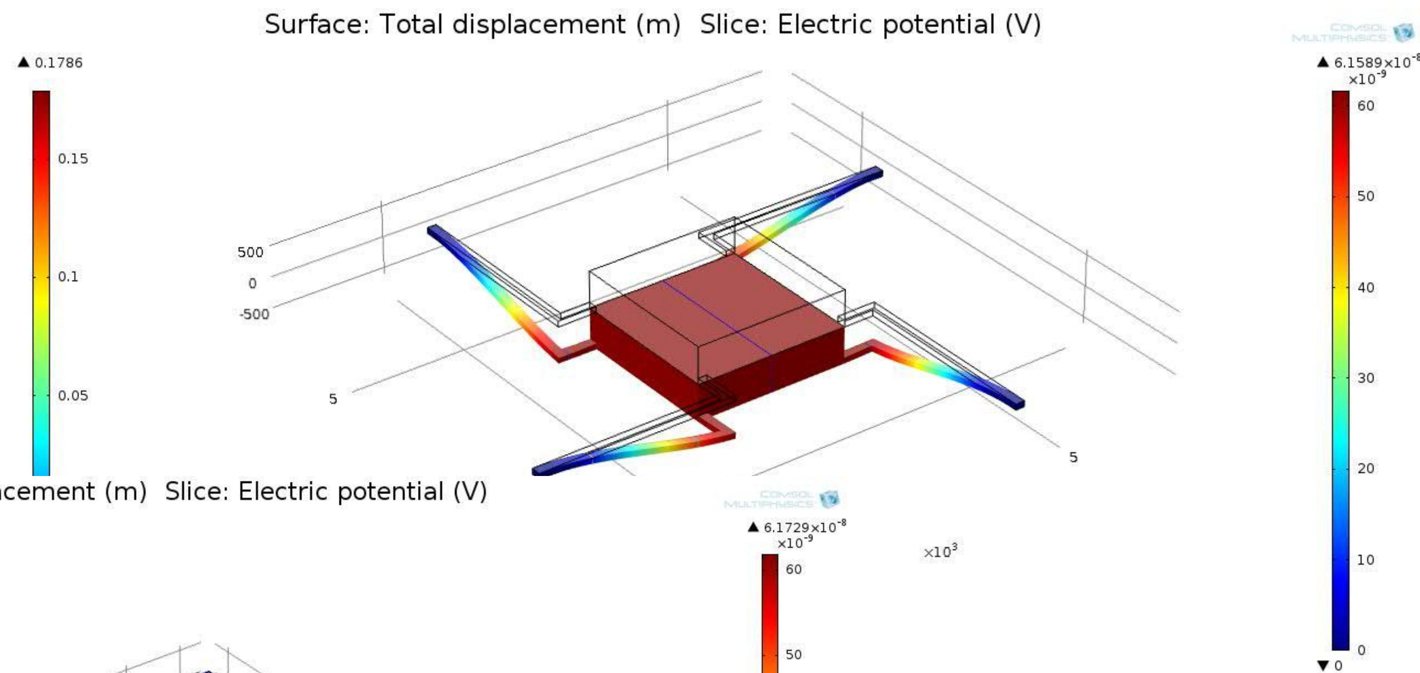
Material (density in kg/m^3)	Eigen frequency (kHz)	Displacement (μm)	Electric potential (V)
PZT (7500)	1.008	2.1896	3.4372
$BaTiO_3$ (5700)	1.434	0.1002	1.9866
ZnO (5680)	1.552	0.2667	4.521

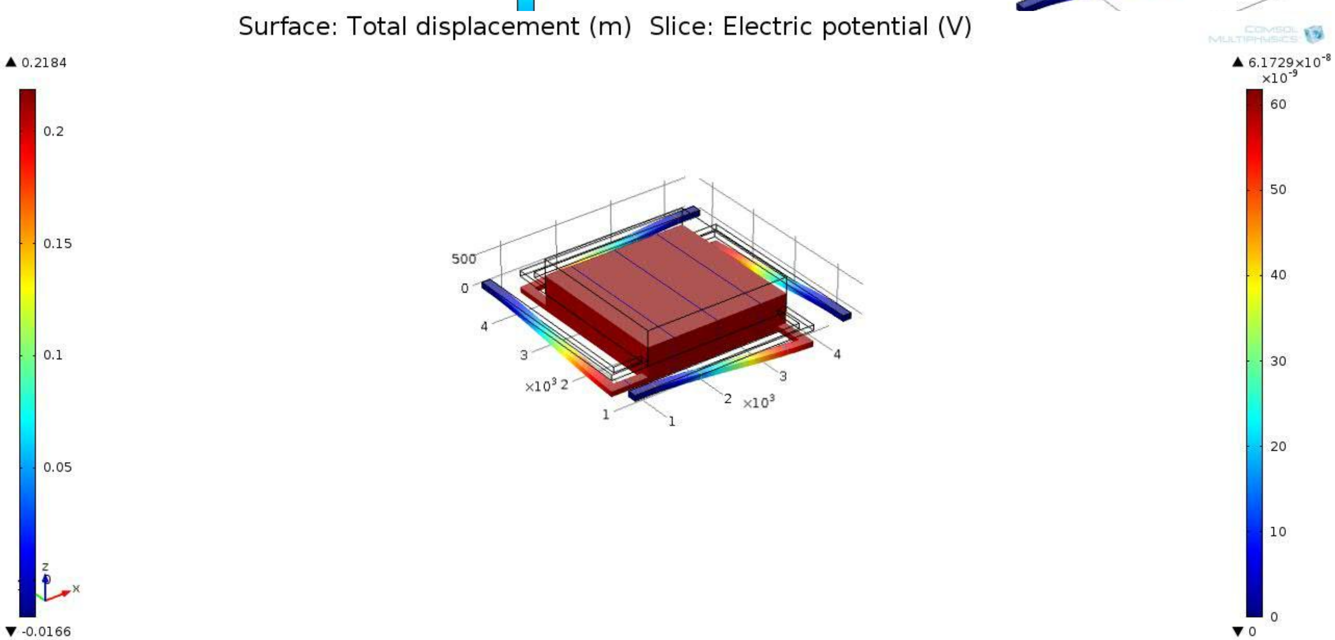
Study at a lower frequency- 25 Hz



Displacement= 0.5109 µm
Voltage = 2.3544 V
(Voltage at 1 kHz= 2.4565V)

Position of suspension legs

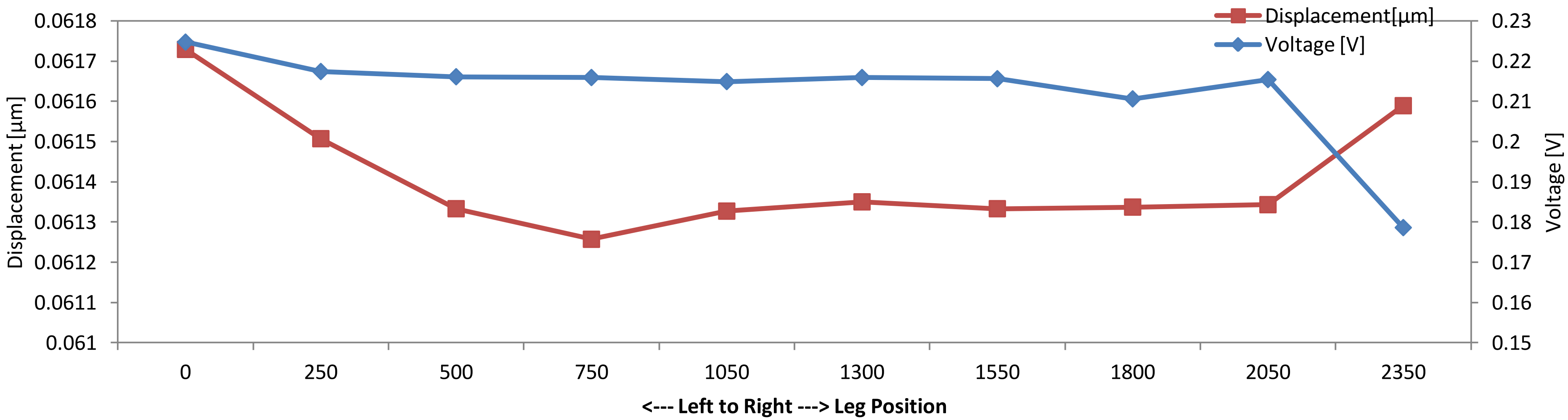




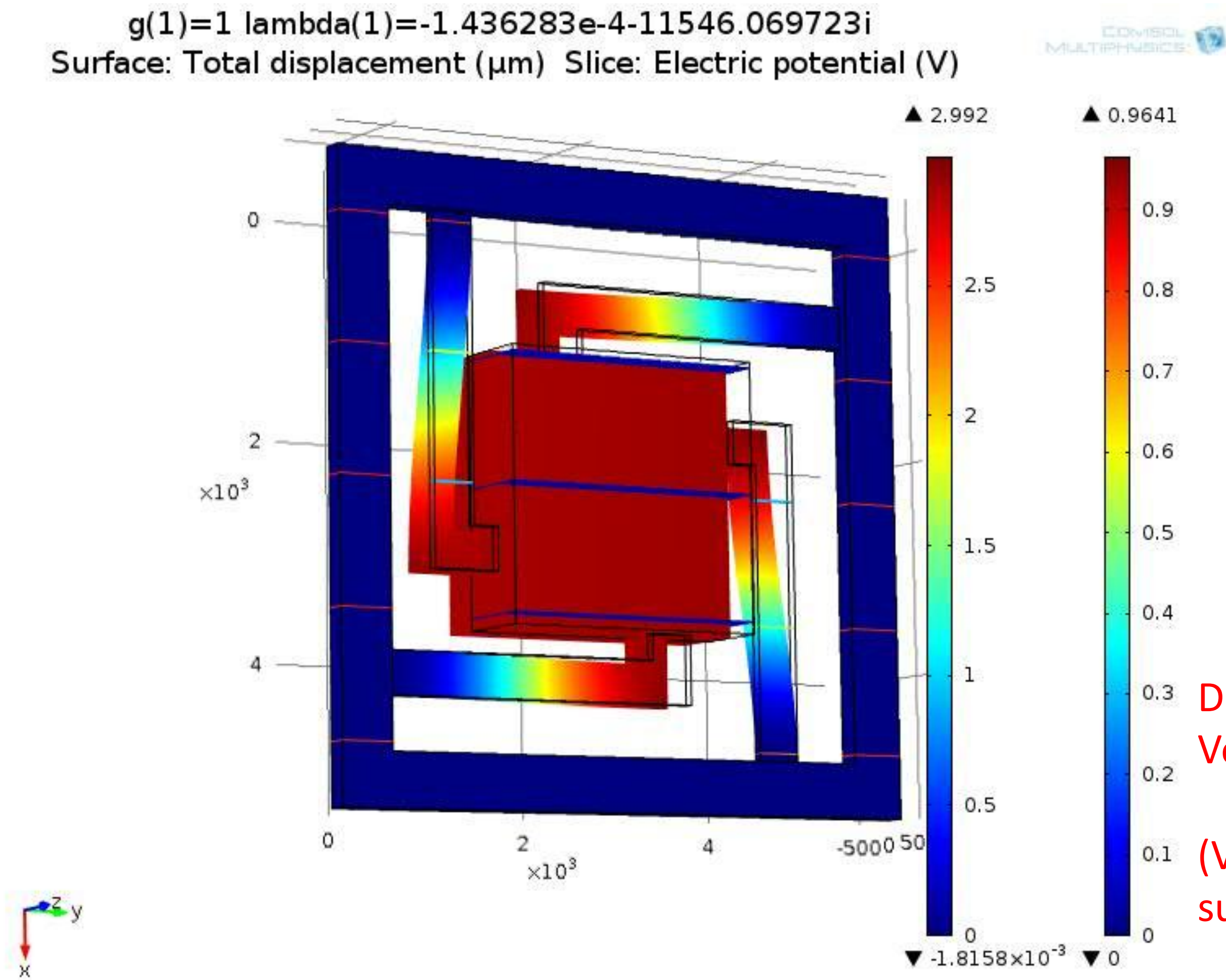
Position of suspension legs

Support position from end[μm]	Voltage [V]	Displacement[μm]
0	0.2247	0.061729
250	0.2174	0.061507
500	0.2161	0.061333
750	0.2159	0.061257
1050	0.2149	0.061327
1300	0.2159	0.06135
1550	0.2156	0.061333
1800	0.2106	0.061337
2050	0.2154	0.061343
2350	0.1786	0.061589

Dimension in [μm]



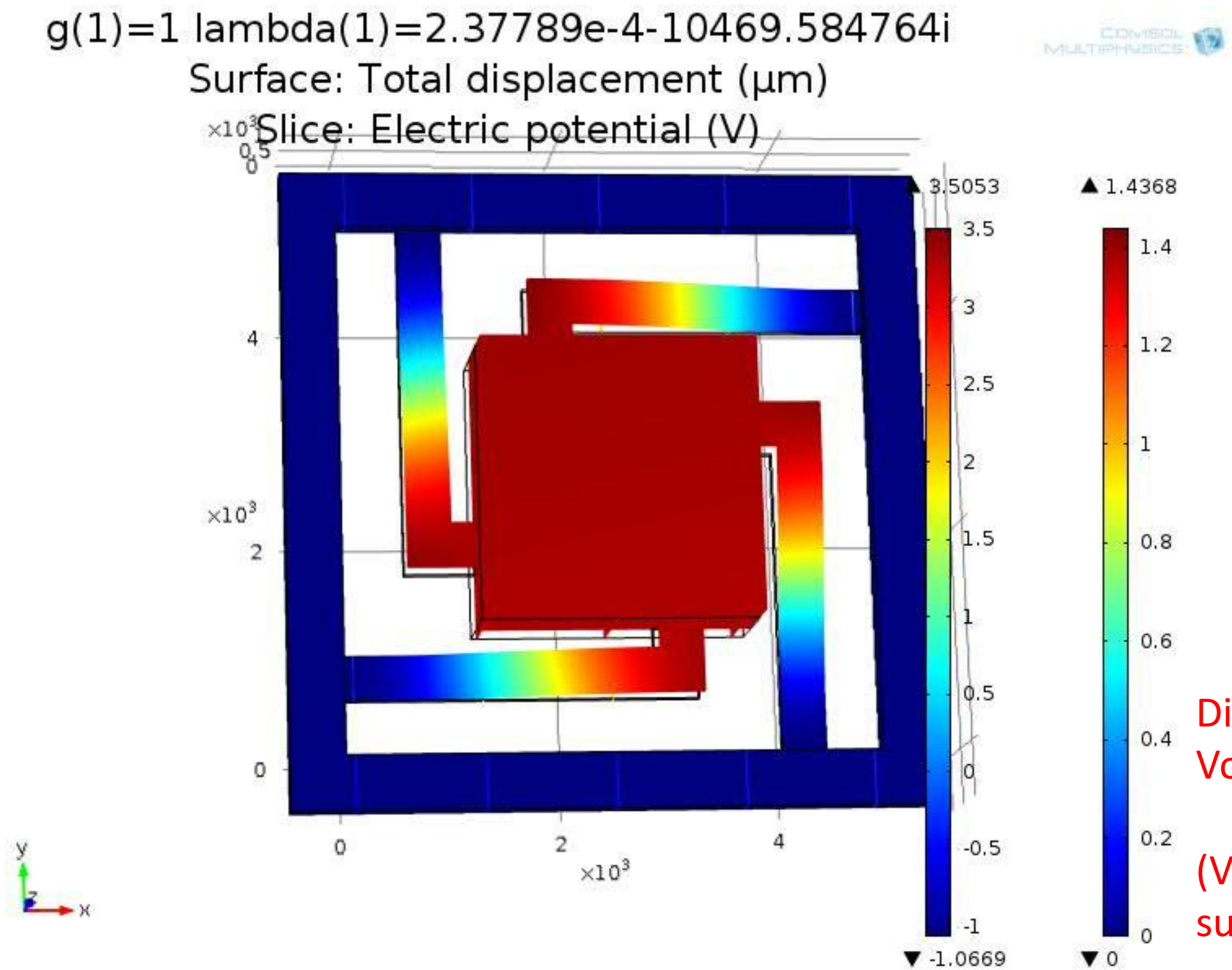
400 µm suspension, 1 kHz



Displacement= 0.9641 µm
Voltage = 2.992 V

(Voltage for 150 µm suspension= 2.4565V)

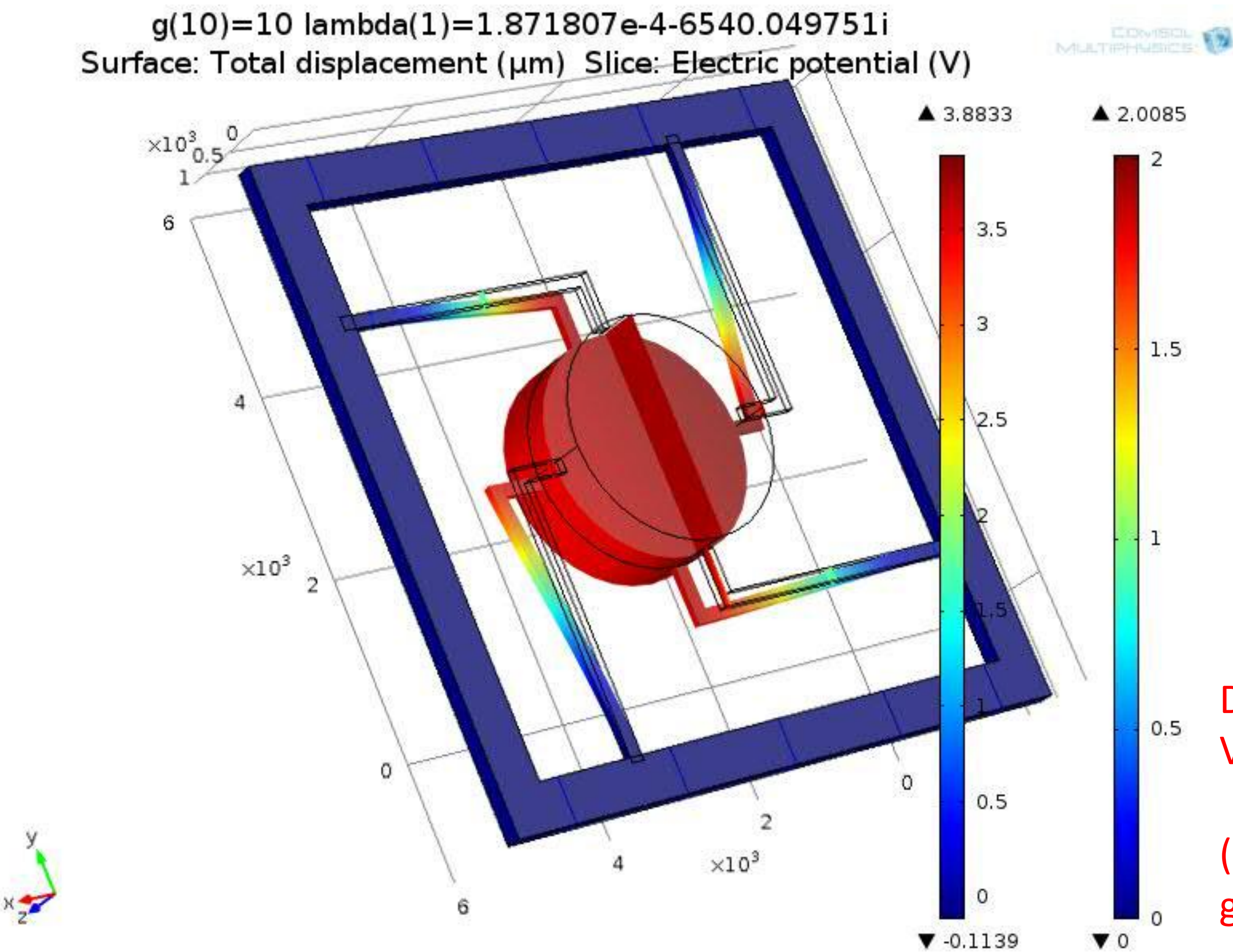
400 µm wide suspension, 25 Hz



Displacement= 1.4368 µm
Voltage = 3.5053 V

(Voltage for 150 µm suspension= 2.3544 V)

Circular proof mass at 1kHz



Displacement= 2.0085 μm
Voltage = 3.8833 V

(Voltage for square geometry= 2.4565V)

Conclusion

- Piezoelectric vibration energy harvester is designed and simulated
- Voltages of the order of 2- 4 V generated at 1kHz and 25 Hz resonant frequencies
- Effect of geometry and materials studied by simulation
- Future work:
  - to incorporate time dependent studies
  - Fabricate the device and test it

Reference

[1] E. P. Yeatman, "Micro -engineered devices for motion energy harvesting," in Electronic Devices meeting, IEEE International, Washington, DC, 2007.

[2] White paper, "Energy Harvesting, ULP meets energy harvesting: A game changing combination for design engineers," Texas Instruments, April 2010.

[3] D. Zhu, "Strategies for increasing the operating frequency range of vibration energy harvesters: a review," Measurement Science and Technology, vol. 21, 2010.

Acknowledgements

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