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Design and Analysis of Three DOF Piezoelectric Vibration Energy Harvester

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Outline

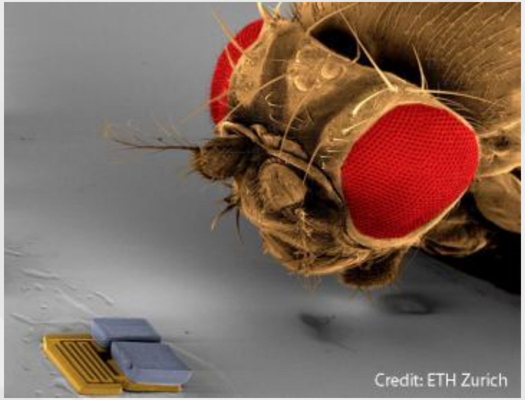
- Introduction to MEMS
- Vibration Energy Harvester
- Design Structure
- Working Principle and Theoretical Analysis
- COMSOL Simulation
- Conclusion and Future Work

What is MEMS?

- MEMS: Micro-Electro-Mechanical Systems

- Definition: Devices and Systems integrated electrical and mechanical components with micron scale.

- Typical MEMS Devices:
  MEMS Pressure Sensor, Accelerometer, Gyroscope, Micro-motor, resonator, Oscillators, Micro-mirror, Optical switch, RF capacitor etc.



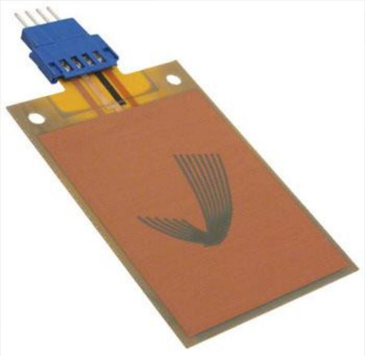
MEMS-and-Bug ETH Zurich

What are Vibration Energy Harvesters

- Vibration Energy Harvester device harvests wasted energy from mechanical vibrations.

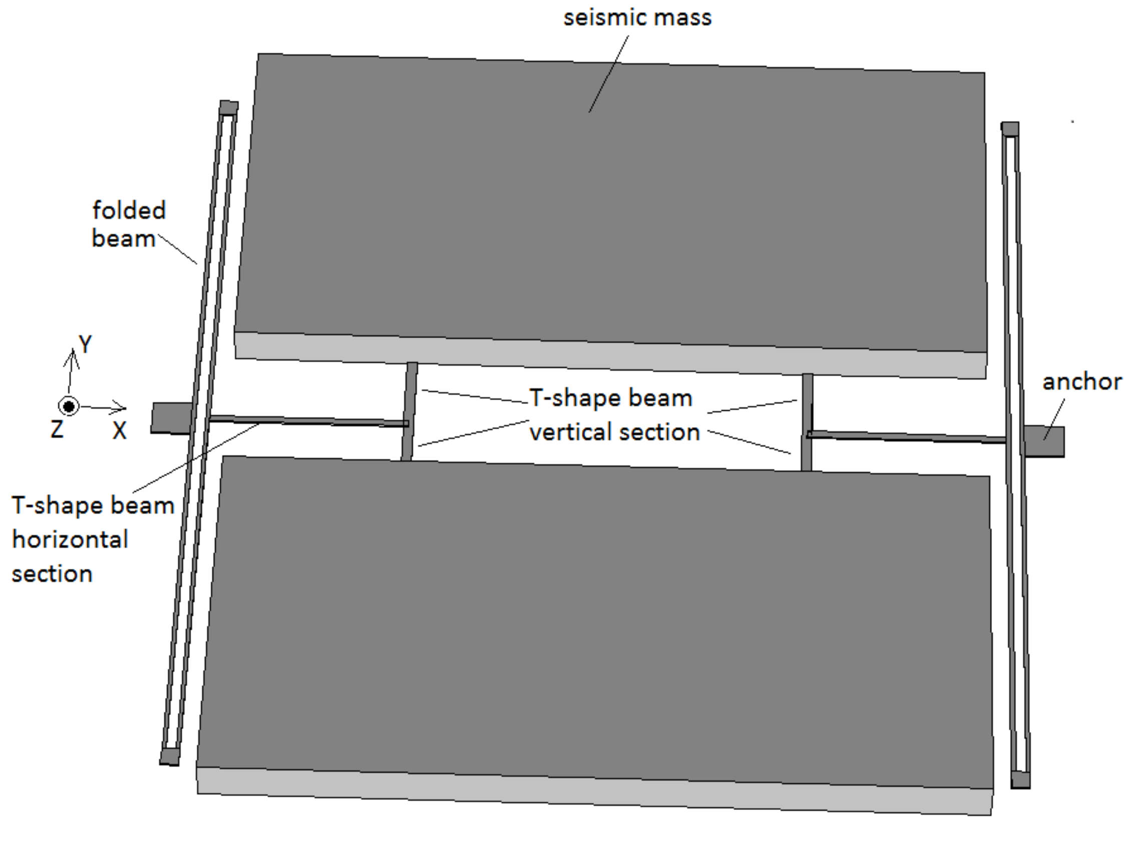
- Piezoelectric materials help energy harvesters to convert mechanical energy into alternating electrical energy (AC).

- AC then electronically converted to DC, which can be used to drive a multitude of wireless applications or to recharge a battery.



A Simple Cantilever Piezoelectric Energy Harvester

Device Structure Design



Working Principle

- The device consists of two mass blocks suspended by four sets of folded beams and two sets of T-shape beams. The folded beams are fixed by two anchors.

- Piezoelectric thin films with top/bottom metal electrodes are pre-deposited on the bottom surface of the T-shape beams. The seismic masses are much thicker than the beams, thus its mass center is above the plane of the beams. This imbalance is intentionally designed to induce out-of-plane movement of both T-shape beams when in-plane vibration is sensed..

- The resulted stress along the beams causes the piezoelectric films to generate electrical voltage output which is passed through a rectifying circuit to charge a battery.

Theoretical Analysis

- The width, length and thickness of each folded beam section are W_{fb}, L_{fb}, t_b respectively. The width, length and thickness of the horizontal section of the T-shape beam are W_{tb1}, L_{tb1}, t_b respectively. The width, length and thickness of each vertical section of the T-shape beam are W_{tb2}, L_{tb2}, t_b respectively. The width, length and thickness of one seismic mass are W_m, L_m and t_m respectively. Density of silicon is ρ, and Young's modulus of silicon is E.

Theoretical Analysis: Resonant Frequency along X direction

- The total spring constant of the device along X direction is

$$K_{X\_tot} = \frac{K_{fb\_xtot} \cdot K_{tb2\_xtot}}{K_{fb\_xtot} + K_{tb2\_xtot}}$$

The total mass of two seismic masses is

$$M = 2\rho W_m L_m t_m$$

Ignoring the mass of piezoelectric films and its top/bottom electrodes, and treating the energy harvester as simplified spring-mass system, the resonant frequency of the energy harvester along X direction is

$$f_x = \frac{1}{2\pi}\sqrt{\frac{K_{X\_tot}}{M}}$$

Theoretical Analysis: Resonant Frequency along Y direction

- The total spring constant of the device along Y direction is

$$K_{Y\_tot} = 2EW_{tb1}^3 \cdot t_b / L_{tb1}^3$$

The resonant frequency of the energy harvester along Y direction is

$$f_y = \frac{1}{2\pi}\sqrt{\frac{K_{Y\_tot}}{M}}$$

Theoretical Analysis: Resonant Frequency along Z direction

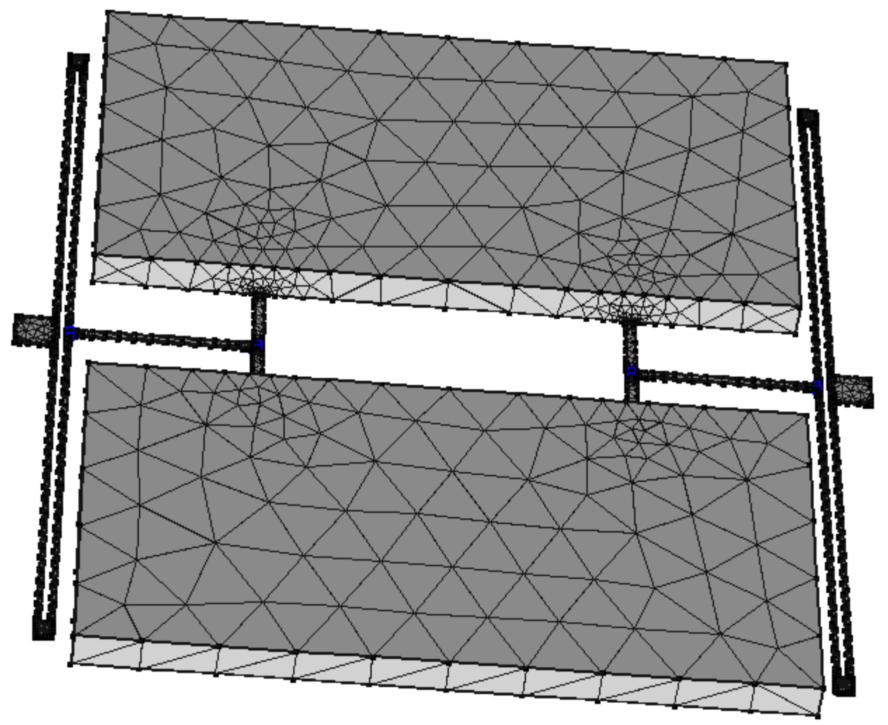
- The total spring constant of the device along Z direction is

$$K_{Z\_tot} = \frac{1}{(1/K_{fb\_ztot} + 1/K_{tb1\_ztot} + 1/K_{tb2\_ztot})}$$

The resonant frequency of the energy harvester along Z direction is

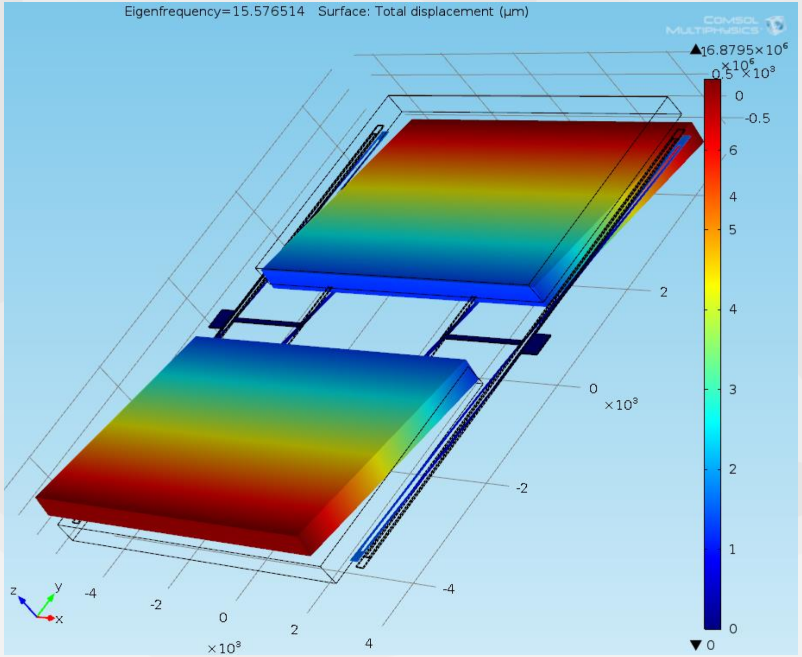
$$f_z = \frac{1}{2\pi}\sqrt{\frac{K_{Z\_tot}}{M}}$$

COMSOL Simulation



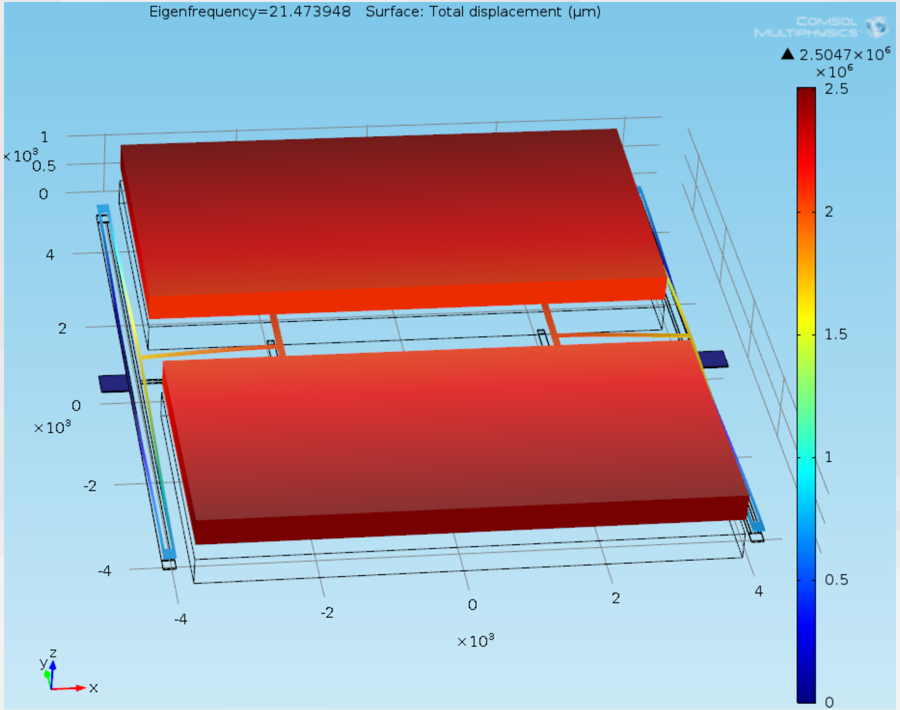
COMSOL meshed model of energy harvester

COMSOL Simulation



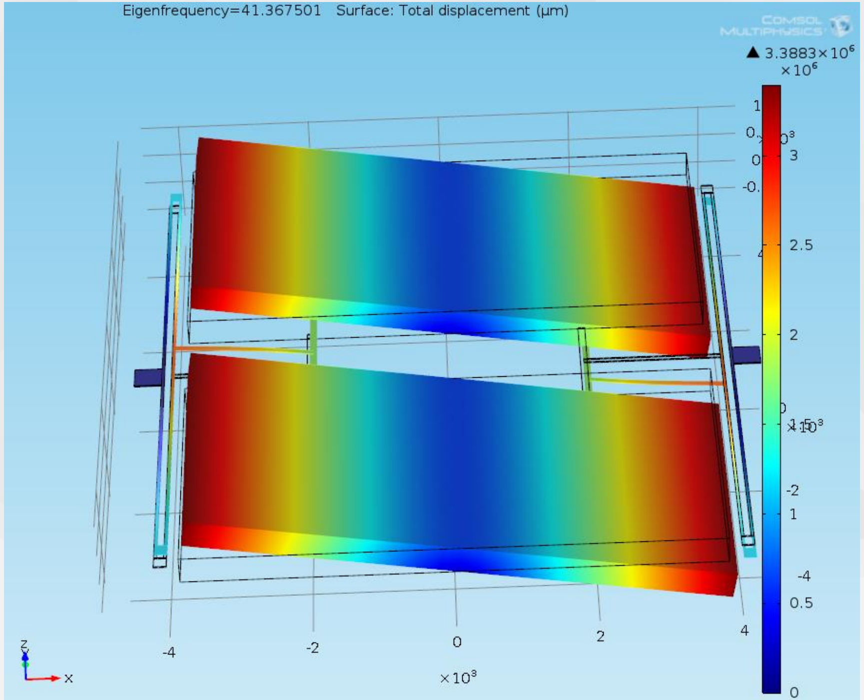
First vibration mode: for vibration along Y-direction (resonant frequency f_y = 15.57514Hz)

COMSOL Simulation



Second vibration mode: for vibration along Z-direction (resonant frequency f_z = 21.473948Hz)

COMSOL Simulation



Third vibration mode: for vibration along X-direction (resonant frequency f_x = 41.367501Hz)

Device Application

Shoe with vibration energy harvester inserted in its sole

Conclusion

- A Novel MEMS piezoelectric Vibration Energy Harvester with Three-DOF Responses is proposed.
- The device has different thickness for its beams and the seismic masses. Due to this imbalance, the inertial force resulted from input vibration leads to a net torque and converts in-plane vibration into out-of-plane movement of the T-shape beams.
- COMSOL simulation is used to simulate its vibrational modes and the corresponding resonant frequencies were derived.
- From the COMSOL simulation results, the working vibration modes in X and Y and Z directions have resonant frequencies of f_x=41.367501Hz, f_y=15.57514Hz and f_z= 21.473948Hz respectively.
- The energy harvester converts the mechanical energy into electrical energy and then stores the energy harvested in the capacitors

Future Scope

- In the future, we will perform stress simulation to find out the maximum stress induced inside the T-shape beams due to input vibrations along X, Y and Z directions.
- We will also perform piezoelectric simulation to find out the actual voltage output due to input vibrations.

Thank you!

Questions?