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Geometric Optimization of Piezoelectric Energy Harvesting System

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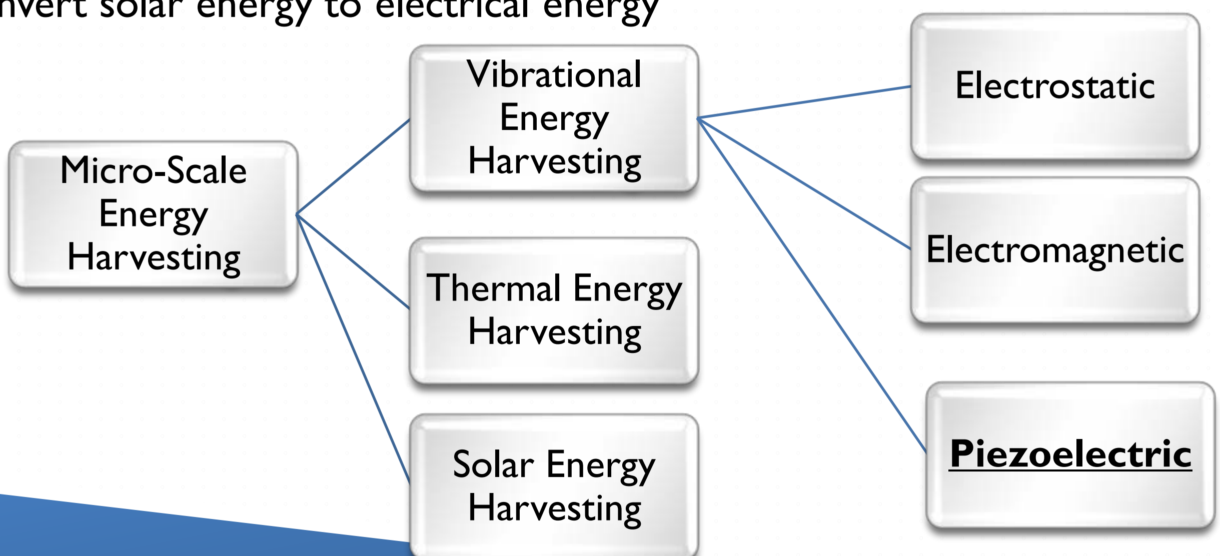
INTRODUCTION:
WHAT IS ENERGY HARVESTING?

- The process of converting available ambient energy into usable electrical energy through the use of certain materials.
- Materials used for energy harvesting are able to:
  - Convert mechanical energy to Electrical energy
  - Convert temperature gradients to electrical energy.
  - Convert solar energy to electrical energy



INTRODUCTION (CONT.) PIEZOELECTRIC ENERGY HARVESTING

- The most versatile technique for vibrational energy harvesting is using piezoelectric materials.

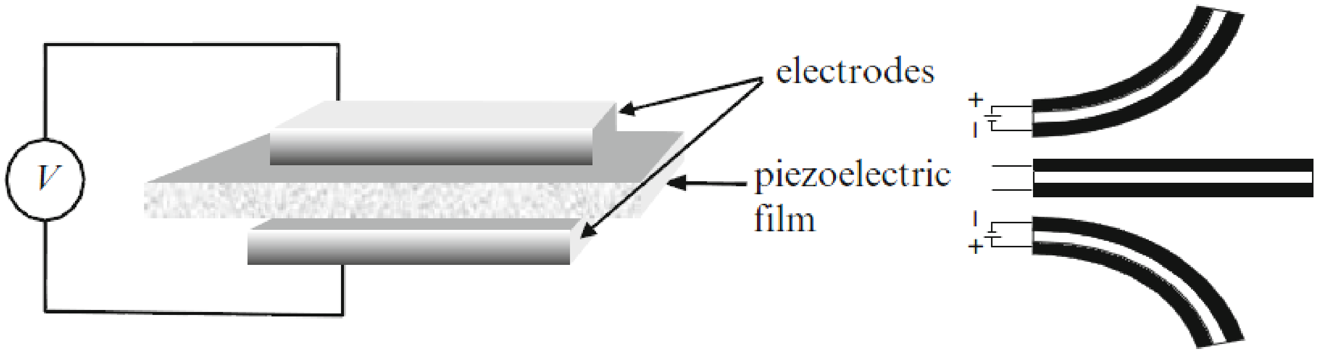
Advantages

- Virtually inexhaustible energy source
- No adverse environmental effect
- Simple transduction mechanism
- Relatively easy to implement in different applications in comparison to other harvesting techniques

Disadvantages

- Harvested power is in the order of a few tens of micro-milli watts
- Harvested power tends to be unregulated and unpredicted
- Optimization techniques are necessary
- The device needs to be excited at certain frequencies

INTRODUCTION (CONT.)
PIEZOELECTRICITY



- Piezoelectric materials generate electric charges when exposed to stresses or strains, the effect is called "piezoelectricity"
- The phenomenon of piezoelectricity was discovered by brothers Pierre and Jacques Curie in 1880.
- When bending a piezoelectric cantilever upwards, a positive electrical potential voltage is generated. However, when the cantilever is bent downwards an electrical potential of the opposite polarity is generated.
- The effect is due to the coupling of both mechanical and electrical fields.

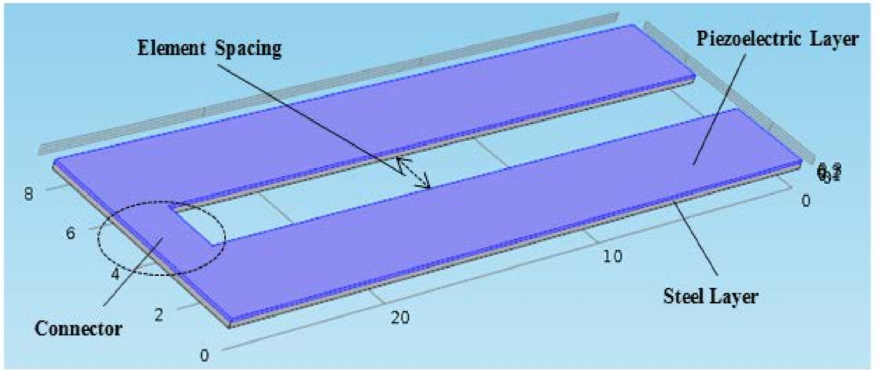
OBJECTIVE & CONTRIBUTION

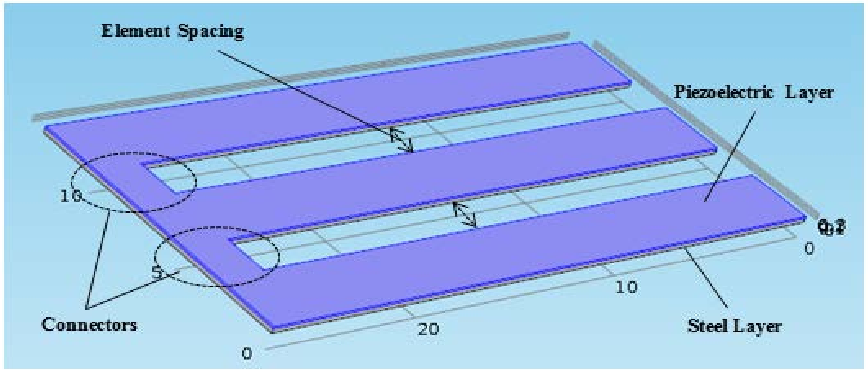
- *The objective of this paper is to is to study the effect of geometrical optimization of an array configuration for a unimorph piezoelectric cantilever element. Steps for achieving this are:*
  1) *Connect a previously optimized cantilever in a two-element and a three element array to increase energy conversion efficiency*
  2) *Optimize the element spacing for the array configuration for maximum output*
- *The device will be simulated in 3D configuration using COMSOL Multiphysics.*
- *Most publications were concerned with the optimization of the harvesting circuits mounted on the piezoelectric harvesters. However; little interest has been given to optimizing the actual design of the piezoelectric device.*

ARRAY CONFIGURATION FOR A PIEZOELECTRIC ENERGY HARVESTER

- Two array configurations are going to be simulated.
- The first is a mechanical series connection of two identical elements
- The second is a mechanical series connection of three identical elements.
- Single elements are a unimorph cantilever, with two layers. The bottom steel layer is 0.2 mm thick.
- Length and width will remain constant through out the simulation Piezoelectric layer thickness is the optimized value of 0.1 mm.
- The element spacing is going to varied from 0.5-2 mm to find the optimum value.

COMSOL Model:





OPTIMIZATION OF PIEZOELECTRIC ENERGY HARVESTER

Settings to calculate the charge output

- customizable variable D is defined on the top boundary of the piezoelectric layer, to measure the electrical displacement of the cantilever (C/m^2)

$$D = dT + \varepsilon_T E = \frac{q}{A} \; (C/m^2)$$

$$q = \iint_S D \, dA$$

  - D: The electrical displacement (C/m^2)
  - q: The amount of electric charge.
  - A: The surface area in m^2

Settings to calculate the open circuit voltage

- A global variable is set on one point on the piezoelectric layer to calculate the open circuit voltage.

$$V = \frac{q}{C} \; (V)$$

  - q = Accumulated charge on piezoelectric terminal (C)
  - C = Capacitance of piezoelectric device (μF)

ARRAY CONFIGURATION FOR A PIEZOELECTRIC ENERGY HARVESTER

Setting Boundary Conditions & Applying Mesh

Two-Element Array

- Same boundary condition as that of the previously optimized cantilever except:
  - Mesh elements along the width is doubled.
  - Body load is 1/2 that of the original (150 N/m^3), since the volume is almost doubled

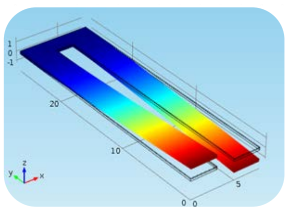
Three-Element Array

- Same boundary condition as that of the previously optimized cantilever except:
  - Mesh elements along the width is tripled.
  - Body load is 1/3 that of the original (100 N/m^3), since the volume is almost tripled.

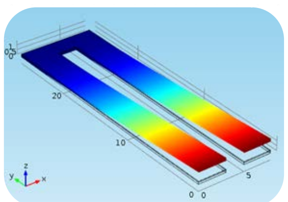
ARRAY CONFIGURATION FOR A PIEZOELECTRIC ENERGY HARVESTER

Eignfrequency Analysis

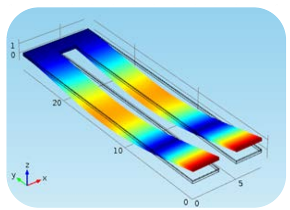
Two-Element Array



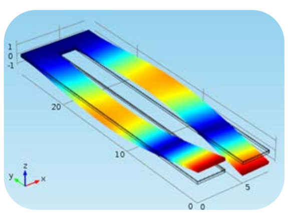
298.3 Hz



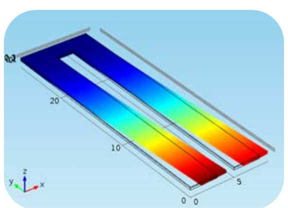
302.8 Hz



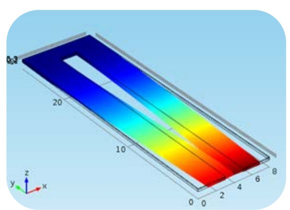
1852.3 Hz



1863 Hz

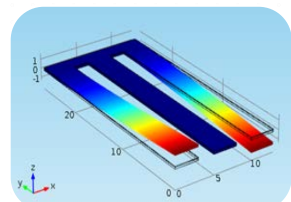


3254.4 Hz

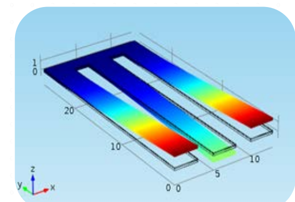


3460.7 Hz

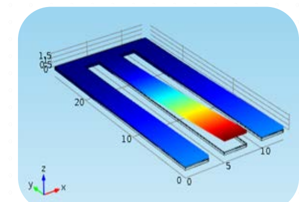
Three-Element Array



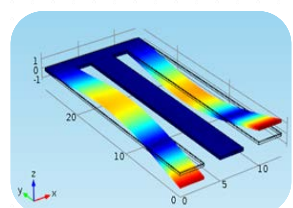
298.6 Hz



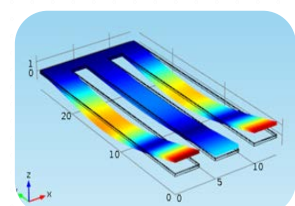
306.4 Hz



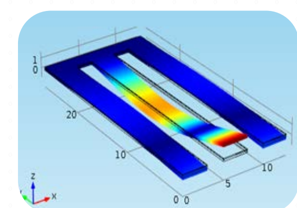
308.4 Hz



1845.3 Hz



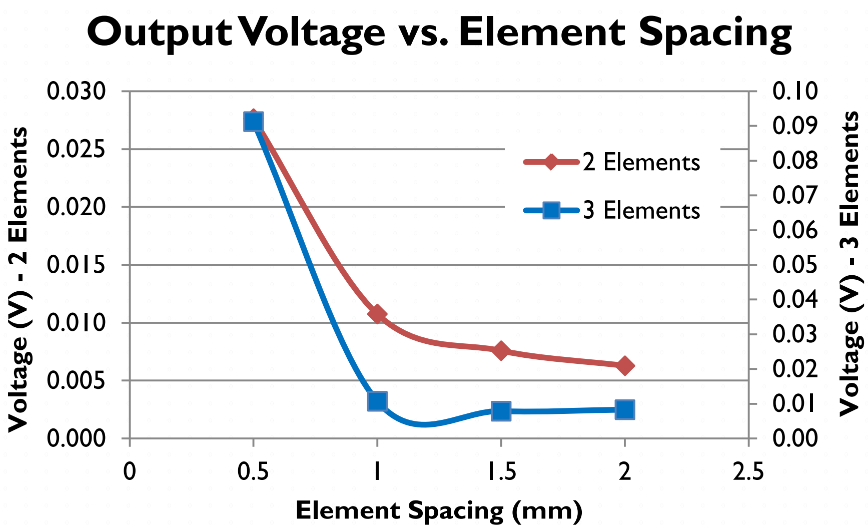
1893.4 Hz

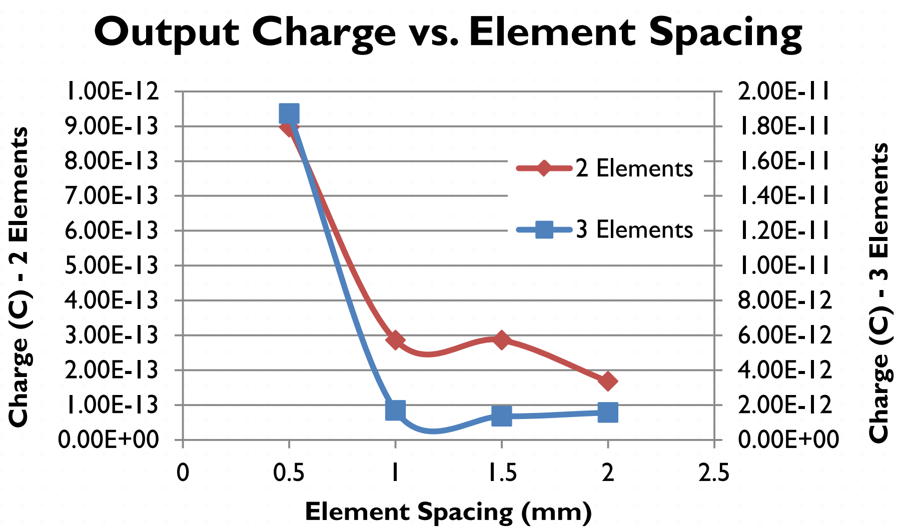


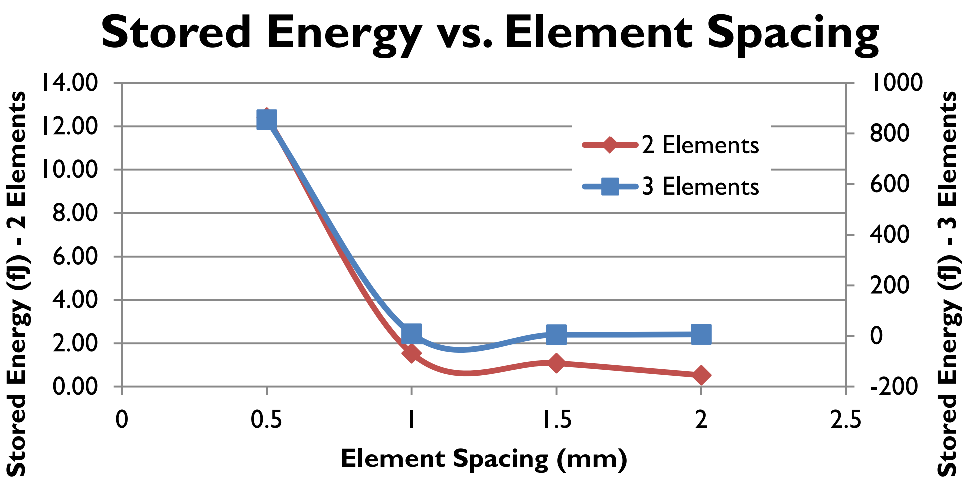
1925.2 Hz

SIMULATION RESULTS

Results when exciting at fundamental resonance frequency

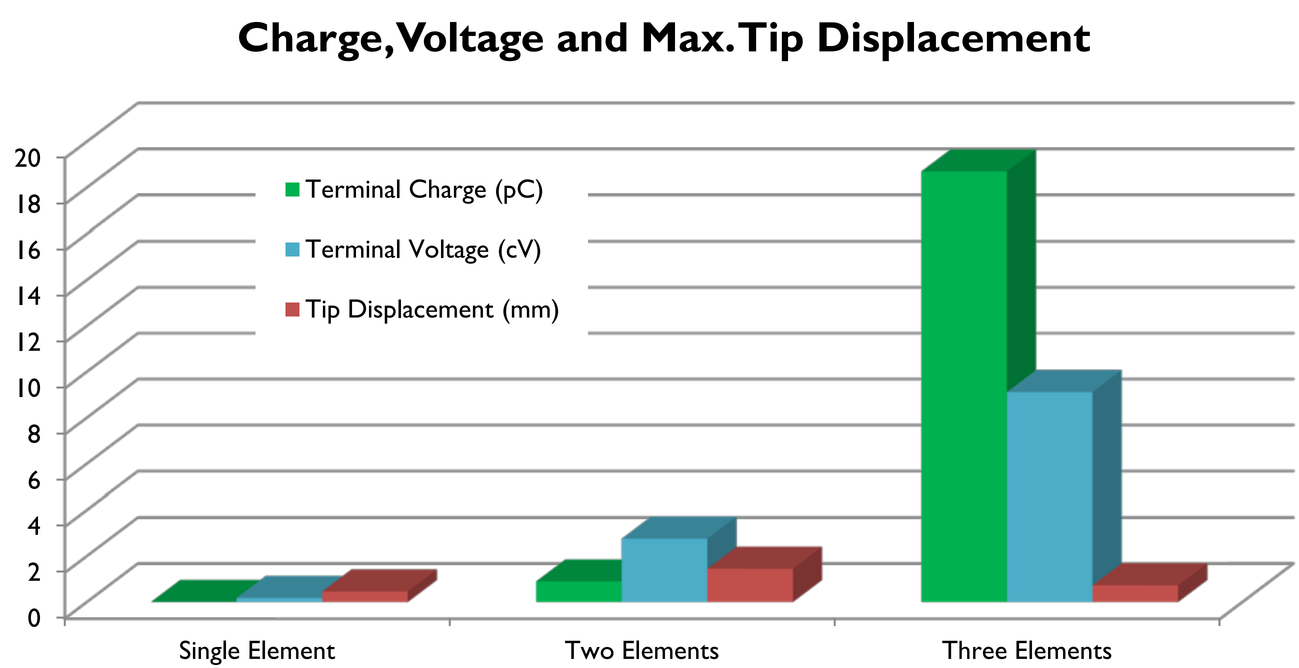






CONCLUSION

- For the array configuration the optimum element spacing is 0.5 mm.
- When simulating at optimum element spacing and at the fundamental resonance frequency, the output charge, voltage and the stored energy are greatly optimized.



CONCLUSION (CONT.)

- The total stored energy increases with the number of elements
- Results are much higher than those obtained when simulating the single unimorph cantilever. The total energy stored was increased to more than 30 times for the two-element array and to more than 1800 times for the three element array (in comparison to a single element).

	Single Element	Two Element Array	Three Element Array
Total Stored Energy	0.04716 fJ	1.54 fJ	854.5 fJ

Questions?

Thank you!