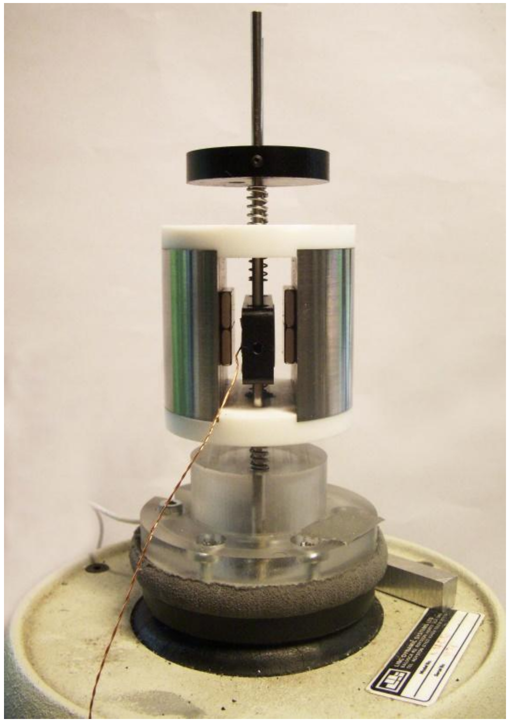
A multiple Dof velocity amplified VEH: experimental analysis and modelling



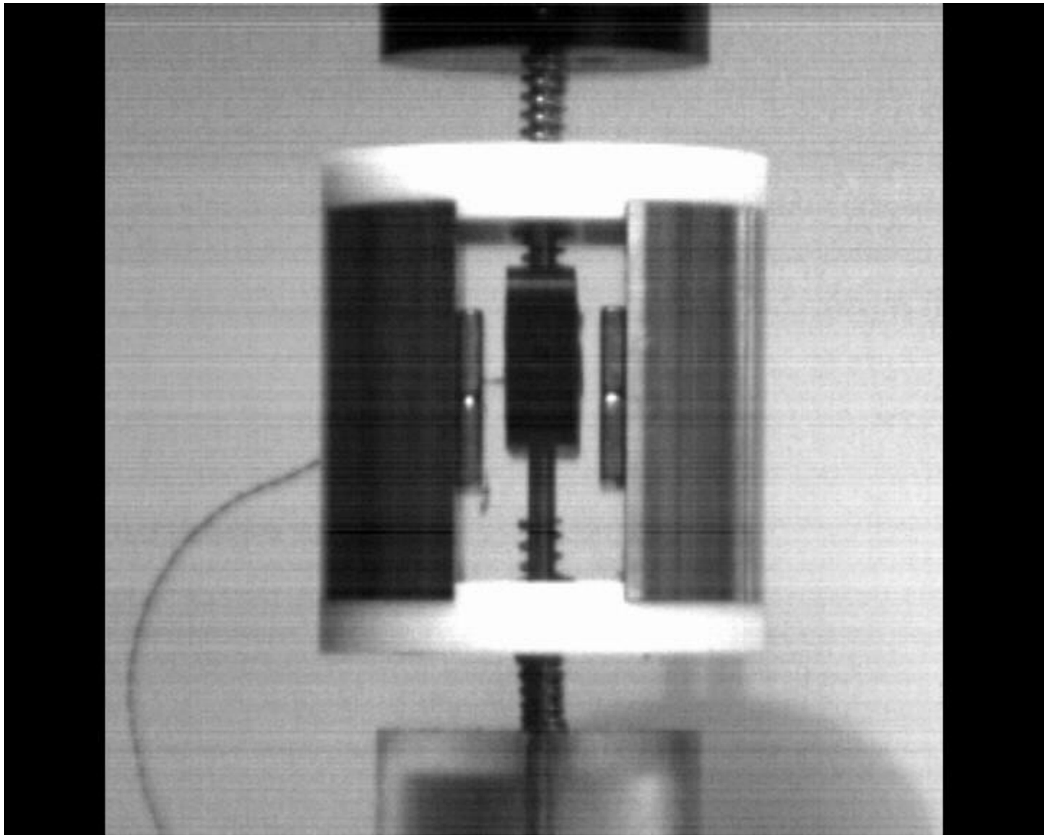
Valeria Nico[1], Elisabetta Boco[1], Declan O'Donoghue[1], Ronan Frizzell[2], Gerard Kelly[2], Jeff Punch[1]

1. *CTVR, Stokes Institute, University of Limerick, Limerick, Ireland*
2. *Efficient Energy Transfer Dept., Bell Labs, Alcatel-Lucent, Dublin, Ireland*

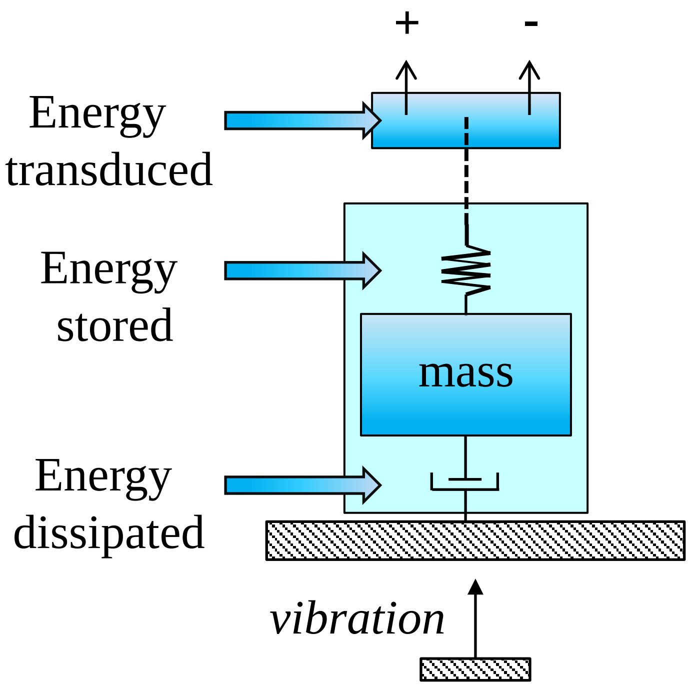
Outline

- Vibrational Energy Harvester
- Electromagnetic Energy Harvester
- Experimental setup
- Harvester prototype results
- Theoretical model of a 2Dof harvester
- Summary and future work

2Dof Energy Harvester



Vibration Energy Harvester



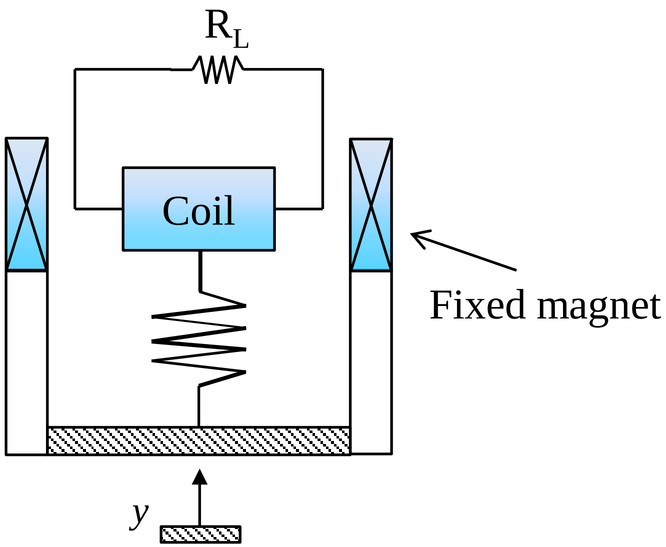
Potential; Friction; Dissipative force due to transduction; Input force

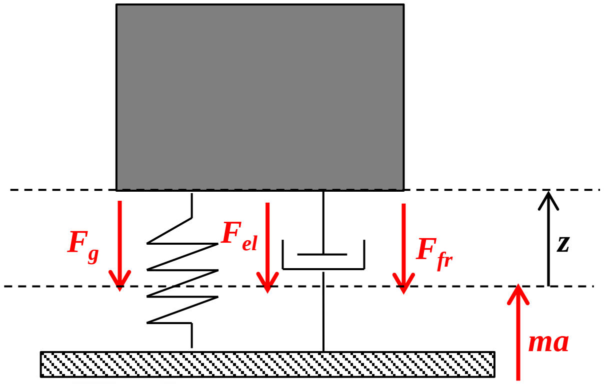
$$\begin{cases} m\ddot{x} = -\dfrac{\partial U(x)}{\partial x} - \gamma \dot{x} - c(x, V) + \xi_z \\ \dot{V} = F(\dot{x}, V) \end{cases}$$

Depend on the transduction mechanism

Linear case: $\dfrac{\partial U(x)}{\partial x} = kx$

Vibrations Harvester: electromagnetic transducer



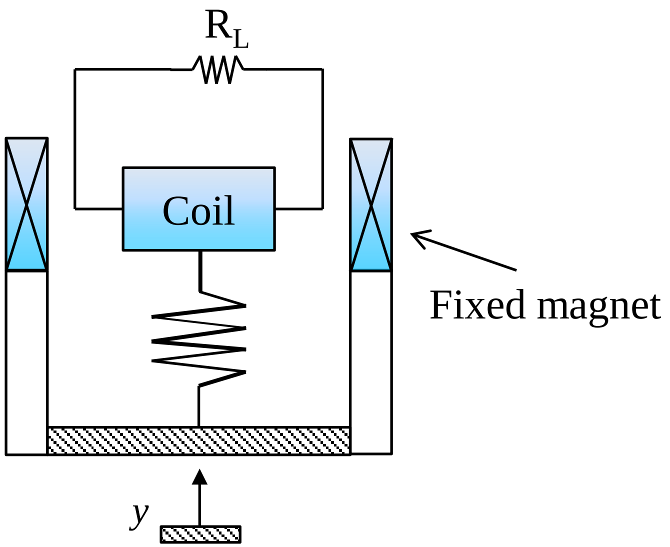


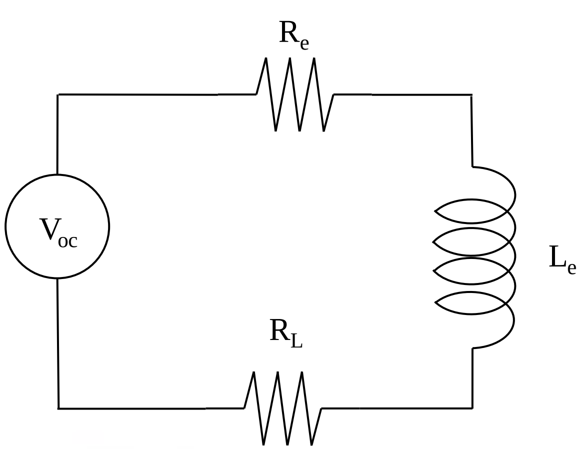
Mechanical part:

$$m\ddot{z} = F_{el} + F_{fr} - ma + F_g$$

$$m\ddot{z} = -kz - d\dot{z} - \alpha V_L - m\ddot{y} - mg$$

Vibrations Harvester: electromagnetic transducer





Faraday's Law

$$V_{oc} = -\frac{d\Phi_B}{dt} = NBl\frac{dx}{dt}$$

N = number of turns
B = strength of the magnetic field
l = length of the wire

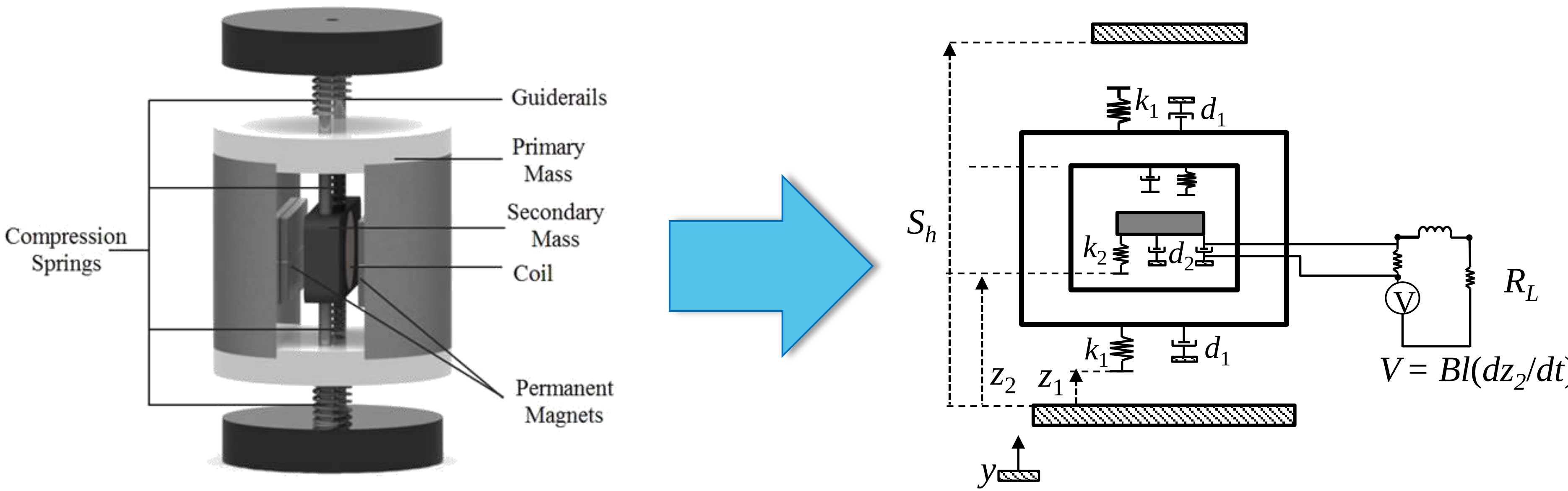
$$V_L = Bl\dot{z} - R_e i - L_e \, {}^{di}/_{dt}$$

$$\dot{V}_L + V_L\left(\frac{R_L + R_e}{L_e}\right) = Bl\frac{R_L}{L_e}\dot{z}$$

$$\dot{V}_L + V_L\omega_c = \delta_c\omega_c\dot{z}$$

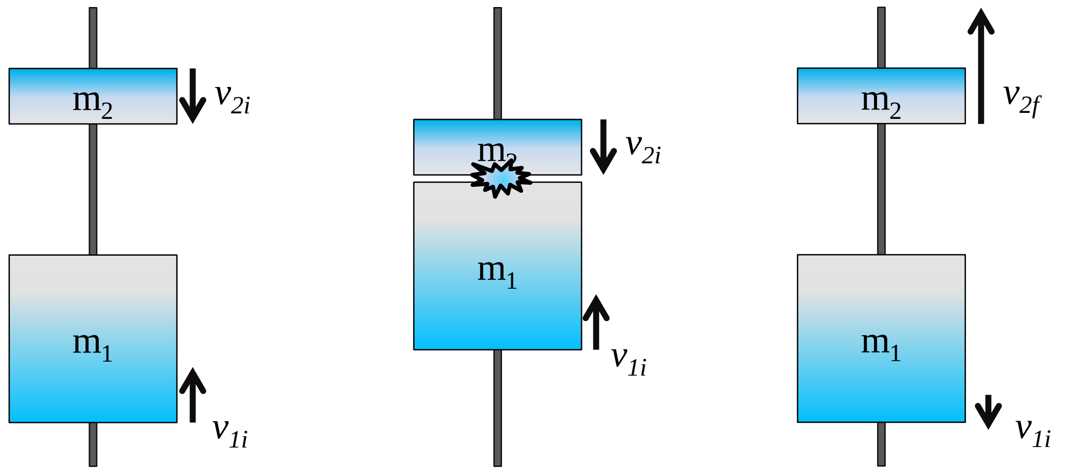
$\alpha = B_z l/R_l$: electric coupling factor;
$\delta_c = B_z l$: conversion factor;
$\omega_c = R_L/L_e$: characteristic cut frequency;
$L_e = \mu_0 N^2 \pi R^2 / h_b$: coil inductance.

2Dof Energy Harvester



- Two masses connected by springs;
- A coil is embedded in the secondary mass and 4 magnets are inside the primary mass;
- Impacts between the masses and between each mass and the housing are allowed;
- Velocity of the secondary mass is increased by exploiting velocity amplification

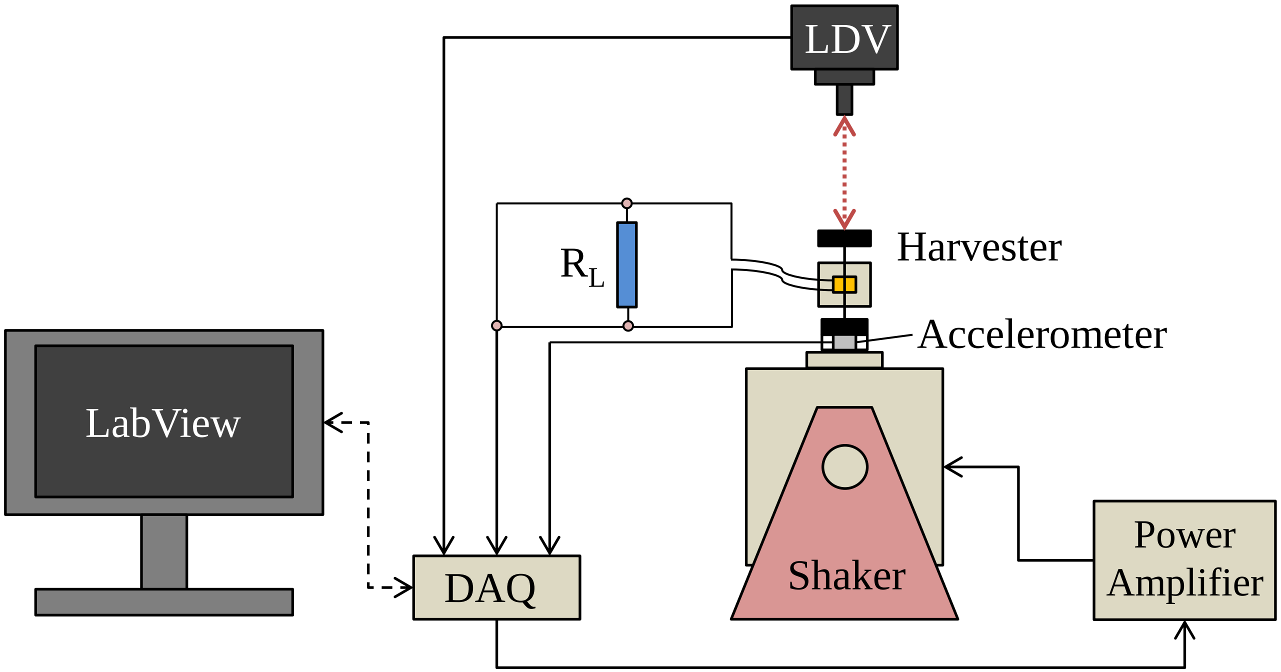
Velocity amplification



- Velocity amplification is achived by utilizing sequential collisions in a series of free moving masses;
- The energy lost in the impact is accounted for through the coefficient of restitution;
- The coefficient of restitution, e, for the impact between m_1 and m_2 is defined as

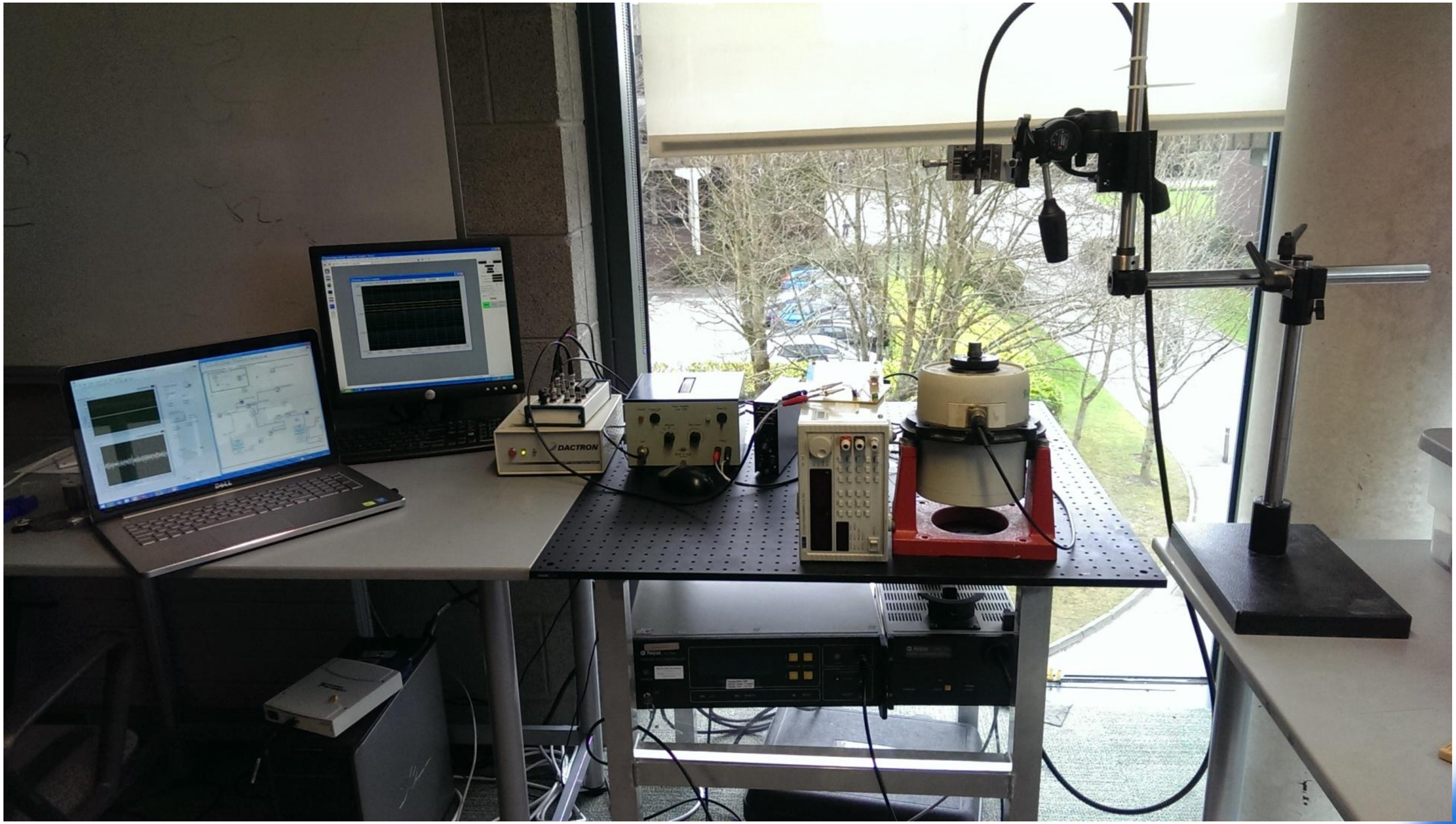
$$e_{2,1} = \frac{relative\ velocity\ after\ collision}{relative\ velocity\ befor\ collision} = -\frac{v_{2f} - v_{1i}}{v_{2i} - v_{1f}}$$

Experimental setup

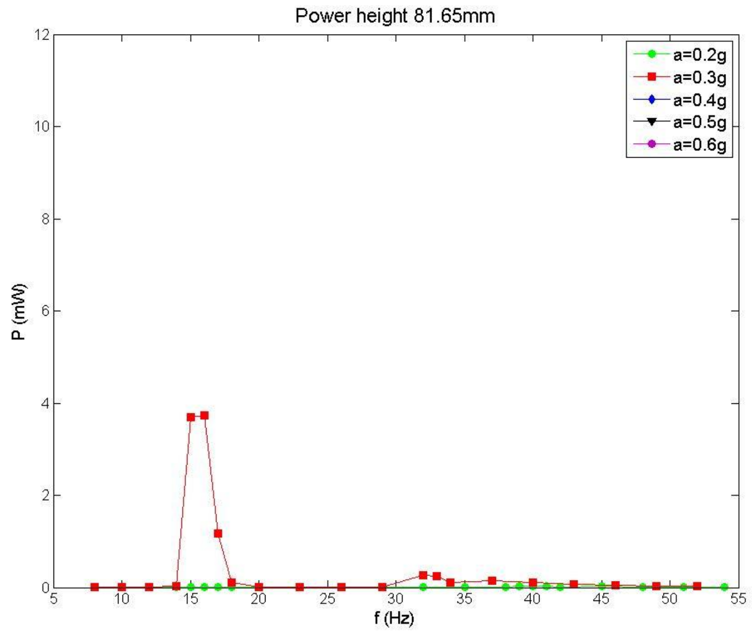


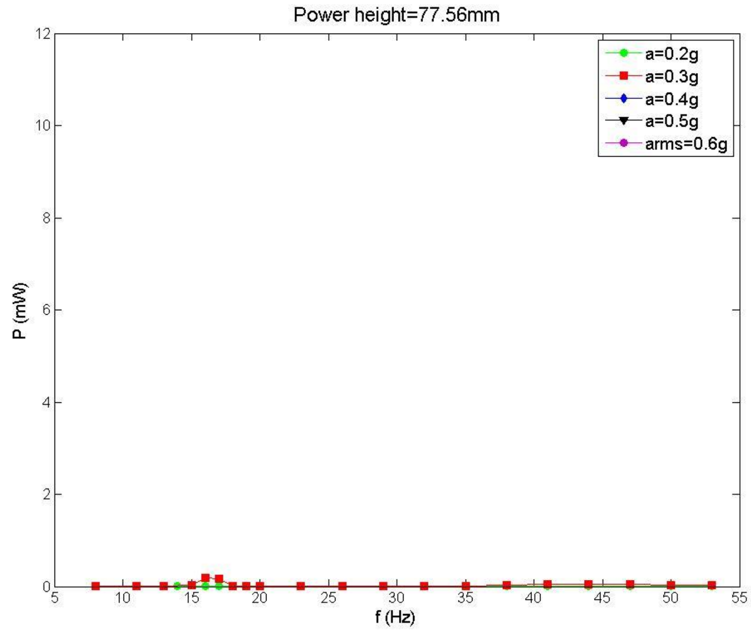
- Labview is used to supply a voltage signal to the shaker through a power amplifier;
- An accelerometer, mounted on the head of the shaker, provides a feedback control of the acceleration;
- The voltage signal of the harvester is measured across a variable load R_L.

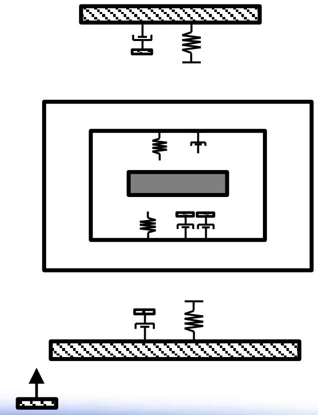
Experimental setup



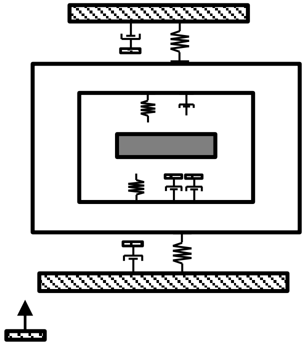
Harvester Power Output





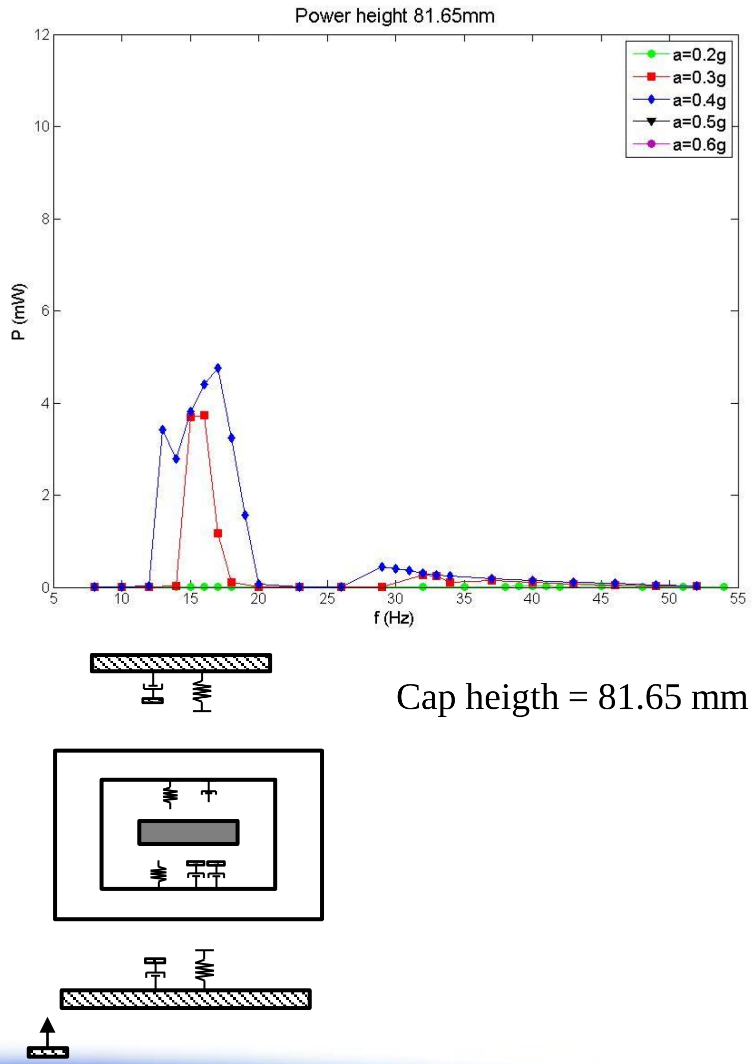


Cap heigth = 81.65 mm

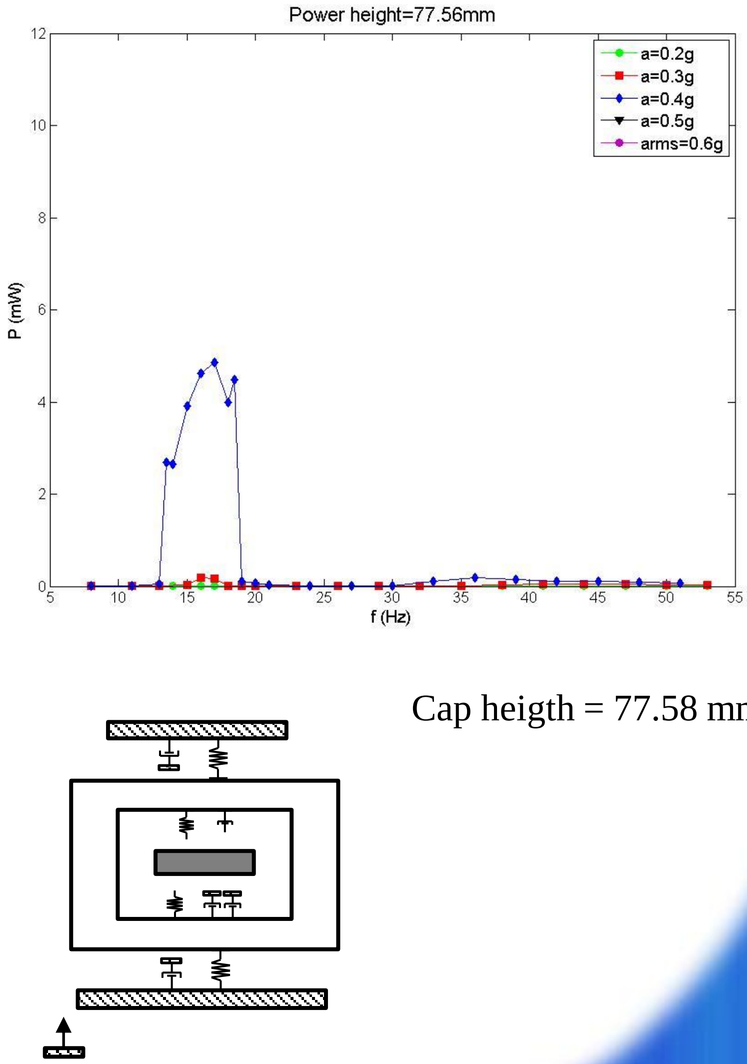


Cap heigth = 77.58 mm

Harvester Power Output

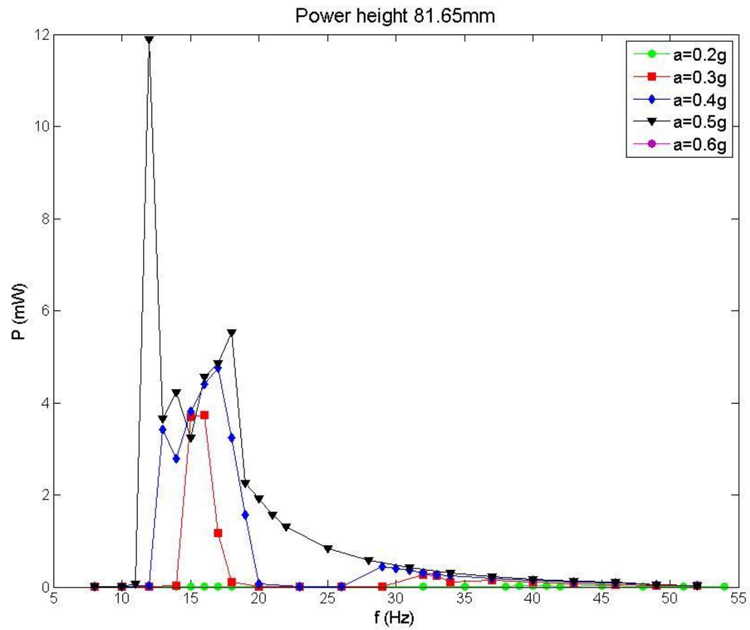


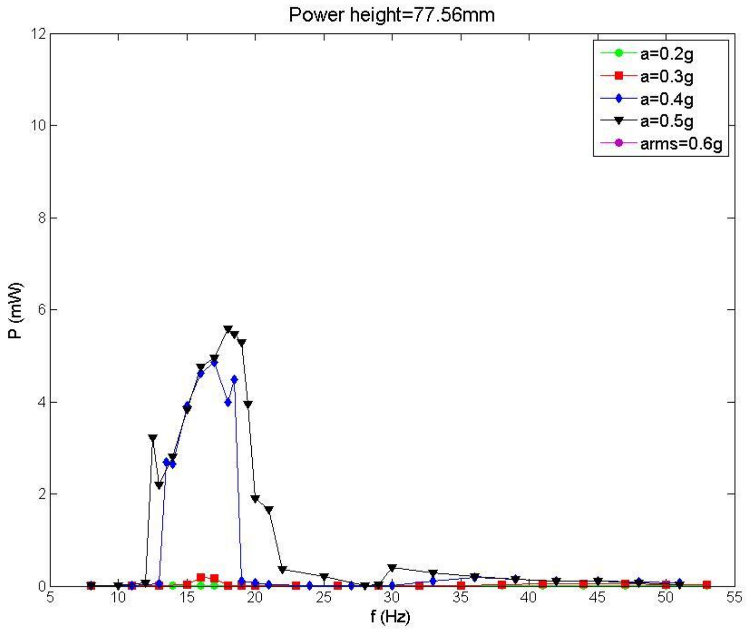
Cap heigth = 81.65 mm

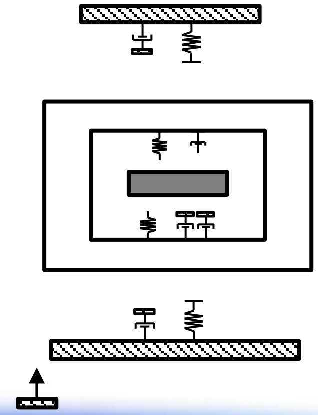


Cap heigth = 77.58 mm

Harvester Power Output

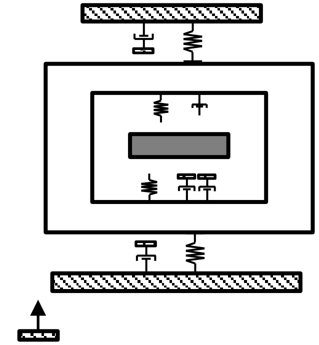




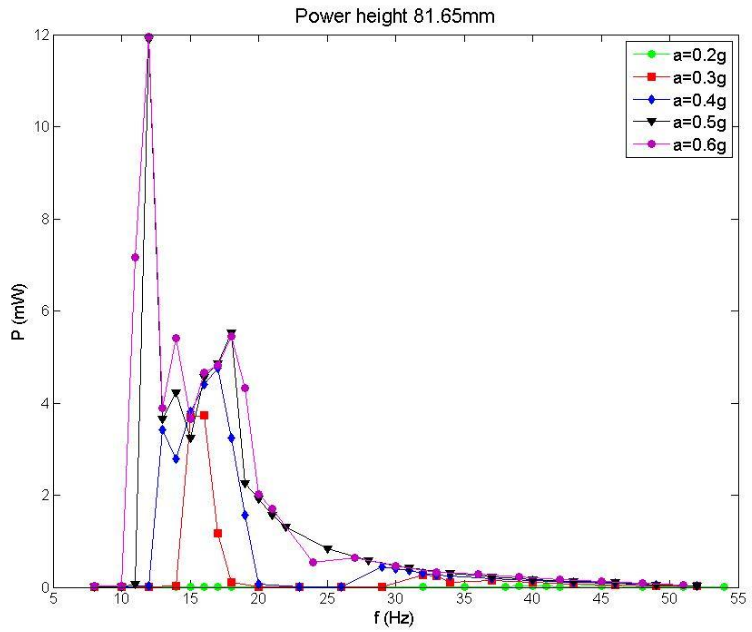


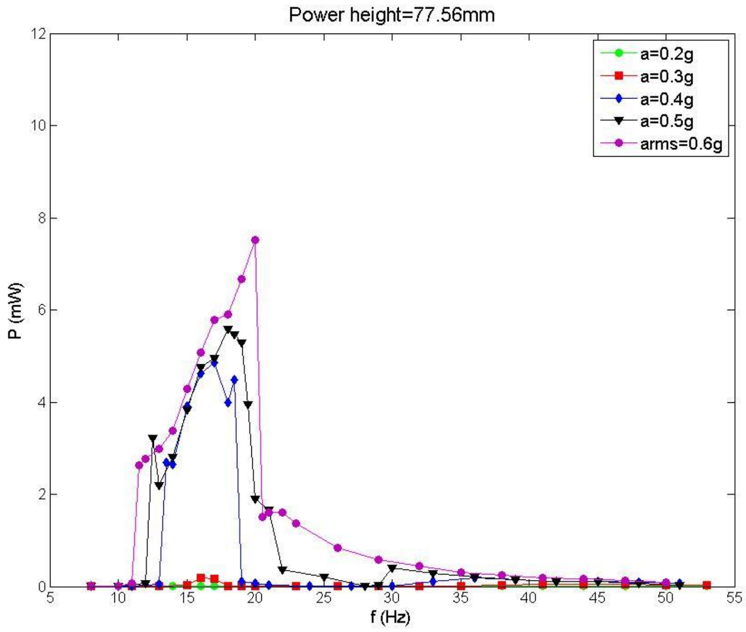
Cap heigth = 81.65 mm

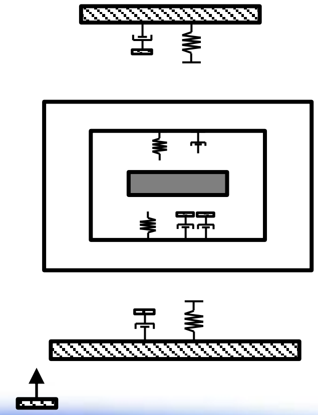
Cap heigth = 77.58 mm



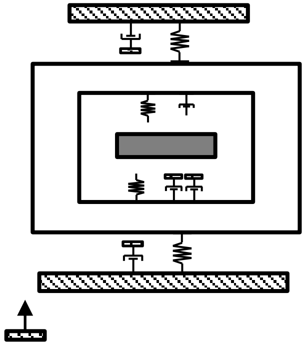
Harvester Power Output







Cap heigth = 81.65 mm



Cap heigth = 77.58 mm

Theoretical model

2 Dof system

Check the position of the mass:

- If it is connected to the lower spring

  ↓

  oscillator equations

- If it is not connected to the spring

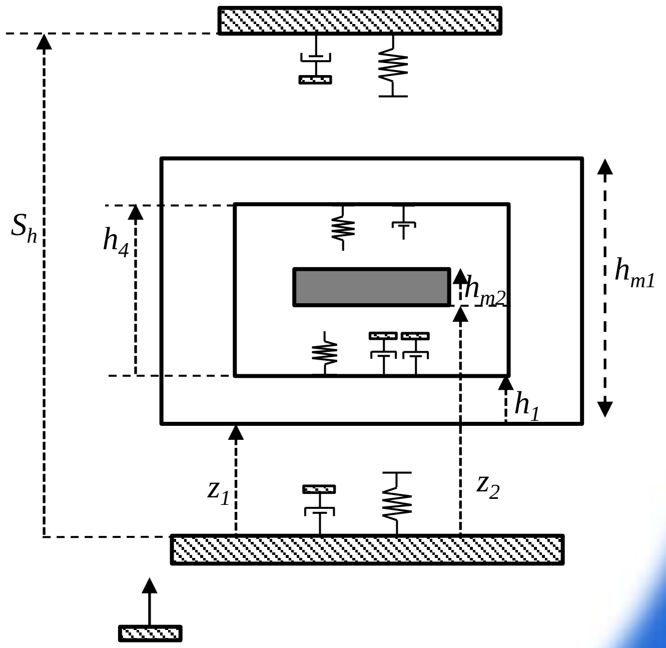
  ↓

  free motion equations

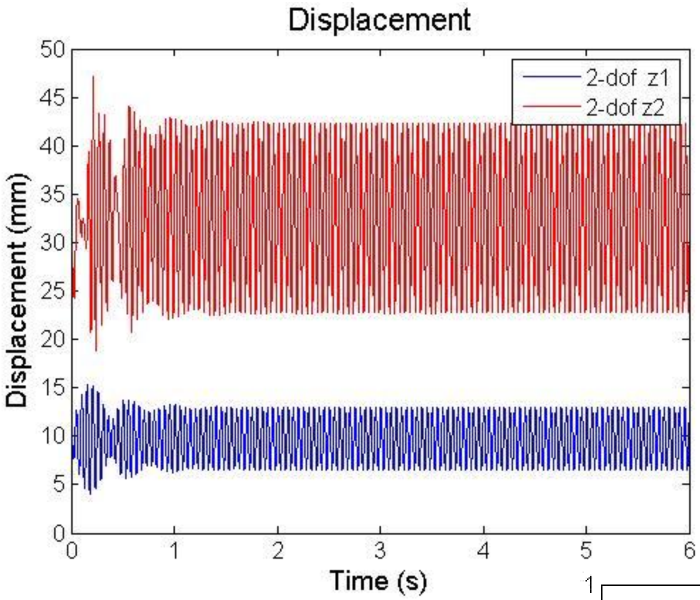
- If it connected to the spring on the top

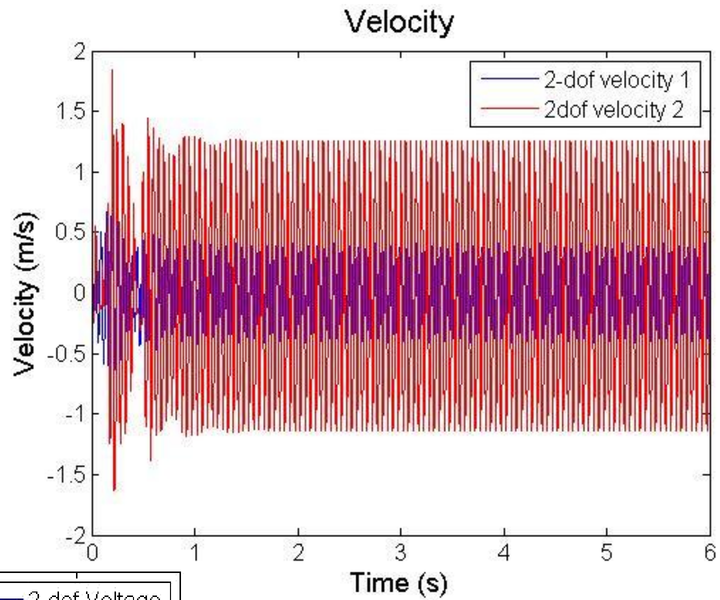
  ↓

  oscillator equations



Theoretical model

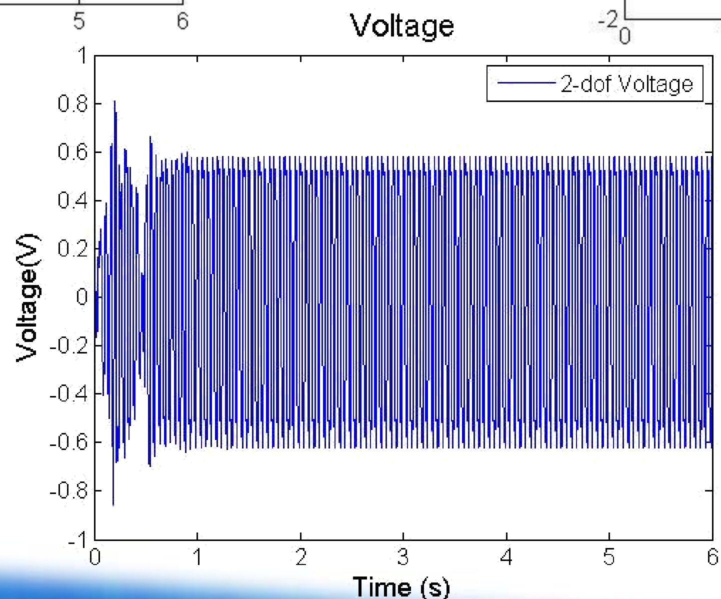


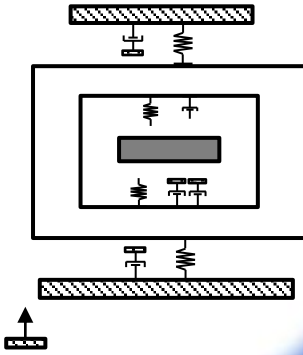


Cap Height = 77.56mm

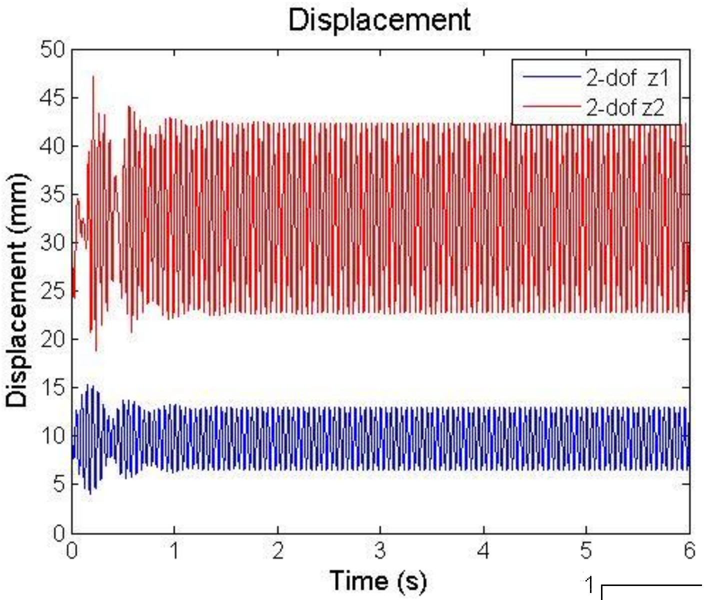
Excitation:

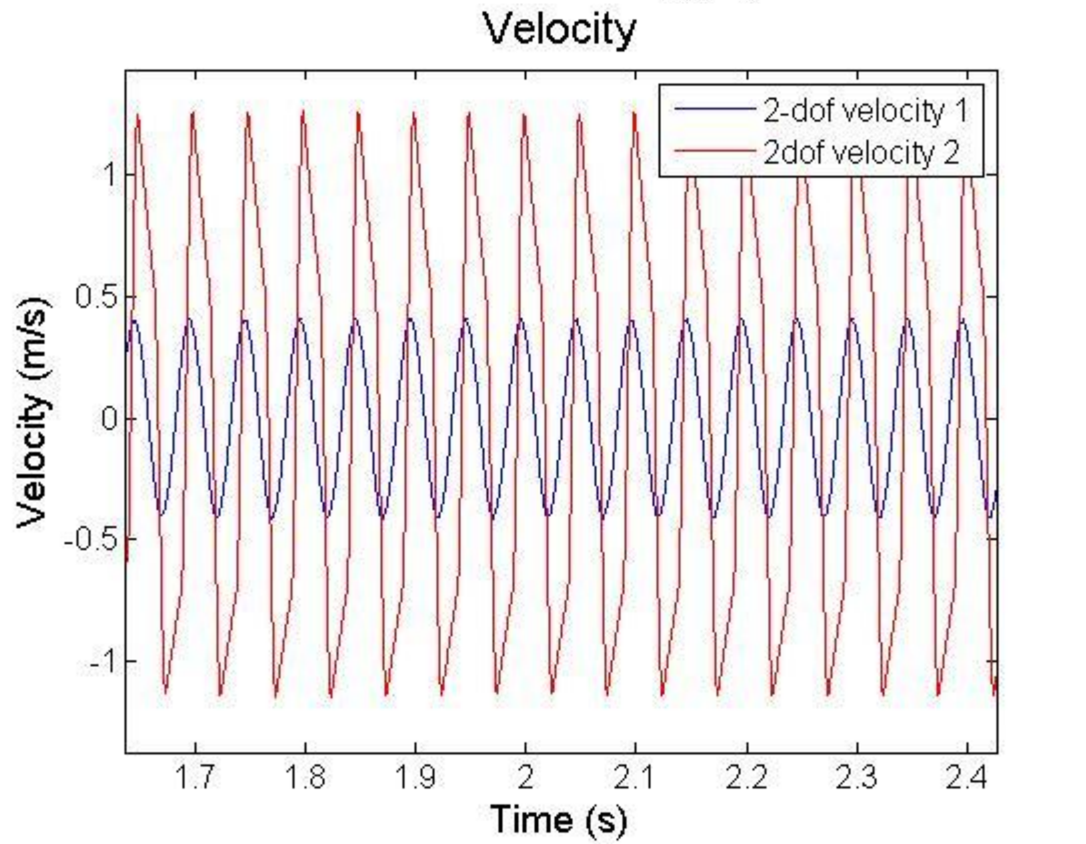
- Sine Wave
- f=20 Hz
- a_{rms}=0.4 g



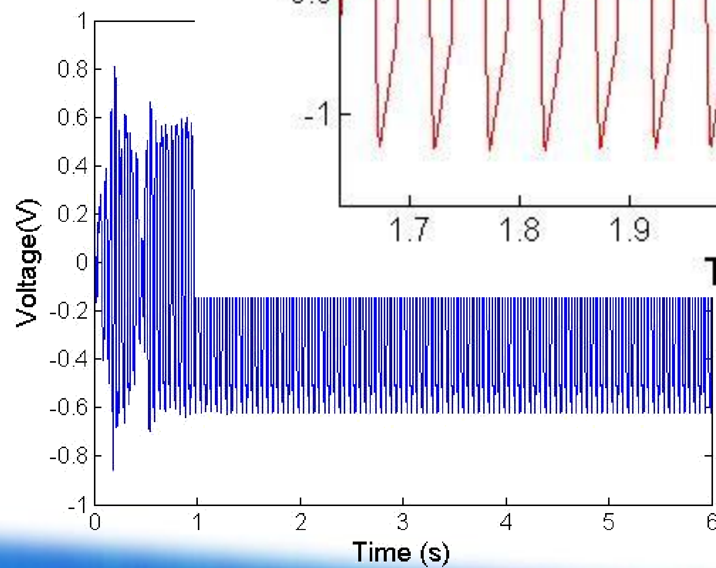


Theoretical model





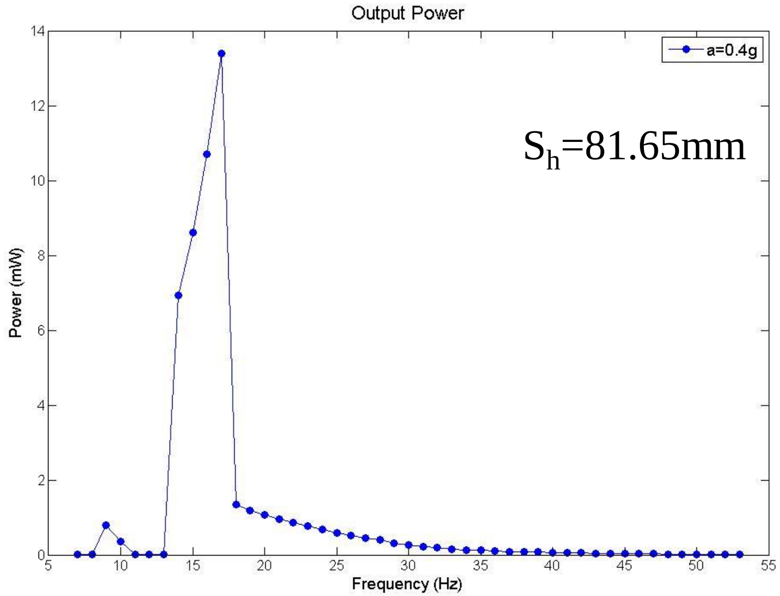
Cap Height = 77.56mm

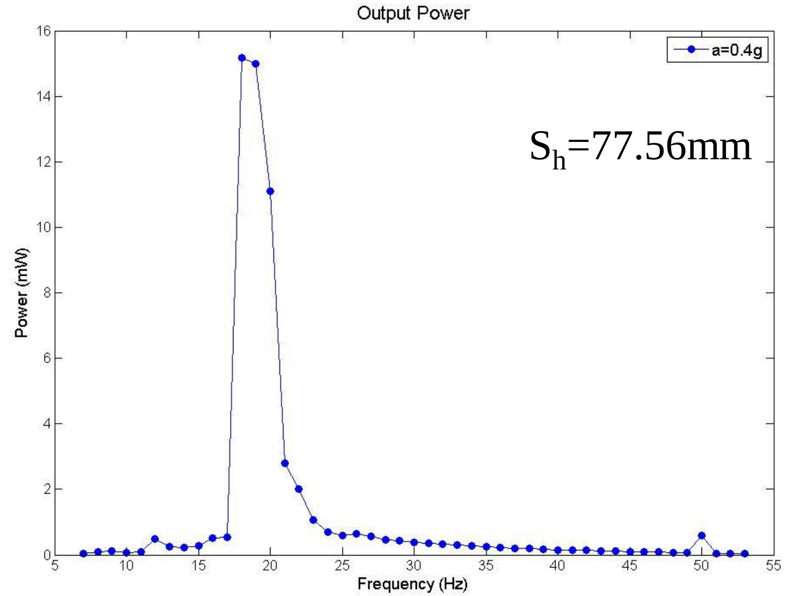


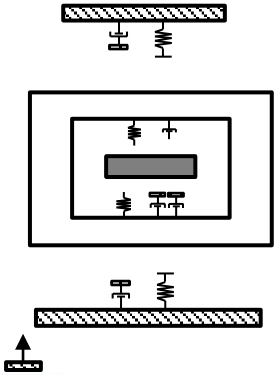
Excitation:

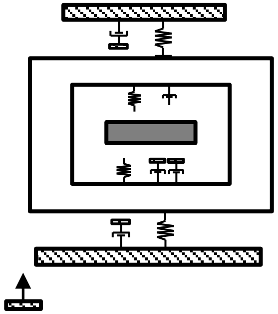
- Sine Wave
- f=20 Hz
- a_{rms}=0.4 g

Theoretical model









Conclusion

- Description of a 2-Dof velocity amplified energy harvester
- Experimental results show two peaks at low acceleration amplitude and a wider response at higher acceleration.
- Theoretical model of a 2-Dof energy harvester
- Simulations show velocity amplification

Future work

Miniaturization of the harvester

THANKS FOR THE ATTENTION!