Benha Faculty of Engineering
Mechanical Engineering Department

M1382 : **Computer Aided Design CAD**

First Semester 2018, Y3

Lecture No. 07

Presented by:

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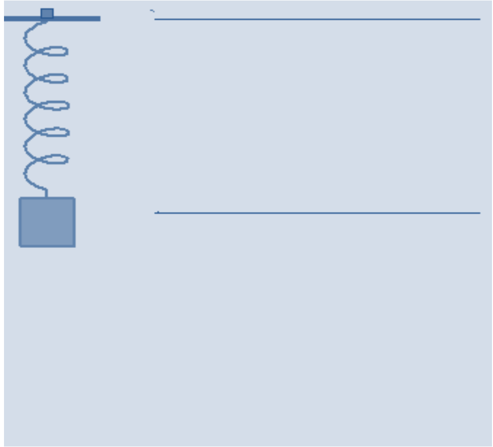
Week	Topics
1	Introduction
2	Introduction to CAD (Solid Modeling)
3	Part modeling
4	Finite element analysis (FEA)
5	Parts assembly using SolidWorks
6	Basic concepts of engineering drafting
7	Linear Static Analysis
8	**Adaptive Analysis and Mesh Control**
9	**Modal Analysis**
10	Design Optimization
11	Case study 1
12	Case study 2
13	Co-simulation SolidWorks and ADMS software
14	Project Discussion

Understand the Basic concepts of Natural Frequencies.

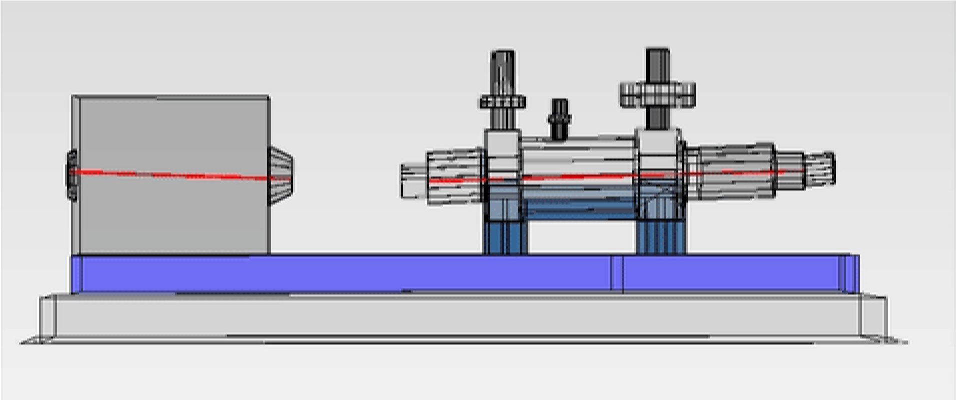
- ✓ All objects will **vibrate** when subjected to **impact, noise or vibration**.
- ✓ And many systems can **resonate**, where small forces can result in **Large deformation**, and **damage** can be induced in the systems.
- ✓ **Resonance** is the tendency of a system to oscillate at maximum amplitude at certain frequencies, known as the system's resonant frequencies. At these frequencies, even small driving forces can produce large amplitude vibrations.
- ✓ **When damping is small**, the resonant frequency is approximately equal to the natural frequency of the system, which is the frequency of free vibrations.



Understand the Basic concepts of Natural Frequencies.

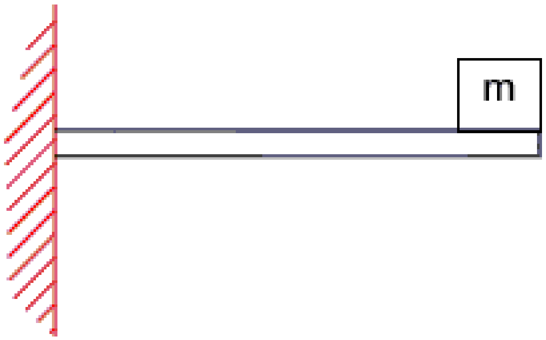
Case 1

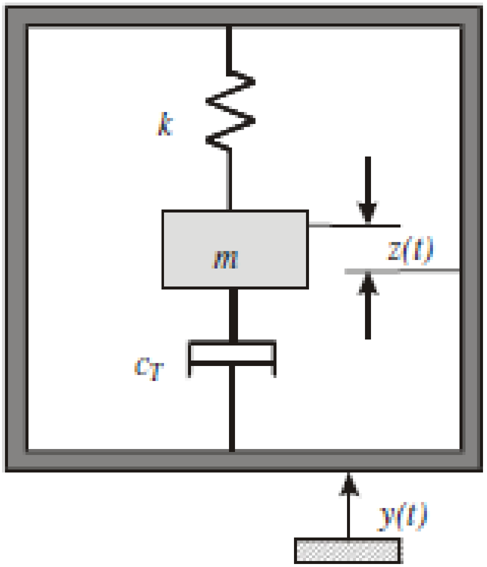
Case 2



Case 3

- Any physical structure can be modeled as a number of **springs, masses and dampers**.
- The assembly of spring-mass-damper systems that make up a mechanical system are called degrees of freedom; and the vibration energy put into a system will distribute itself among the degrees of freedom in amounts depending on their **natural frequencies** and **damping**, and on **the frequency** of the energy source.
- The response of the system is different at each of the different natural frequencies; and these deformation patterns **are called mode shapes.**

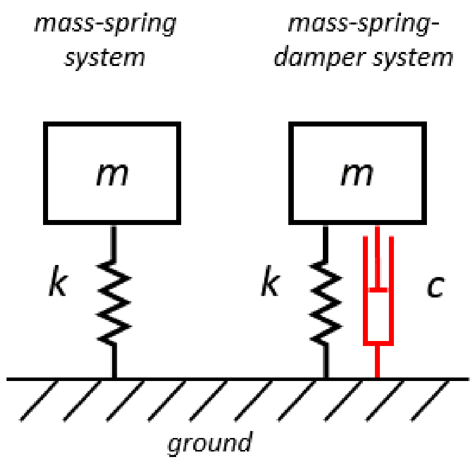




$y(t) = Y \sin(\omega t)$.

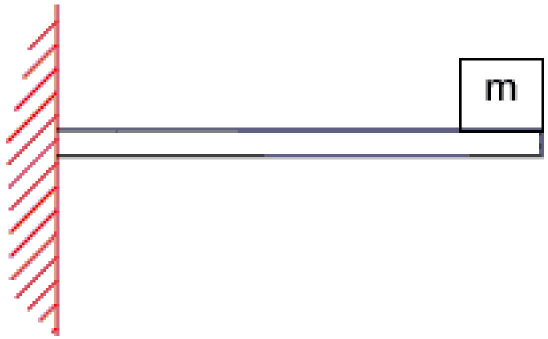
- ✓ **Frequency analysis** (or **Modal analysis**) is the study of the dynamic properties of systems under excitation. Detailed frequency analysis determines the fundamental vibration mode shapes and corresponding frequencies.

- ✓ Both the **natural frequencies** and **mode shapes** can be used to help design better systems for noise and vibration applications.



https://www.youtube.com/watch?v=VIlBI6nrnRc

- ✓ For the simple cantilever beam system, the natural frequency can be expressed as !!!!!
- ✓ The first three natural frequencies of the cantilever beam can then be expressed as !!!!



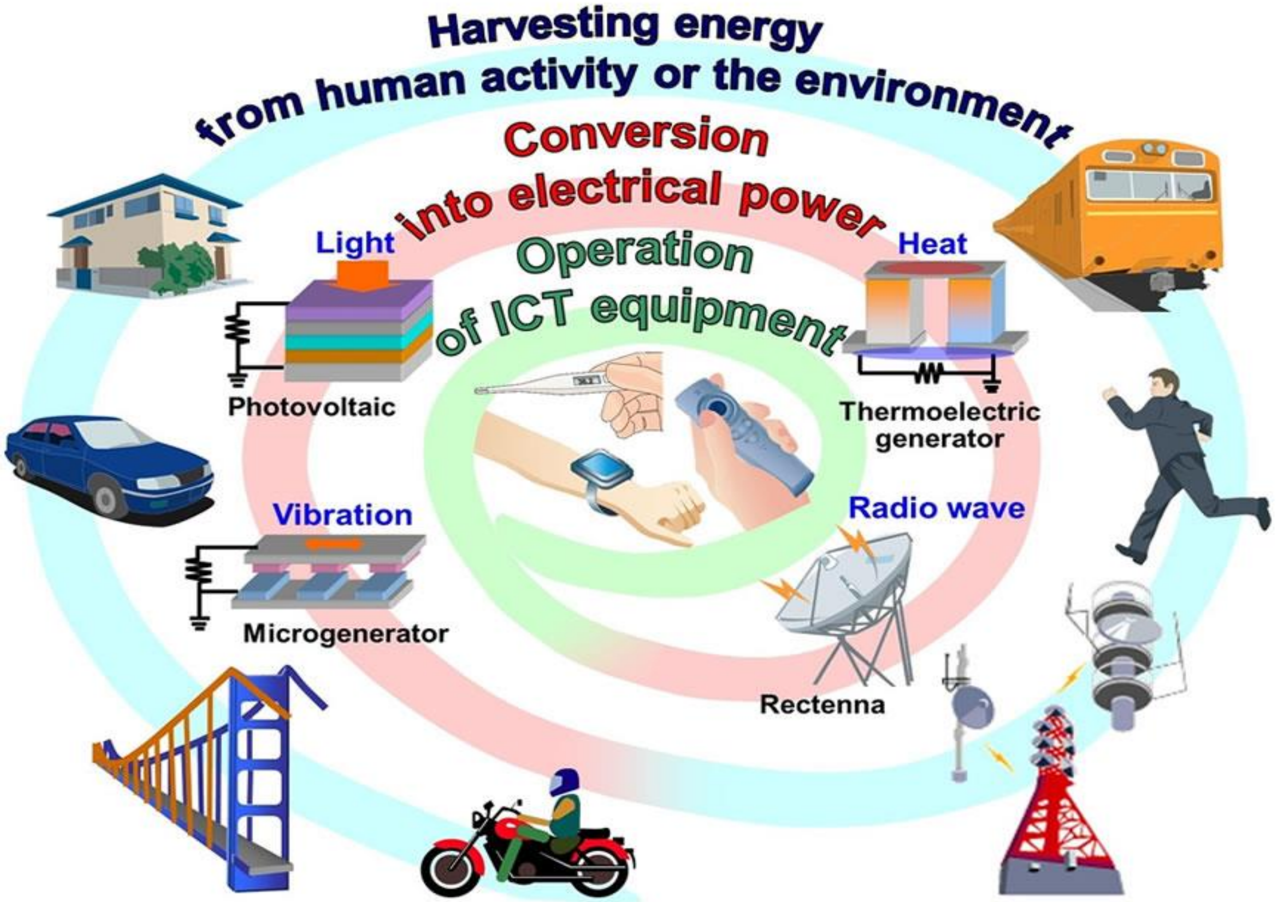
Please verify your Mathematical equation with the results from SOLIDWORKS simulation

Case study

Development of Energy Harvesting Device

INTRODUCTION

Energy Sources



ICT : Information and Communication Technology

INTRODUCTION

Needs for energy harvesting device

Environmental Monitoring

Habitat Monitoring (light, temperature, humidity)
Integrated Biology

Medical remote sensing

Emergency medical response
Monitoring, pacemaker, defibrillator

Structural Monitoring

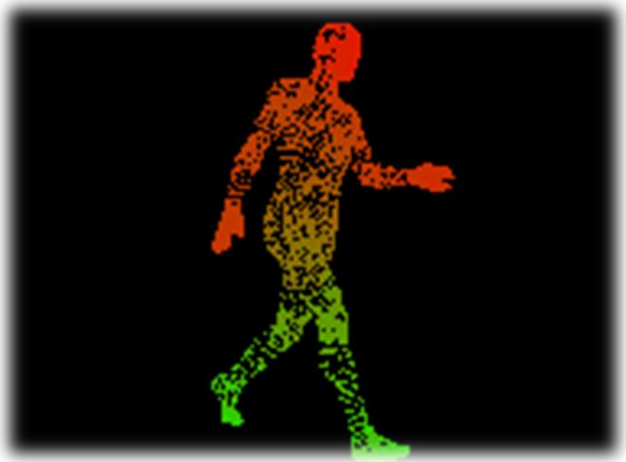
Interactive and Control

RFID, Real Time Locator, TAGS
Building, Automation
Transport Tracking, Cars sensors

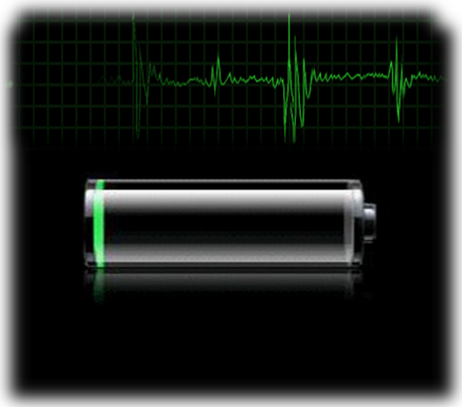
Military applications and Aerospace

Almost 90% of WSNs applications cannot be enabled without Energy Harvesting technologies that allow self-powering features

OBJECTIVE



Human Motion Analysis



Pacemaker

LITERATURE REVIEW

Transduction mechanism

Mechanical vibration

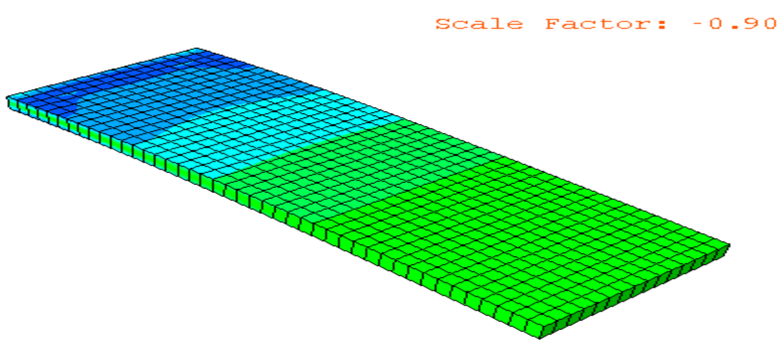
Transduction
Transducer

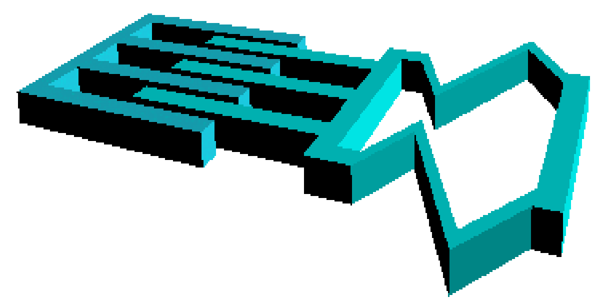
Electrical energy

The transduction mechanism can generate electricity by

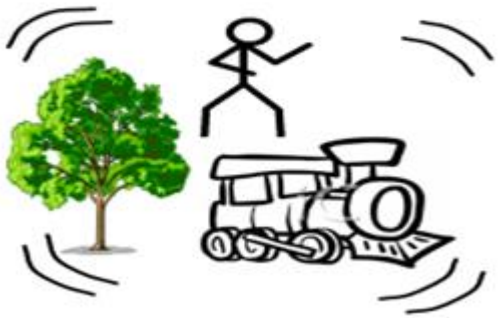
Mechanical stress

Relative displacement

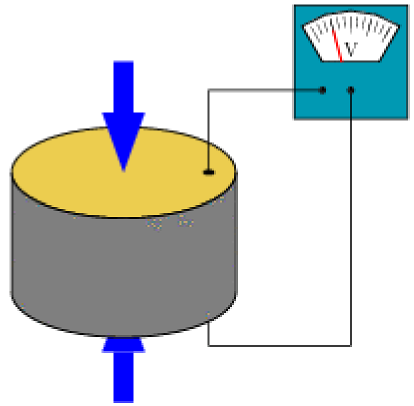




LITERATURE REVIEW



Vibration



Power

Piezoelectric material PZT ??

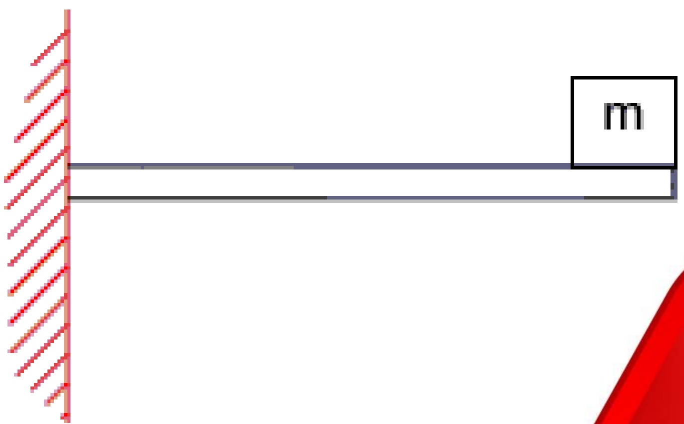
- Simple structure
- No external voltage source
- Compatible with MEMS

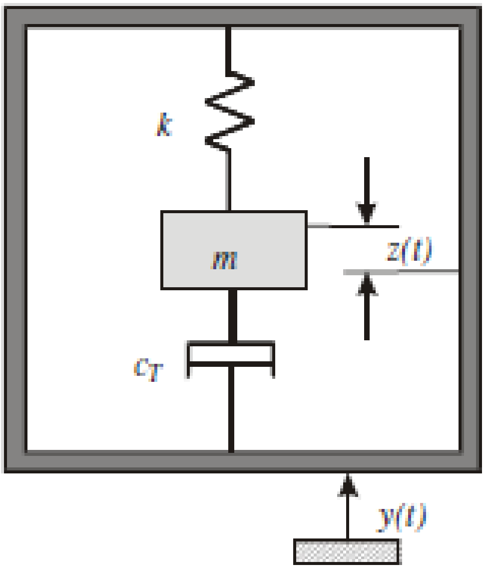
Vibration source + **Harvesting system** = **Power**

Mathematical model

The differential equation of motion
is described as

$$m\,\ddot{z}(t) + c\,\dot{z}(t) + k\,z(t) = -m\,\ddot{y}(t)$$



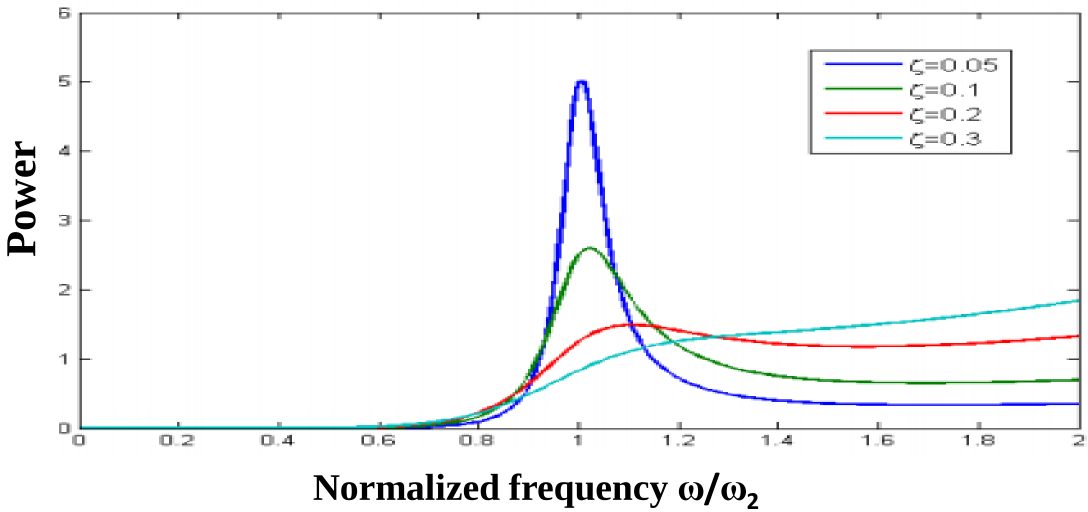


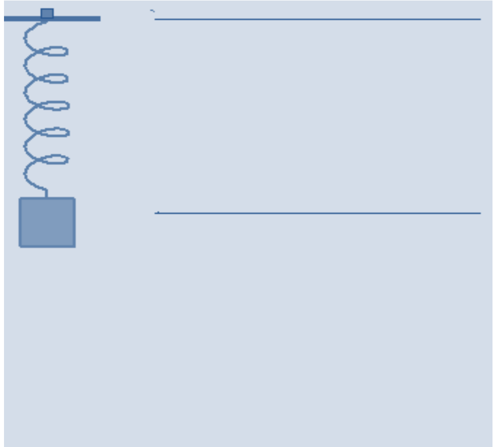
$y(t) = Y\sin(\omega t).$

Problem !!!!!!

Maximum power dissipation (P_d) occurs when the device is operated at ω_n and in this case *power* is given by the following equations:

$$P_{\mathrm{d}} = \frac{m\zeta_{\mathrm{T}} Y^2 \left(\frac{\omega}{\omega_{\mathrm{n}}}\right)^3 \omega^3}{\left[1-\left(\frac{\omega}{\omega_{\mathrm{n}}}\right)^2\right]^2 + \left[2\zeta_T\left(\frac{\omega}{\omega_{\mathrm{n}}}\right)\right]^2}, \longrightarrow P_{\mathrm{d}} = \frac{mY^2\omega_{\mathrm{n}}^3}{4\zeta_{\mathrm{T}}}$$

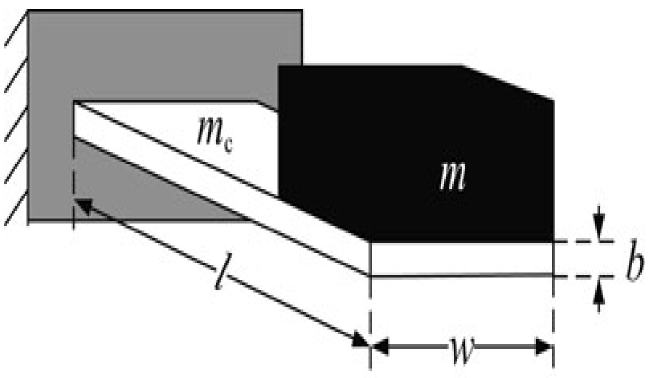


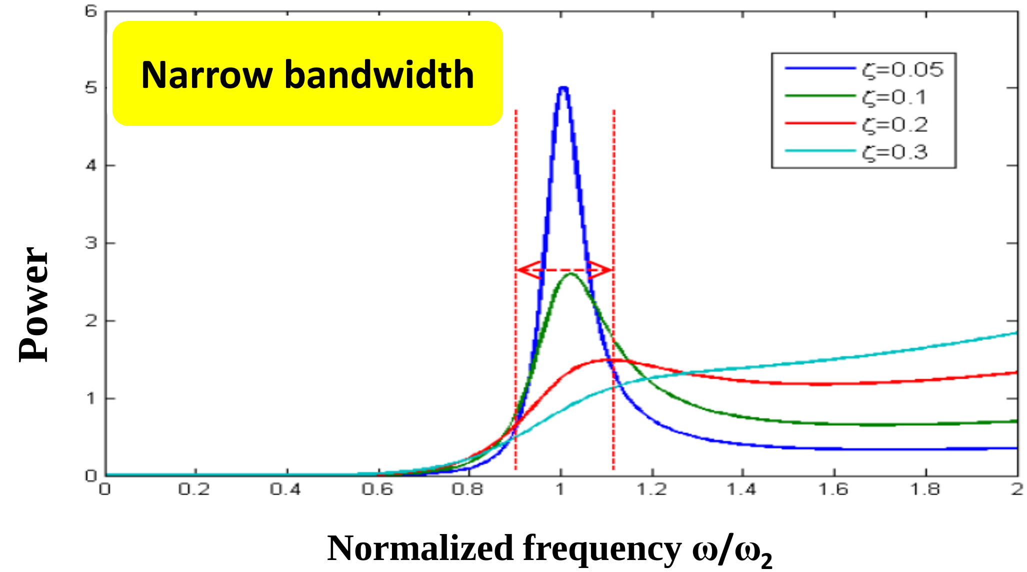


Solution

From literature review we have two approaches in enhancing energy harvesting system

First approach	→	Objective	→	High power





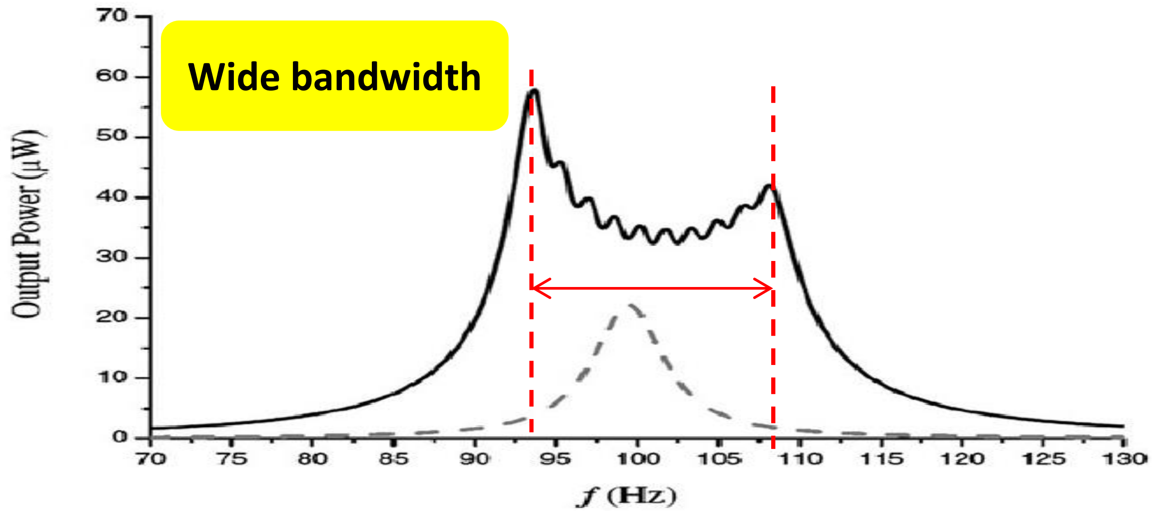
Approaches :

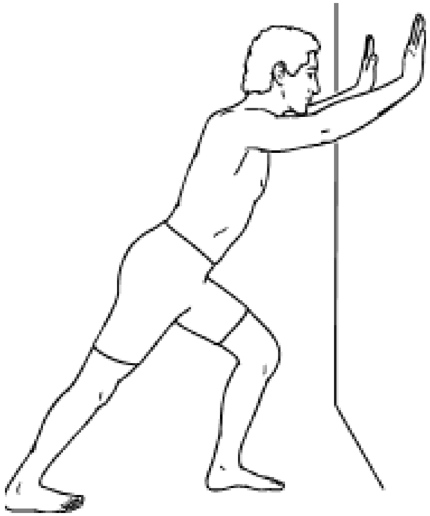
1. changing dimensions.
2. moving the center of gravity of proof mass.
3. variable spring stiffness.

$$P_d = \frac{m Y^2 \omega_n^3}{4\zeta_T}$$

Solution

Second approach → Objective → Wide bandwidth





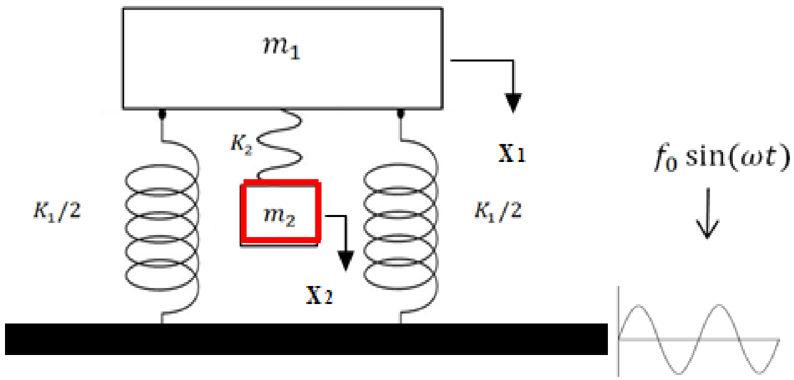
Approaches :

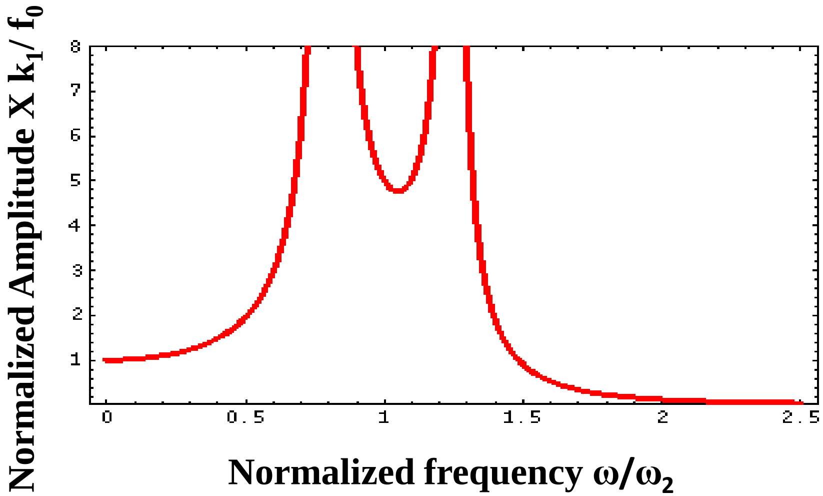
1. **Resonant Frequency Tuning Techniques**.
2. **Multimodal Energy Harvesting**.
3. **Nonlinear Energy Harvesting Configurations.**

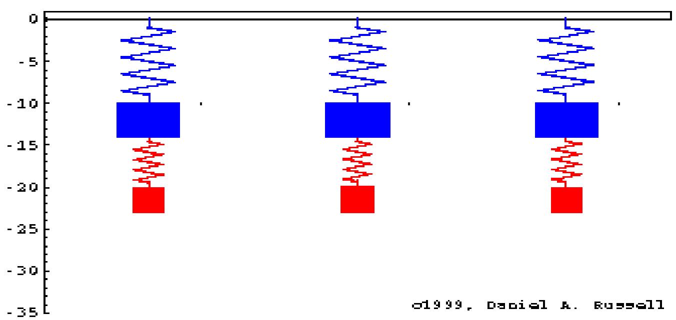
My idea !!!

→ Vibration absorber

- ✓ WIDE Bandwidth
- ✓ HIGH Power



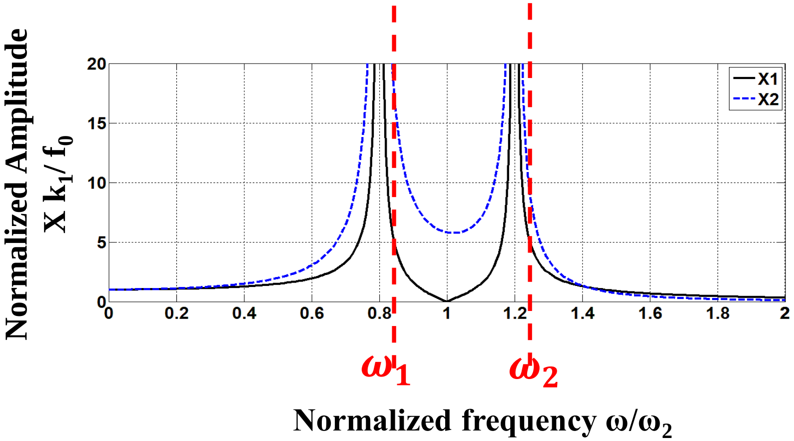




m_1 = mass of the system called primary mass.
m_2 = mass of the absorber called secondary mass.
k_1 = spring stiffness of the system.
k_2 = spring stiffness of the absorber.

ENERGY HARVESTER DESIGN PROCEDURES

- From the characteristic equation of this system :



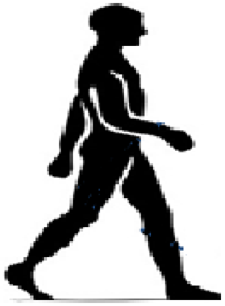
$$\omega_1^2 * \omega_2^2 = \frac{k_1}{m_1} * \frac{k_2}{m_2} \qquad (1)$$

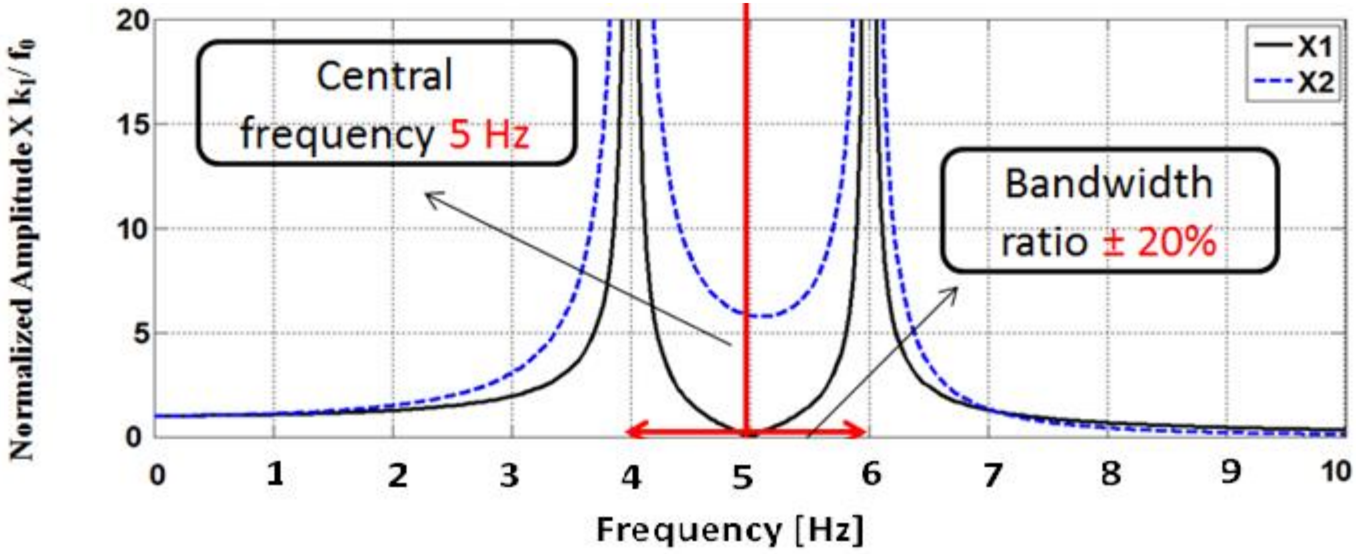
$$\omega_1^2 + \omega_2^2 = \frac{k_1}{m_1} + \frac{k_2}{m_2} + \frac{k_2}{m_1} \qquad (2)$$

ENERGY HARVESTER DESIGN PROCEDURES

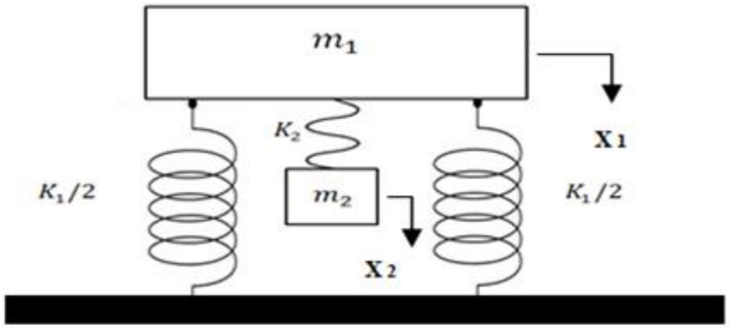
➢ **The selection procedure is based on the following criteria:**

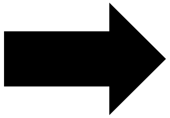
1. Central frequency of the human motion frequency range. (5 Hz)
2. Frequency bandwidth of the human motion (20% Bandwidth ratio)

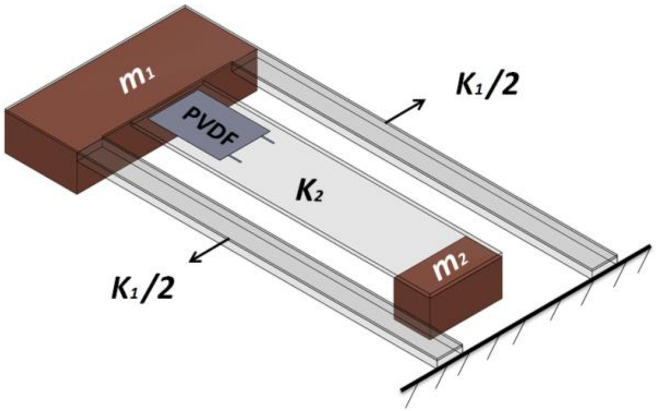




Design layout







Design model

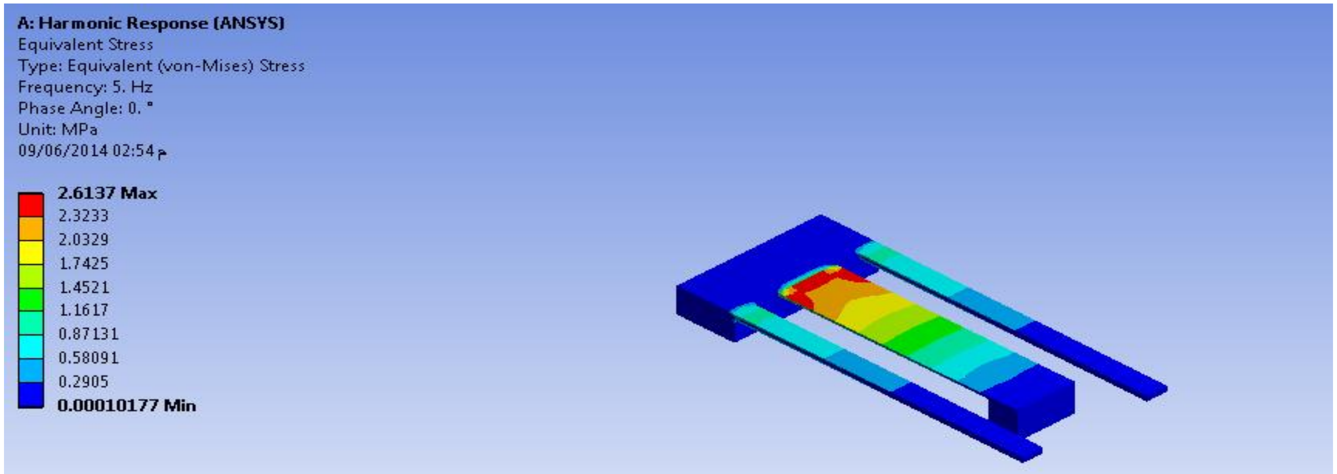
Design layout

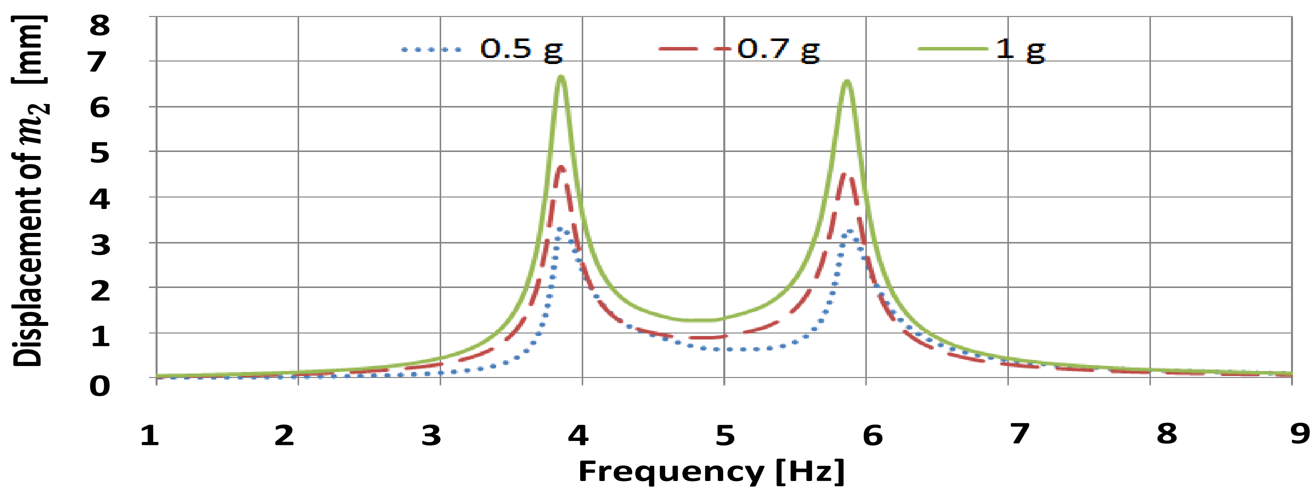
- Based on the design procedures the system parameters (m_1, m_2, k_1, k_2) can be obtained as follows :

m_1	m_2	k_1	k_2
85 gm	13.4 gm	70 N/m	12 N/m

ANSYS SIMULATION

Harmonic Response Analysis , Stress analysis





Stress Analysis and Voltage Generation

$$v_{oc} = g_{31} \times t_p \times \sigma$$

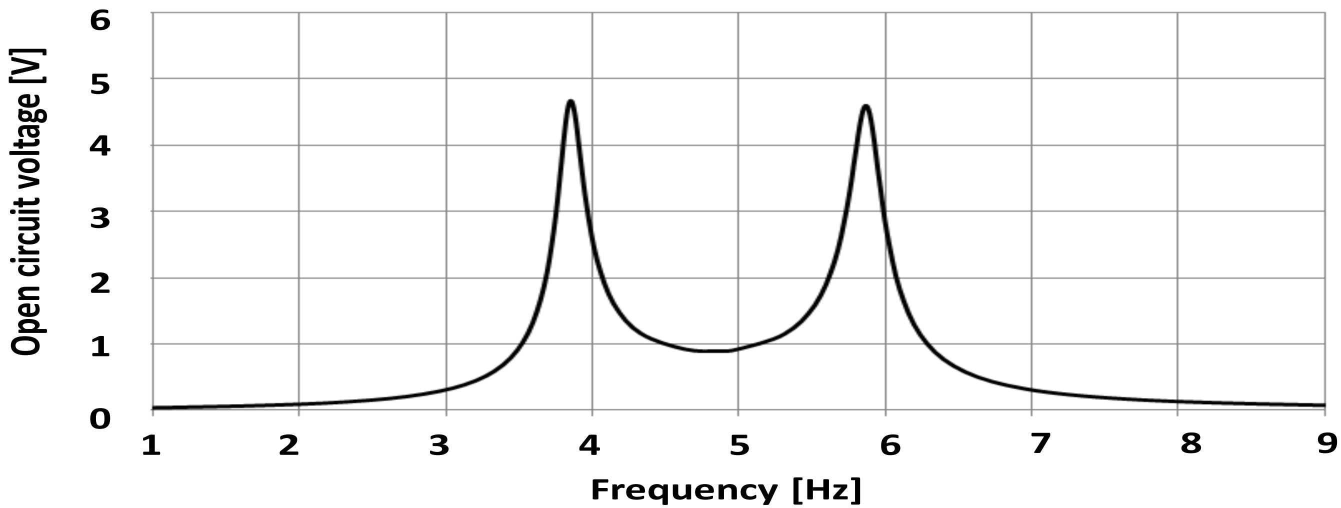
Where:

v_{oc} The Open circuit voltage that generated across the piezoelectric.

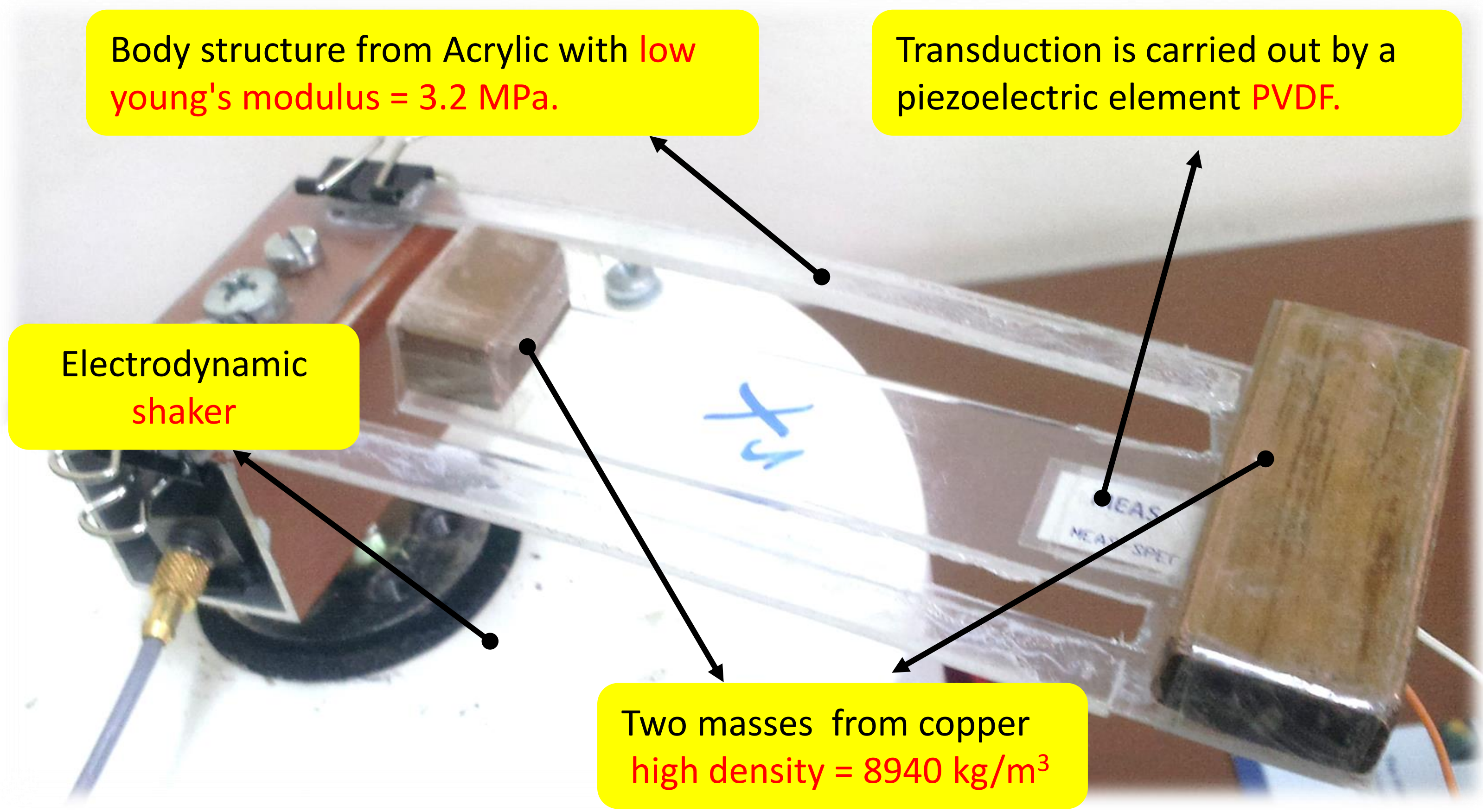
g_{31} Piezoelectric stress coefficient.

t_p Piezoelectric thickness .

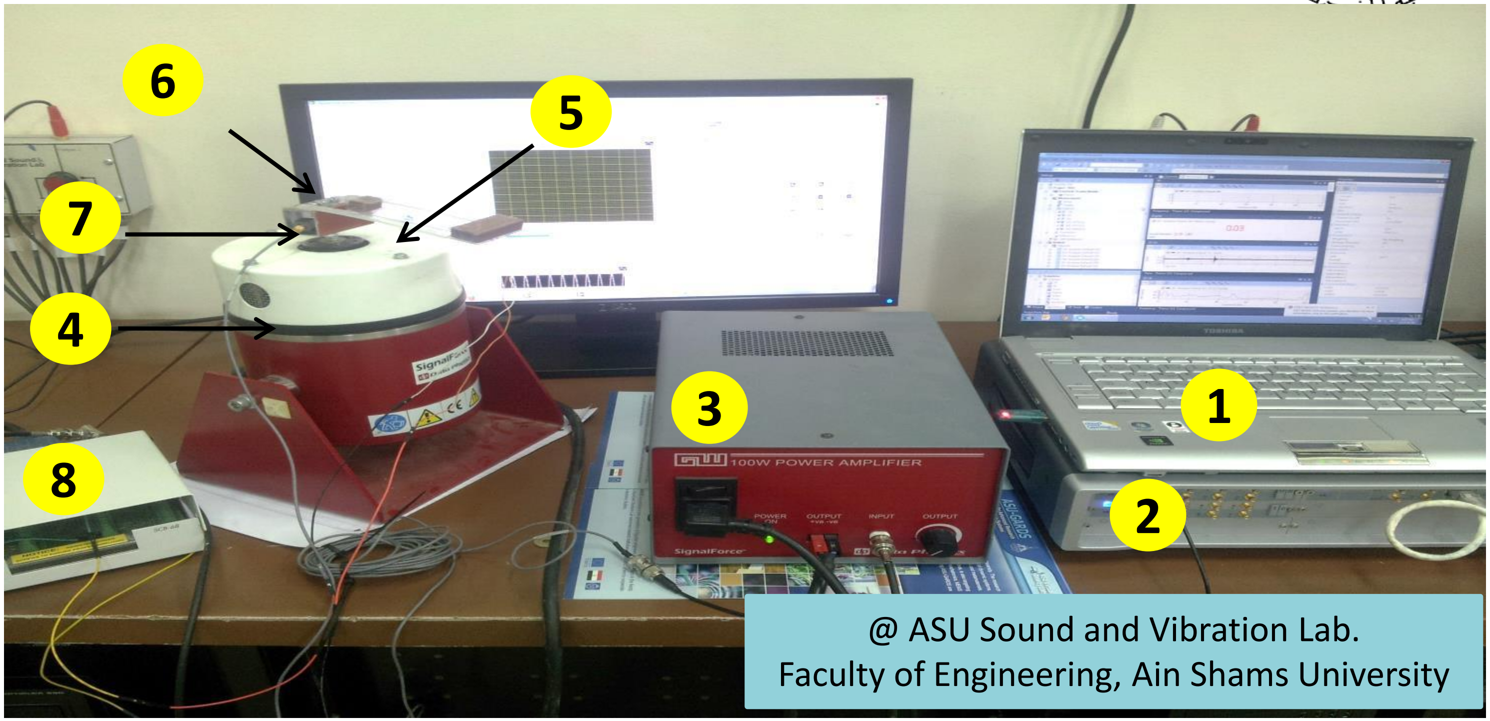
Parameters	Description	Value
g_{31}	Piezoelectric coefficient	216×10^{-3} V m N^{-1}
t_p	Piezoelectric thickness	15 µm



Energy harvester prototype

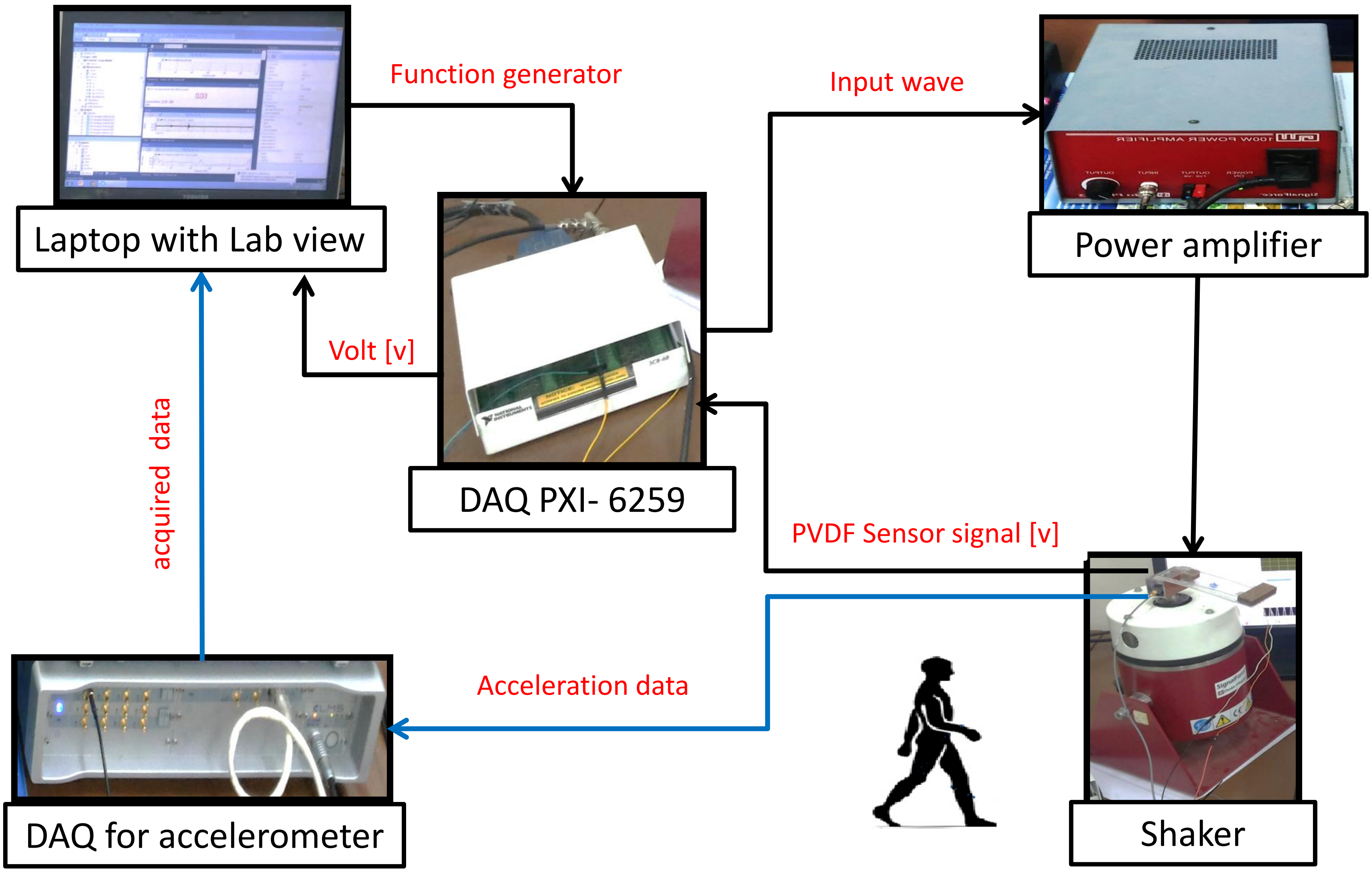


PROTOTYPE FABRICATION AND EXPERIMENTAL RESULT

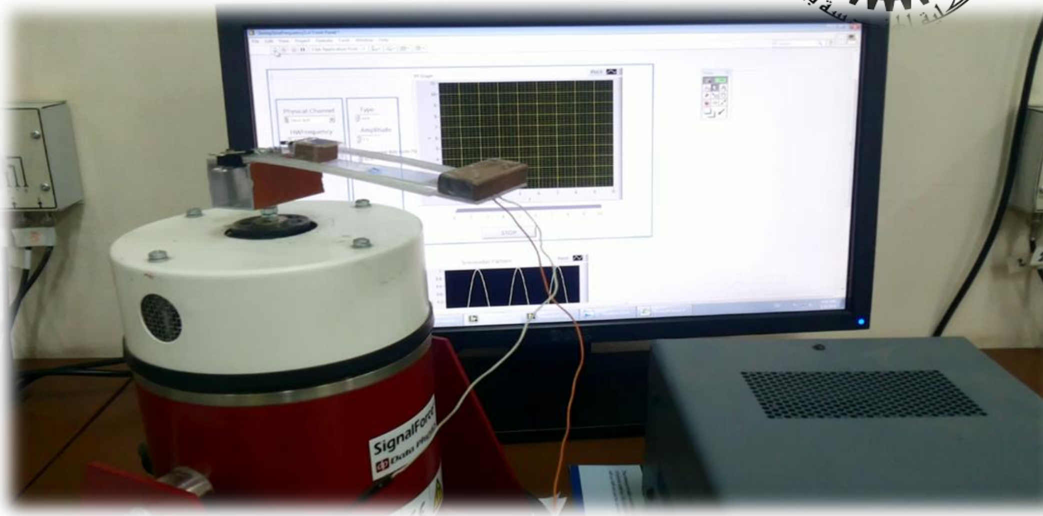


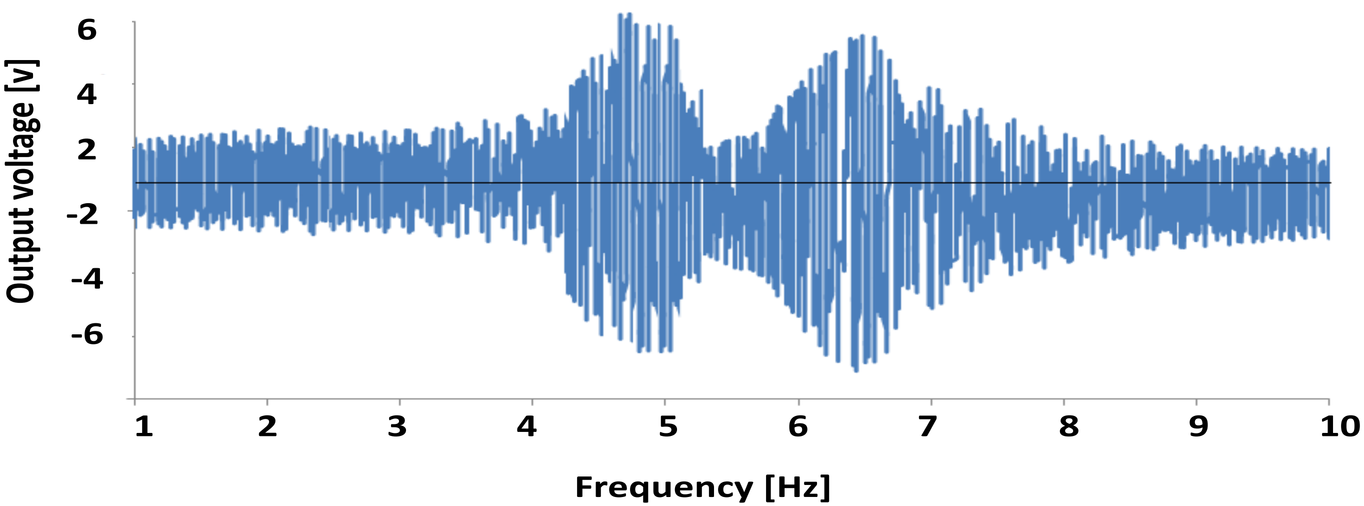
1. Laptop with Lab view Signal Express
2. LMS data acquisition system for accelerometer
3. Shaker power amplifier 9263 modules
4. Electromagnetic shaker
5. PVDF piezoelectric harvester
6. Aluminum holder
7. Accelerometer
8. PXI-DAQ 6259

PROTOTYPE FABRICATION AND EXPERIMENTAL RESULT



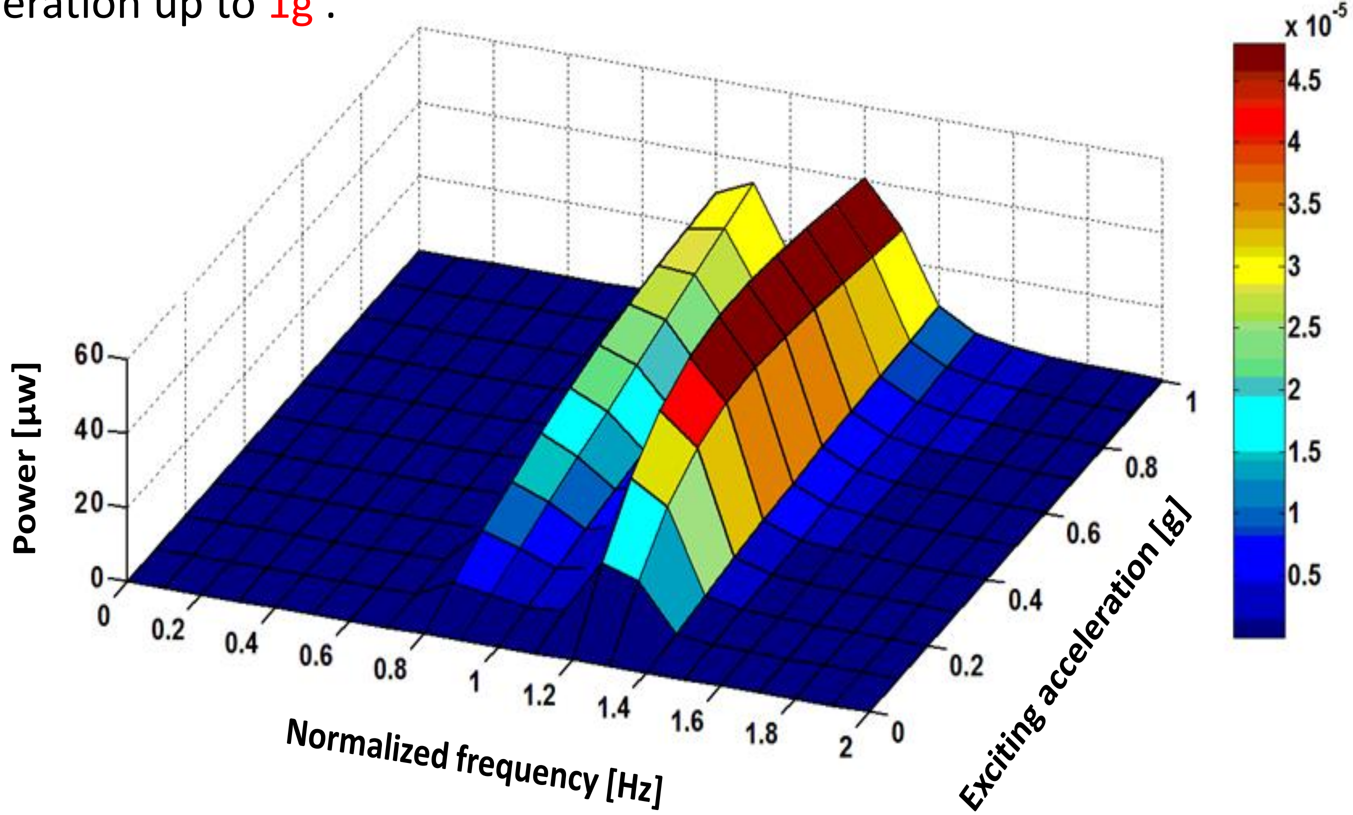
Voltage Generation



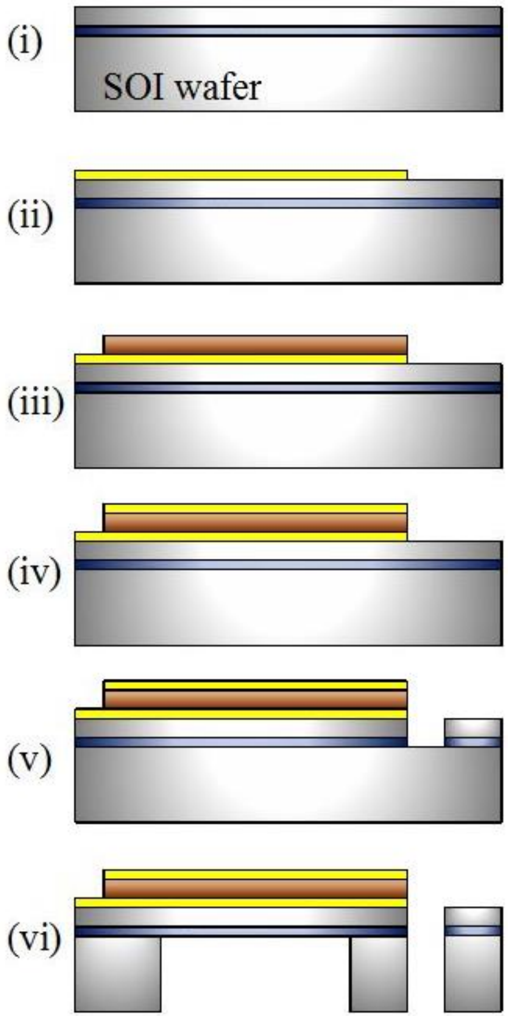


Power Generation

Based on 2 MΩ resistance, the calculated mean value of the harvested power by the device at the targeted frequencies and bandwidth is 18µW at different acceleration up to 1g .



Miniaturize!!!!



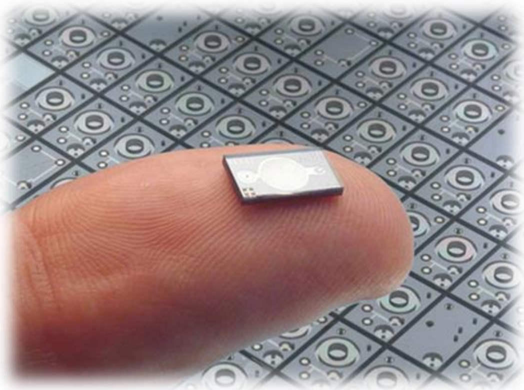
Silicon wafer

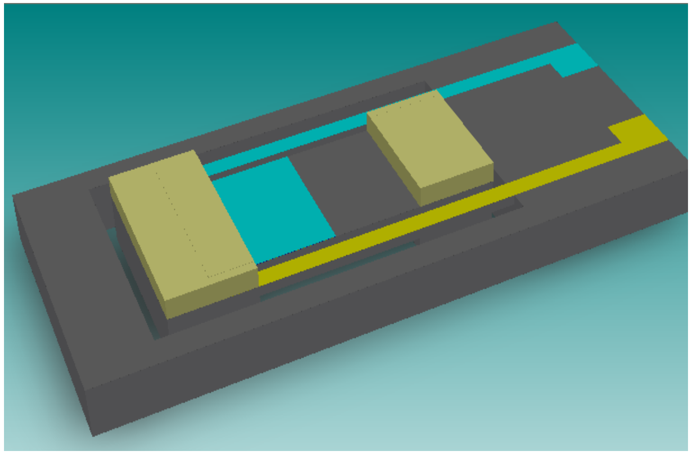
Aluminum deposition

PZT sputtering

Aluminum deposition

Mass etching

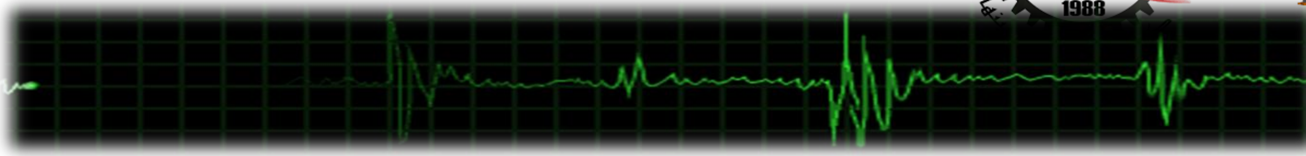




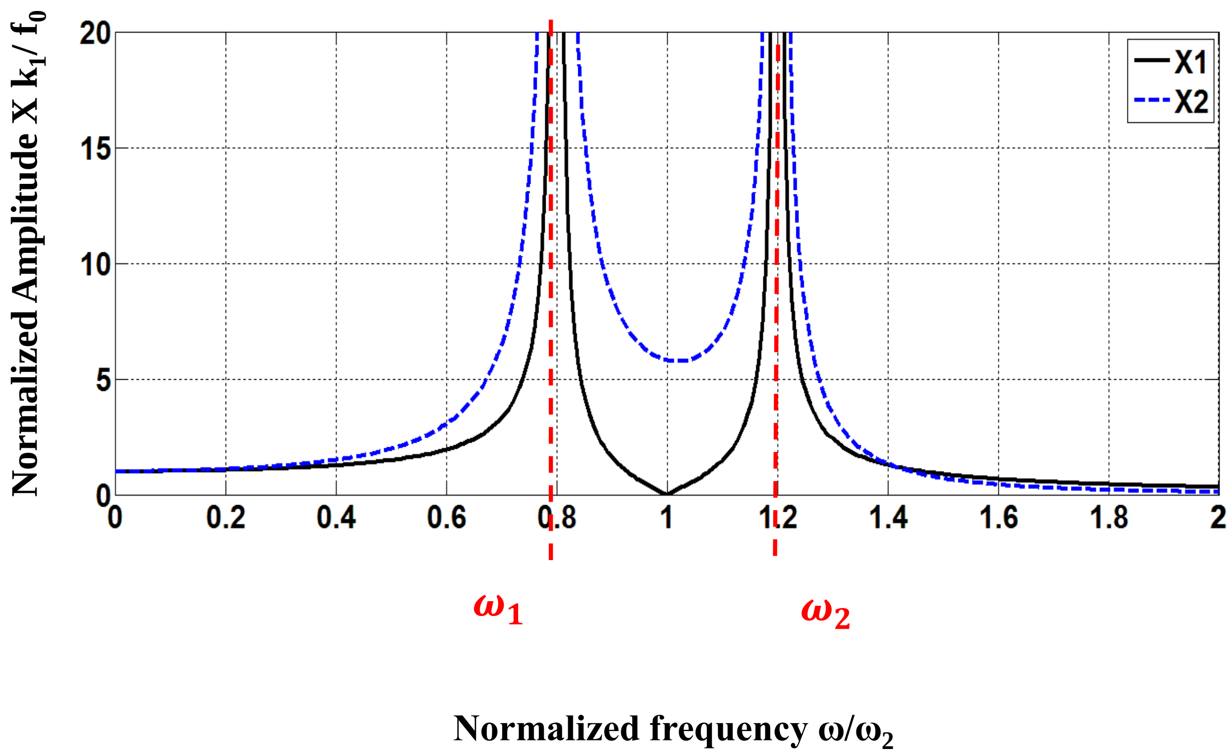
Si SiO_2 Al PZT Si SiO_2 Al PZT

Discussions and conclusions

conclusions



Design the energy harvester device based on vibration absorber lead to more controllable in the bandwidth.



Ref: SolidWorks Teacher Guide Lesson

Thank You for Attention !!

Any Questions