NANOELECTRONICS

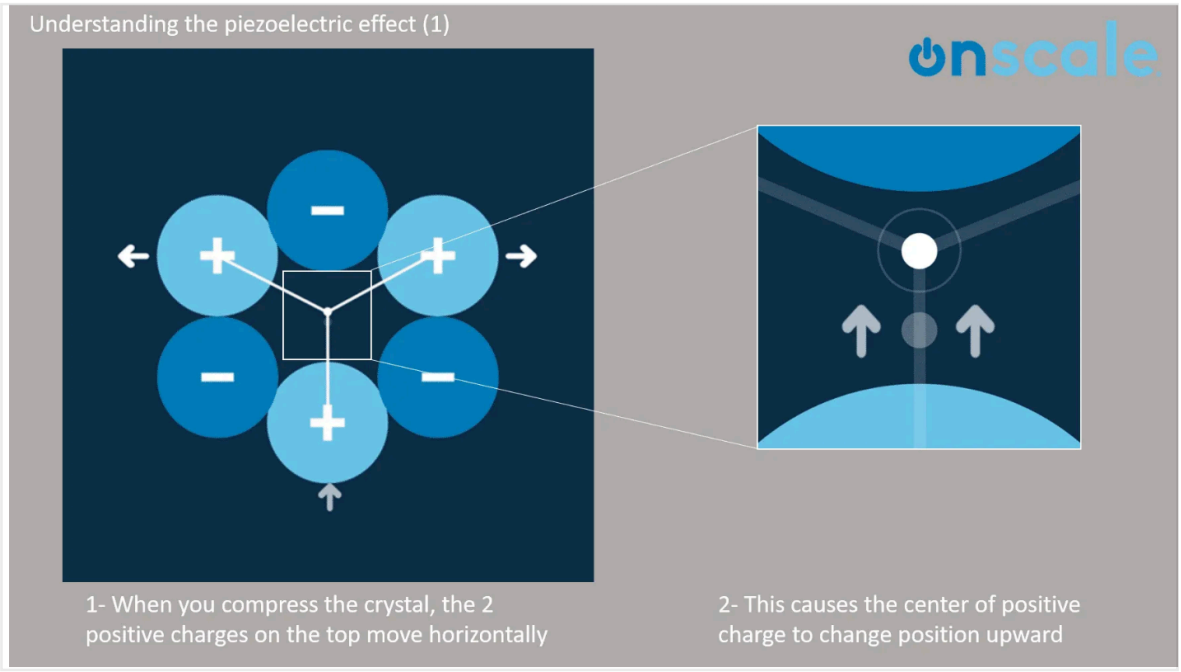
To give a start let us understand what is piezoelectric Effect

Piezoelectric Effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The word Piezoelectric is derived from the Greek piezein, which means to squeeze or press, and piezo, which is Greek for “push”.

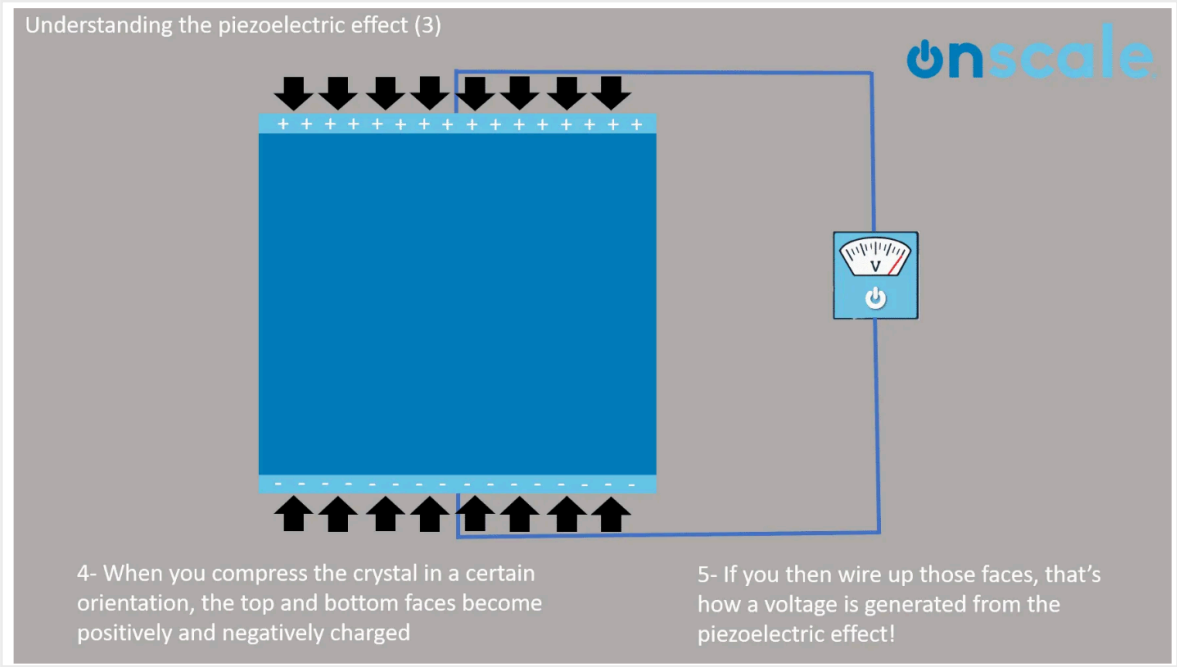
In crystalline piezoelectric materials, the **unique distribution of charges** gives rise to a dipole moment when the material is deformed.

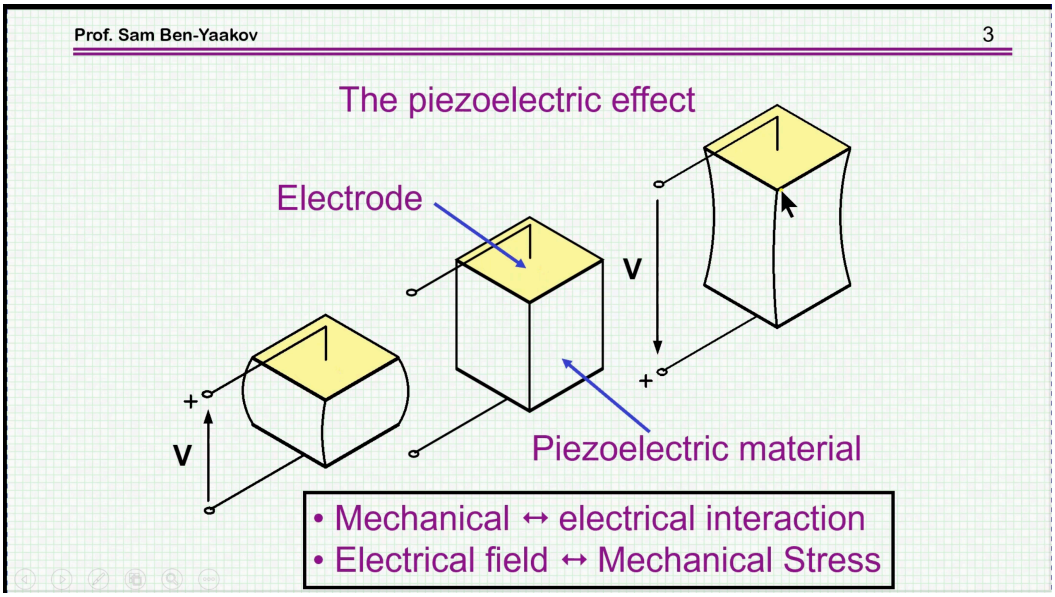
But why charge is changing for piezoelectric materials and not for any other material?

Like we mentioned in the previous part, it is because of the special arrangement of the piezoelectric material crystals in a hexagonal configuration.



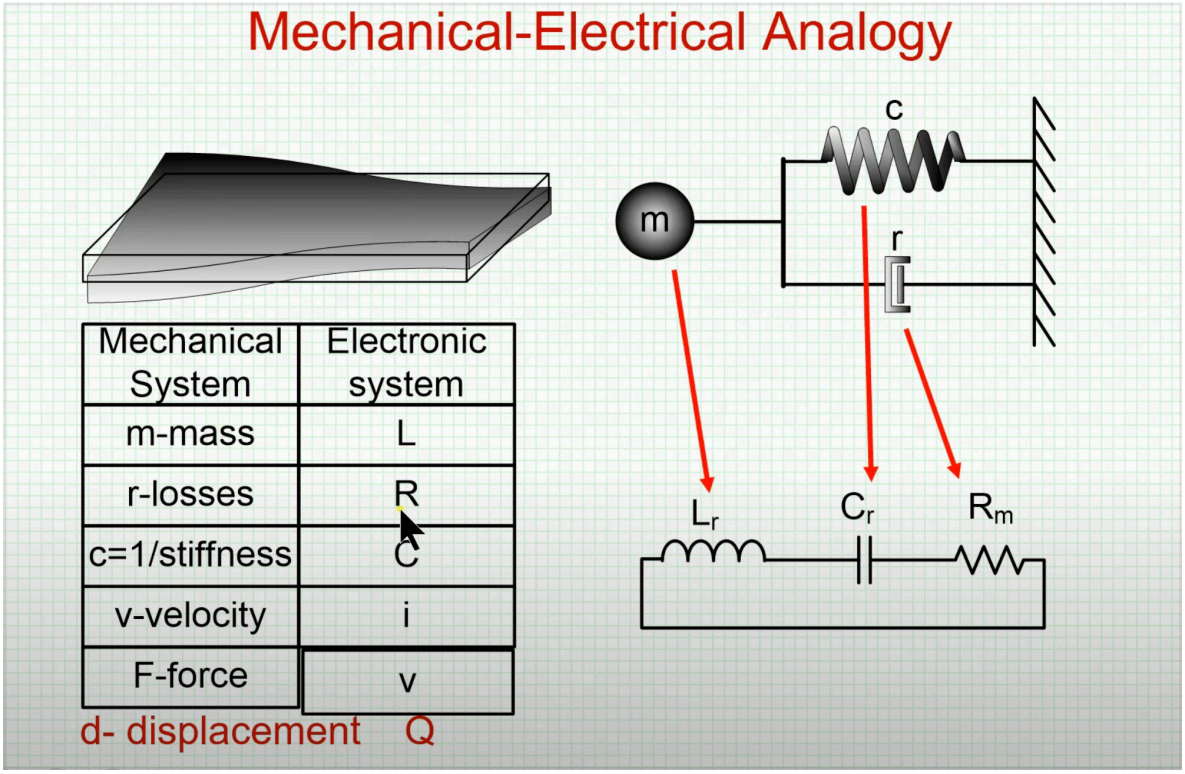
When you compress the crystal in a certain orientation, you are slightly shifting the average position of the positive charges in one direction and the average of the negative charges in the other direction.
This create an accumulation of positive charges on one face and an accumulation of negative charges on the other face.





Direct and Inverse Piezoelectric Effects:

- **Direct Piezoelectric Effect:** When mechanical stress is applied to a piezoelectric material, it generates an electric charge.
- **Inverse Piezoelectric Effect:** When an electric field is applied to a piezoelectric material, it undergoes mechanical deformation.



Applications:

- Piezoelectric materials find applications in various devices, including sensors, actuators, ultrasound transducers, and energy harvesters.

WHY PIEZOELECTRIC VIBRATIONAL ENERGY HARVESTING?? WHAT UPPPER HAND DOES THIS INNOVATION HAVE OVER THE PRESENT TECHNOLOGY??

Small Form Factor and Lightweight:
Piezoelectric devices can be designed to be very compact and lightweight, making them suitable for applications where space and weight are critical factors. This is particularly advantageous in micro and nanoscale devices.

Scalability:
Piezoelectric energy harvesting can be scaled easily for different applications. Whether it's a small sensor or a larger structural application,

the technology can be adapted to meet the specific power requirements of the system.

High Energy Density:
Piezoelectric materials can have high energy density, allowing them to generate significant electrical power from even low-amplitude vibrations. This is especially valuable in environments where there are ambient vibrations or mechanical movements.

Wide Range of Operating Frequencies:
Piezoelectric devices can be tuned to resonate at specific frequencies, allowing them to efficiently capture energy from vibrations within a certain frequency range. This adaptability makes them suitable for various environments.

Environmental Friendliness:
Piezoelectric energy harvesting is a clean and environmentally friendly technology. It doesn't rely on chemical processes, fuel, or external power sources, making it a sustainable solution for powering low-energy devices.

Long Lifespan:
Piezoelectric materials are known for their durability and longevity. When properly designed and implemented, piezoelectric energy harvesting systems can have a long operational lifespan with minimal maintenance requirements.

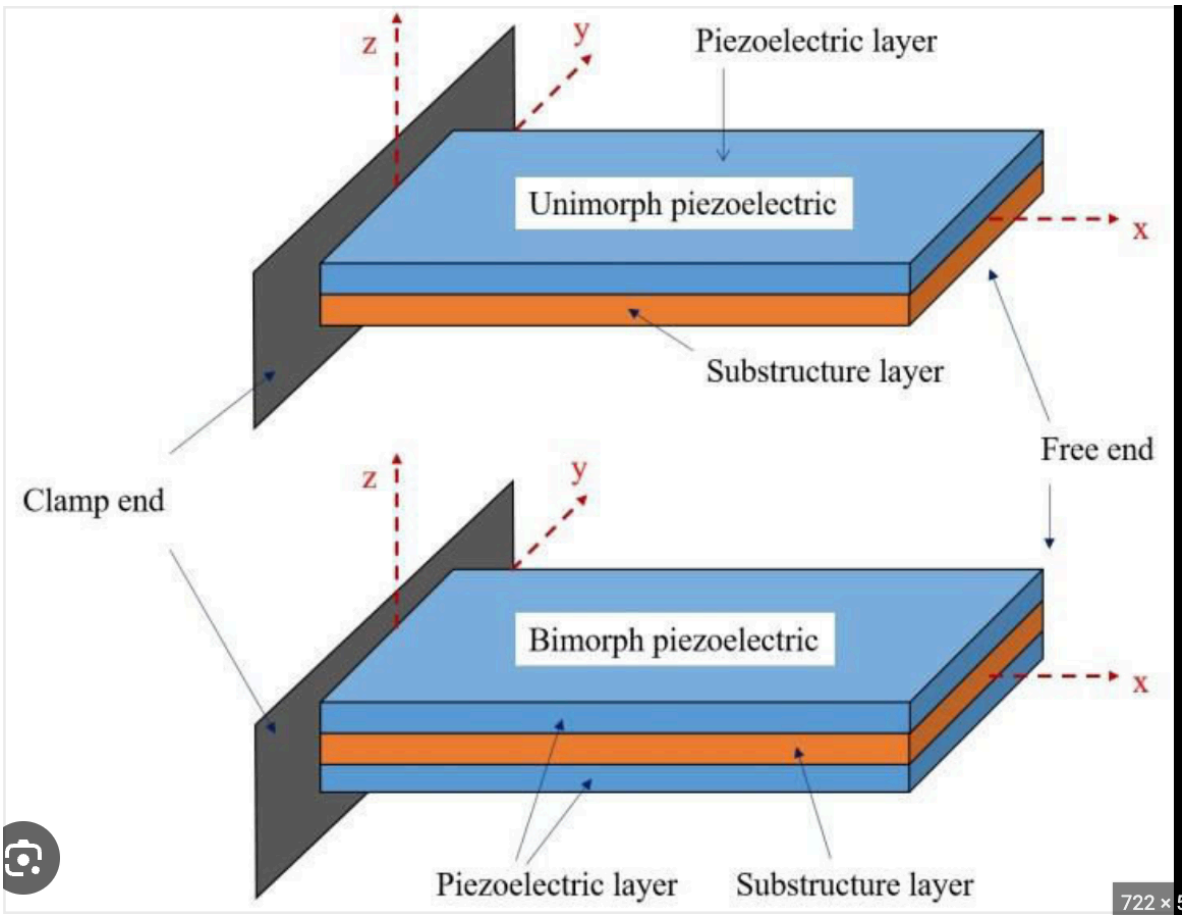
Harvesting from Various Sources:
Piezoelectric energy harvesting can capture energy from a variety of sources, including ambient vibrations, mechanical vibrations, and even human motion. This versatility broadens its range of potential applications.

Integration with Structural Components:
In some applications, piezoelectric materials can be integrated into structural components of devices or infrastructure, allowing for dual functionality—structural support and energy harvesting.

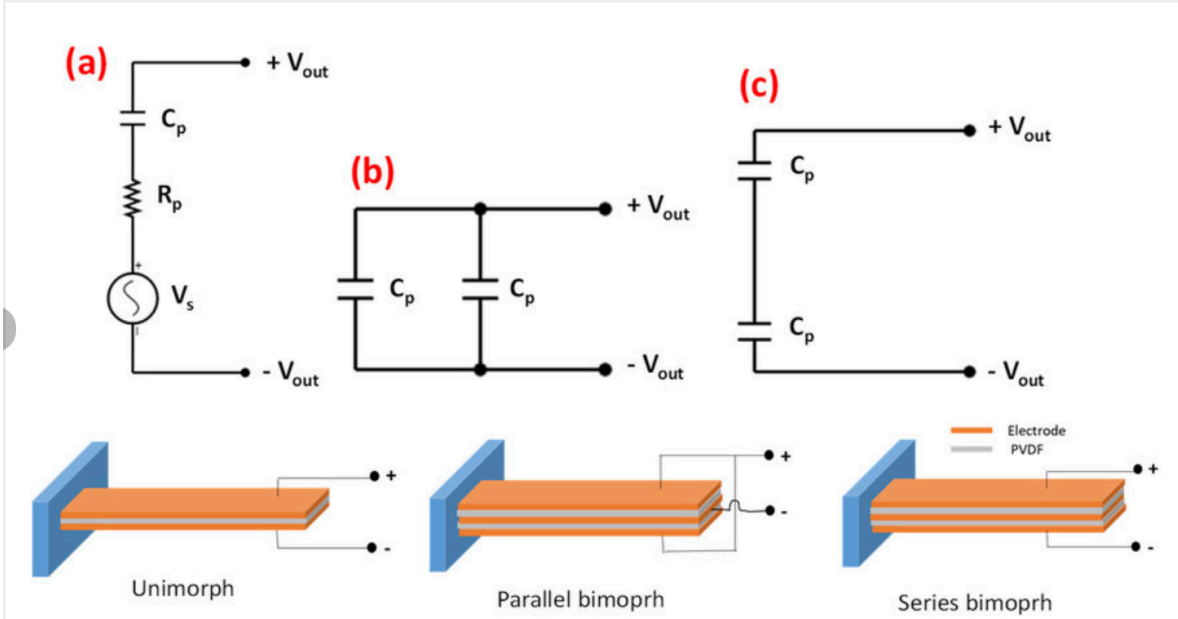
Low Operating Costs:
Once implemented, piezoelectric energy harvesting systems often have low operating costs as they don't require ongoing fuel or external power sources. This can be advantageous in remote or hard-to-reach locations.

Wireless and Autonomous Devices:
The ability to harvest energy from ambient vibrations allows for the creation of wireless and autonomous devices that can operate independently for extended periods, eliminating the need for frequent battery replacements.

TWO TYPES OF PIEZOELECTRIC NEMS CANTILEVER

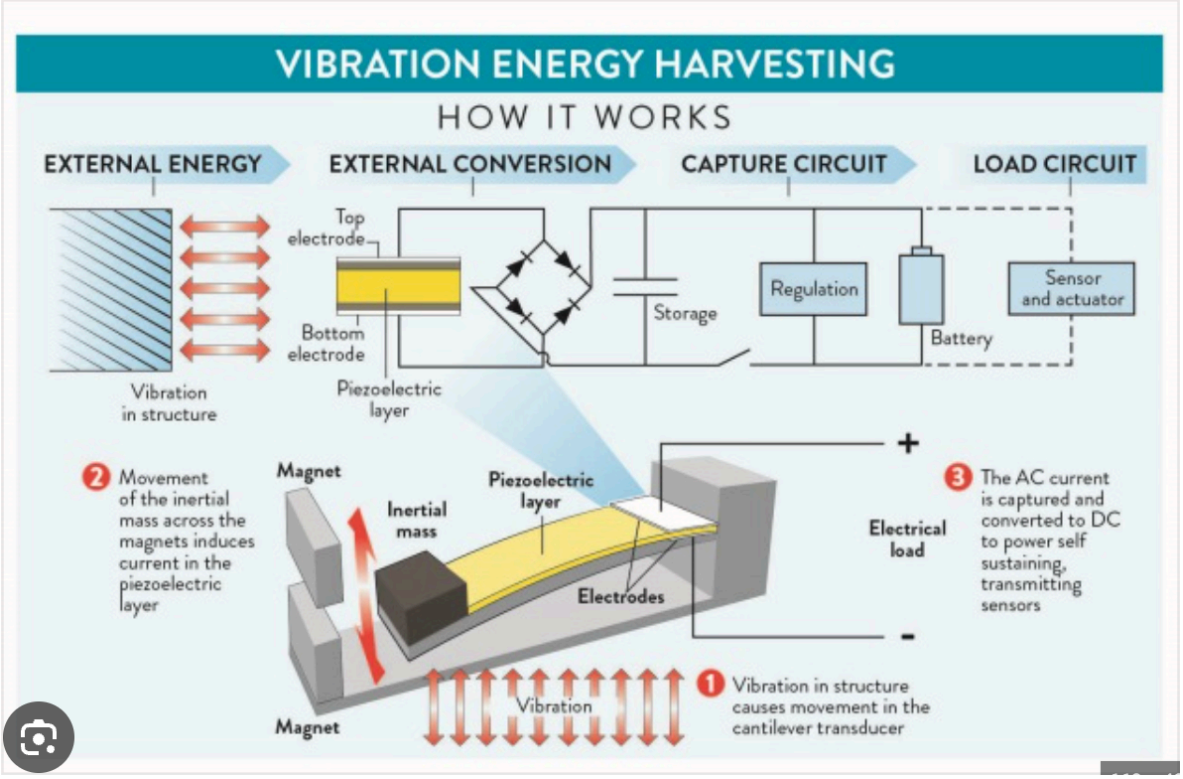


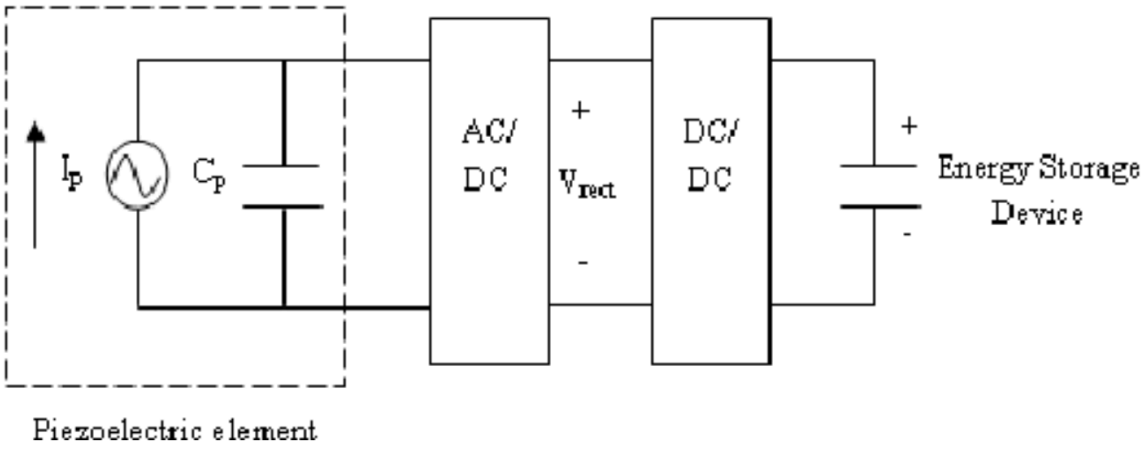
THESE ARE THE EQUIVALENT CIRCUITS FOR DIFFERENT TYPES OF CONNECTIONS



Voltage generator piezoelectric circuit model (a) unimorph (b) parallel bimorph (c) series bimorph [12].

THIS IS THE BASIC BLOCK DIAGRAM OF THE PIEZOELECTRIC ELEMENT





Stages of piezoelectric energy harvesting circuit.

THE BASIC COMPONENTS OF THE PIEZOELECTRIC ENERGY HARVESTER

Piezoelectric Material:

The heart of the piezoelectric energy harvester is the piezoelectric material itself. Commonly used materials include lead zirconate titanate (PZT) and various ceramics. These materials exhibit the piezoelectric effect, generating an electric charge when subjected to mechanical stress.

Supporting Structure:

The piezoelectric material is often mounted or embedded in a supporting structure. This structure is designed to efficiently transmit mechanical vibrations to the piezoelectric material. The choice of materials and geometry is important for optimizing energy transfer.

Mass (Proof Mass or Proof Body):

In many piezoelectric energy harvesters, there is a mass component that is attached to the supporting structure. This mass enhances the device's response to vibrations, amplifying the mechanical strain experienced by the piezoelectric material.

Electrodes:

The piezoelectric material has electrodes attached to its surfaces. These electrodes collect the electric charge generated by the piezoelectric effect. One side of the material experiences positive charge, while the other side experiences negative charge during deformation.

Electrical Circuit:

The electrical circuit connected to the electrodes provides a pathway for the generated electric charge to flow. This circuit typically includes elements such as resistors, capacitors, and sometimes inductors to optimize the power transfer and voltage output.

Rectifier Circuit (Optional):

In some designs, a rectifier circuit may be included to convert the alternating current (AC) output from the piezoelectric material into direct current (DC). This is often necessary for practical applications, where a stable DC voltage is required.

Energy Storage (Optional):

In applications where a continuous power supply is needed, an energy storage component such as a capacitor or a rechargeable battery may be included. This allows the harvested energy to be stored and used when needed.

External Load or Device:

The electrical energy generated by the piezoelectric harvester can be used to power an external load or device. This can range from sensors and actuators to wireless communication modules or low-power electronics.

Protective Enclosure (Optional):

Depending on the application environment, a protective enclosure may be used to shield the harvester from environmental factors such as moisture, dust, or physical damage.

Adjustable Parameters (Optional):

Some designs incorporate adjustable parameters, such as tuning mechanisms or adaptive electronics, to optimize the performance of the energy harvester for specific vibrational frequencies.

OUR MAIN GOAL - TO ASSESS THE FINAL OUTPUT POWER

Let us first gain some mathematical insight

Mechanical power is converted into electrical power when damping is present. For a sinusoidal excitation vibration, the electrical power generated by the system is given in Equation (1) [14]:

$$P = \frac{m\zeta Y^2 \left(\frac{\omega}{\omega_n}\right) \omega^3}{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\zeta \frac{\omega}{\omega_n}\right]^2}$$

POWER WOULD BE MAXIMUM WHEN THE INPUT VIBRATION FREQUENCY EQUALS THE RESONATING FREQUENCY OF THE PIEZOELECTRIC CANTILEVER

$$P_{max} = P(\omega_n) = \frac{mY^2 {\omega_n}^3}{4\zeta}$$

Conclusions for power generation from the above formulae:

- Firstly, if we set the resonant frequency of the generator equal to the proof mass frequency, the maximum power generated is constrained by the proof mass's movement. This limitation can be quantified by expressing the maximum power in terms of the maximum distance the proof mass can travel.

- Secondly, in applications where vibration frequencies are well-defined and concentrated around a single point, a low damping factor leads to higher peak responses and increased power generation.

- Thirdly, it is evident that power is directly proportional to the proof

mass. Consequently, a larger proof mass is always advantageous for optimizing energy harvesting.

These equations are fundamental in understanding the behaviour of the piezoelectric energy harvester and its response to vibrational energy. They provide insights into the power generation and resonant characteristics of the system.

1. **Equation (1)**:
   - This equation represents the electrical power generated by the system in response to a sinusoidal excitation vibration. It is given by the formula:$P = \zeta * \omega * Y * A$
   -
   - Where:
     - P: Electrical power generated
     - ζ: Damping ratio
     - ω: Resonant frequency
     - Y: Amplitude of vibration
     - A: Excitation acceleration magnitude
2. **Equation (2)**:
   - This equation shows that the maximum output power occurs at the resonant frequency of the generator when the driving vibration frequency matches the resonant frequency. It is given by the formula:$P_{max} = \zeta * \omega * Y^2$
   -
3. **Equation (3)**:
   - This equation expresses the power in terms of the excitation acceleration magnitude of the input vibration. It is given by the formula:$P = 0.5 * A^2 * \omega^2 * Y^2$
   -
4. **Equation (4)**:
   - This equation calculates the equivalent stiffness of a horizontal cantilever beam subjected to a vertical harmonic excitation. It is given by the formula:$k = E * I / L$
   -
5. **Equation (11)**:
   - This equation represents the resonant frequency of the piezoelectric cantilever beam. It is given by the formula:$\omega_n = (k / m)^{0.5}$