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Design and Development of MEMS Based Array Structured Vibrational Energy Harvester

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Abstract: Rapid advances in microelectromechanical structures (MEMS) have enabled the improvement of efficient electricity harvesting equipment, converting ambient vibrational power into usable electric electricity. This newsletter offers the layout and simulation of a MEMS-primarily based array structure vibrational electricity harvester. This is optimized for effective electricity conversion. The proposed harvester ambitions to remove mechanical vibrations from renewable energy resources and convert them into power through piezoelectric effects. It consists of a circular array of rectangular factors, each attached to a heavy weight, to improve the efficiency of electricity incidents. This specific structural configuration ensures surest use of space even as making sure maximum strength harvesting performance. To attain great electricity conversion efficiency, Harvester's PZZ-5H uses piezoelectric substances with excessive electromechanical bonding. The array factors are mainly advanced with prolonged beam lengths and comparatively low widths and thicknesses, which efficaciously make use of low frequency vibrations. The resonant behavior of the structure is analyzed the use of COMSOL Multiphysics software, which provides insight into the mechanical and electric residences of the harvester. The simulation is executed to decide the resonant frequency, ordinary shift, and output voltage under one-of-a-kind boundary conditions. The effects display that the harvester reaches a most output voltage of 1 V whilst it quickens 1 g. This demonstrates its potential as a sensible solution for applications with low strength sources, especially wi-fi sensor networks, biomedical gadgets and IoT-primarily based clever structures. Additionally, through using the available area correctly, the circular array shape considerably increases power density. This study highlights the effectiveness of MEMS-based piezoelectric harvesting in recording environmental vibrations and the conversion into usable electric electricity that contributes to the development of self-successful electronic systems. Future work will cognizance on optimizing material houses and research talents for multi-faceted electricity harvesting to improve normal performance.

Keywords: MEMS, Vibrational Energy Harvester, PZT-5H, Array Structured Energy Harvester

1. Introduction

Over the last few a long time, there was a slow increase in research on power harvesting generation. Digital devices have gotten smaller in size and consumed less energy due to developments in strength harvesting technology [1]. The amount of energy required to perform a device has been reduced to micro-watt and Nano-watt ranges because of rapid improvement in microelectronics and device minimization [2]. Due to its superior performance as compared to different harvesters, Vibrational strength harvester is used to transform mechanical strain into useful electric power [3]. Vibration strength harvesting can be defined as a technique of extracting electrical energy from vibrations of numerous underutilized environmental assets [4]. Saadon and Wahab reviewed various MEMS-based designs and concluded that rectangular-shaped cantilever arrays provide an optimal balance between power output and fabrication complexity. Vibrational energy harvesters are normally favored due to the subsequent capabilities which include smooth production, ease of operation, versatility, layout simplicity and as well as the reality that they do no longer require any form of supply excitation to perform. The majority of digital devices are powered with the aid of batteries, which have a constrained life time and have an effect on the device's overall performance. As a result, the tool's overall performance can be maintained by using the use of incorporated energy harvesters in place of batteries [5]. The electrical energy received with the aid of scavenging the ambient vibrational electricity of the environment can be applied to strength a variety of makes use of, which include biofuels, wireless sensor devices, and implantable scientific device consisting of pacemakers. The performance of a vibrational electricity harvester is inspired via characteristics like beam period, breadth, thickness, evidence mass, resonating frequency, and kind of piezoelectric cloth. At low resonating frequency green output is generated whilst beam length is massive with extraordinarily smaller width and thickness, along with a heavy weight proof mass [5, 6-8]. Wahib *et al.* concluded that pinnacle proof mass is the first-class desire after analyzing the extraordinary architectures of array designs because it delivers a good amount of power with a compact length. They discussed the different array configurations and found that top proof mass structures deliver higher energy efficiency compared to back-etch mass and interdigitated electrode designs [9]. Array based Vibrational electricity harvester harvests strength over a huge variety of frequencies not like unmarried detail vibrational strength harvester that's restricted to slender frequency variety [10, 11]. Rectangular-shaped systems" are most typically hired in MEMS-based totally energy harvesters. In step with an overview study by way of "Saadon and Sidek," they're easy to install and powerful at scavenging energy from ambient vibrations. In step with Roundy *et al.* fabrication can be completed in a easy way by means of deciding on designs of rectangular form. They confirmed the feasibility of MEMS vibrational electricity harvesters for self-powered sensor networks [12]. The electrostatic harvesting approach offered by using Tashiro *et al.* Produces 36microwatt power from the vibrations of the dog's heart which is sufficient to produces enough energy to run a coronary heart pacemaker. They developed an electrostatic harvester that successfully converted heart vibrations into electrical energy, demonstrating the feasibility of MEMS energy harvesters in biomedical applications. MEMS-based power harvesting has won full-size interest due to its ability to strength small digital devices with the aid of converting ambient vibrations into electric energy. Over the years, researchers have explored diverse energy harvesting mechanisms, consisting of electromagnetic, electrostatic, and piezoelectric techniques. Amongst those, piezoelectric electricity harvesting has been extensively studied due to its excessive power conversion efficiency, ease of integration, and scalability. Early studies focused on unmarried-detail cantilever-based totally designs, but they had been confined in terms of frequency range and electricity output. To overcome those boundaries, array-primarily based systems had been added, bearing in mind broader frequency response and advanced power extraction from low-amplitude vibrations. Numerous researchers have worked on optimizing the layout and material residences of MEMS-based totally piezoelectric harvesters [13].

Additionally, Zhang *et al.* developed an AlN-based piezoelectric energy harvester, highlighting the potential of alternative materials for improved environmental sustainability. A key challenge in MEMS-based vibrational energy harvesters is the narrow frequency bandwidth, which restricts their application in real-world scenarios where vibrations occur over a range of frequencies. They developed an AlN-based piezoelectric energy harvester. Because of its low fabrication costs and environmental friendliness, AlN is favored [14]. Balguvhar *et al.* built piezoelectric device to scavenge energy from bridge vibrations. A power harvester with various beam lengths and proof masses is designed to resonate at multiple frequencies, but its cost and size are its constraints [15]. To address this issue, multi-frequency and wideband energy harvesting techniques have been explored. Shahruz proposed a multi-frequency harvester with different beam lengths and proof masses to enhance energy extraction over varying frequencies [16]. Additionally, simulation studies using COMSOL Multiphysics have played a crucial role in optimizing harvester designs before fabrication. Despite significant progress, further research is needed to improve the efficiency, scalability, and real-world applicability of MEMS-based vibrational energy harvesters. Future studies should focus on hybrid energy harvesting techniques that combine piezoelectric, electromagnetic, and electrostatic methods for enhanced energy output [17-19]. Further advancements in miniaturization, power density, and integration with energy storage systems are required to make these devices more practical for IoT, biomedical, and smart sensor applications. Experimental validation of simulation results and real-world deployment in industrial and biomedical settings will be critical in ensuring the commercial viability of MEMS-based energy harvesters [20-23].

The article by X. Tian et al. discusses ultrasonic energy harvesters for medical implants, MEMS piezoelectric ultrasonic energy harvesters, and focuses primarily on low-temperature fabrication techniques. These ultrasonic energy harvesters utilize piezoelectric layers which can be deposited below 250°C. Because of this, ultrasonically-excited perpetual energy converters can be used in multi-functional pacemakers and biosensors. These energy harvesters are well suited for long term implants as well as chronic biosensors. Enhanced functionality without requiring additional batteries means that electronics such as pacemakers and biosensors can be made much more compact [24].

M. Sun, X. Liao described an energy harvesting microsystem composed of a multi-source energy harvesting module integrating a microwave amplifier into a single chip. The module utilizes a dual function of amplifying RF signals and harvesting energy from RF, thermal, and vibrational sources all on a single chip which is compatible with CMOS processing. These are important for connected sensors and compact IoT. These techniques are important for addressing design problems for high-frequency circuit and energy harvesting module co-design in low power communication environments [25].

F. Ambia *et al.* designed a MEMS biomechanical electrostatic energy harvester specifically tailored for electro-mechanical medical devices like pacemakers. The researchers concentrated on the biomechanical energy input like chest motion or heartbeats and created a biomechanical MPPT (Maximum Power Point Tracking) adaptive interface model for pacemakers. The interface aimed to enhance consistent energy transfer from the body. The results achieved indicate the interface's capability for consistent energy transfer rendering it efficient for applications with stringent energy supply conditions. This brings us one step closer to medical implants with self-sustaining energy systems requiring infrequent or no battery replacements [26].

M. Sun, X. Liao reported the development of a new multisource energy harvesting circuit (RF, vibration, and thermal) including a self-heath monitoring sensor and RF power amplifier. The new architecture integrates signal amplification with the device's self-heath monitoring ensuring effective operation of energy harvesting while amplifying signals as well as sustaining device operation. The device operates in a balance between efficiency and reliability controlled by energy-aware feedback control implemented in the dynamic environment. This architecture serves smart, remote, maintenance-free, multifunctional wireless devices for health monitoring systems [27].

In this research, COMSOL Multiphysics software is used to model a MEMS-based Array structured vibrational energy harvester. The main goal of this research is to design and build a vibrational energy harvester with the highest possible output efficiency. As it produces more efficient output, Array structured vibrational energy harvester is preferred over unimorph and bimorph vibrational energy harvester. The design model is built with PZT-5H piezoelectric material because it produces more displacement and therefore resulting the highest output potential. The following is a brief description of the paper: Section II includes the modeling of a vibrational energy harvester. Section III explains modeling equations. Section IV discusses the results of a study. Section V finishes with a conclusion.

2. Design and Modeling of Energy Harvester

In this paper, Array Structured Vibrational Energy harvester is designed and developed using the Silicon as base material over which a layer of silicon-dioxide layer is coated which acts as insulating layer and prevents the energy harvester from damage by the resisting the flow of current through energy harvester. All the Array elements attached to circular shaped proof mass are coated with a coating of 'PZT-5H' piezoelectric material. COMSOL Multiphysics software is used to model and simulate the design Structure. The design structure of array based Vibrational Energy harvester is displayed in the Figure 1.

The energy harvester's structural dimensions are 1000 ×1000 ×25.7 μm^3. The energy harvester is designed and built with 1000μm long and 1000μm broad dimensions, as well as a thickness of 25.7μm. The array element's length and width are 600 micro-meters and 20 micro-meters, respectively. All of these rectangular-shaped array elements, arranged in a circular fashion, are joined together and connected to a circular-shaped proof mass. The circular-shaped proof mass has a radial dimension of 175 μm.

The Figure 2. elaborated the structure of MEMS energy harvester which consist of different layers, the base layer is Substate layer which is a Silicon material, Sio_2 is an insulator, the next layer is piezoelectric material and final layer is a metal layer which is used to harvest the electric energy. Among the variety of piezoelectric materials available in nature. Synthetic piezoelectric material PZT-5H composed of Lead, Zirconate and Titanate is preferred for building the design because of its ability of producing a highly efficient output.

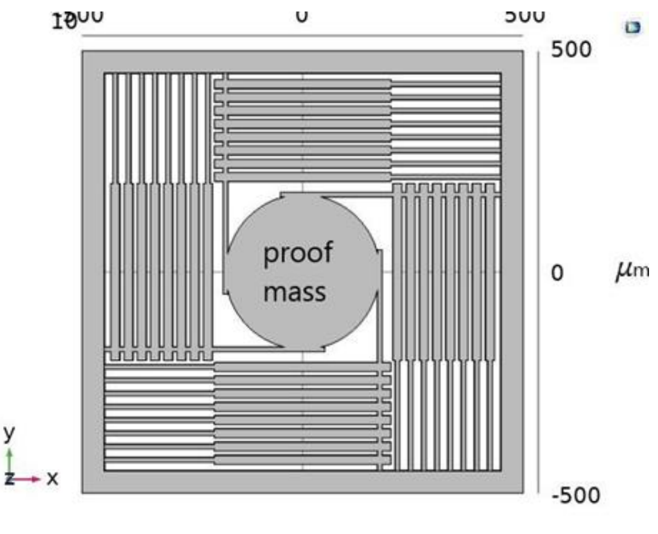

Figure 1. Array Structured Vibrational energy harvester

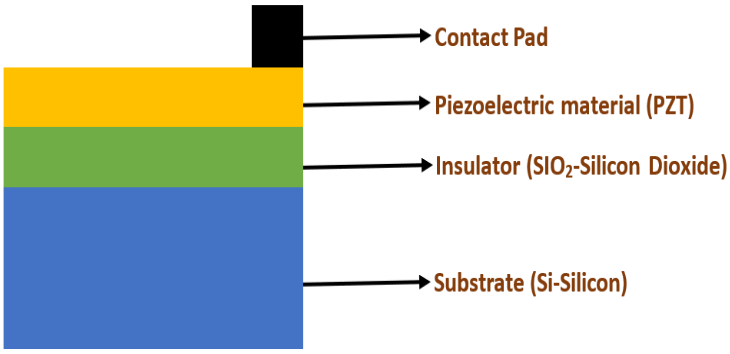

Figure 2. Front view of the energy harvester.

Table 1. Characteristics of PZT-5H piezoelectric material.

PZT-5H Parameters	Value
Charge coefficient (d_{31})(C/N)	741
Dielectric constant(ε_r)	3400
Voltage coefficient(g_{31})(Vm/N)	0.217
Young's modulus(GPa)	210.0
Poisson ratio	0.310
Density (kg/m^3)	7500

Table 2. Specifications of Silicon (Si), Silicon-dioxide (SiO2).

Material	Specification of materials			
	Young's modulus (GPa)	Density [kg/m^3]	Poisson ratio	Relative Permittivity
Silicon(Si)	170	2329	0.28	11.7
Silicon dioxide(SiO2)	70	2200	0.17	3.9

Table 3. Dimensions of vibrational energy harvester

Dimensions	Length L(μm)	Breadth B(μm)	Thickness T(μm)
Silicon (Si)	1000	1000	25
Silicon dioxide(SiO2)	1000	1000	0.2
PZT-5H	600	20	0.5

PZT-5H material displaces more in comparison with other materials which results in producing more output potential along with more output power. Thus to fulfill the requirement of more output power and voltage, PZT-5H piezoelectric material is favored over other piezoelectric materials. Table 1 lists the characteristics of the 'PZT-5H' piezoelectric material. Due to its excellent piezoelectric properties, PZZ5H is widely selected for the harvesting of vibrational energy.

The load factor (D31 = 741 C/N) is ideal for energy harvesting as it determines the ability of a material to generate electrical loads under mechanical tension. The dielectric constant (ær=3400) represents the ability of a material to preserveelectrical energy and improve the efficiency of converting mechanical vibrations into electrical performance. Additionally, the voltage coefficient (G31 = 0.217 VM/N) defines the efficiency of load generation under stress. Young's module (210 GPA) shows the stiffness of the material that affects its resonant behavior. The Poisson ratio (0.31) ensures how the material deforms under load, the density (7500 kg/mâ³) ensures the stability of the structure and maintains a high electromechanical clutch factor. These properties make PZZ-5H an ideal material for MEMS-based piezoelectric energy harvesting.

The performance of MEMS-based vibrational energy harvesting depends heavily on material selection is shown in Table 2. Due to the high young module (170 GPA), silicon (SI) is chosen as the structural foundation, ensuring mechanical robustness. Medium density (2329 kg/mâ³) is suitable for MEMS production. Siliconeum dioxide (SIOâ) serves as an insulating layer to prevent electrical leakage and mechanical damage, with a young module (70 GPA) and density (2200 kg/mâ³). The Poisson ratio indicates that all materials under voltage have relatively low deformation. With a young module (210 GPA) and a high relative perpetrator (1704.4), the PZZ-5H is the perfect material for energy harvesting as it allows for efficient load generation. High perpetrators improve dielectric storage capacity and make them very effective in MEMS applications.

A MEMS-based vibrational energy harvester consists of several layers each contributing to its overall function listed in Table 3. The silicon layer (SI) forms a basic structure with dimensions of 1000 µu x 1000 µu 25 µm, ensuring mechanical support and stability. A thin layer of silicon dioxide (SIOâ) (0.2 µm thick) is added as an insulating layer to prevent electrical leakage and mechanical failure. The PZZ-5H layer, 600 µm long, 20 µm wide and 0.5 µm thick, is the piezoelectric component of the nucleus. This layer is optimized for maximum vibration shifting to ensure efficient energy conversion. The reduction in width and thickness of PZT-5H increases sensitivity to vibration and structural integrity. These dimension options contribute to achieving high energy power due to their low resonance frequencies.

Table 4. Specifications of the Proof mass in vibrational energy harvester

Proof mass Parameters	Value
shape	Circular-shaped
Radius	175 µm
Material	Silicon
Thickness	25.7 µm

The proof mass plays an important role in improving the energy harvester's capabilities through external vibrations. The harvester uses circular evidence of a 25.7 µm thickness made of silicon with a radius of 175 µm listed in Table 4. This addition of verification chunks ensures that manufacturers can resonate effectively at low frequencies. This is essential for harvesting ambient vibrations that are common in real life environments. The proof mass improves the mechanical stretch of the PZT-5H layer and increases the electrical output. By optimizing the dimensions of the evidence, energy service values can achieve higher shifts and efficient energy conversion, making them suitable for low power applications such as IoT devices and wireless sensor networks.

2.1 Modeling Equations of Energy Harvester

Piezoelectric materials have two modes of operation: 31 mode and 33 modes. The 31 mode works as follows: with strain applied in direction-1, the piezoelectric layer vibrates in direction-3, producing electric charge through thickness i.e. through direction3. The electric charge is generated in direction-3 in 33 mode due to beam vibrations caused by strain excitations in that direction (direction3) [21].

Force applied to a piezoelectric material produces charge, which can be described mathematically as follows Q α F.

$$Q = d \times F \text{ coulombs} \quad (1)$$

Where Q refers to the charge acquired by the piezoelectric material.

d represents the crystal's charge sensitivity (Coulombs/Newton).

F denotes the amount of mechanical force applied to the material.

Basic expression of the output voltage (Vo) in terms of charge (Q) and capacitance (C) is given as follows:

$$Vo = \frac{Q}{C} \quad (2)$$

Where Vo represents the output Voltage in terms of volts, charge in terms coulombs is indicated by Q and C is the capacitance of the energy harvester.

$$\text{Capacitance } C = \frac{\varepsilon 0 \varepsilon r A}{t} \quad (3)$$

Substituting equation (1), (3) in equation (2)

$$\text{Voltage } Vo = \frac{d \times F \times t}{\varepsilon o \varepsilon r A} \quad (4)$$

$$\text{Vo} = \left(\frac{d}{\varepsilon o \varepsilon r}\right) \times (t) \times \left(\frac{F}{A}\right) \quad (5)$$

$$Vo = g \times t \times P \quad (6)$$

Where Vo indicates the output voltage and g signifies the voltage sensitivity (Vm/N).

P represents the pressure applied to the piezoelectric energy harvester's crystal (N/m^2).

The thickness of the crystal is denoted by t. (meters) [5].

MEMS-based energy harvesters are measured based on the power density (In microwatts per cubic millimeter (µW/mm^3), which refers to the electrical power produced relative to the volume of the device. MEMS power density marks the performance of a compact harvester and is directly important for the compactness and performance of the device. It also indicates how well the surrounding energy is converted to electrical energy. Size constraints exist in MEMS devices in biomed and IoT sectors. As such, autonomous operation is only possible when high power density is achieved. Externally supplied power is then rendered unnecessary. Choice of materials, device layout and overall shape, energy conversion system efficiency, and the accuracy in resonance tuning all impact the power density. The following equation is used to estimate the power density.

$$PD(Power\ Density) = \frac{P_o}{V_o} \quad (7)$$

Where Po is maximum output power and Vo is Harvested power which shown in equation 6. The resultant power density is calculated with the help of above equation, observed power density is approximately ~19.5 µW/mm³.

The load resistance sweep is used to identify the resistance at which the MEMS energy harvester can deliver maximum power. A peak is seen in output power by varying the external load resistance and measuring the output power. This peak corresponds generally to the internal impedance of the harvester. The load sweep assists in the design of matching circuits towards an improved energy extraction efficiency. The harvested energy load varying from 1K Ohm to 1 M Ohms with following equation. The resonant frequency has estimated for each case.

$$P_o = \frac{V_o^2}{R_L} \quad (8)$$

Where R_L is a load resistance.

3. Results and Discussions

3.1 Displacement Analysis

The displacement of the vibrational energy harvester is very important for determining the vibrational energy harvester's performance. The vibrating energy harvester provides the maximum output and is regarded to be the most efficient if it displaces the more, hence the displacement of the array-structured vibrational energy harvester should be higher to produce the most efficient results. This Figure 3. Shows the shift behavior of the vibrational energy ports of the array structure under external vibrations. Emissions are an important factor in determining the efficiency of harvesters, as larger shifts lead to higher energy conversions. The harvester is designed to achieve maximum shift in resonance frequencies and ensure efficient energy harvesting. Using circular masses and optimized beam dimensions improves shifting and thus maximizes electrical output. This diagram shows that design parameters can be set to increase the shift. This allows for more effective and reliable MEMS-based energy harvesting.

3.2 Resonating frequency

The resonant frequency is the frequency at which the energy harvester generates the maximum amount of the output. The vibrational energy harvester will produce the maximum output at low resonant frequencies is shown in Figure. 4. As a result, in order to achieve efficient output results, the resonance frequency of the vibrational energy harvester should be as minimum as feasible. This diagram illustrates the variation in shifts with respect to frequencies at various boundary loads. The graphics show that the shift increases significantly as the system approaches the resonant frequency and reaches a peak before returning to a higher frequency. This behavior shows that the harvester is most effective at natural resonance frequencies, where it produces the highest mechanical stretch and electrical load. The data ensures that low frequency vibrations produce the optimal shift. This makes the device suitable for crop energy from low-amplitude ambient vibrations. The change of load resistance can observe as the change of resonance frequency which presented in Table 5. The calculated and observed frequency has matched which shown in resonance frequency response.

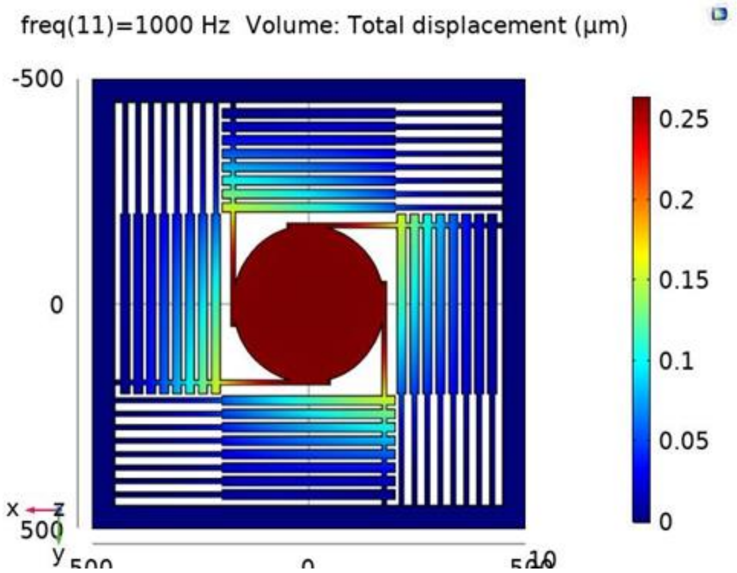

Figure 3. Displacement of array structured vibrational energy harvester

Table 5. Load resistance and frequency estimation

S.No	Load Resistance (R_L)	Resonance Frequency	Harvested voltage (V_o)
	1K	60	0.257
	10k	70	0.541
	100K	80	1
	1M	90	0.78

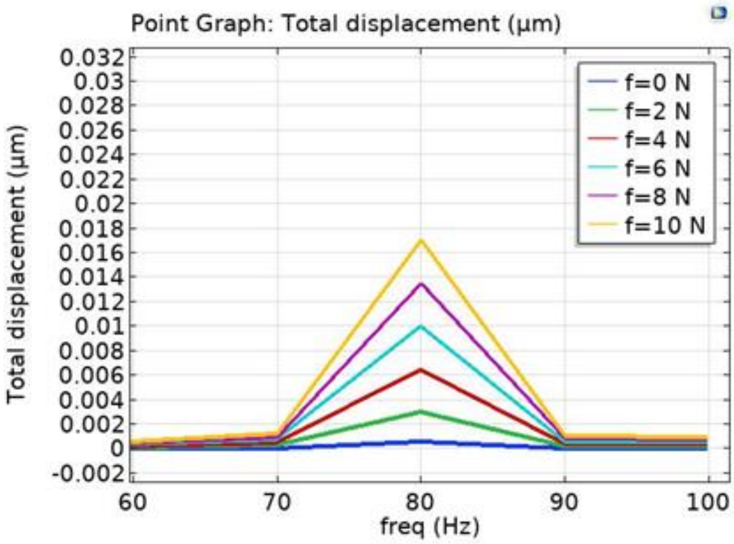

Figure 4. Displacement plot of vibrational energy harevester

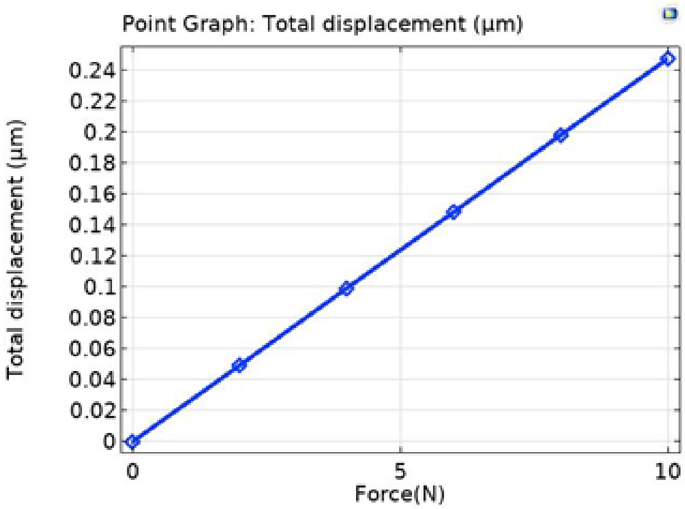

Figure 5. Relation between displacement and force

The line graph depicts the overall displacement of an array structured vibrational energy harvester in relation to frequency at various boundary loads. The displacement curves of the array structured vibrational energy harvester exhibited a substantial rise over time until it reached the resonating frequency and attained a peak value at the resonating frequency, after which it dropped drastically even as the frequency increased. It is observed that with an increase in boundary load the displacement of the vibrational energy harvester increases thereby producing the efficient output.

The line graph shown in Figure. 5. Gives the information about the displacement of an array structured vibrational energy harvester at a point with respect to boundary load. It is observed that the displacement curve of the array structured vibrational energy harvester increases linearly over time with an increase in the boundary load. As a result, as the vibrational energy harvester's boundary load rises, the displacement rises which overall increases the energy harvester's total efficiency. This diagram shows a Liney diagram showing the relationship between shifts and application forces in vibrational energy harvesting. The results show a linear increase in shifts as the boundary load increases. This shows that the harvester efficiently converts mechanical tension into shifts. The higher the applied force, the greater the deformation of the PZT-5H piezoelectric layer, and the better the load generation. This relationship is extremely important for energy harvest design and can function efficiently under a variety of vibrational conditions, including industrial and biomedical applications.

3.3 Stress

Stress is also a crucial factor in determining the performance of the array structured vibrational energy harvester. When stress is minimal, the vibrational energy harvester is very efficient and produces the greatest amount of output. As a result, the vibrational energy harvester's stress should be as low as feasible in order to achieve a high-efficiency output. This Figure. 6. Shows the voltage distribution within the structure of Harndos. Tension is an important parameter as excessive voltage can cause material fatigue and failure over time. Simulation results show that tensions around the firm have ended and the concentration of evidence connection points, a major area of mechanical extension.

A properly optimized voltage distribution ensures that the harvester functions without mechanical impairment. By choosing PZT-5H and silicon as the structural material, the harvester balances mechanical strength with efficient energy conversion.

3.4 Output voltage

The output potential parameter influences the array structured vibrational energy harvester's performance and efficiency. If an energy harvester has a high output potential, it is considered to be highly efficient. As a result, the vibrational energy harvester's output potential should be high in order for it to be more efficient [9].

The array structured vibrational energy harvester built and simulated with COMSOL Multiphysics software can generate 1V as an output voltage under the influence of a 1g boundary load acceleration is shown in Figure 7. This diagram shows the output voltage generated by the harvester when exposed to external vibrations. The results of Comsol -Multipiphysics -Simulation show that the mixer stall generates an output voltage under 1G accelerated loads. The voltage output is directly connected to the shift and the created force to confirm the effectiveness of the piezoelectric design of the harvester. The high output voltage makes this energy kernel suitable for low performance applications.

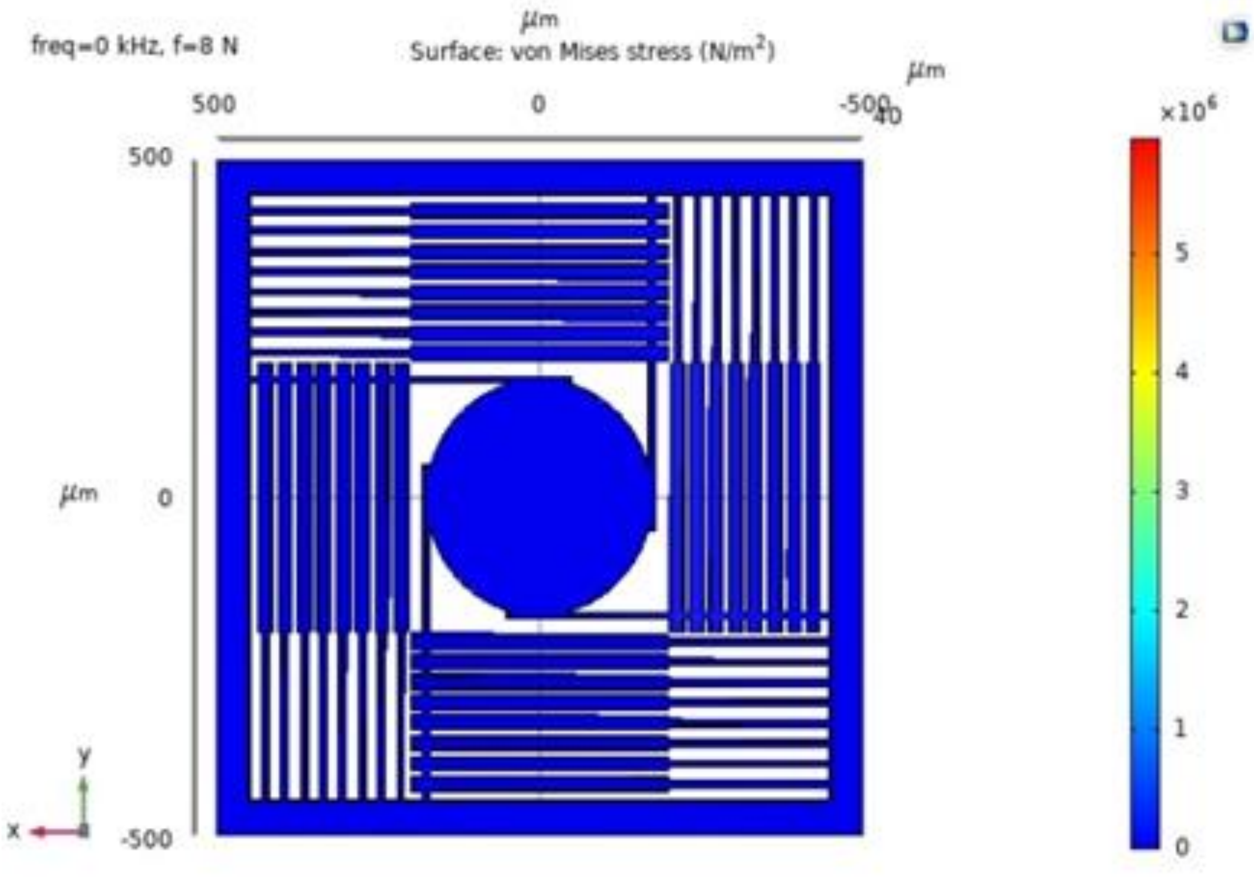

Figure 6. Stress of the array–structured vibrational energy harvester

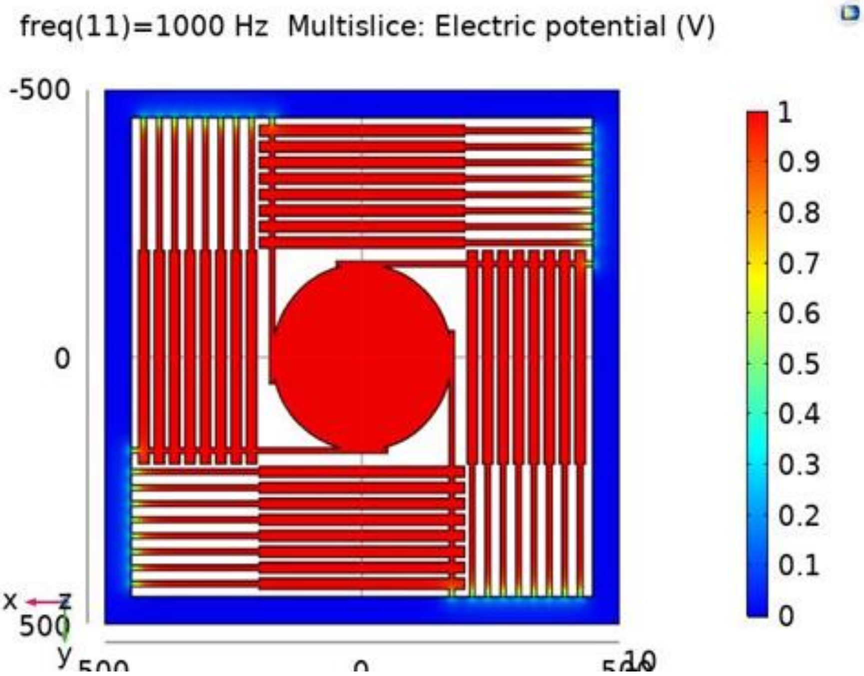

Figure 7. Electrical potential of vibrational energy harvester

4. Conclusion

This study introduces the structure, simulation, and performance analysis of MEMS-based array structure vibrational energy harvesters. It aims to convert the vibrational energy of an area into electrical performance. The harvester contains many rectangular elements arranged in circles; each attached to a heavy weight to improve energy acquisition efficiency. Using PZT-5H piezoelectric materials ensures high electromechanical coupling and optimizes the conversion of mechanical vibrations to electrical energy. The structural and electrical performance of the harvester was evaluated by COMSOL-Multiphysics simulations by the most important parameters such as resonance frequency, overall shift, and output voltage focus. The results showed that the mixer table reached a maximum output voltage of 1 V at an external acceleration of 1 g. It demonstrates its effectiveness as a sustainable energy use solution for low energy devices such as wireless sensor networks, biomedical implants, and IoT-based applications. The circular array configuration not only optimizes space use, but also increases power density suitable for integration into compact and resource-related environments. The results of this study highlight the potential for piezoelectric energy harvesting in MEMS-based harvesting in combating the growing demand for self-electronic systems. However, further improvements can be considered to improve the efficiency of Harvnist. Future work will focus on material optimization, structural modifications, and integration of multi-frequency energy use mechanisms to increase operational bandwidth. Furthermore, experimental validation of simulated results provides deeper insight into actual performance. Overall, this study contributes to the further development of vibrational energy harvesting technology by proving an efficient MEMS-based solution that can be converted to usable electrical energy using environmental vibrations. This research paves the way for future innovation in sustainable energy solutions for microelectronics and self-supporting sensor networks.

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Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

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