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# Low-Cost Piezoelectric Sensor Characterization for Energy Harvesting Applications †

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**Abstract:** Energy harvesting engineering field constitute a promising area to provide electrical power for low-power electric applications obtained from other sources of energy available in the environment such as thermal, electromagnetic, vibrational and acoustic by using transducers. Vibrational sources stand out as a main alternative to be used for generating electric power in sensor nodes, microelectronic devices due to greater energy conversion efficiency and the use of simple structure. The cantilever is the main system implemented in studies of obtaining electric energy from vibrations using piezoelectric transducers. Most of piezoelectric transducers in the literature are not yet commercially available and / or are difficult to access for purchase and use it. This paper proposes the characterization of low-cost piezoelectric transducers, configured as sensors, for Energy Harvesting applications using three different sizes of circular piezoelectric diaphragms (diameters: 3.4cm, 2.,6cm and 1.5cm) PZTs. For all three different PZTs it was found that the maximum power transfer occurs for a resistive load of 82kΩ. The maximum power generated in the load for the three PZTs was 40uW, 14uW and 1.4W, RMS voltages 2.8V, 2.10V and 0.6V, acceleration of 1.3g and at vibration frequency approximate of 7Hz.

**Keywords:** Piezoelectric diaphragms; low-cost; bovine milk adulteration; chromatic technique.

## 1. Introduction

Currently several applications such as wireless sensor network, electronics embedded in clothing and biomedical devices such as pacemakers, require a high degree of electronic integration and low power consumption [1-4]. One way to extend the life of these electronic devices without battery replacement is to use transducers that can generate electricity from other sources of energy in the medium such as thermal, electromagnetic and mechanical (vibrational and acoustic) energy. This technique is known as Energy Harvesting. One of the main ways to generate electricity is the piezoelectric energy harvest, which uses a direct energy conversion from vibrations and mechanical deformation to the electrical energy. This source has shown to be promising in the generation of electrical energy in electronic devices such as sensor nodes, microelectronic devices due to higher energy conversion efficiency and the use of simple structure.

Different aspects of piezoelectric energy harvesting have been attract researches attention. One of piezoelectric energy harvesting field front is to develop new composite material in order to achieve higher electric power generation [5-8]. Also the performance of new beam and piezoelectric sensors forms for electric energy generation has been study [9-14]. Despite this several aspects, many practical issues such the high cost of piezoelectric transducers have limited it's in energy harvesting applications. Based on this issue, this work propose the characterization of low cost commercial piezoelectric transducers for energy harvesting applications. These type of transducers are commonly known as the piezoelectric diaphragms, which have similar characteristics to conventional lead zirconate titanate (PZT) ceramics, and it's have been used in structure and electric power devices monitoring [15-17].

The outline of this article is as follows: section 2 presents the basics concepts of energy harvesting, piezoelectric transducers and the transducer used in this work. The experimental setup is described in Section 3, and then, in Section 4 the results are discussed. The conclusion of this paper is presented in section 5.

## 2. Cantilever and Piezoelectric Sensor

Fig. 1 shows a schematic of a cantilever structure compose by a beam fixe at one side and free at other side, a tip mass fixed at free side and a piezoelectric sensor fixed near at fixed beam side. At our experiment the system vibration is induced by a oscillating force generated (z-axis) by an eccentric motor fixed at free beam side. As the motor voltage increase, the oscillation also increases and the beam vibrates at excitation frequency. An accelerometer was fixed at mass tip in order to measure acceleration and the mechanical energy.

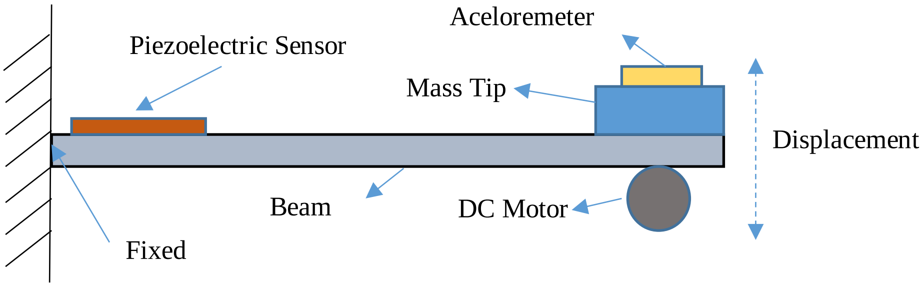


**Figure 1.**Cantilever schematic.

As the beam is fixed at one side and the free beam side oscillating, the beam and piezoelectric sensor deform (bend) generating an electric field [15-16], [18]. The cantilever beam must oscillate at resonance frequency in order to provide higher diaphragm deform and consequently higher electric power generated. The piezoelectric diaphragms used in this work consist of a circular brass plate with a circular piezoelectric ceramic. The thickness of plate and piezoceramic are 0.22 mm and the transducer element can be varying from 9 mm to 25 mm [15].

## 3. Experimental Setup

Figure 1(a) shows our experimental cantilever setup and the three piezoelectric sensors with different sizes (Murata 7BB-12, 7BB-20 and 7BB27). The accelerometer and piezoelectric sensor signal acquisition were performed using a NI USB-6211 data acquisition (DAQ).

(a) (b)

**Figure 2.** Experimental Setup (a) and Piezoelectric sensors (b).

The weight of the beam, the tip mass plus motor were about 200g. The beam´s dimension is 20cmx5cm . Three different sizes of the commercial piezoelectric sensor was tested (Fig. 2b). A LabView program was developed to acquire and to show the accelerometer and piezoelectric sensor signals and also calculate the electric power delivered to a resistive load.

## 4. Results and Discussion

We found a frequency resonance of 7.7 Hz and acceleration of 1.3g (where g is the gravity acceleration) Fig. 3 shows the voltage generated for the three different piezoelectric sensors. The maximum output RMS voltage obtained were 2.9 V, 2.10 V and 0.6 V for the large, medium e small sizes respectively. For all transducers sizes, we found the maximum power transfer 82 kΩ approximately (Fig. 4). The maximum electric power at load 82 kΩ measured were 40 μW, 14 μW and 1.4μW.

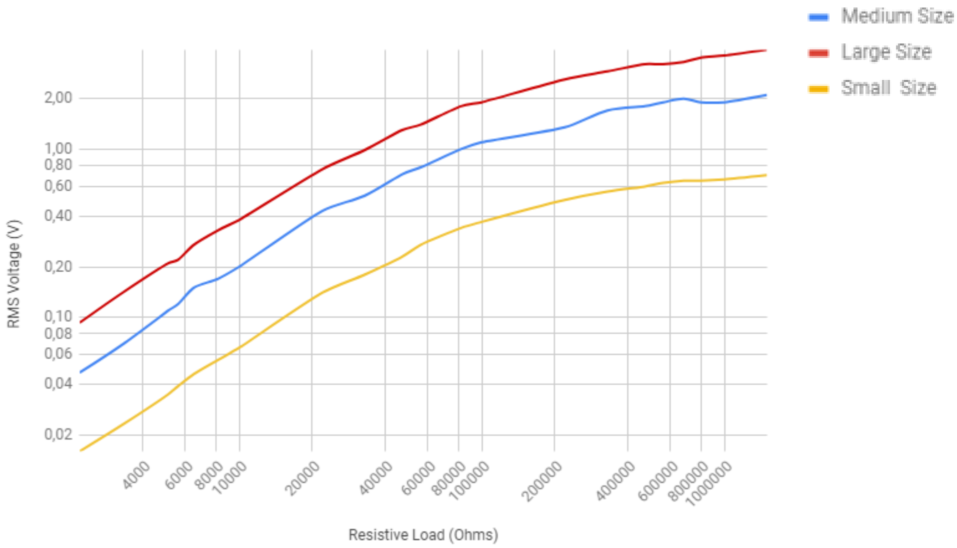


**Figure 3.** Measurement results of RMS voltage.

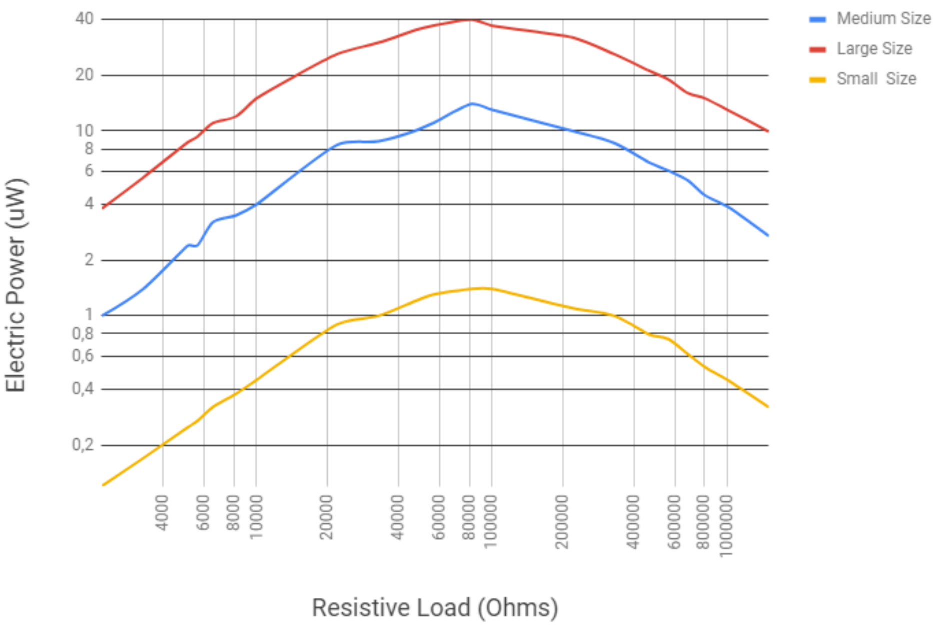


**Figure 4.** Measurement results of electric power.

For better comparison among the three PZTs sizes, Table 1 shows the power density per unity of area. At first glance one can though that by associating small PZTs in parallel we can increase the total electric power generated. However, as one can see the PZT large generates more electric power per area unity and., therefore, is preferable to use large PZTs instead associate smaller PZTs.

**Table 1.** Electric Power Density.

| Sensor´s Size | Active Diameter (cm) | Maximum Electric Power (μW) | Maximum Density Electric Power (μW/cm²) |
|---|---|---|---|
| Large | 2.1 | 40 | 11.55 |
| Medium | 1.7 | 14 | 6.17 |
| Small | 0.9 | 1.4 | 2.20 |

## 5. Conclusions

Piezoelectric energy harvesting is an important research field to develop alternative source power for low-power sensor networks and wearable electronic applications. In this work low-cost piezoelectric diaphragms were characterized for energy harvesting applications. Three different transducers size were performed generating 40 μW, 14 μW and 1.4 μW for large, medium and small sizes respectively. We found density electric power of 11.55μW/cm$^2$, 6.17 μW/cm$^2$ and 2.20 μW/cm$^2$ for the large, medium and small sizes respectively at resonance frequency of 7,7 Hz. Although it is possible to associate several small sizes of this kind of diaphragm to achieve high electric power generation, we found that by using larger sizes of this transducers lead to higher density of electric power generated. Therefore, for the same area available a greater size of piezoelectric is preferable.

**Author Contributions:** all authors contributed in writing, proofreading, and providing suggestions for the improvement of the paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

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