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# ANALYSIS OF AN INNOVATIVE TECHNIQUE FOR PIEZOELECTRIC ENERGY HARVESTING

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**Abstract:***There are multiple ambient sources of energy in our environment; all we need is the right technology to extract energy from them. This method is called Energy Harvesting or Energy Scavenging. As the name suggests, it is used to extract low power electrical energy from respective sources, and power up small electrical systems or store in a battery. One of the methods of Energyharvesting through piezoelectric transducers is discussed here. The harvested energy depends upon a number of factors such as scheme of arrangement, electromechanical coupling coefficient of piezoelectric sensors, number of sensors, conditioning circuit etc. As a part of this research one of the efficient methods of energy harvesting technique is studied.Here we will discuss our findings and future scope of work in this field, so this can be applied to a larger scale.*

***Keywords:*** *Energy Harvesting, Piezoelectric transducer, Boost circuit, Scheme of arrangement, Sensor, Actuator, Storage device/load.*

## I. INTRODUCTION

Energy harvesting is a topic that has gained attention over the past few decades. There are multiple sources of ambient energy and existing technologies to extract electrical energy from it. The world is shifting to these new sources of energy rather than being reliant on non-renewable sources, such as fossil fuels. By principle Energy can neither be created, nor be destroyed [1], it can only change from one form to another. The energy that was considered lost in the form of mechanical force, stress or vibrations can be harvested using the piezoelectric transducer. Humans spend energy during routine activities such as walking, running jumping etc. and normally that energy consumed is considered as lost but it can be harvested as electrical energy using the vibrations we create in our shoes or on the floor [5-6]. This energy can be used to charge a mobile phone or store in a battery. In accordance with the same, an energy harvesting circuit has been implemented and studied.

A piezoelectric transducer, being a versatile component in electronics, can be used as an Actuator (sound buzzers), a Sensor for mechanical vibrations and here we used it as a source to extract energy from it[2]. The power of harvested energy from one transducer depends upon the stress applied to it, provided the physical properties remain the same. There are several techniques available for converting mechanical vibration energy to electrical energy out of which the most prevalent methods are electrostatic, electromagnetic and piezoelectric conversion. The portable devices must have their own power sources rather than exhausting batteries [3]. The piezoelectric material is used to obtain the energy lost due to vibration of the host structure such as mobile floor, roadway, pedestals, rail, runway etc. where a continuous strain is experienced and this strain or vibration energy which was wasted earlier may be transformed into usable electrical energy to power up the low power electronic and electrical devices thereby providing a prolonged life to the power supply or to provide the endless energy to a device [5].

In this paper, we demonstrate an effective way to derive electrical energy from vibrations created on the floor while walking, running jumping etc. The round diaphragm PZT shown in Figure 1 is used to harvest this energy, which is rectified through a full wave bridge rectifier.

The output from rectifier can be amplified through a DC-DC boost circuit to store in a battery or connect to a load. A different approach to the arrangement of piezoelectric in a matrix for a piezoelectric tile energy harvester is studied and discussed.

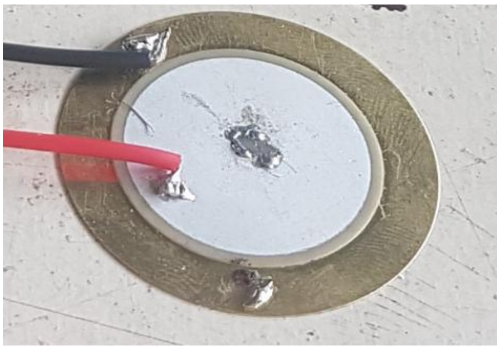


***Figure 1. Round Diaphragm Piezoelectric***

## II. FUNDAMENTALS OF PIEZOELECTRIC TRANSDUCER

*A. Evolution of Piezoelectric Ceramics*

The history of piezoelectricity goes way back to 1880's when quartz and Rochelle salt exhibited great potentials. With time, various technological advancements derived different types of materials that followed the piezoelectric effect. The next evolved material was ferroelectric ceramic Barium Titanate ($BaTiO_3$). During the same period, PZT (Lead Zirconium Titanate) was developed at the Tokyo Institute of Technology. This became widely popular because of its high reproducibility and propagation. Furthermore, it has a high piezoelectric coefficient and dielectric constant which helps develop more power at the similar inputs. Another material, PVDF (PolyVinylidene Fluoride) with high piezoelectric effect was reported in 1969[3]. Nowadays, the most commonly used ceramic is PZT andthat is the reason why we are using in our research.

*B. Principle of Working*

Piezoelectric materials belong to ferroelectrics class of materials. These materials have local charge separation, exhibiting electric dipole. When the material is heated above a typical temperature called Curie temperature, and a strong electric field is applied to it, the dipoles which were earlier oriented randomly among the material structure will orient themselves along the applied field. It will retain its orientation even after the material is cooled.

The converse piezoelectric effect is when an electric potential is applied to it, mechanical vibrations are produced which may result in sound. This is one application of piezoelectrics, used as sound buzzers. Direct piezoelectric effect is when it produces electric potential when mechanical vibrations are given as an input[2]. This effect makes it applicable as a sensor and also a source of energy harvesting, in this case. There are two equations that derive both direct and converse effect of the piezoelectric transducer.

(IEEE Standard on Piezoelectricity, ANSI Standard 176-1987):

Direct piezoelectric effect: $\{D\} = [e]^T\{S\} + [\alpha^S]\{E\}$ (1)

Converse piezoelectric effect: $\{T\} = [c^E]\{S\} - [e]\{E\}$ (2)

$\{D\}$: electric displacement vector, $\{T\}$: stress vector, $\{S\}$: strain vector, $[\alpha^s]$: dielectric matrix at constant material strain, $\{E\}$: electric field vector, $[e]$: dielectric permittivity matrix, and $[c^E]$: Matrix of elastic coefficients at constant electric field strength [3].

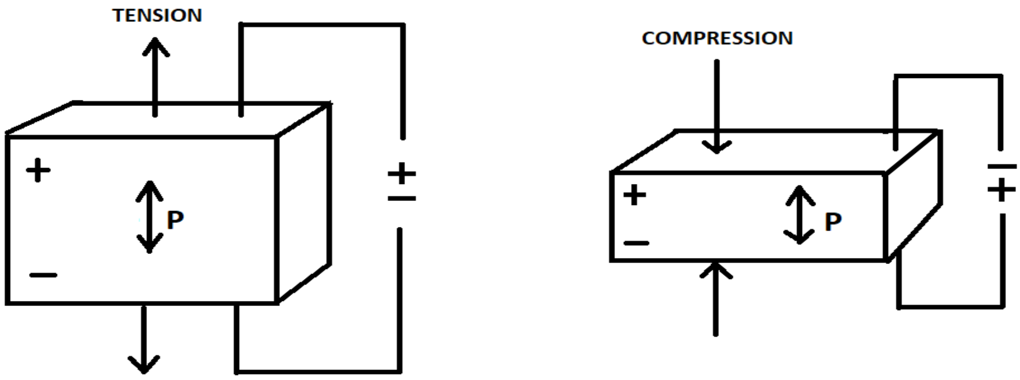



***Figure 2. Compression and Decompression of PZT forming AC signal***

The transducer generates an AC signal when fed with mechanical vibrations as an input [1]. For an instance, one tap on the PZT part generates an AC signal with varying amplitude electrical signal, depending upon the intensity of the tap. The strain on PZT when deformed creates the positive half of the AC, while forming back to original orientation generates a relative negative potential that completes the AC signal output. The same is demonstrated through Figure 2. The transducer induces maximum charge when it is stressed under Self Resonant Frequency (SRF) range[3].The transducer can be imagined as an AC current source with a high resistance and capacitance connected in parallel. The circuit equivalent is shown in Figure3.

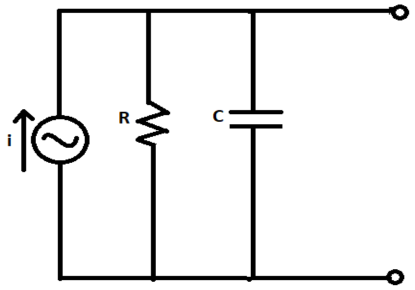



***Figure 3. Piezoelectric Equivalent Circuit***

The self-resonant frequency of the piezoelectric is calculated through the Helmholtz's equation.

$$f_0 = \frac{C}{2\pi}\sqrt{\frac{4a^2}{d^2(t+ka)}}$$

Where $f_{00}$: resonant frequency (in Hz), C: velocity of energy wave, a: radius of ceramic diaphragm (cm.), d: diameter of the support, t: thickness of the support and k: material constant.

## III. DESIGN AND ANALYSIS

*A. Harvester Model Design*

The harvester design that has been modelled is shown in block diagram in Figure 4. This piezoelectric harvester is basically, used to study the energy generated. The circuitry is discussed in the following topics.

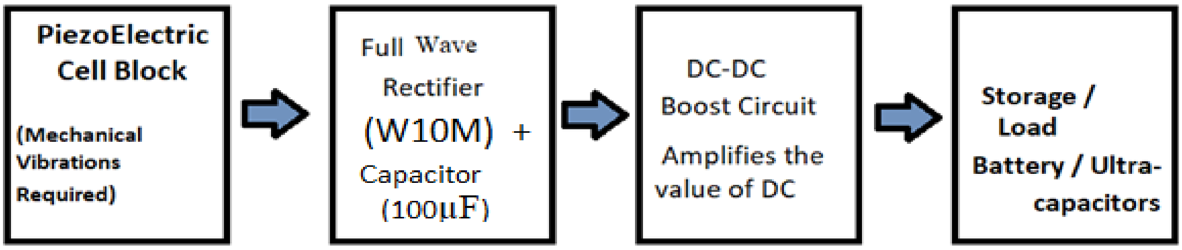



***Figure 4. Schematic for Harvester Working Flow***

The piezoelectric cell block consists of a matrix of piezoelectric transducers that are connected in a way to provide maximum current flow. The piezoelectric element connections are made in parallel in most of the tests. Output from this parallel connection is fed to bridge rectifier. An example of parallel connections is shown in Figure 5.

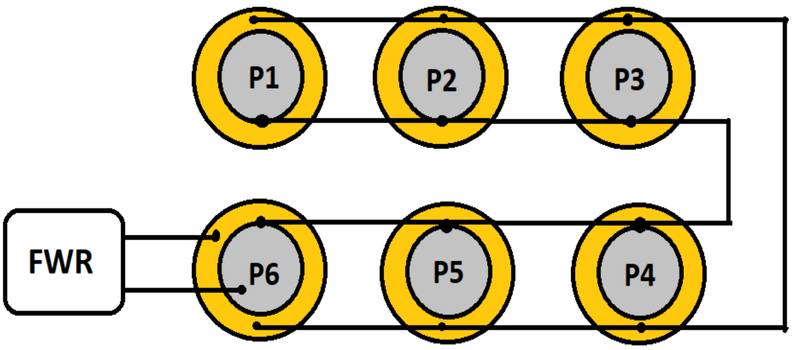



***Figure 5. Parallel connection of elements***

FWR: Full Wave Rectifier.
Full bridge rectifier is next step in energy generation. This converts the AC signal from the piezoelectric cell block to dc signal so it can be stored or connected to load. For bridge rectifier, a 4 pin IC W10M is used.[7]This is creating a considerable amount of voltage drop which can be reduced by using low drop diodes or dedicated IC LTC®3588-1 [9] for rectification.

DC-DC boost circuit boosts the voltage to a comparative higher level. This is an integral part of the system as the energy harvested is low power signal. An electrical circuit that implements boost is shown in Fig. 6. The output from boost circuit can be directly connected to load or be stored in a battery.

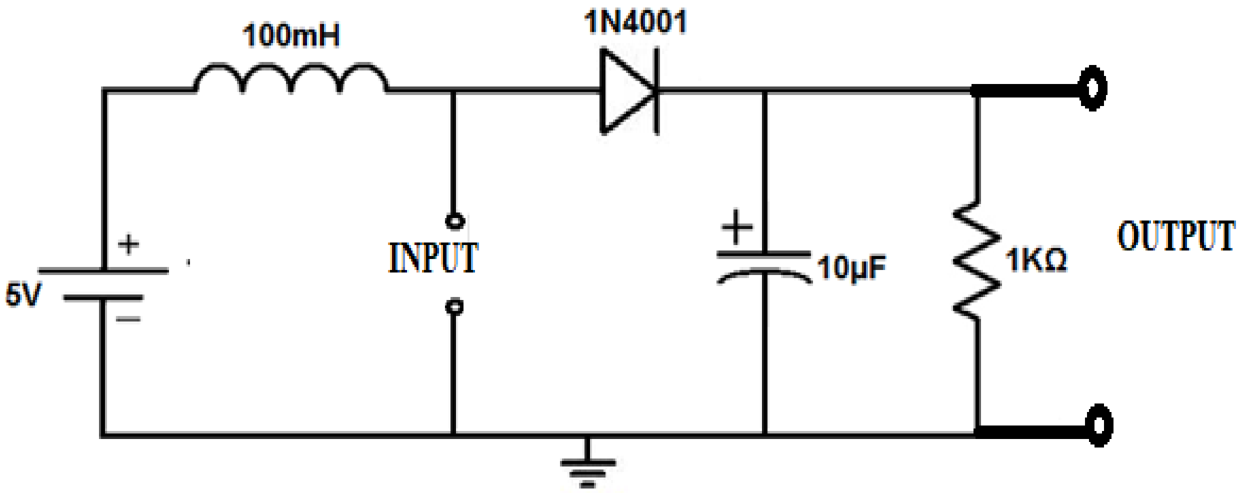
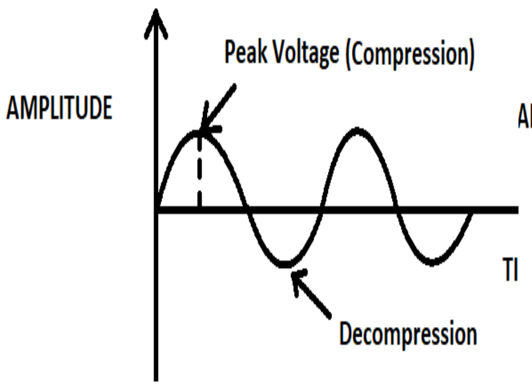



*Figure 6. DC-DC Boost Converter Circuit*

*B. Expected Design Flaw in Parallel Connection*
The elements are connected in a parallel connection as shown in Figure 5. As per the application, P1 and P6 will witness compression and decompression, due to strain, at the same instant of time (although different intensities). The AC signal generated is shown in Figure 7. With the same concept, P2 and P5 generate a signal that differs from previous signal in time domain, as shown in Figure 8. Because these AC signals get overlapped and dissipated due to parallel connection, an alternate design of connection of the elements is used in this test as shown in Figure 9.



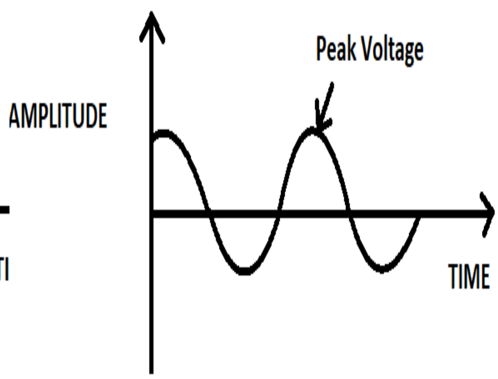




***Figure 7. Signal from P1 &P6 (similar in time domain)  Figure 8. Signal from P2 &P5 (similar in time domain)***

*C. New design proposed*
As discussed previously, the connections of elements needed to be rearranged to increase the productivity of the harvester. Elements in a horizontal row face the compression and decompression of PZT at the same time (vibrations created while walking on piezoelectric tile), so the AC signal does not cancel each other out. Now, the elements in same horizontal row have a separate full wave rectifier so the output from each row gets added up as DC signal to boost the power of the harvester.

The power from each horizontal row gets added up as a DC signal. Furthermore, if extra arrays of elements when separately combined with low drop full wave rectifier are added, we would get a more powered harvested output.

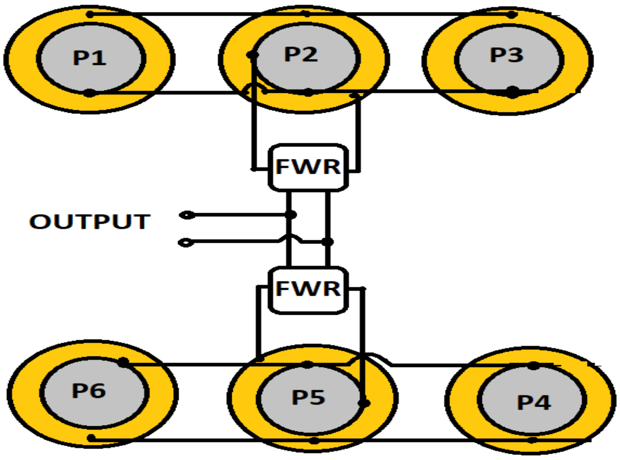



*Figure 9. Proposed design for piezoelectric elements arrangement*

## IV. RESULTS AND CONCLUSION

*A. Output from the Harvester*

The assumed piezoelectric transducer as an RC resonant circuit resonating at Self Resonant Frequency (SFR), the combined resistance(Equation 3) and capacitance(Equation 4) of an array of piezoelectric (P1, P2 & P3) is given below:

$$R = R1 \parallel R2 \parallel R3 \tag{3}$$

$$C = C1 + C2 + C3 \tag{4}$$

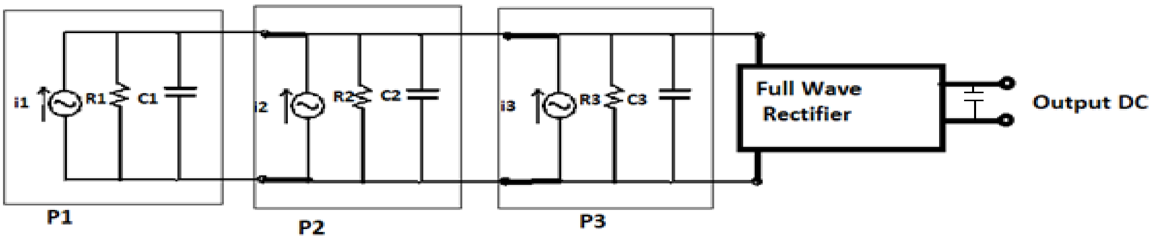



*Figure 10. Connected elements in a grid*

As per the Kirchhoff'slaw, current generated by a grid can be given by equation (5).

$$i = i1 + i2 + i3 \tag{5}$$

The power output for a full wave bridge rectifier with single transducer is given in equation 6.

$$P_{R} = C_i * V_R * f_i * (V_I - V_R - 2V_{di}) \tag{6}$$

$P_R$: total power output of the bridge rectifier unit with one piezoelectric diaphragm, $C_i$: plate capacitance of the piezoelectric transducer, $V_R$: voltage at rectifier output, $f_i$: excitation frequency of the transducer, $V_I$: open circuit voltage at the output of PZT unit and $V_{di}$: diode voltage drop.

The total power of the grid is combination of the power of two rows of three transducers each. Let us suppose the power of row 1 is $P_{R1}$ while the power of row 2 is $P_{R2}$. The total power of the circuit is given by the equation 7.

$$P_t = P_{R1} + P_{R2} \tag{7}$$

The outputs as obtained from the above mentioned circuitry are as follows:

Rectified output $V_{DC}$ (peak to peak) ~ 9.1V (when no load connected)

Frequency ~ 6.41Hz

Rectified output $V_{DC}$ ~ 1.45V (when load is connected)

Frequency ~ 3.20 Hz

The mentioned arrangement of transducer elements was done and thus, a few snapshots of readings and working are given below. Figure 11 depicts the circuit assembled on a breadboard with the arrangement mentioned in Figure 9. The output of this working has been captured on a CRO (Cathode Ray Oscilloscope) and is depicted in Figure 12. This output has been captured with no load connected to circuit. The output when LED is connected as a load to the rectified DC output from the circuit.

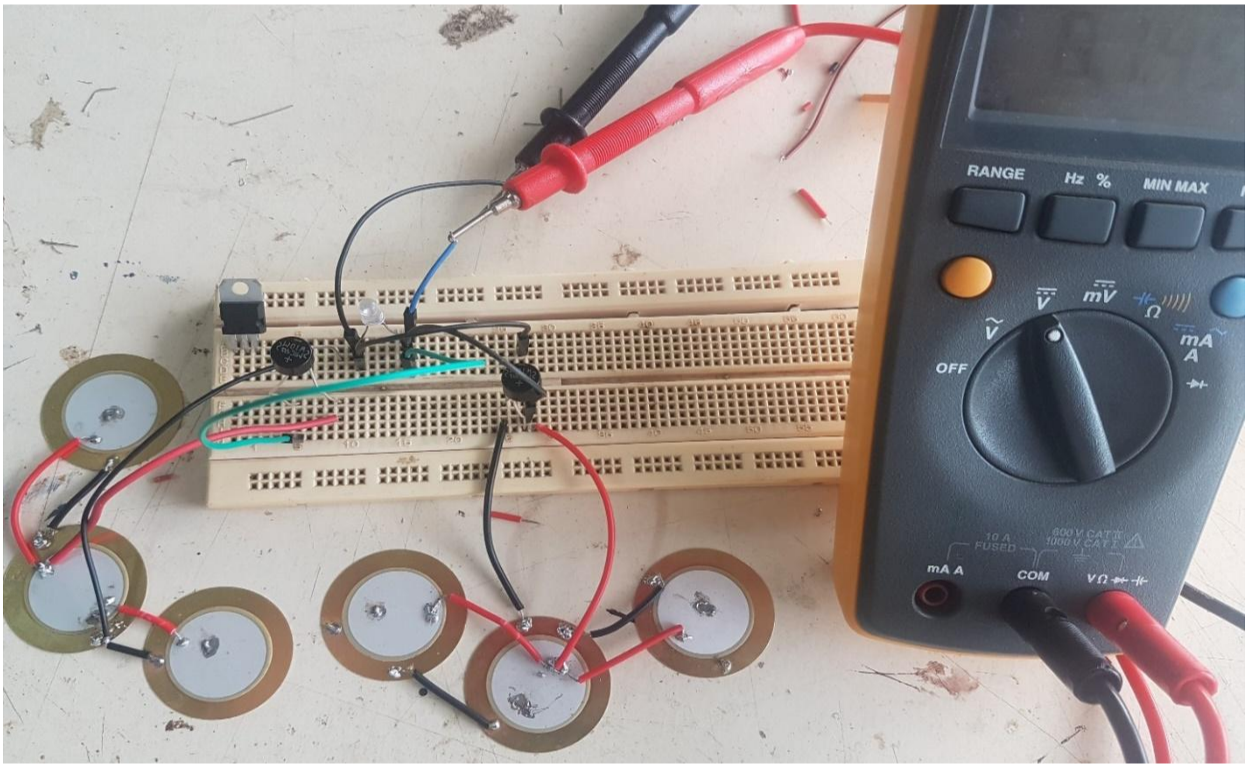



*Figure 11. Assembled test setup for energy harvesting*

The working test setup for the piezoelectric energy harvester, is assembled on a breadboard, which the same as arrangement shown in Figure 9. This gives a $V_{RMS}$ that is approximately equal to 1.45V. The output of the circuit is an LED. This has been shown in Figure 13 where LED glows as a result of mechanical vibrations input to the PZT ceramic. Figure 12 is the snapshot of the waveform output on oscilloscope, which gives the approximate value of Peak-peak voltage $V_{PK}$ as 9.1V, when no load is connected to the circuit.

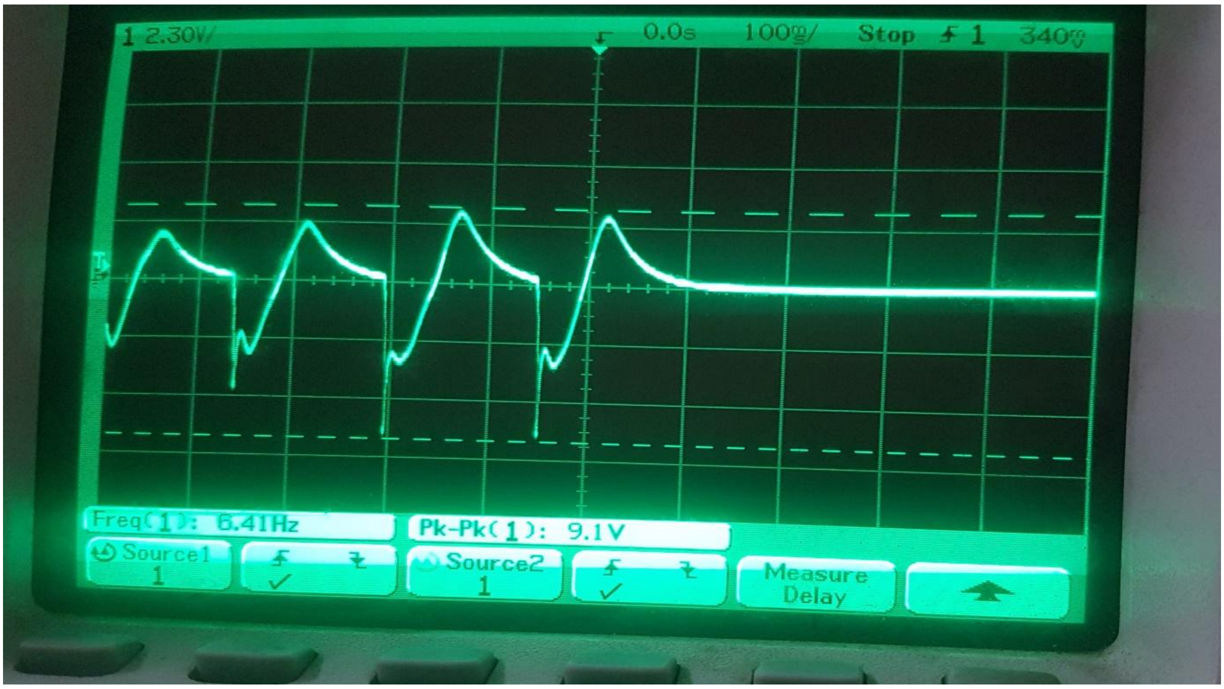



*Figure 12. Output captured on an Oscilloscope*

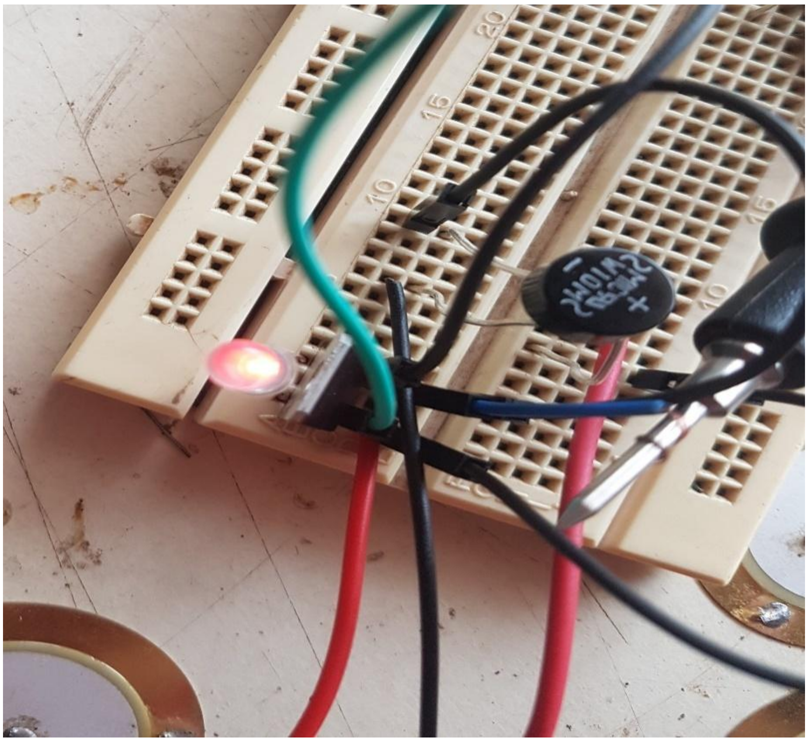


***Figure 13. LED connected as a load***

*B. Future Scope*

This field of energy harvesting is going to attract even more attention in the upcoming years. As an untapped market, and to explore various ambient sources of energy other than solar, this will gain popularity and will begin to commercialize soon. There is going to be a huge demand for self-powered electronics in the years to come. The proof-of-concept has been done all across the globe and it has turned out to be a success.Bimorph or both side PZT coated transducer is also available nowadays. Various companies are developing stripes of PZT rather than circular diaphragms, for effective scavenging of energy [8]. An integrated circuit LTC®3588-1 is used for effective piezoelectric energy harvesting. This IC provides low drop rectifier with a high efficiency Integrated Hysteretic Buck DC/DC[9].

There can be various factors to work on and improve the efficiency of this whole process in order to generate a considerable amount of energy. These factors include the type of material used (PZT, PVDF etc.), quality of the material used (thickness of material layer, piezoelectric coefficient, dielectric constant etc.), design of arrangement of elements and also the circuitry used to process the harvested electrical energy(low drop rectifiers, fast charging ultra-capacitors etc.).

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