

# Power Harvesting System in Mobile Phones and Laptops using Piezoelectric Charge Generation

Karthik Kalyanaraman, Jaykrishna Babu

**Abstract**—This paper targets the transformation of mechanical energy to electrical energy using piezoelectric materials. With piezoelectric materials, it is possible to harvest power from vibrating structures. It has been proven that, micro to milliwatts of power can be generated from vibrating materials. In gadgets like mobile phones, television remotes, laptops and other devices which employ key depressions for operation, mechanical vibrations are produced while pressing the keys. If these vibrations are successfully harvested, the resulting energy could serve as an ancillary source of energy for charging the batteries. This paper presents a model of piezoelectric transducer for a gadget like, mobile phone, prototype of the power scavenging circuit, and the overall circuit for charging the mobile battery using the generated energy.

**Index Terms**—Charge development, Diaphragm type piezoelectric crystal, Key depressions, Piezoelectric effect.

## I. INTRODUCTION

Unused power exists in various forms such as industrial machines, human activity, vehicles, structures and environment sources. Among these, one of the promising sources of recovering energy is from the vibrations generated by the key depressions of any keypad integrated device such as a mobile phone. Primarily, the selection of energy harvester as compared to other alternatives such as battery depends on two main factors, cost effectiveness and reliability. In recent years, several energy harvesting approaches have been proposed using solar, thermoelectric, electromagnetic, piezoelectric and capacitive schemes which can be simply classified into two categories, (i) power harvesting for sensor networks using MEMS/thin/thick film approach, and (ii) power harvesting for electronic devices using bulk approach [1],[2].

Applications for piezoelectric materials have expanded into many fields since the discovery of the effect by Curie brothers in 1880-1881 [3]. Examples include “active” sports equipment such as tennis racquets and skis that use strain to power actuators for feedback control loops, and watches that use body motion to supply power.

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Other applications which have been suggested include the use of aircraft engine vibrations, airflow over wings, vibrations induced by driving on a road and periodic vibrations induced by rotating machinery or engines. In another form, the energy harvester can supplement the other energy alternatives such as battery and prolong their lifetime [4], [6].

Conversion of mechanical low frequency stress into electrical energy is obtained through the direct piezoelectric effect, using a rectifier and DC-DC converter circuit to store the generated electrical energy. There are three primary steps in power generation: (a) trapping mechanical AC stress from available source. (b) Converting the mechanical energy to electrical energy using piezoelectric transducer. (c) Processing and storing the generated electrical energy. The mechanical output can be in the form of burst or continuous signal depending on the cyclic mechanical amplifier assembly. Depending on the frequency and amplitude of mechanical stress, one can design the required transducer, its dimensions, vibration mode and desired piezoelectric material. The energy generated is proportional to frequency and strain and higher energy can be obtained by operating at the resonance of the system [5].

## II. OVERVIEW

The idea pertains generally to a mechanism for capturing mechanical energy and converting it to electrical energy, and is particularly useful for continually charging or providing emergency power to mobile, laptops and battery powered devices that are handled or carried by people. The mechanism comprises of elongated piezoelectric elements for generating electric energy from mechanical energy [4].

It is an objective of the present idea to provide an ancillary source of energy having no power supply unit, which converts vibration energy generated for charging a battery. According to the present idea, a piezoelectric material is mounted below the keys of the particular device. During key depressions, the piezoelectric material is subjected to vibrations due to the pressure applied on the keys and therefore, the piezoelectric material is expanded or contracted. The piezoelectric material is provided with a pair of electrodes. AC voltage generated in the pair of electrodes provided in the piezoelectric material is rectified and stored in a capacitor. The charge thus present in the capacitor is used for charging a separate battery which is incorporated separately with the main battery of the device. This battery could be used during emergency situations for powering the device for a short span of time.

### III. CHARGE GENERATION WITH PIEZOELECTRIC MATERIAL

Piezoelectric effect is expressed in single crystals, ceramics, polymers, composites, thin-films and relaxor-type ferroelectric materials, but the majority of the energy harvesting devices fabricated in the past work have been made up of polymers (PVDF) and ceramics (lead zirconate-lead titanate, PZT). Electromagnetic generators use electromagnetic force to move free electrons in a coil around the permanent magnet rotator. Piezoelectric material, which is used as non conductive material does not have free electrons, and therefore electrons cannot pass freely through the material. Piezoelectric ceramics do not have free electrons, but are made up of crystals that have many "fixed" electrons. These fixed electrons can move slightly as the crystals deform by an external force. This slight movement of electrons alters the equilibrium status in adjacent conductive materials and creates electric force. This force will push and pull the electrons in the electrodes attached to the piezoelectric crystal as shown in Fig 1 [2].

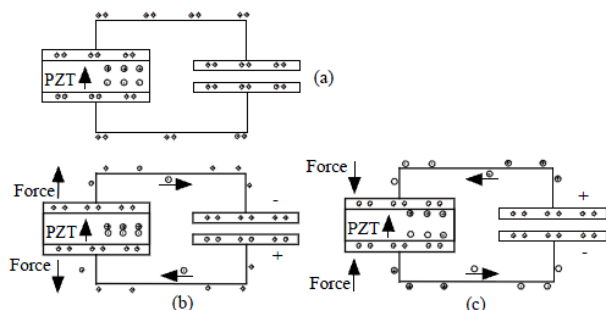


Fig. 1. Schematics of the PEG (Piezoelectric Generator) illustrating the movement of charge due to applied force (a) when no force applied (b) when tensile force applied (c) when compressive force applied [2].

Dielectric properties are observed on piezoelectric ceramics. The positively charged atoms are not in the centre of the crystal, creating a charge dipole. The direction from the centre to the positively charged atom is called the poling direction and in general is randomly distributed throughout the polycrystalline ceramic as shown in Fig. 2 (a). This poling direction can be modified by heat and voltage conditions. Piezoelectric crystals have their own temperature characteristics, known as Curie temperature. Common piezoelectric material has its own Curie temperature. Once the piezoelectric crystal is heated above Curie temperature, it loses its polarity and a new poling direction will appear by the application of the voltage across the piezoelectric material. The new poling direction appears along the applied voltage (Fig. 2 (b)) [2].

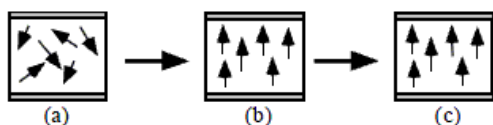


Fig. 2. Poling process: (a) before poling (b) Apply voltage through the electrode at above Curie temperature (c) Remove external voltage and cool down.

The poling direction is a very important property in piezoelectric material. Depending upon the poling direction, the input-output relations change [2].

The most common types of mechanical loading investigated for piezoelectric energy harvesting devices are 33 and 31 loading, which are depicted in Fig. 3 where x, y and z are represented as 1, 2, and 3, respectively. In the 33 loading mode the voltage and stress act in the same direction, and in the 31 mode, the voltage acts in the 3 direction, while the mechanical stress acts in the 1 direction.

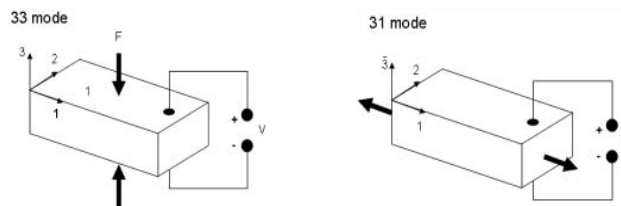


Fig. 3. Poling direction: 33 mode and 31 mode respectively.

For devices with a rectangular cross section, the poling direction is denoted as the 3 direction, and the 33 loading refers to the collection of charge on the electrode surface perpendicular to the polarization direction when tensile or compressive mechanical forces are applied along the polarization axis. When a material experiences 31 loading, the charge is collected on the electrode surface perpendicular to the polarization direction, for example, when the force is applied perpendicular to the axis of polarization.

### IV. BLOCK DIAGRAM

The basic block diagram of the proposed model is shown in Fig. 4. It consists of 3 main blocks, (a) piezoelectric power generation (b) rectification (c) storage of DC voltage. AC voltage is generated from the piezoelectric material which is rectified by the rectification block and then it is stored in a storage device such as a battery.

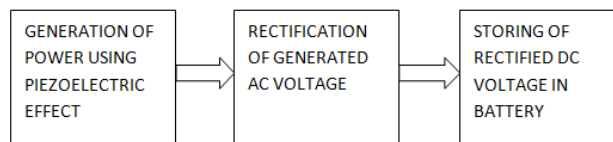


Fig. 4. Block diagram

### V. DESCRIPTION (PIEZOELECTRIC PROTOTYPE MODEL FOR A MOBILE PHONE KEYPAD)

A diaphragm assembly comprises at least two piezoelectric diaphragm members arranged in a stacking direction. An interface layer is situated between adjacent piezoelectric diaphragm members. The interface layer in the stacking direction is displaceable and incompressible or resilient. The interface layer permits lateral movement of the adjacent piezoelectric diaphragm members relative to the interface layer in a direction perpendicular to the stacking direction. The interface layer can comprise, for example, an incompressible liquid or a semi fluid or a compressible gas. A gasket can be used to seal the substance in the interface layer if necessary.

### VI. FIGURE DESCRIPTION

Fig. 5 shows the basic model of a diaphragm type of piezoelectricity generation. A circular groove is formed in the n-Si substrate (4), which is a silicon single crystal substrate integrated with a polyvinyliden fluoride (PVDF) plate or film (2). It consists of a pair of electrodes (1) which is spanned over the groove to cover it. The pair of electrodes is formed of metallic thin film on both sides of the piezoelectric material. The electrodes are connected to the output terminals A-A'. The device's key button provides a weight at the centre of the PVDF film. When a key depression occurs, the PVDF film expands and contracts due to which an electromotive force is generated between the pair of electrodes. It is preferable to provide a hole (5) reaching the circular groove in the rear surface of the n-Si substrate. Fig. 5 shows the state of the whole setup after a key depression occurs. Connection is established so that the AC voltages are superimposed and provided at the terminals A-A' [7], [2].

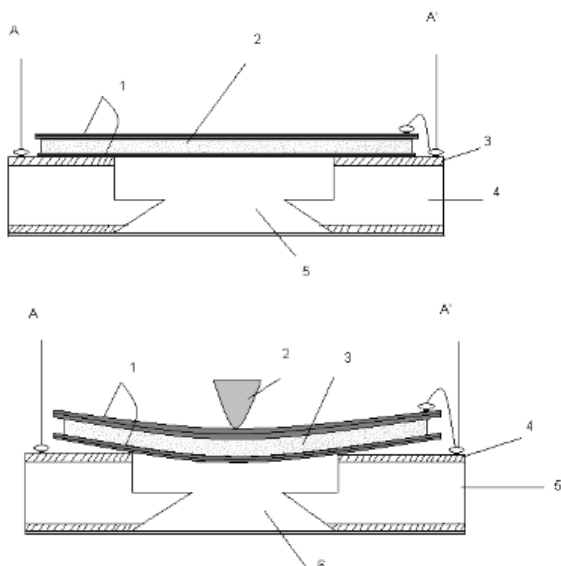


Fig. 5. Basic model of diaphragm type piezoelectricity generation.

1. Electrodes
2. Piezoelectric material (PVDF)
3. SiO<sub>2</sub>
4. n-Si
5. Hole for the central part of film to deform itself.

### VII. DESCRIPTION (PIEZOELECTRIC PROTOTYPE MODEL FOR LAPTOP'S KEYBOARD)

Fig. 6 shows a diaphragm type PE generator. The output of this model is extracted through the electrodes AA'. When the film is subjected to an external pressure due to the occurrence of key depression while typing the keyboard, it compresses into the space (5) between the spring and the piezoelectric material and returns back to its original position when the pressure on the key is released. This downward and upward motion of the film causes vibrations in it. Since the film is itself a piezoelectric material it generates electricity in the form of very low voltage. This creates charges in the electrodes [7].

According to the law of inertia, the film returns back to its original position if an external force drives it to do so. Here

the external force is air resistance. When the film is initially pressed, the extent to which it bends downwards is more. After a small time interval due to air resistance the magnitude of the downward bend reduces gradually. This causes a vibration of a high frequency. The displacement of the centre most part of the film is more than 0.1mm initially. After sometime the displacement decreases and the film comes back to its original position. From Fig 6 it can be seen that, if the central part of the film displaces itself from its original position, then it tends to touch a low tension spring that is connected to a secondary piezoelectric crystal. Since the spring has a low tension, the film tends to deform the spring by applying a very low pressure. This pressure is transferred to the secondary crystal. Since the primary film touches the spring more than once, the spring transfers the pressure more than once to the secondary crystal. The secondary crystal is placed on a rigid surface (a perfect solid). Hence the solid cannot be deformed. Now, due to the pressure in the crystal, it starts to vibrate. By the property of piezoelectric effect, an AC voltage is generated in the axis that is perpendicular to the axis on which pressure is applied. So a perfectly conducting medium is placed on that particular axis. This conductor transfers the charges developed to a medium where the charges could be stored [2], [7].

For the secondary piezoelectric material, a stack arrangement is employed. These materials operate in longitudinal direction (orthogonal direction to the layer). Common stack arrangements are made with large number of thin piezoelectric disks that are glued together [2].

Fig. 7 illustrates the state of the piezoelectric module before and after key depression.

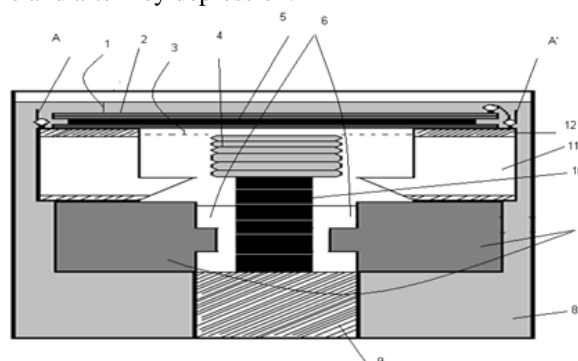


Fig. 6. Diaphragm type PE generator.

A-A' electrodes for the primary crystal

1. 0.3-0.33mm for keyboard
2. Keypad
3. <0.1mm
4. Low tension spring
5. Primary piezoelectric crystal (PEC)
6. Perfect conductors for secondary PEC
7. Charge storage space for charges from secondary PEC
8. Hard casing to avoid deformation of structure
9. Perfect solid to generate high pressure
10. Secondary PEC
11. n-Si
12. SiO<sub>2</sub> substrate.

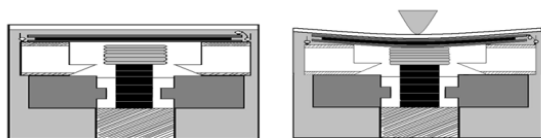


Fig. 7. State of the piezoelectric module before and after key depression.

### VIII. CIRCUITRY

Fig. 8 illustrates the overall circuit diagram of the entire process. The rectifier shown in the Fig. 8 maybe either a full wave rectification circuit or a half wave rectification circuit based on the combination of diodes or a voltage double rectifier. Since a diode is being used in the rectifier, a p-n junction diode or a Schottky diode can be used. The Schottky diode has a threshold voltage which is smaller than that of a p-n junction diode. For example, if the diode is formed on a silicon substrate, a p-n diode may have a threshold voltage of approximately 0.065 volts while the threshold voltage of a Schottky diode is approximately 0.30 volts. Accordingly, the uses of Schottky diode instead of p-n diode will reduce the power consumption required for rectification and will effectively increase the electrical charge available for accumulation by the capacitor. When the electromotive force in the piezoelectricity generation section is small, a Schottky diode having a low rising voltage is more preferable.

The bridge rectifier section provides rectification of the AC voltage generated by the piezoelectric section. By arranging the rectification section on a monolithic n-Si substrate, it is possible to form a very compact rectification section.

A typical diode can rectify an alternating current—that is, it is able to block part of the current so that it will pass through the diode in only one direction. However, in blocking part of the current, the diode reduces the amount of electric power the current can provide.

A full-wave rectifier is able to rectify an alternating current without blocking any part of it. The voltage between two points in an AC circuit regularly changes from positive to negative and back again. In the full-wave rectifier shown in Fig 8, the positive and negative halves of the current are handled by different pairs of diodes.

The output signal produced by the full-wave rectifier is a DC voltage, but it pulsates. To be useful, this signal must be smoothed out to produce a constant voltage at the output. A simple circuit for filtering the signal is one in which a capacitor is in parallel with the output. With this arrangement, the capacitor becomes charged as the voltage of the signal produced by the rectifier increases. As soon as the voltage begins to drop, the capacitor begins to discharge, maintaining the current in the output. This discharge continues until the increasing voltage of the next pulse again equals the voltage across the capacitor. The rectified voltage is stored into a storage capacitor as shown in Fig. 8, which

gets charged upto a pre-decided value, at which the switch closes and the capacitor discharges through the storage device or the battery. In this way the energy can be stored in the capacitor, and can be discharged when required [9].

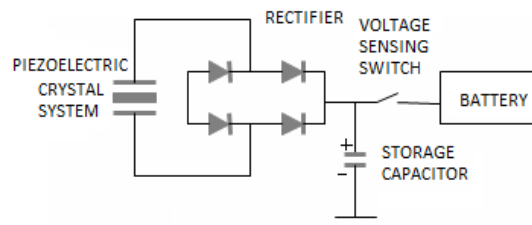


Fig. 8. Circuit diagram of the whole process

### IX. RESULTS

The material used for the current application is a PZT with 1.5 Mpa lateral stress operating at 15Hz. The volume of the material used is 0.2cm<sup>3</sup>. The output power produced is 1.2W. The energy/power density is 6mW/cm<sup>3</sup>. The output voltage is 9V [8]. This voltage can be used to produce the required amount of charge after being processed.

### X. CONCLUSION

The design of the proposed energy conservation system for mobile phones and laptop keyboards has been presented in this paper. The design presented here will be quite effective in providing an alternate means of power supply for the mentioned devices during emergency.

Further, the approach presented in this paper can be extended to many other applications where there is scope for similar kind of energy conservation.

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