Energy Harvesting from Piezoelectric Material using Human Motion

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Abstract:

Energy is the input to drive and improve the life cycle. It is the gift of the nature to the human beings. The consumption of the energy shows the progress of the human being. Energy is present in different forms. In this research paper, we intend to explain the process of energy harvesting from piezoelectric material by using human motion. The concept of energy harvesting, which is a process of capturing the ambient waste energy and converting it into usable electricity, the extremely low power electrical and mechanical devices such as micro electromechanical systems (MEMS) make such renewable power sources very attractive. In this design, we use the piezoelectric sensors in order to change the pressure so that an electrical output could be generated. The output of the piezoelectric sensor is given to the boost converter. The MOSFET in the boost converter amplifies the voltage. The microcontroller uses control in the MOSFET driver circuit which in turn controls the microcontroller.

Keywords: *Microcontroller, Piezoelectric Sensor, DC to DC Converter, MOSFET*

I. Introduction

With the recent advances in the field of micro electro mechanical systems (MEMS), portable electronics and wireless sensors have become ubiquitous because of their apparent advantages over the wired devices, such as small size, flexibility can be placed almost anywhere, ease of implementation without the expense and trouble of cabling, low power consumption etc.[1]. These application characteristics of wireless devices decide that the development trend in electronic technology is multi-function, light-weight, miniaturization, low costs, short response time, high accuracy and high reliability as well [2]. The renewable or the sustainable power sources are therefore required to either replace or to augment the capacity of the battery in order to increase the lifespan and the reliability of a wireless device or to realize the small volume and fully self-powered electronics and to mitigate the environmental pollution which is caused by inappropriate disposal and recycling of the batteries. The earliest energy harvesting can be traced back to the windmills in the ninth century. People have been started utilizing the light, heat, vibration and others ambient energy for many decade. Since small autonomous wireless devices such as the wireless sensors which are developed in the MEMS technology demand a little power, small scale energy harvesting devices show that the potential in order to replace the conventional batteries by converting the ambient waste energy into electricity and power ensures the low power consumption and small size of the devices. A variety of the ambient sources such as the solar, thermal, acoustic noise, acoustic energy, nuclear power, human and mechanical vibration have been studied as an additional energy supplier for the last decades. Among them, thermoelectric generators, vibration/kinetic driven power generator and solar cells are more widely studied because of their ubiquity, high efficiency and potentials to miniaturization. The piezoelectric ceramics has been used to convert the mechanical energy into electricity for many years [3]. A brief introduction about piezoelectricity will help to understand the theoretical background of the piezoelectric power harvesting. The piezoelectric materials can become electrically polarized or undergo a change in the polarization when subjected to a stress because the slight change in the dimension of a piezoelectric material results in the variation in the bond lengths between actions and anions which are caused by stress. This phenomenon was discovered on many crystals, for instance, tourmaline, topaz, quartz, Rochelle salt and cane sugar by Jacques and Pierre Curie brothers in 1880 and named as piezoelectricity or piezoelectric effect, which describes a relationship between stress and voltage. Conversely, a piezoelectric material will have a change in the dimension when it is exposed in an electric field. This inverse mechanism 8is called as electrostriction. Those devices which utilize the piezoelectric effect in order to convert the mechanical strain into electricity are called as transducers, which can be used in sensing applications, such as the sensors, microphones, strain gauges etc. while those devices which utilize the inverse piezoelectric effect in order to generate a dimension change by adding an electric field are called as actuators and are used in the actuation applications, such as the positioning control devices, frequency selective device etc.

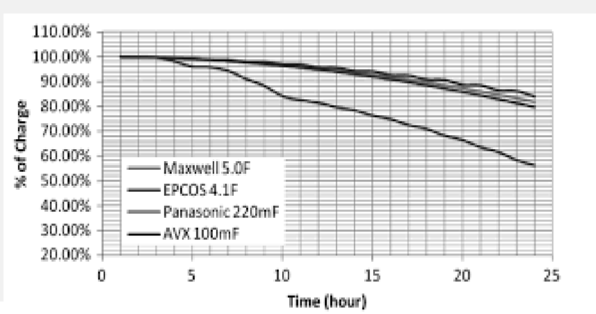

Figure 1 Comparison of the Output Power Density and the Lifetime among Battery, Solar and Vibration Energy Sources

We can also see from table 1 that outdoor solar energy has the highest power density, but indoor solar energy has a rather low energy density. Solar cells are a mature technology and a mature research area. Vibration energy shows a relatively high power density. Figure 1 depicts the power densities and the lifetime of the various batteries and two potential ambient energy sources, solar and vibration, which show a high power density and an infinite lifetime. Among these, the batteries expose their biggest disadvantage, limited life span. Solar lighting has the highest output power density in the direct sunshine, but it is not applicable to embedded applications (such as medical implant) where no or not enough light available [4]. The mechanical vibration has been demonstrated to offer great potential, limited life span and relatively high power density where there is an insufficient light source.

Energy source	Potential power density
Solar (Direct)	10's mW/cm^2
Solar (indoor)	10's µW/cm^2
Mechanical vibration	100's µW/cm^3
Human motion	10's to 1000's µW/cm^3
Thermoelectric	10's µW/cm^2
Radio-frequency	100's µW/cm^3
Airflow	100's µW/cm^3
Acoustic noise	10's µW/cm^3

Table 1 Power Density Comparison of Ambient Energy Sources

II. System Design

In this research paper, we explain the method of energy harvesting from the piezoelectric material by using human motion. The block diagram which is shown in Figure 2 describes different parts of the proposed system such as the piezoelectric sensor, DC to DC Converter, MOSFET Driver, Microcontroller, Battery and Inverter.

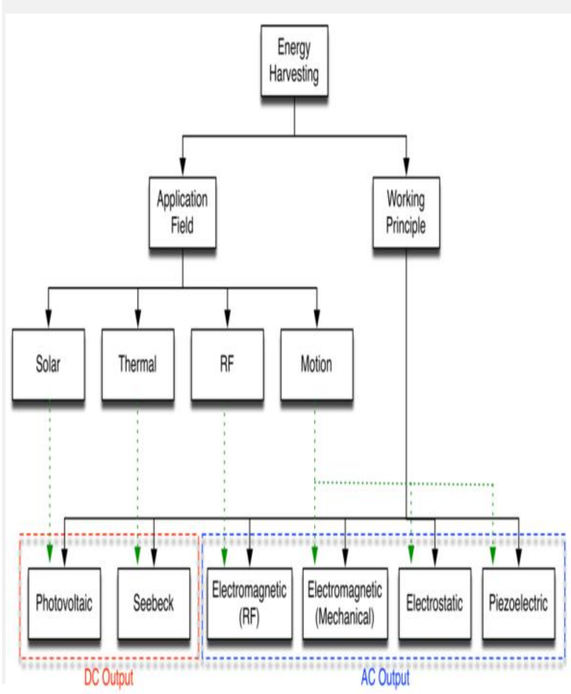

Figure 2 Block Diagram of Proposed System

A. Piezoelectric Sensor:

The piezoelectric sensors rely on the piezoelectric effect, which was discovered by the Curie brothers in the late 19th century. While investigating a number of naturally occurring materials such as tourmaline and quartz, Pierre and Jacques Currie realized that these materials had the ability to transform the energy of a mechanical input into an electrical output. More specifically, when a pressure [piezo is the Greek word for pressure] is applied to a piezoelectric material, it causes a mechanical deformation and a displacement of charges. Those charges are highly proportional to the applied pressure [Piezoelectricity].

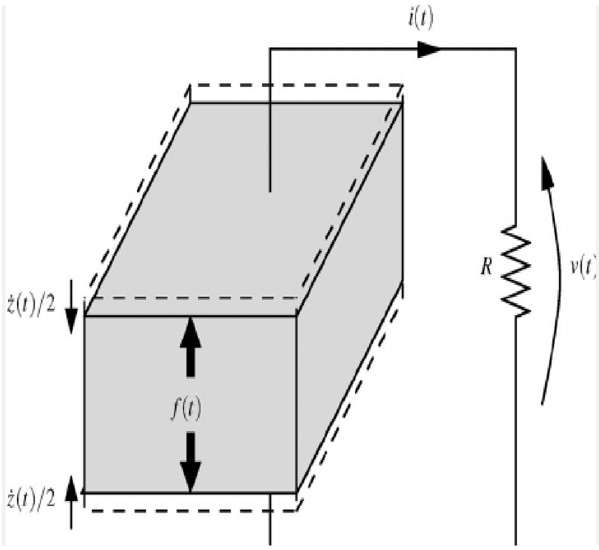

Figure 3 Block Diagram of a Piezoelectric Transducer

A quartz (SiO_2) tetrahedron is shown in the figure above. When a force is applied to the tetrahedron (or a macroscopic crystal element) a displacement of the cation charge towards the center of the anion charge occurs. Hence, the outer faces of such a piezoelectric element get charged under this pressure. Many creatures use an interesting application of piezoelectricity. The bones act as the force sensors. Once loaded, the bones produce charges which are proportional to the resulting internal torsion or displacement. Those charges stimulate and drive the buildup of new bone material. This leads to the strengthening of structures where the internal displacements are the greatest. With the advancement in time, this allows the weaker structures to increase their strength and stability as the material is laid down proportional to the forces which are affecting the bone. The high modulus of elasticity of many piezoelectric materials is comparable to that of many metals and goes up to 105 N/mm^2. Depending on the way a piezoelectric material is cut, three main types of operations can be distinguished.

[1] Transversal

[2] Longitudinal

[3] Shear

Figure 4 Gallium Phosphate Sensing Elements

A Gallium Phosphate crystal is shown with typical sensor elements which are manufactured out of it. Depending on the design of a sensor different “modes” to load the crystal can be used:

[1] Transverse

[2] Longitudinal

[3] Shear

The arrows indicate the direction where the load is applied.

The charges are generated on both the “x sides” of the element. The positive charges on the front side are accompanied by the negative charges on the back. Two main groups of materials are used for the piezoelectric sensors:

[1] Piezoelectric Ceramics

[2] Single Crystal Materials

The ceramic materials (for example, PZT Ceramic) have a piezoelectric constant/sensitivity that is roughly two orders of the magnitude which is higher than those of the single crystal materials and can be produced by an inexpensive sintering process. The piezoelectric sensors offer a unique set of capabilities that cannot be found in any other sensing principles. As discussed earlier, the inherent temperature stability, the amplitude range and the signal quality make it very interesting, in particular where no static information is needed.

B. DC to DC Converter:

The DC to DC Converter converts an input voltage to a higher output voltage. The DC to DC Converter is also called a step-up converter; DC to DC Converters are used in battery powered devices, where the electronic circuit requires a higher operating voltage than the battery can supply, for example, notebooks, mobile phones and camera flashes. The microcontroller runs at 8 MHz so the 8-bit PWM output is 31250 Hz. The inductor and the output capacitor is calculated as below. The diode is a standard Schottky type, but make sure that we specify the one that can handle the full voltage difference and the peak current. The switch just has to be able to handle the maximum voltage plus some for the purpose of safety. Note that this design is meant for ‘static’ output currents, not for variable current draw designs. The boost circuit works by connecting the power inductor L_1 to the ground so that the current can flow through it by turning on Q_1. After a little bit of time, we disconnect it from the ground (by turning off Q_1) this means that there is no longer a path for the current in L_1 to flow to the ground. When this happens, the voltage across the inductor increases (this is the electric property of the inductor) and charges up C_1.

III. Results

This system is used for recharged rechargeable battery. The ability to take the energy which is generated during the human motion (walking) through the piezoelectric material to charge a discharged battery is the basic objective behind carrying out this research project. The aim of this system is to recharge a battery of 6 Volts.

IV. Conclusion

The piezoelectric power harvesting device is applied to a lower frequency (100-200 Hz) and higher acceleration amplitude (> 1 g, gravitational acceleration) vibration environments. By using the DC-to-DC converter, we can boost up the generating power. Therefore, by recharging the battery, the recharge is very fast than any other system. This system is fixed at any position. Like stairs, toll booth road. The system generates the power without the use of any kind of commercial energy source.

V. References

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VI. Author's Biography:

Mr. Abhinav V. Deshpande

My name is Mr. Abhinav V. Deshpande. I have done B.E. in the branch of Electronics & Telecommunication Engineering from G. H. Raisoni College of Engineering, Nagpur in the year 2010 with an aggregate of 63%. I have also done M. Tech. from the same institute in the branch of Electronics Engineering in the year 2012 with a CGPA of 7.90 on a scale of 10.00. I have also passed the Ph.D. Entrance Test (PET) which was conducted by RTM Nagpur University in the years 2013 and 2015 respectively with valid scores of 55 marks and 55.75 marks as well as the Ph. D. Entrance Test (PET) which was conducted by Gondwana University, Gadhchhiroli in the year 2015 with a valid score of 51 marks respectively. I am having 1 year teaching experience since I worked as an Assistant Professor on Contract Basis in the Department of Electronics & Telecommunication Engineering at Prof. Ram Meghe Institute of Technology & Research, Badnera, Amravati-444701 with a consolidated salary of 36000 per month. I have published 38 research papers in different and reputed International Journals and 1 research paper is presented as well as published in the Proceedings of International Conference. I have also published 1 book in Saarbrucken, Germany in the year 2012. I am having the memberships of 6 different and reputed professional organizations. I am pursuing Ph.D. in the School of Electronics Engineering (SENSE) at Vellore Institute of Technology (VIT), Vellore and the area of research is Digital Image Processing and many other different areas related with the Electronics Engineering Domain.