Green Power Generation in Mobile Phones and Laptops

Anjushree Prasad
Dept. of Mechatronics
MIT Manipal

Sukanya S.Meher
Dept. of E.C.E
MIT Manipal

Parul Dhingra
Dept. of E.C.E
MIT Manipal

ABSTRACT
With the increase in the use of portable devices in the present era, there arises a need to develop greener and more efficient methods of generating energy to power these devices. Despite vacuum tube electronics' weight and large associated battery, people living in the early 1900s have lugged such enormous "portable" radios to picnics and other events off the power grid. As electronics became smaller and required less power, batteries could grow smaller, enabling today's wireless and mobile applications explosion. Portable devices (such as telephone, GPS, Walkman) are more and more popular and sophisticated. Thus they require more and more energy for comfortable use of new functionalities (TV on telephones, video on Walkman). The problem of the too frequent energy recharges of these objects, which make them less and less "nomadic", is then a topical subject. Indeed, the interest of having the video-telephony on the mobile phone becomes very limited since it is necessary to recharge the device more than once a day. One of the satisfactory response to this problem is to not always dependent on batteries and to look at the most promising alternatives at short or medium term.
This technical paper focuses on such advanced methods of energy harvesting using piezoelectric material, photovoltaic cells, human generated power and virus based. . The increasing prevalence and portability of compact, low power electronics requires reliable power sources. Compared to batteries, ambient energy harvesting devices show much potential as power sources. Energy harvesting has grown from long-established concepts into devices for powering ubiquitously deployed sensor networks and mobile electronics. Systems can scavenge power from human activity or derive limited energy from ambient heat, light, radio, or vibrations.

General Terms
Green power harvesting, portable devices

Keywords
Energy harvesting, mobiles, laptops, piezoelectricity, human movement, photovoltaic, virus based

1. INTRODUCTION
Batteries are nowadays the main way to give the necessary energy to portable devices. This technology is used because it has a high power density and can be activated very easily. It has also some disadvantages which are more and more penalizing for a lot of new applications. Indeed, energy density is quite low (until 200 Wh/kg) and seems to be improved at a very low rate compare to the other technologies. Despite of the announcements of breakthrough with nanotechnology, at quite short term, batteries can't fulfil the increasingly need of energy for nomadic devices. The demand for energy harvesting for devices will quadruple over the next four years, according to market researcher.
Portable devices take now a very important place in our everyday life. Thus it is more and more difficult to do without telephone or even PDA in certain cases. However with the rapid improvement of these devices and the arrival of "all-in-one" or convergence fix/mobile with always more services, a new problem has arrived the autonomy. This handicap of the recharge was relatively low since the telephone was only used to call but nowadays with the TV, the video-telephony, Internet, this one becomes a capital stake. One of the key aspects of vibrational energy harvesting is the way it can be tightly integrated into equipment. 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.

2. PROPOSED TECHNOLOGIES FOR POWER GENERATION

2.1 Piezoelectricity
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. The design presented will be quite effective in providing an alternate means of power supply for the devices during emergency too.

2.1.1 Methodology
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. 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.

2.1.2. Energy harvesting Piezoelectric Circuit

A piezoelectric harvester is usually represented electrically as a current source in parallel with a capacitor and resistor. The current source provides current proportional to the input vibration amplitude. For the sake of the following analysis, the input vibrations are assumed to be sinusoidal in nature and hence the current is represented as $i_p=I_p \sin w_p t$, where $w_p=2\pi f_p$ and f_p is the frequency with which the piezoelectric harvester is excited. The power output by the piezoelectric harvester is not in a form which is directly usable by load circuits such as micro-controllers, radios etc. which the harvester powers. The voltage and current output by the harvester needs to be conditioned and converted to a form usable by the load circuits. The power conditioning and converting circuits should also be able to extract the maximum power available out of the piezoelectric energy harvester. Commonly used analog and digital circuits require a regulated supply voltage to operate from. Since the piezoelectric harvester outputs a sinusoidal current, it first needs to be rectified before it can be used to power circuits.

We use a circuit using full wave bridge rectifier. The capacitor $_{Cr}$ at the output of the rectifier is assumed to be large compared to C_p and hence holds the voltage at the output of the rectifier V_r essentially constant on a cycle-to-cycle basis. The non-idealities of the diodes V_d is represented using a single parameter which is the voltage drop across the diode when current from the piezoelectric harvester flows through it. Every half-cycle of the input current waveform can be split into 2 regions. For the full-bridge rectifier, in the interval between $t=t_{on}$ to $t=_{toff}$ and, the piezoelectric current i_p flows into C_p to charge or discharge it. In this interval, all the diodes are reverse biased and no current flows into the output capacitor C_r. This condition continues till the voltage across the capacitor C_p is equal to $V_r+ 2V_d$ in magnitude. When this happens, one set of diodes turn ON and the current starts flowing into the output. This interval lasts till the current i_p changes direction. At low values of V_r, most of the charge available from the harvester flows into the output but the output voltage is low.

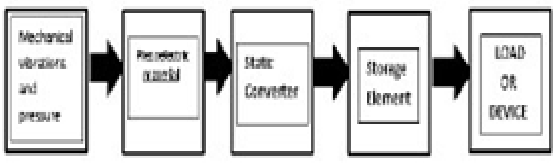

Figure 1: Basic block diagram of piezoelectric harvester.

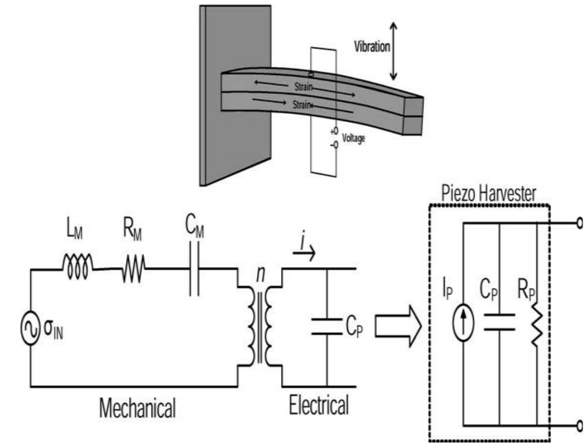

Figure 2: Equivalent circuit of piezoelectric harvester.

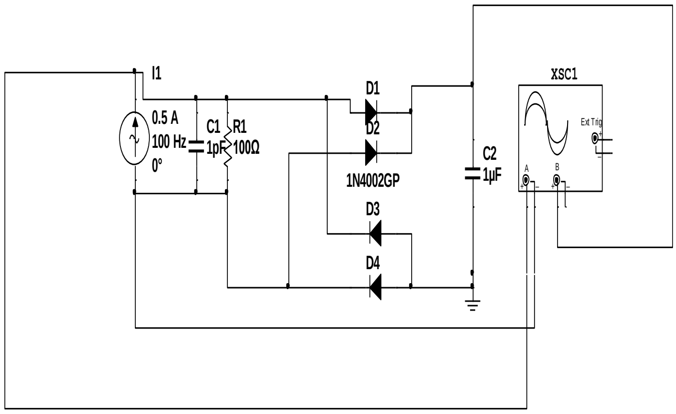

Figure 3: Energy harvesting circuit

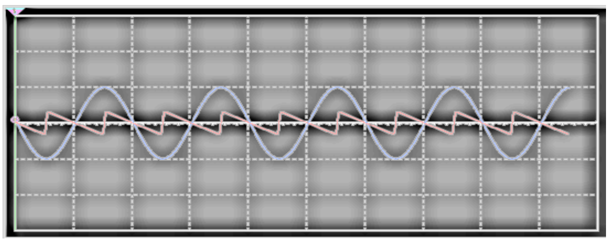

Figure 4: Simulation Results

2.1.3 Product Description

A sheet of piezoelectric material is placed beneath the keypad of a mobile phone or a laptop, or otherwise the keys itself are made of the piezoelectric material. When we press the keys we are supplying the mechanical energy to the piezoelectric material, and the piezoelectric material responds to it by generating a voltage proportional to the force applied. That charge produced will be send to the battery which stores the charge, thus the battery gets charged. If the voltage generated is more than the battery specifications then the adapter used in between would bring it down to the required value. A switch can be used just in front of the battery so that whenever there is no need for 'piezoelectric charging' the switch can be opened and charging stops.

2.1.4 Prototype Model For Mobile Phone Keypad

Fig. 5 shows the basic model of a diaphragm type of piezoelectricity generation. A circular groove is formed in the n-Si substrate (5), which is a silicon single crystal substrate integrated with a polyvinyliden fluoride (PVDF) plate or film (3). It consists of a pair of electrodes on both surfaces (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 (6) reaching the circular groove in the rear surface of then-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'

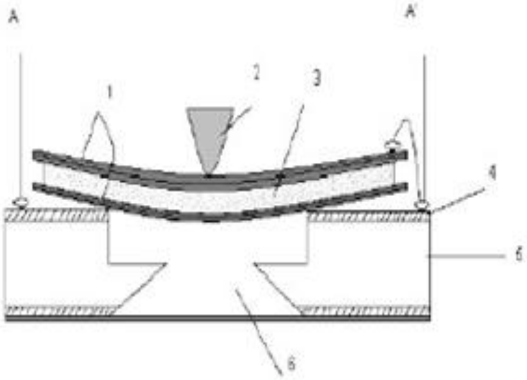

Figure 5: Basic model of diaphragm type piezoelectric generation

1. Electrodes
2. Pressure being applied
3. Piezoelectric material (PVDF)
4. SiO2
5. n-Si
6. Hole for the central part of film to deform itself.

2.1.5 Piezoelectric Prototype Model For Laptop 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 between the spring and the piezoelectric material and returns to 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. 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 decrease sand the film comes back to its original position. From Fig 7 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. 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.

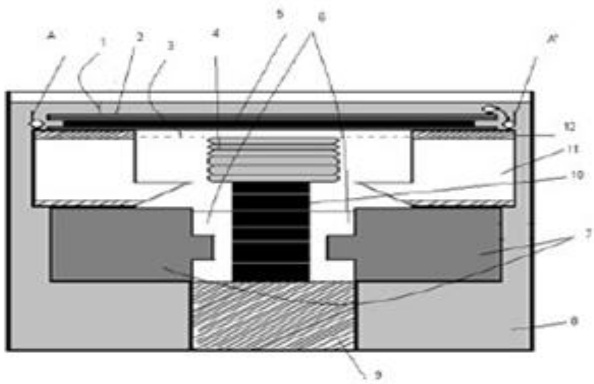

Figure 6: Diaphragm type PE generator

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. SiO2 substrate

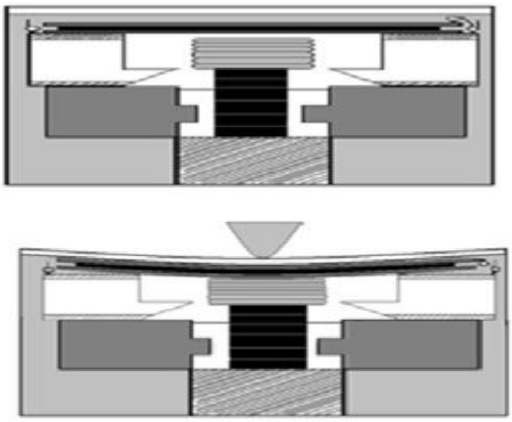

Figure 7: Unstressed and stressed condition of diaphragm type piezoelectric generator

2.2 Human Activity

2.2.1 Energy harvesters in shoes (Moonie Harvesters)

The pressure exerted by a person while walking can be converted into electrical energy to power portable devices. This is done by embedding a moonie harvester into a shoe. The "Moonie,' is a metal ceramic composite transducer that has been developed by sandwiching a poled lead zirconate titanate (PZT) ceramic between two specially designed metal end caps. The operating principle of the moonie harvester is also shown in Figure 8. The structure serves as an amplifier for the input force which, in this case, is the weight of the person wearing the shoe.The force on the heel presses the curved plates which in turn expand the piezoelectric disk sandwiched in between the steel plates. The stress is evenly distributed on the disk as opposed to beam structures where the majority of the stress is located at the fixed end of the beam.The energy output of one step was recorded as 81 µJ which translates to 162 µW for two shoes when walking 2 steps per second. The power density at 1 step / s frequency was measured as 56 µW/cm3. The size of the piezo element was 17.5 mm in diameter and the thickness was 500 µm. The material used was PZT-5H .

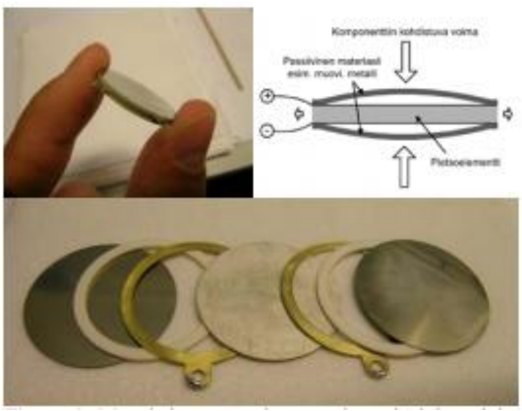

Figure 8: Moonie harvester

2.2.2 Active human movement

By pressing, shaking, winding springs with cranks, human can obtain interesting powers (up to 100 W with a bike for example). But these systems are, for the same power, more cumbersome than a battery. The incontestable advantage of this type of source is to be renewable and always available (energy of the human body) but these technologies have the inconvenience of soliciting the user to produce energy.It is also necessary to take into account the fatigueness (tiredness, repetitiveness) caused by the use of these devices.Some products are available in the market, but they are mainly used for short emergency calls. Otherwise, for longer use, it is often more practical to use a primary battery or a second rechargeable batterythan to use these dynamo products.

2.2.3 Passive human movement

The aim, here, is to harvest energy from natural movements of the human body like walk, breathing, heat. Many studies on this subject have been carried out but for each study, the scavenged power is very weak (about 40 mW for a mass of 50 g hanged to the hip during walk, 10mW for shoes equipped with piezoelectric material). This little amount of harvested energy is mainly due to the very low frequency of the human walk and to the weight strain. However, scavenging few Watts should not be a problem for the user, since the walk corresponds to a power of about 50 W to 100 W on flat ground. Thereby, to make up for the slowness of the human movement, we propose a new approach. The system tries to exploit any oscillating movement e.g. from the walk, using a small rotating machine, electronic power conversion and automatism to optimize the energy coupling. This can be called a "mecatronic" system. The energy can directly recharge the mobile or be stored in an external battery pack. Theory has shown that a 1 to 5 W power could be obtained from a small generator fastened on the belt and using the leg movement.

2.3 Photovoltaic

To use solar power in order to power mobile devices seems to be a very interesting solution because it's a no pollutant and a renewal way to produce energy. The Fig. 9 is a mobile phone charger that one can be recharged using solar power. A lot of improvements have been made in this domain and the efficiency of solar panel begins to be interesting. Researches in new semiconductor compound allow new fields for solar cells power system with more efficiency. Multilayer Solar Cells (III-V compound as GaInAs) can reach efficiencies close to 40 % which is the highest absolute solar conversion efficiency achieved. New solar cells semiconductor material as ZnMnTe from Lawrence Berkeley National Laboratory (LBNL) and Cornell University are also candidate to high efficiency solar cells. They have found that it is possible to split the conduction band of ZnMnTe by adding oxygen to the semiconductor alloy and by tailoring the exact proportion of oxygen impurities in the alloy, the energy levels can, in theory, be tuned to produce triple-band material capable of more than 50 % conversion efficiency. Despite these advancements, some obstacles are still very important issues. For example, solar panels work at their maximum efficiency when they are directly under the sunlight. For portable device which contains a lot of electronics and often a liquid crystal display, staying a long time sun-exposed can be fatal. This can be solved by separating the solar charger and the phone. A good solution might be to add a battery to the solar panel, and to charge the devices (phone, MP3 player, camera etc.) whenever they are not used, for example in the user bag. This has lead to a France Telecom Research and Development patent pending. But high efficiency solar cells are still expensive devices. Other solution could be low cost solar cells using organics materials but they reach only 8 % conversion efficiency which is not enough to recharge a battery in a short time, and are very sensible to UV, they can be used for short life, low energy smart devices.

Figure 9: Mobile phone charger

2.4 Virus Based Piezoelectric Energy Generation

Extensive research is being carried out to harness energy from a virus known as M13 bacteriophage, which have shown to exhibit piezoelectric properties.M13 bacteriophage has the ability to generate electricity when compressed but lacks the toxicity of the traditional elements. Scientists from the University of California, Berkeley have found that the pencil-shaped M13 is potentially a perfect energy source because the virus is not harmful to humans. It is also cheap and easy to make to the extent that scientists can get trillions of viruses from a single flask of infected bacteria. The shape of the virus is important because M13 can be easily assembled into thin sheets. The prototype piezoelectric devices are composed of engineered M13 bacteriophages that self-assemble into thin films.

To test whether the phages could produce power, the team first genetically engineered the virus's proteins to harbour additional copies of a negatively charged amino acid called glutamate. They added glutamates to the negatively charged end of the protein to increase its negative charge and thus its piezoelectric properties. To make a generator, the researchers laid down a film of millions of these phages atop one electrode. The phages naturally assemble themselves lying flat, side by side, all pointing in the same direction.

The team first used piezoelectric force microscopy to confirm that M13 bacteriophages demonstrate inherent piezoelectric properties. These properties are down to the structure of the viruses and, in particular, their coat proteins. The researchers were then able to optimize the peizoelectric strength of the viruses even further by modifying pVIII coat protein. This was achieved using recombinant DNA techniques to effectively add negatively charged amino acids to one end of the helical pVIII protein and increase the charge difference between the protein’s positive and negative ends, boosting voltage. This indicates that the phage-based piezoelectric devices can be scaled up to generate a higher energy output. The use of the thin films of M13 bacteriophage to generate power by layering multiple $1cm_2$ films between two electrodes and connecting the setup to an LCD was demonstrated. When pressure was repeatedly applied and released, the micro generator produced up to 6 nA of current and 400 mV of potential, equivalent to about a quarter of the voltage of an AAA battery. Encouragingly, when two devices of the same polarity and similar electromechanical response were combined in parallel or in series, the resulting current or voltage, respectively, could be increased even further. Because biotechnology techniques enable large-scale production of genetically modified phages, phage-based piezoelectric materials potentially offer a simple and environmentally friendly approach to piezoelectric energy generation. Additional levels of control and optimization may come from exploring different viral particles and their diverse structural proteins.

However, a disadvantage of this new type of generator remains that it produces far less power than conventional piezoelectric devices. Nevertheless, materials scientists at the Georgia Institute of Technology in Atlanta believe that it shows the possibility of expanding the nanogenerator into biostructures, which can be important for medical and biological applications, such as implantable sensors for diagnosing blood sugar levels for diabetics. Extensive research is being carried out on this technique of power generation so as to overcome the above mentioned disadvantage so that there non-toxic materials can be put to use.

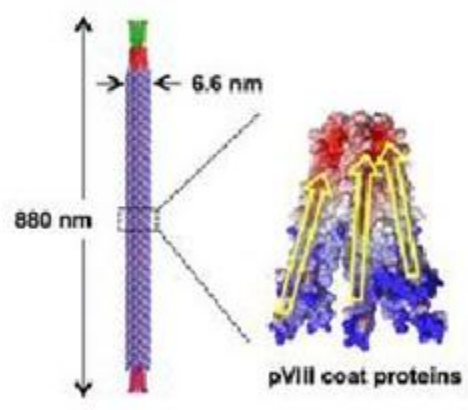

Figure 10: The modified coat proteins

3. CONCLUSION

The power and autonomy requirement of portable devices is growing at a fast rate despite the availability of power management techniques and energy aware software. Internal device batteries cannot meet the energy demand of more than 10 Wh. Although many different techniques are available to harvest energy from various environments to power electronics, the amount of available raw energy (for example, sunlight, vibration, heat) and the surface area or net mass that the device permits, limits the power yield. Nonetheless, researchers are striving to combine better power management techniques with electronics that consume less energy, enabling embedded devices to perform more useful operations with the limited power that they can scavenge. Energy harvesting is an area of rapid development, and the day approaches when component life rather than battery charge will limit low-duty-cycle sensor systems.

As the power consumption of mobiles and laptops falls with the latest silicon technology, the energy produced by energy harvesters can be used more effectively. The design presented here will be quite effective in providing an alternate means of power supply for the mentioned devices during emergency. With efficient power-scavenging circuits power can be created faster than it is drained from a device, creating what would effectively be an everlasting battery. It is a new approach to lead the world into implementing greener technologies that are aimed at protecting the environment. Further experimentation needs to be carried out so that the approach presented in this paper can be extended to many other applications where there is a scope for similar kind of energy conservation. If implemented efficiently at a large scale, this concept could lead us into a world where there is perennial battery power.

4. REFERENCES

[1] M. Umeda, K. Nakamura, and S. Ueha, BAnalysis of the transformation of mechanical impact energy to electric energy using piezoelectric vibrator,[Jpn. J.Appl. Phys.,vol. 35, no. 5B, pp. 3267–3273,May 1996.

[2] Mitcheson, P. D., E. M. Yeatman, et al. (2008) "Energy harvesting from human and machine motion for wireless electronic devices."

[3] Beeby, S. P., M. J. Tudor, et al. (2006). "Energy harvesting vibration sources for Microsystems applications." Measurement Science and Technology 17(12): R175-R195

[4] Despesse G, Jager T, Chaillout J, Leger J,Vassilev A, Basrour S and Chalot B 2005" Fabrication and characterisation of high damping electrostatic micro devices for vibration energy scavenging Proc. Design, Test Integration and Packaging of MEMS and MOEMS pp 386–90

[5] Karthik Kalyanaraman, JaykrishnaBabu "Power Harvesting System in Mobile Phones and Laptops using Piezoelectric Charge Generation" published in Proceedings of the World Congress on Engineering and Computer Science 2010 Vol II, WCECS 2010, October,20-22, 2010, San Francisco, USA

[6] Meninger S, Mur-Miranda J, Lang J,Chandrakasan A, Slocum A, Schmidt M and Amirtharajah R 2001 Vibration to electric energy conversion IEEE Trans Very Large Scale Integration(VLSI)

[7] Sunghwan Kim, "Low power energy harvesting with piezoelectric generators", (2002)

[8] Revathi G and Ingitham R ,"Piezoelectric energy harvesting system in mobiles with keypad and sound vibrations" published in IJERT on Vol-1 Issue 4,June 2012. Proceedings of the IEEE 96(9): 1457-1486.

[9] Conference Center, Montreal, Canada, April 2004 R.J. Kuipers, "Engineering a human powered mp3 player", Graduation report, Delft University of Technology, Delft, 2003

[10] M. Ruellan, S. Turri, H. B. Ahmed and B. Multon, "Electromagnetic resonant generator", IEEE IAS annual meeting, Hong Kong, CDROM proc., 2-6 Oct 2005

[11] Sunghwan Kim, "Low power energy harvesting with piezoelectric generators", (2002),R. Sood, Y. B. Jeon, J. H. Jeong, and S. G. Kim," Piezoelectric micro power generator for energy harvesting", 2004.

[12] Sebastian Antony (2012, May 15) Berkely scientists turns harmless virus into Piezoelectric generator. [Online] Available:http://www.extremetech.com/extreme/129389-berkeley-scientists-turn-harmless-virus-into-piezoelectric-generator

[13] Robion, D. Sadarnac, F. Lanzetta, D. Marquet, T. Rivera "Breakthrough in Energy Generation for Mobile or Portable Devices" published in Telecommunications Energy Conference, 2007. INTELEC 2007.

[14] A. J. Jansen, "Advances in human-powered energy systems in consumer products", Proceedings of the Design 2004, 18-21 May 2004