Vibration Energy Harvesting Using Piezoelectric Material for Wireless Sensor Network

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In these recent years, energy harvesting using piezoelectric material has been quite popular being research topic. As well as wireless sensor network (WSN) which are widely used. Due to wireless sensor application and environment, it is impractical to used fixed-energy alternative like battery or fuel cells with an expected lifetime of more than 10 years which once the sensors deployed usually preclude changing or re-charging the batteries. This paper presents energy harvesting by scavenging ambient energy, e.g. solar energy, thermal gradients and vibration. Vibration sources are ubiquitous and available in most places like air ducts, train, building structure and heart pace. Roundy *et al* have modeled, designed and built small cantilever-based devices with MEMS (Microelectromechanical system)technology using piezoelectric materials that can scavenge power from low-level ambient vibration sources and turn them into electricity to power the sensor node.

Keywords : energy harvesting, vibration, MEMS, wireless sensor network, piezoelectric.

Wireless sensor networks (WSN) have been widely used in many applications and environments and have created potential market opportunities. WSN applied in many fields, such as aeronautics, buildings structures, transportation, have bring the needs of increasing WSN productivity by reducing power consumption and lower maintenance period resulting decrease of expenses. Batteries and fuel cells have been used for long times to power sensors and low-power devices, but the limited lifetime of this power sources brought up a solution ofenergy harvesting. Aimed at converting ambient energy into electricity, this green technology also gives a theoretically unlimited lifetime to sensor nodes.

Energy harvesting method is an option for scavenging ambient energy like solar energy, thermal gradients and vibration-based devices. However, these options have their own limitation, solar method requires sunlight, thermal gradients need sufficient temperature variation, vibration-based need sufficient vibration sources. While vibration sources are generally more ubiquitous and can be found in many places like air ducts, train and building structures.

There are multiple techniques for converting vibration energy into electrical energy. There are electrostatic, electromagnetic and piezoelectric conversions.In this paper, we focus on discussing vibration energy harvester using piezoelectric materials that can scavenge power from low-level ambient vibration sources. An appropriate power conditioning and capacitive storage, the resulting power source is sufficient to support networks of ultra-low-power, peer-to-peer wireless nodes.

PROBLEM

This vibration energy harvester device would perform based on where it is placed. Due to environment vibration available, this device will provide less power while on a calm place.Assume that one of sensor node was placed on a place with vibration in low frequency range and doesn't generating enough energy to power the sensor and wireless network.

Power source	Power (μW)/cm^3	Energy (Joules)/cm^3	Power (μW)/cm^3/yr	Secondary storage needed?	Voltage regulation?	Commercially available?
Primary battery	N/A	2,880	90	No	No	Yes
Secondary battery	N/A	1,080	34	N/A	No	Yes
Micro fuel cell	N/A	3,500	110	Maybe	Maybe	No
Ultracapacitor	N/A	50–100	1.6–3.2	No	Yes	Yes
Heat engine	1×10^6	3,346	106	Yes	Yes	No
Radioactive (^{63}Ni)	0.52	1,640	0.52	Yes	Yes	No
Solar (outside)	15,000*	N/A	N/A	Usually	Maybe	Yes
Solar (inside)	10*	N/A	N/A	Usually	Maybe	Yes
Temperature	40*†	N/A	N/A	Usually	Maybe	Soon
Human power	330	N/A	N/A	Yes	Yes	No
Air flow	380‡	N/A	N/A	Yes	Yes	No
Pressure variation	17§	N/A	N/A	Yes	Yes	No
Vibrations	375	N/A	N/A	Yes	Yes	No

* Measured in power per square centimeter, rather than power per cubic centimeter.
† Demonstrated from a 5°C temperature differential.
‡ Assumes an air velocity of 5 m/s and 5 percent conversion efficiency.
§ Based on 1 cm^3 closed volume of helium undergoing a 10°C change once a day.

TABLE 1
Energy and Power Sources Comparison
(Table taken from [1])

From table 1 above shown that vibration energy sources generates quite a number of power comparing with another ambient energy sources with vibration energy harvester model built by researcher.

VIBRATION ENERGY HARVESTER METHODS

Researchers have built vibration-based energy harvester using 3 types of electromechanical transducers: electromagnetic, electrostatic and piezoelectric. It is concluded that the most efficient types depends on the specific application. Table 2 compares three types of transducers.

Type	Practical maximum (millijoules/cm^3)	Aggressive maximum (millijoules/cm^3)
Piezoelectric	35.4	335
Electrostatic	4	44
Electromagnetic	24.8	400

Table 2
Energy Storage Density Comparison
(Table taken from [1])

Practical values show the maximum power currently achieved by standard materials and process. Aggressive values show values that theoreticallypossible.By referring to table above, this paper discuss about vibration energy harvester using piezoelectric materials that tested to be the most effective. From table 2 shown that piezoelectric is the most effective materials for vibration energy harvesting in most applications.

At table 1, the value of power generated by vibration energy harvester was generated by a model built by Roundy et al using a 1 cm^3 design with piezoelectric materials and vibration source of 2.5 m/s^2 at 120Hz.

DEVICE CONFIGURATION

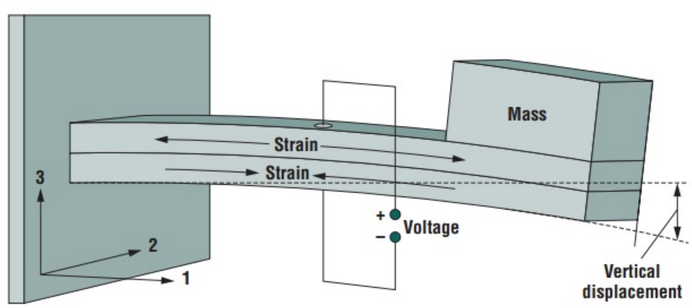

Figure 1. A two-layer bender mounted as cantilever beam. Top and bottom layers are piezoelectric.
(Figure taken from [1])

Figure 1 shows the configuration of the vibration energy harvester looks like. It built from two layers of piezoelectric with central layer (usually metal) not drawn in this figure.These two layers are mounted as a cantilever beam. At the end of the beam, there is a mass to as the figure shows, the mass is used to lower the natural frequency of the piezoelectric beam and increase the output power of the energy harvesting device.

By bending the beam down produces tension in the top layer and compresses the bottom layer. A voltage gained from across each of the layers.

POWER OUTPUT

When vibrations drive the device, the generator provides an AC voltage. Power output generated by this device really depends on the dimension, mass put on the tip of the beam, natural frequency and driving frequency of the beam. Power output is maximized when the natural frequency matches the driving frequency. Natural frequency depends on the stiffness and mass, and increase in mass will necessitate an increase in stiffness to maintain the natural frequency. Roundy *et al* increases stiffness by making the piezoelectric beam thicker or wider, thus increasing the amount of piezoelectric material.As the last row of table 1 indicates, vibration source of piezoelectric materials can generate approximately 375 $\mu W/cm^3$ which can contribute quite enough power to drive a WSN node.

POWER MANAGEMENT& APPLICATIONS

A simple wireless sensor network node comprises sensors, microcontrollers, radio transceiver and power supply. These components are known as energy consumptive, in order to power this WSN by energy harvesting, it is necessary to reduce power consumption of sensors, microcontrollers and radio transceiver.

Most microcontrollers and RF chip manufactures (i.e. Atmel, Microchip, Texas Instruments, etc.) have used “global system vision” which by reducing power consumption of device both for working and standby modes. Boisseau shows power consumption in three state of a WSN: standby, active, and transmission peak. Power consumption for each state shown below was an example from ratio of power consumed by WSN in three states:

- 1 – 5 μW : standby mode’s power consumption
- 500 μW – 1 mW : active mode’s power consumption
- 50 mW : transmission power peak.

Values of power consumption shown above indicates that today's vibration energy harvesting cannot supply a WSN node in a continuous mode. Assuming that WSN node stay in active mode which consume about 500 μW – 1 mW of power while energy harvester built could generate about 375 $\mu W/cm^3$.

In order to face the problem of energy consumption, another solution came out by having the WSN get into standby mode which consume much less power than active mode. By adopting an intermittent operation mode as presented in figure 2. Energy is stored in a buffer(capacitor of battery) (a). Perform measurement cycle when energy in buffer is enough to power sensors and microcontrollers (b). Transmit the data of measured value with RF transceiver to base station using the residual power in the buffer (c). Wait for a new measurement cycle while the buffer is charging.

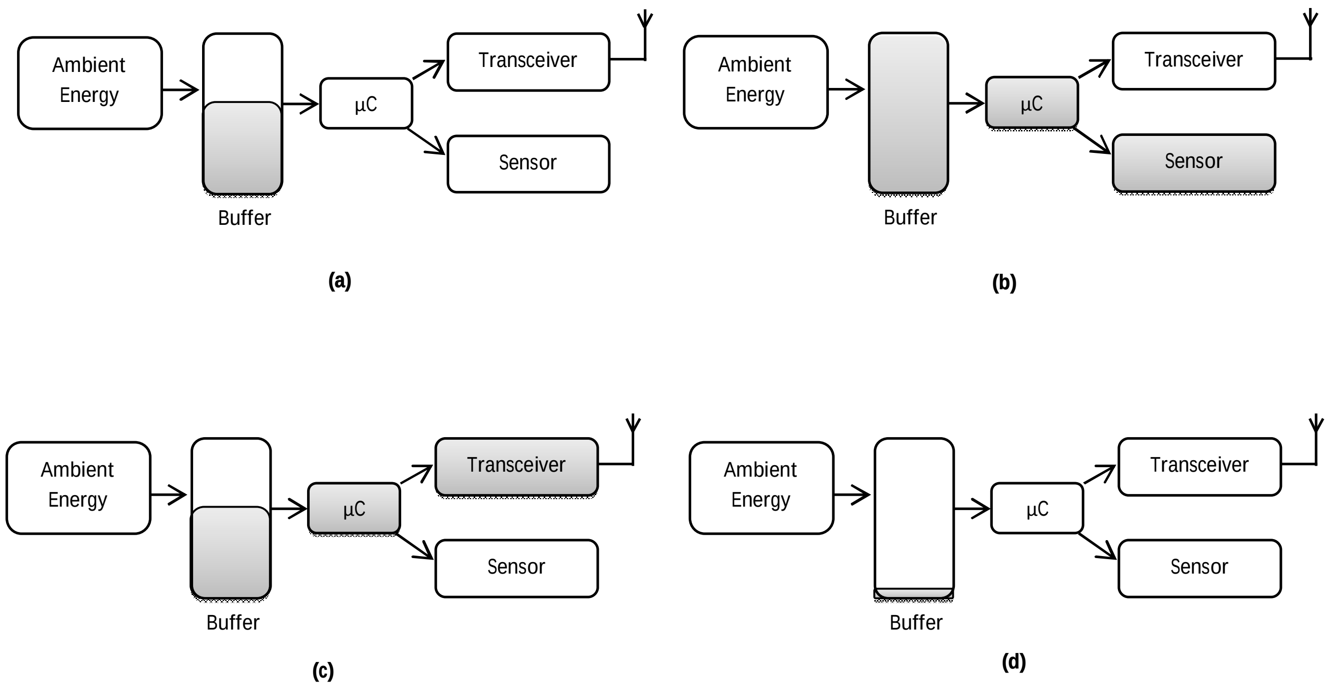

Figure 2. WSN Measurement Cycle

In order to apply this energy harvester which generated AC voltage and low current. Using flyback converter or DC/DC converter which located between rectifier and energy storage. This converter allow DC/DC conversion that can reach more than 80 percent of efficiency and need quite simple control circuits that generally consume less than 5 μW.

CONCLUSION

Due to consumption reductions, it is possible to replace battery with vibration energy harvester for WSN. Today's vibration energy harvester still generates small amount of energy to power heavier application, a WSN is a fit application with ultra-low-power components, though WSN with vibration energy harvester cannot work in full performance or small frequencies of workload.

By increasing vibration energy harvester output power and decreasing the power consumption of the device, it is possible to use energy harvester in more low-power application besides WSN. Increasing vibration energy harvester could be achieved in several ways, such as frequency tuning which an attempt to match resonance frequency of the beam with driving frequency.

By using MEMS technology in building vibration energy harvester makes an on-chip-integrated energy harvester possible. By this mean, there will be more applications of low-power devices and small in size powered with vibration energy harvester.

REFERENCES

1. S. Roundy, E.S. Leland, J. Baker, E. Carleton, E. Reilly, E. Lai, B. Otis, J.M. Rabeaey, P. K. Wright, V. Sundararajan, Improving Power Output for Vibration-Based Energy Scavengers, *IEEE Pervasive Computing*, 4 (2005) 28-36.
2. A. Townley, Vibrational Energy Harvesting Using MEMS Piezoelectric Generators.
3. V.R. Challa, M.G. Prasad, Y. Shi, F.T. Fisher, A Vibration Energy Harvesting device with bidirectional resonance frequency tenability, *Smart Materials and Structures*, 2008.
4. S. Boisseau, G. Despesse, Vibration Energy Harvesting for Wireless Sensor Networks: Assessments and Perspectives, www.eetimes.com, 2012.