Piezoelectric Microgenerator Rectifying Circuit Simulation using LTspice

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Abstract—**Energy harvesting using piezoelectric becomes popular due to its miniature size and have the potential to replace the used of battery that has limited lifespan. One of the methods in harvesting ambient energy is through the form of vibration energy. The vibration energy is then converted into electrical energy. In this paper, a piezoelectric generator system is designed to harvest energy from ambient environment at specific vibrational frequency. The AC output from piezoelectric is rectified using a bridge rectifier and then stored in a supercapacitor. The simulation results using LTspice has shown a promising outcome with an output voltage reaching 8V using LTC 4358 with an internal 20mΩ N-channel MOSFET.**

Keywords—Energy Harvesting, Piezoelectric, Microgenerator, Rectifier, Supercapacitor, DC-DC Converter

I.   Introduction

The advancement of wireless sensor technology and low power electronic has brought attention of using abundance energy from ambient environment as their main power source which is able to be converted into electrical energy to operate low power electronics devices. This application is known as energy harvesting or energy scavenging. Of course, this is also appropriate to consider as a small scale renewable energy, which has no negative effect on health and nature.

Energy harvesting or renewable techniques can be divided into higher and lower output generation. Higher power output can be achieve up to a few kilo Watts and even Mega Watts through the use of solar, wind, ocean wave and hydro powered generator. For lower power output in the range up to a few milli Watts generated through human, physical motion, vibration, temperature changes, which will be more relevant in this research. The focus of this paper is on harvesting energy from ambient vibration through piezoelectricity. Piezoelectric is used due to its simplicity in terms of structure and electrical circuitry.

Today, as wireless systems are grown steadily over wired system which is due to the rapidly demand on the wireless sensors and portable electronics, therefore energy harvesting is becoming important. Wireless sensor network (WSNs) comprises of sensor nodes that can independently collect the data such as pressure, humidity, gas and temperature etc over the target area [2]. One interesting features of WSNs is wide range of applications such as environmental monitoring, healthcare, agriculture, military to security systems. Advancement in the development of IC design circuit and wireless sensor has reduced power consumption of the devices.

Typically, power small for electronic device require a dc voltage of 3.3V. Therefore, the use of battery and external power source is not practical for small electronic device. The lifespan of battery is finite and require continuously battery replacement work that will deter WSN usage. This can become tedious task, very expensive and even impossible for embedded deployments.

The main concern here is about the wireless system capability in order to combine with advances technology to implement the system that more intelligent, sophisticated, smaller and require no tedious work for maintenance. To overcome the power requirements problem and reduction in costs, one method to replace the battery is by using piezoelectric techniques. This technique is basically captured the vibration or kinetic energy from ambient environment than convert to electricity form. The conversion of vibration is by straining the piezoelectric material. The vibration is caused by cantilever beam structure that oscillates freely. The strain will cause the charge separation across the device. The charge separation will produce the electric field.

Piezoelectric was first discovered by Pierro Currie in 1880. The word of piezoelectric comes from Greek word "piezein" means "to press". Piezoelectric power generators consist of electrode and ceramics that is small enough to fit into the micromechanical system (MEMS). When pressure is applied to the piezoelectric material, the mechanical deformation will be occurred and result in the electrical potential [3]. The output from piezoelectric generator is in the form of alternating current (AC) should be converted to direct current (DC) through rectifier bridge and a smoothing capacitor. This actually constitutes ac to dc converter.

Rectified voltage is charged by supercapacitor until the capacitor voltage reached preset threshold. The power generated by supercapacitor will be fed to the step down DC-DC converter or buck converter.

The efficiency of buck converter is about 95% and making them useful to convert from higher to lower voltage but at the same time the current is sufficiently step up and supplied to the load. In order to implement low power consumption system, a low power microcontroller and RF solution is choose.

II.   Piezoelectric and Generator

Piezoelectric generate energy by the concept of self-charging structures. Usually, the structure is composed of metallic or carbon fiber. This structure is an elastic material that will be vibrating when force is applied as shown in Figure 1. For self charging structure, resonance phenomenon plays an important role for piezoelectric power output. The key challenge here is the source of vibration must be resonant with piezoelectric device to be efficient. The resonance frequency is based on dynamic of entire composite structure that produces an effective frequency for maximum power generation not from the piezoceramics layers. Thus, to obtain the desired voltage output is highly important to reach the better accuracy from the mechanical view.
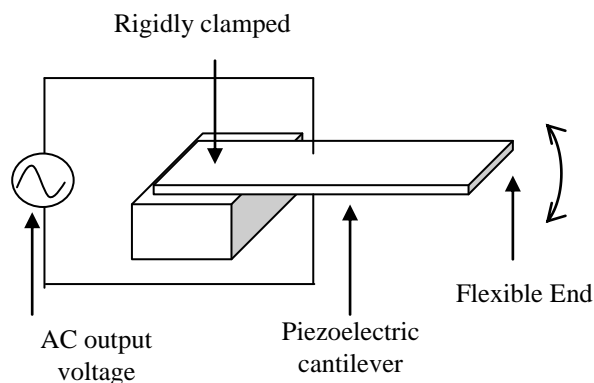

Figure 1 Schematic diagram of a piezoelectric micro generator in the form of a cantilever structure generating AC output voltage

The ability of piezoelectric to detect vibration and has high efficiency in conversion from mechanical to electric energy [1] is the advantage of piezoelectric compare to other mechanism. Compare to the electromagnetic, piezoelectric has the highest energy density. Moreover, it has simple structure and easy to fabricate.

Usually to generate power from piezoelectric device, one end of the cantilever must be clamped while free to the end. However, there are some problem appear due to clamping effect. It will prohibit the generator to produce more precise output. To overcome this problem, free standing thick film piezoelectric device is used [9]. This structure is the improved solutions for obtaining optimum performance for piezoelectric generator. It also can fit into small size wireless sensor module.

III.   Rectifying and Storage Circuit Design

The bridge rectifier will rectify the AC voltage generated from the output of piezoelectric. However, regarding the low power level from the piezoelectric microgenerator, the rectification scheme must be chosen properly so that the output from the piezoelectric is efficiently transferred to the load. The process of rectification is before the electrical being supplied to the load, the current from ac supply must be converted to the unidirectional form [4]. The diode bridge is the most applicable for piezoelectric energy harvesting because it provides full wave rectification that conduct every half cycle rather than use half wave rectification method. The output from bridge rectifier also gives smaller output voltage ripple and produce smoother output waveform.

Among the entire bridge rectifier, Schottky diode is suitable for this application. BAT 754 series Schottky barrier (double) diode is chosen because it has very low forward voltage and also low diode capacitance [5]. The normal diode has voltage drop about 0.6 to 1.7 volts. However, Schottky diode has much lower voltage drop between 0.15 to 0.45 volts. As a results, it enhances the system efficiency and also higher the switching speed. Common semiconductor type has PN junction. However, Schottky diode junction is made of metal contact (anode) and semiconductor (cathode). This characteristic can protect the circuit from any damage or defect.

The forward voltage of Schottky diode can be selected by design. The Schottky barrier is within the Schottky diode. When the electricity that passes through Schottky diode is in contact with the metal, it can cause the electricity to become free moving electrons. This can improve the time switching speed of the Schottky diode.

Supercapacitor has the similar principle with the conventional capacitor. The only difference is supercapacitor has much higher surface area and has thinner dielectric compared the conventional capacitor. Supercapacitor can overcome the limitation when using battery which was low power density, short life cycles and require longer time for fully charging. Supercapacitor is actually the combination of advantage of both battery and capacitor. It provides greater efficiency and has low energy density. Low energy density can brings to feasibility for high power application.

For limited thickness surface, planar supercapacitor is the most suitable as energy storage device. It offers low ESR with high capacitance that is fit into small packaging. Previously, high ESR has limiting the electric double layer capacitor from the memory backup applications. Lower ESR has improved the power capability of supercapacitor. The larger value of supercapacitor, the longer time it takes to charge the supercapacitor. Figure 2 shows the comparisons of energy storage devices.
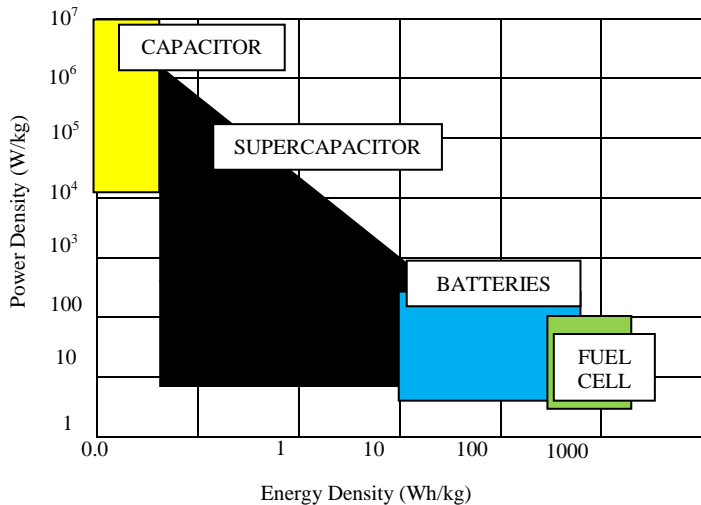
Figure 2 Ragone Plot energy storage devices adapted from [7]

The Ragone plot illustrates the power and energy density of various energy storage devices. Among all the storage devices, supercapacitor has large power and energy density. From the plot, it can be seen that supercapacitor region overlap both capacitor and battery region. The supercapacitor has higher capacitance values than battery. The single cell of supercapacitor is rated at 2.5V, while dual cell devices are rated at 4.5V and 5.5V according to the customer requirement. The voltage of supercapacitor is intended to be less than supply voltage.

Figure 3 and 4 are DC-DC step down converter circuit using LTC 3642. In order to investigate the performance of rectifying circuit, LTC 4358 with an internal 20mΩ N-channel MOSFET is used to compare the conventional bridge circuit using Schottky diode. The performance of charging circuit is determined using supercapacitor charger IC LTC 3255-1 as shown in Figure 5.
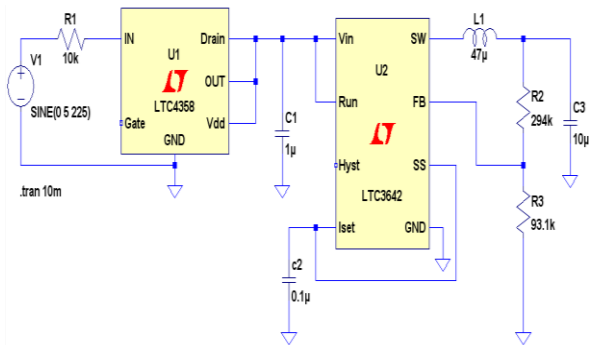

Figure 3 Schematic diagram of a rectifier with an ideal diode that uses an internal 20mΩ N-channel MOSFET using LTspice
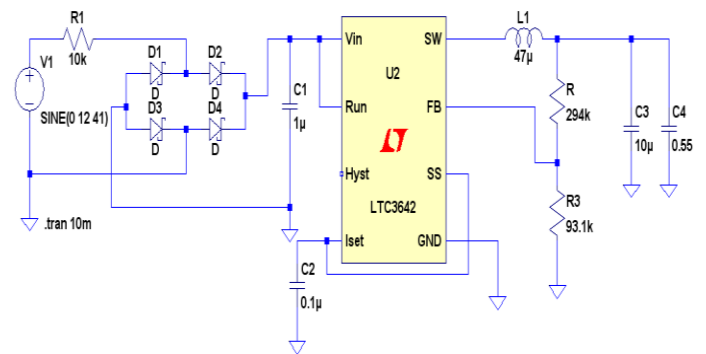

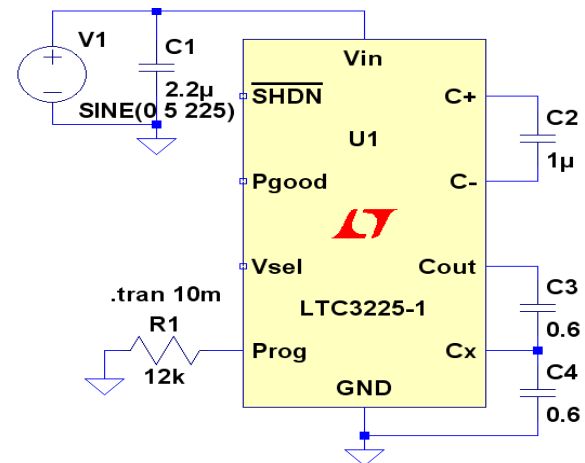**Figure 4** Schematic diagram of a bridge rectifier using Schottky diode

Figure 5 Schematic diagram of charging supercapacitor circuit

IV.   **LTspice Simulation Results and Discussion**

In comparison with an ideal diode, we used LTC 4358 that contains an internal 20mΩ N-channel MOSFET. The simulation results show that the IC circuit has superior voltage output compared to the use of Schottky diode as shown in Figure 6.
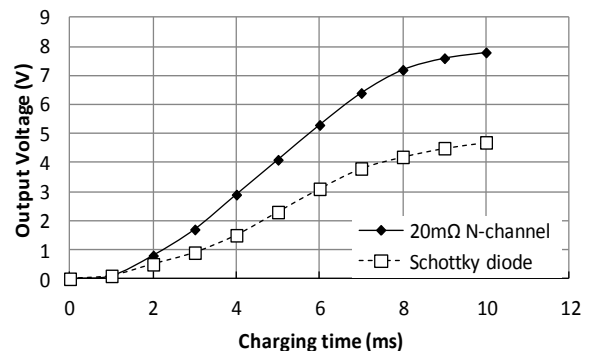

Figure 6 Output from ideal diode that uses an internal 20mΩ N-channel MOSFET compared to the bridge rectifier using Schottky diode

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The output from diode that uses an internal 20mΩ N-channel MOSFET generated about 8.5V compared with Schottky diode which generated only 4.8V when simulated with the same "piezoelectric" input value.

Figure 7 below shows the result of supercapacitor charging circuit. The circuit is design to charging two supercapacitors in series. The supercapacitor is connected in series because to avoid from overvoltage damage between these two supercapacitor. Thus, balancing resistor is not required for this circuit. This application is not suitable for small input voltage value because it has low input noise, low quiescent current and low external parts count. The charging rate is about 0.5V/s.
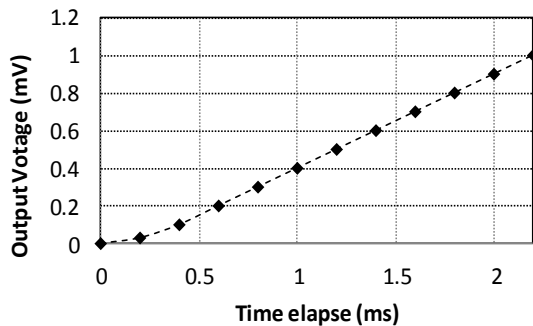

Figure 7 The output voltage from the supercapacitor

V Conclusion

Energy harvesting through vibration using piezoelectric material is potentially replacing or compliment a battery as the energy source for powering ultra low electronic devices. From the simulation results using LTspice, we can improve the voltage output up to 8V using LTC 4358 with an internal 20mΩ N-channel MOSFET compares to a voltage output of 5V using conventional Schottky diode. We also show that supercapacitor charging rate for the circuit is 0.5V/s. Further work will concentrate on the simulation and lab experiment in order to develop self charging wireless sensor node using piezoelectric. The properly design energy harvester system will result in reliable and efficient system.

Acknowledgement

References

[1]   S. Mehraeen, S. Jagannathan, and K. Corzine, "Energy harvesting using piezoelectric materials and high voltage scavenging circuitry," *2008 IEEE International Conference on Industrial Technology*, pp. 1–8, Apr. 2008.

[2]   M. Yoshida, T. Kitani, M. Bandai, T. Watanabe, P.Chou, and W.K. G. Seah, "Probabilistic data collection protocols for energy harvesting sensor networks", *2011 IEEE 36th Conference on Local Computer Networks*, pp. 366-373, Oct. 2011.

[3]   R. A. Peura and J.G. Webster, "PRINCIPLES", pp. 45-90, 2008.

[4]   William Shepherd and Li Zhang, "Power Converter Circuits", Marcell Dekker, Inc, pp. 4-6, 2004.

[5]   D. Zhu, S. P. Beeby, M. J. Tudor, N. R. Harris, "A credit card sized self powered smart sensor node", *Sensor and Actuators A: Physical*, 2011.

[6]   Rick Cory, "Schottky Diodes", *Skyworks Solutions Inc*, 2009.

[7]   M. S. Halper, J.C. Ellenbogen, "Supercapacitors: A brief overview", *The MITRE Corporation*, 2006.

[8]   S. Roundy, P.H. Wright, J.M. Rabaey, Energy scavenging for wireless sensor networks with special focus on vibration, Kluwer Academic Publisher, Norwell, MA 02061, USA, 2004.

[9]   S.L. Kok, N.M. White, N.R. Harris, "Free-standing thick-film piezoelectric device", Electronics Letter, Feb, vol.4, no.4, 2008.

[10]   Linear Technology, "150mA Supercapacitor Charger,"LTC3225/LTC3225-1 datasheet, 2008