Self-Powered Supercapacitor for Low Power Wearable Applications

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Abstract. Piezoelectric generators can be used strong vibrations convert to electrical power, it can be stored and utilized in low power devices such as radio frequency identification tags (RFIDs), wireless, global position system (GPS) and sensors. Since most low power devices are wireless, it is important that they have their own independent power. Traditionally, electrical energy comes from heavy lead acid and lithium ion batteries, which contain chemicals that are not environmental friendly. More importantly, lead acid and lithium ion batteries have an average lifespan of 500–1000 cycles, compared to carbon-based supercapacitors (10 lakhs cycle). With the introduction of a wide range of portable, wearable electronics devices and health monitoring equipment, Piezoelectric power harvesting equipment is one of the most applications of portable electronic power supply. Supercapacitors are promising electrochemical energy storage devices which possessing very high power density, rapid charge, and discharge rates with a long lifecycle. Supercapacitors hold high power density as compared to dielectric capacitors and hence supercapacitors are extensively utilized for powering several portable electronic devices. Supercapacitors explore a wide range of applications as they can deliver a high power within a very short period. In this paper describes various supercapacitor powered potential applications in various sectors like flexible, portable, wearable electronics, implantable healthcare and biomedical sensor, etc.

Keywords: Piezoelectric, Self-powered, Supercapacitor, Energy Harvesting

1. Introduction

Piezoelectric harvesting has proven to be a solution to replace conventional lead and lithium ion batteries in remote place power supply applications. The power management perspective was introduced after reviewing the current research literature on piezoelectric energy harvesting focusing on low frequency vibration mechanics from circuit design as shown in figure 1. Piezoelectric energy can be used for low power generation due to its high energy storage capacity. The piezoelectric energy harvester to convert low frequency vibration stored harvesting electrical energy. The reason for choosing piezoelectric is the high energy storage capacity. In piezoelectric generator, the piezoelectric sensor is used as a harvesting vibrational material and the supercapacitor storage element [1-5].

Figure 1. Schematic diagram of Energy harvesting various power range portable electronics
Figure 2. Schematic diagram of ambient energy source and energy harvesting technologies.

These chip systems have powerful energy-saving schemes, such as shutting down idle work. In fact, these devices require very little power to use, so most sensors are wireless because they run easily on batteries. Unfortunately, the batteries need to be replaced regularly, which is very expensive to produce and the most difficult maintenance. [6,7]. The sensory atmosphere is an effective wireless energy solution for harvesting the surrounding mechanical, thermal, solar and electro-magnetic forces as shown in Figure 2.

Analog devices provide ICs with high power for ultra-low power generation applications. Power management products that convert energy from piezoelectric, photovoltaic and thermocouples provide high-performance conversion to source controlled voltage and charge batteries, supercapacitors and storage devices. Booster converters operate on small 20 mV high capacity battery chargers, expanding the possibilities of automation and industrial control, wireless sensors, navigation, applications and portable electronics. [8-10] Current low power controllers, op amps, comparators, voltage monitors, ADCs, DACs and low power storage devices provide additional blocks for standalone systems as shown in Figure 3.
Figure 3. Block diagram of Energy harvesting system

The renewable energy environment is very energy efficient, so energy harvesters are a good source of energy for IoT applications, eliminating the need to replace and dispose of batteries. However, low-power harvesters are often unable to provide the high capacity needed to collect and transfer data. This article shows how to use a supercapacitor mounted on an energy harvester to provide the maximum power needed using a small piezoelectric strip. A standard power supply consists of a power harvester that connects a large charging circuit directly to the supercapacitor with a direct load. The high C and low ESR of the supercapacitor keep the electrical energy constant for the load while breaking its high power [11 - 14].

Over the past decade, flexible electronics, wearable equipment, and portable devices have become increasingly important in various fields such as mobility, consumer technology, biomedical, sports, clean and natural energy. Therefore, as high power consumption is required, these electronics require smart power storage devices. In a variety of energy storage systems, supercapacitors are an important tool that can bring high energy in a very short time with new energy storage methods.

Much research has been done on the field of supercapacitors in the manufacture of fine electrodes and electrolyte components and in the construction of energy-efficient storage systems. Initially, supercapacitors were produced from high-carbon materials by forming a double layer. Recently, the interest of two building materials has been improved using low energy carbon materials and poor performance, as well as a combination of two components to overcome the surface area of pseudo supercapacitors. Nowadays, supercapacitors are taking over applications in many fields such as wearable electronics, flexible electronics, portable electronics, electric vehicle transport, power storage, biomedical, military and aerospace. This paper describes the extensive use of supercapacitors, their real-time use in modern technology and the end of simpler methods [15 - 24].

2. Energy Harvesting Methodology

Ambient power sources include light, temperature fluctuations, vibration beams, RF signal signals or other sources that can generate electricity through a transducer. Piezoelectric materials can produce up to 100 μW / cm² depending on their size and shape and are shown on figure. 4.

Figure 4. Block diagram of principle of piezoelectric materials.
The Piezoelectric transducer application demonstrates that piezoelectric system shown in figure 4, when plugged in to air transmission line, produces 100 µwatts of power at 3.3V. The piezoelectric harvester deviation is 0.5 cm at a frequency of 50Hz. Energy harvesting through human movement is an attractive way to obtain clean and stable electricity. Piezoelectricity is the electrical energy produced by mechanical pressure (e.g. walking, running). When pressure is applied, electrical energy flows throughout. Commonly used resources: solar power, triboelectric power nano generator and piezoelectric power. This study focuses on the use of piezoelectricity because it relies on mechanical pressure to obtain electrical energy and some resources are not always reliable. Compared to three nano generators of large capacity storage, the piezoelectric has more energy-saving properties than other energy-producing methods.

Figure 5. Arrangement of piezoelectric generator inside a shoe insole.

Piezoelectric sensors should be placed on the two main parts of the shoe where high pressure will occur. A piezoelectric generator is installed inside the shoe insole. The shoe has two points, where the pressure is very strong and the heel and toe, and the piezoelectric sensor wing are the exact location shown in Figure 5. The piezoelectric array arrangement fixes the shoe insole. One sensor can produce 3-5 volts in a constant pressure application, in which case four sensors are connected in parallel, which increases the probability of obtaining the highest gains. It is more advantageous to use piezo polymeric materials than piezoelectric materials when it comes to using sensors, as polymer films can be easily made in different sizes. However piezo ceramic sensor was used in this work because it is available for sale at low cost.

The design includes piezoelectric generator units connected to the series. The front panel inserts the generator in a straight line with the rear panel having a circular motion. The acquisition and charging side collects continuous or continuous power inputs from the piezoelectric generator and charges its power efficiently to a very large bank. During the charging process, the supercapacitor voltage is monitored regularly. When it reaches 5.2 V, it can power the rectifier output module and the charging circuit.

The piezoelectric generator is mounted on the shoe. As a person moves, pressure builds up on the ground and this pressure can be converted into electrical power and used to charge the supercapacitor. This energy storage system uses biomedical sensor applications.
There are many studies that successfully explore power augmentation in laboratories, but the overall efficiency of the underlying systems is limited to the trade-off between the capacities of each system. The functional cycle of a supercapacitor with a high-performance life cycle is investigated based on a systematic analysis of piezoelectric power generation from a power management perspective.

3. Results

Successful design of complete wireless systems requires energy-saving microcontrollers and transducers used from low-power electronic applications. The LTC3588-1 is a complete power generation solution designed for high impedance sources such as piezoelectric energy harvester shown in Figure 6. It features a full bridge rectifier and a highly efficient buck converter of low power bridge rectifier that transfers power from the device to the output at a controlled capacity capable of supporting loads up to 100mA. LTC3588-1 is available in a 10-lead MSE package with 3 mm × 3 mm DFN.

![Simulink model of Piezoelectric-driven supercapacitor for charging and discharging.](image)

Figure 6. Simulink model of Piezoelectric-driven supercapacitor for charging and discharging.
Figure 6 shows the power generation system with the methods of harvester, transducer and power condition circuit that converts this stored electrical energy into a controlled power supply. The voltage rectifier may also need a controllable power supply network between the energy harvester and the energy storage element to block the power supply or to adjust the AC output signal in the case of a piezoelectric harvester. Operating Example LTC3588-1 the output power of the transducer must exceed the minimum power limit, which increases the specific power limit set at the input pins D0 and D1. To transmit high power, the power transducer must have open circuit voltage and a short-circuit current of input voltage, which is twice the required input as shown in Figure 7. These requirements must be kept to a minimum uninterruptible power supply capacity.

The piezoelectric harvester, which is the constant current charging of the supercapacitor, can be detected by exposing the active frequency of the buck boost control using software used for pulse width modulation. The test results validate the electric circuit piezoelectric generator model, the presence of a current charged supercapacitor, and simple circuit control designed as shown in Figure (8-12).
4. Application of self-powered device:

4.1. Wearable Electronics:

The wearable electronics device represents wearable bio-sensors and wearable bio-medical devices. Since all of these electronics devices require electric power to operate, portable electronics systems are an integral part of portable devices. In fact, the energy storage materials in these electronic devices must be flexible and comfortable for the user. Presented here are critical reviews of devices designed for power conversion and storage applications used on mobile devices. The main focus is on the construction of solar cells, piezoelectric generators, batteries and supercapacitors for portable device applications shown in Figure 13. These devices should be attached to the fabric. Integration is possible. Restricted to devices made of fiber and ribbon. Other major challenges and future guidelines will also be followed [24 - 27].

Flexible Electronics

Solid state supercapacitors have many flexible applications by current and future generations. Flexible supercapacitors can be easily connected to wearable clothing and act as a power supply to various electronics devices such as mobile phones. The power generated by piezoelectric harvester
can be stored in large storage and used for charging mobile phones. An example is a high-power t-shirt called a “sound charge” that can generate electricity under the pressure of sound waves. The T-shirt tested at the produced enough power to recharge two basic mobile phones over the weekend as shown in Figure 14. [28 - 32]

Healthcare Applications:

Piezoelectric-charged supercapacitors are used in various integrated health systems where up to 1 million microwatts are required. These supercapacitors are used for pacemaker operations, insulin pumps, and health care systems. Ongoing glucose monitoring systems (CGM) monitor blood sugar levels throughout the day. CGM users insert a small sensory wire under their skin using an automated device. This attachment has a CGM sensor placed so that the sensor can measure glucose readings during the day and night. A small, reusable transmitter leads the sensor and sends real-time readings to the receiver offline, allowing the user to view the data. In some applications, a compatible smart device with a CGM application acts as a display device. A good receiver or smart device shows the current sugar levels, as well as the historical trend in the levels. A compatible CGM receiver and smart device can be set to send alerts to the user when the glucose limit is reached [33 - 39].

With the advancement of technology in the wireless network and microelectromechanical system, smart sensors designed to be set up in remote locations, such as pull-sensing health sensors and medical sensors implanted in the human body, have lost a CGM (continuous glucose monitor) device. It provides “real time” glucose reading and trends in glucose levels. The glucose level reads under the skin every 1–5 minutes (10–15 min delay). This suggests that high and low glucose monitors turn on alarms and inform diabetes management practice. Finding a battery replacing sensor is expensive and costly every time. In embedded cases, access is impossible and devastating. With the advent of energy-efficient harvesting technology, the lifespan of those sensors can be significantly extended or replaced by their own batteries, as shown in Figures 15. [40 - 45]
Conclusion

Many new promising supercapacitor devices are also designed for portable and wearable electronics. It is made up of advanced development sandwiches, planers, wires, fibers, cables and wearable and flexible supercapacitors. Research has advanced on supercapacitors such as piezoelectric, shape-memory, thermal management systems and extension working systems. In flexible electronics, supercapacitors have evolved from integrated applications to energy-saving systems to portable and wearable electronics, smart clothing, automotive, energy-saving systems, implantable medical devices, and emerging technologies such as the use of military and space technology.

Reference

1. Hofmann, H.F., Ottman, G.K. and Lesieutre, G.A. 2003. “Optimized Pieoelectric Energy Harvesting Circuit Using Step-down Converter in Discontinuous Conduction Mode,” IEEE Trans. Power Electron., 18:696-703.
2. Le, T.T., Han, J., Jouanne, A.V., Mayaram, K. and Fiez, T.S. 2006. “Piezoelectric Micro-power Generation Interface Circuits,” IEEE J. Solid-State Circuits, 41:1411-1420.
3. Ottman, G.K., Hofmann, H.F., Bhatt, A.C. and Lesieutre, G.A. 2002. “Adaptive Piezoelectric Energy Harvesting Circuit for Wireless Remote Power Supply,” IEEE Trans. Power Electron., 17:669-676.
4. Simjee, F.I. and Chou, P.H. 2008. “Efficient Charging of Supercapacitors for Extended Lifetime of Wireless Sensor Nodes,” IEEE Trans. Power Electron., 23:1526-1536.
5. Ramadass, Y.K.; Chandrakasan, A.P 2011 “A battery-less thermoelastic energy harvesting interface circuit with 35 mV startup voltage” IEEE J. Solid-State Circuits, 46, 333–341.
6. Granstrom, J.; Feenstra, J.; Sodano, H.A.; Farinholt, K. “Energy harvesting from a backpack instrumented with piezoelectric shoulder straps” Mater. Struct.16, 1810–1820.
7. George, H.B. 2010 “True Grid Independence: Robust Energy Harvesting System for Wireless Sensors Uses Piezoelectric Energy Harvesting Power Supply and LiPoly Batteries with ShuntCharger.LT J. Analog Innovation.36–38.
8. Rocha. J.G, Gonçalves L. M, Rocha .P. F, Silva. M. P., And Lanceros-Méndez. S. 2010 “Energy Harvesting From Piezoelectric Materials Fully Integrated In Footwear”-IEEE Transactions On Industrial Electronics, Vol. 57, No. 3.
9. Faruk Yildiz Sam 2013 “Energy Harvesting From Passive Human Power “Houston State University International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 7.
10. Cerovsky, Z. and Mindl, P. 2005. “Regenerative Braking by Electric Hybrid Vehicles Using Supercapacitor and Power Splitting Generator,” In: Proceedings of European Conference on Power Electronics and Applications, Dresden, Germany.
11. Gualous, H., Louahlia-Gualous, H., Gallay, R. and Miraoui, A. 2007. “Supercapacitor Thermal Characterization in Transient State,” In: Proceedings of 42nd IAS Annual Meeting on Industry Applications, New Orleans, LA, USA, pp. 722-729.
12. Hofmann, H.F., Ottman, G.K. and Lesieutre, G.A. 2003. “Optimized Pieoelectric Energy Harvesting Circuit Using Step-down Converter in Discontinuous Conduction Mode,” IEEE Trans. Power Electron., 18:696-703.
13. Karthaus, U. and Fischer, M. 2003. “Full Integrated Passive UHF RFID Transponder IC with 16.7-W Minimum RF Input Power,” IEEE J. Solid-State Circuits, 38:1602-1608.
14. Kasyap, A., Johnson, D., Horowitz, S., Nishida, T., Ngo, K., Sheplak, M. and Cattafesta, L. 2002. “Energy Reclamation from a Vibrating Piezoelectric Composite Beam,” In: Proceedings of 9th International Congress on Sound and Vibration, Orlando, USA, Vol. 271.
15. Le, T.T., Han, J., Jouanne, A.V., Mayaram, K. and Fiez, T.S. 2006. “Piezoelectric Micro-power Generation Interface Circuits,” IEEE J. Solid-State Circuits, 41:1411-1420.
16. Maxwell. 2005. Charging of Ultracapacitors, Datasheet, Maxwell Technologies, Inc., San Diego, CA. Maxwell. 2009. BOOSTCAP Ultracapacitors Information Sheet, Available at: http://www.maxwell.com (accessed date January, 2009).
17. Ottman, G.K., Hofmann, H.F., Bhatt, A.C. and Lesieutre, G.A. 2002. “Adaptive Piezoelectric Energy Harvesting Circuit for Wireless Remote Power Supply,” IEEE Trans. Power Electron., 17:669-676.
18. Ramadass, Y.K. and Chandrakasan, A.P. 2009. “An Efficient Piezoelectric Energy-harvesting Interface Circuit Using a Biasflip Rectifier and Shared Inductor,” In: IEEE International Solid-State Circuits Conference, San Francisco, USA, pp. 296-297.
19. Rashid, M.H. 2003. Power Electronics: Circuits, Devices and Applications, 3rd edn, Prentice Hall, Englewood Cliffs, NJ.
20. Simjee, F.I. and Chou, P.H. 2006. “Everlast: Long-life Supercapacitoroperated Wireless Sensor Node,” In: Proceedings of International Symposium on Low Power Electronics and Design, Tegernsee, Bavaria, Germany.
21. Simjee, F.I. and Chou, P.H. 2008. “Efficient Charging of Supercapacitors for Extended Lifetime of Wireless Sensor Nodes,” IEEE Trans. Power Electron., 23:1526-1536.
22. Sodano, H.A., Inman, D.J. and Park, G. 2004. “A Review of Power Harvesting from Vibration Using Piezoelectric Materials,” The Shock and Vibration Digest, 36:197-205.
23. Sodano, H.A., Park, G., Leo, D.J. and Inman, D.J. 2003a. “Use of Piezoelectric Energy Harvesting Devices for Charging Batteries,” In: Proceedings of SPIE 10th Annual International Symposium on Smart Structures and Materials, San Diego, CA, USA, Vol. 5050.
24. Sodano, H.A., Park, G., Leo, D.J. and Inman, D.J. 2003b. “Model of Piezoelectric Power Harvesting Beam,” In: Proceeding of ASME International Mechanical Engineering Congress and Exposition, Washington, D.C., USA, Vol. 40.
25. Tan, Y.K., Lee, J.Y. and Panda, S.K. 2008. “Maximize Piezoelectric Energy Harvesting Using Synchronous Charge Extraction Technique for Powering Autonomous Wireless Transmitter,” In: IEEE International Conference Sustainable Energy Technologies, Singapore, pp. 1123-1128.
26. Umeda, M., Nakamura, K. and Ueha, S. 1997. “Energy Storage Characteristics of a Piezogenerator Using Impact Induced Vibration,” Jap. J. Appl. Phys., 36:3146-3151.
27. S.A. Haque et al. Review of cyber-physical system in healthcare. International Journal of Distributed Sensor Networks, 2014, 2014.
28. Aragues et al. Trends and challenges of the emerging technologies toward interoperability and standardization in e-health communications. IEEE Communications Magazine, 2011.
29. P. King et al. The uk prospective diabetes study (ukpds): clinical and therapeutic implications for type 2 diabetes. British Journal of Clinical Pharmacology, 1999.
30. Murakami et al. A continuous glucose monitoring system in critical cardiac patients in the intensive care unit. In 2006 Computers in Cardiology, pages 233–236. IEEE, 2006.
31. M. Ali et al. A bluetooth low energy implantable glucose monitoring system. In EuMC 2011, pages 1265–1268. IEEE, 2011.
32. J. Lucisano et al. Glucose monitoring in individuals with diabetes using a long-term implanted sensor/telemetry system and model. IEEE Transactions on Biomedical Engineering, 2016.
33. KAU. Menon et al. A survey on non-invasive blood glucose monitoring using nir. In ICCSP 2013, pages 1069–1072. IEEE, 2013.
34. MUH. Al Rasyid et al. Implementation of blood glucose levels monitoring system based on wireless body area network. In Consumer Electronics-Taiwan (ICCE-TW), 2016 IEEE International Conference on, pages 1–2. IEEE, 2016.
35. N. Wang and G. Kang. A monitoring system for type 2 diabetes mellitus. In Healthcom 2012, pages 62–67. IEEE, 2012.
36. TN. Gia et al. Iot-based fall detection system with energy efficient sensor nodes. In NORCAS 2016, pages 1–6. IEEE, 2016.
37. S. Sudevalayam and P. Kulkarni. Energy harvesting sensor nodes: Survey and implications. IEEE Communications Surveys Tutorials, 2011.
38. M. Taghadosi et al., L. Albasha, N. Qaddoumi, and M. Ali. Miniaturised printed elliptical nested fractal multiband antenna for energy harvesting applications. IET Microwaves, Antennas Propagation, 2015.
39. V. Jelicic et al. Analytic comparison of wake-up receivers for wsns and benefits over the wake-on radio scheme. In PM2HW2N ’12, pages 99–106. ACM, 2012.
40. L. Gu et al. Radio-triggered wake-up capability for sensor networks. In RTAS 2004, pages 27–36, 2004.
41. Kuan-Yu Lin, T. K. K. Tsang, M. Sawan, and M. N. El-Gamal. Radio-triggered solar and rf power scavenging and management for ultra low power wireless medical applications. In 2006 IEEE International Symposium on Circuits and Systems, pages 4 pp.–5731, May 2006.
42. S. F. Al-Sarawi. Low power schmitt trigger circuit. Electronics Letters, 38(18):1009–1010, Aug 2002. 18. M. Ali. Low Power Wireless Subcutaneous Transmitter. PhD thesis, 2010.
43. International Commission on Non Ionizing Radiation Protection. Icnirp guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields (up to 300 ghz). Health Physics, 1998.
44. Blood glucose monitoring. Diabetes Australia,https://www.diabetesaustralia.com.au/blood-glucose-monitoring [accessed 2016-12-22].
45. Blood Sugar Level Ranges. Diabetes.co.uk, https://www.diabetes.co.uk/diabetescare/blood-sugar-level-ranges.html [accessed2016 – 12 – 22].