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Investigation of Energy Scavenging Interface Circuit for Embedded Systems in WSN

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Abstract

Objectives: To investigate and design energy scavenging interface circuit for embedded systems focus on wireless sensor network (WSN) using photovoltaic cell. Experimenting with storage elements like super capacitors. **Methods/ Statistical Analysis:** Embedded systems in wireless sensor networks are the sensor node which plays an important role in monitoring applications. These sensor nodes are battery powered and have limited lifetime. To increase the lifetime of the sensor node energy scavenging is a better solution along with storage element like super capacitor and rechargeable batteries. In the presented work sensor node power requirements are calculated and based on calculations a solar energy scavenging interface circuit was designed and experimented. **Findings:** Performance analysis of photovoltaic cell and proposed circuit was done successfully with super capacitor as storage element. Charge and discharge characteristics of the super capacitors shows that the sensor node lifetime can be increased significantly and keep it alive for almost full day. Presented work outlines our real-time experiences with the energy scavenging interface circuit in terms of simulation and experimental work. **Novelty/Improvement:** The proposed system will work as a base for further experimentation to improve the scavenger design in wireless sensor network. Larger value of super capacitor can improve the system performance. More experiments can be done by having both options of super capacitor and rechargeable batteries.

Keywords: Embedded Systems, Energy Scavenging, MPPT, Power Management, PV Cell, Supercapacitor, WSN

1. Introduction

Embedded systems are ubiquitous and deployed in various applications like wireless sensor networks (WSNs) to provide the measurement of temperature, humidity, pressure and other surrounding parameters depending on the application. The application scenario for WSNs is dominated by the long life constraints, since the cost of physically deploying the sensor nodes often surpass the cost of the nodes themselves. Energy is the limiting factor in achieving extreme (months to years) system wide lifetime.[1,2] Scavenging energy from the environment is a desirable and increasingly important capability in several emerging applications of embedded systems such as sensor networks, biomedical implants, etc. While energy scavenging has the potential to enable near-perpetual system operation, designing an efficient energy scavenging system that actually realizes this potential requires an in-depth understanding of several complex tradeoffs.[3,4] There are three possible ways to address the problem of powering the emerging wireless technologies (wireless sensor network):[5]

1. Improve the energy density of storage systems.
2. Develop novel methods to distribute power to nodes.
3. Develop technologies that enable a node to generate or "scavenge" its own power.

The storage density of both rechargeable and primary batteries has been conducted for many years and continues to receive substantial focus. These technologies promise to extend the lifetime of wireless sensor nodes; however they cannot extend their lifetime indefinitely.

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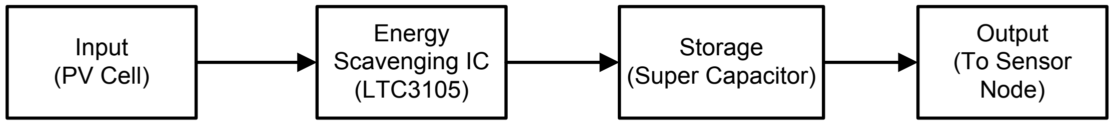


Figure 1. Energy Scavenging Inferface Circuit Block Diagram.

The most common method other than wires of distributing power to embedded electronics is through the use of Radio Frequency (RF) radiation. Many passive electronic devices, such as electronic ID tags and smart cards, are powered by a nearby energy rich source that transmits RF energy to the passive device, which then uses that energy to run its electronics.[6] However, this method is not practical when considering dense networks of wireless nodes because an entire space, such as a room, would need to be flooded with RF radiation to power the nodes. The amount of radiation needed to do this would probably present a health risk.

The third method, in which the wireless node generates its own power, has not been explored as fully as the first two. The idea is that a node would convert "ambient" sources of energy in the environment into electricity for use by the electronics.[7,8] This method has been dubbed "energy scavenging", because the node is scavenging or harvesting unused ambient energy. Energy scavenging (also known as energy harvesting) is the process of generating electrical energy from environmental energy sources. There exists a variety of different energy sources such as solar energy, kinetic energy, or thermal energy. Energy scavenging is the most attractive of the three options because the lifetime of the node would only be limited by failure of its own components[9]. However, it is also potentially the most difficult method to exploit each forms of ambient energy, and therefore, there is no one solution that will fit all, or even a majority of applications. Environmental energy is an attractive power source, and it provides an approach to make the sensor nodes self-powered with the possibility of an almost infinite lifetime.[10]

The study on energy scavenging mechanism for wireless sensor network conclude that energy scavenging systems are attractive solutions to increase the autonomy of embedded and personal devices attempting to achieve perpetual operation. Different performance metrics gives the idea of an improvement in the existing design approaches for energy scavenging wireless sensor network. The comparison of various scavenging techniques such as solar energy, vibration, acoustic energy, temperature variation, etc present some general assumptions and define some important terminologies, and metrics that will be used in designing the energy scavenging Wireless Sensor Network (WSN) management and control framework.[11] We have designed an interface circuit to scavenge energy from the environment and give it to the sensor node to full fill power requirements with a single solar cell, an energy scavenging circuit that is tailored to the needs of low-power applications of embedded computing.[12] The performance of the circuit characterize by means of simulation and experimental results. It is expected to achieve improved and cheap implementation with infinite lifetime.

The remainder of presented work is organized as follows: Section 2 emphasizes on energy scavenging interface circuit implementation. Section 3 discusses analysis and results. Sections 4 comprise of conclusion and possible improvements for future research directions. Section 5 acknowledgements and Section 6 references.

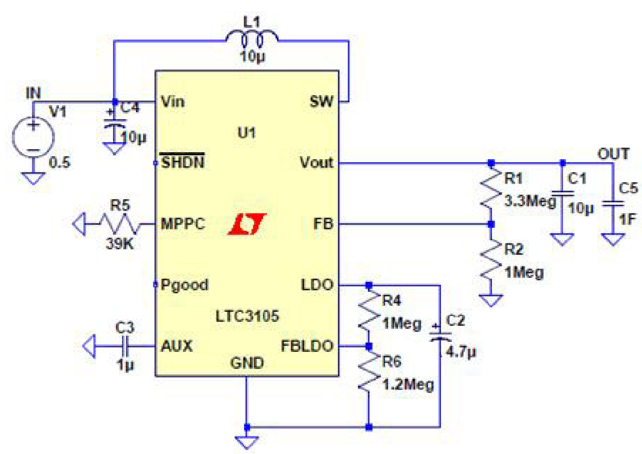
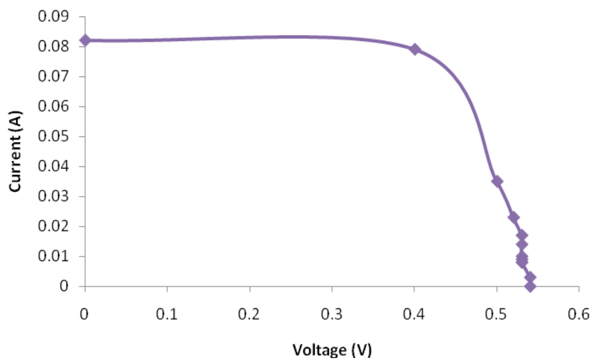


Figure 2. Schematic Diagram of Energy Scavenging Interface Circuit.

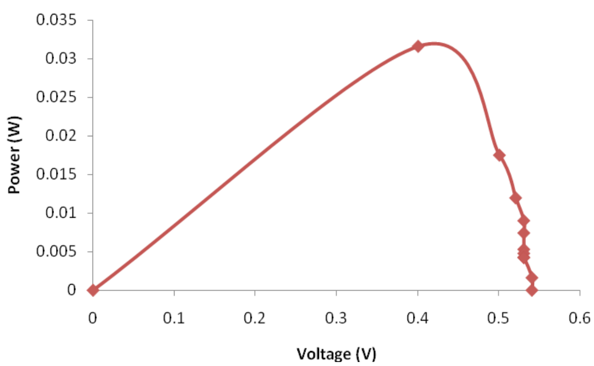
2. Energy Scavenging Interface Circuit Implementation

A simplified block diagram of energy scavenging interface circuit using Photovoltaic (PV) cell is shown in Figure 1.

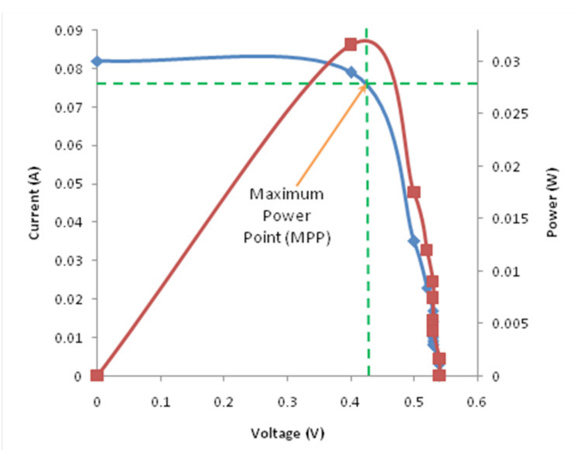
It consists of four blocks with input as PV cell with ratings of 0.5V, 100 mA; LTC3105 to scavenge energy from PV cell; Storage element as super capacitor of 1F, 5.5V; and output block to be interface with sensor node. The schematic diagram of the energy scavenging interface circuit is shown in Figure 2.



(a) I-V Curve

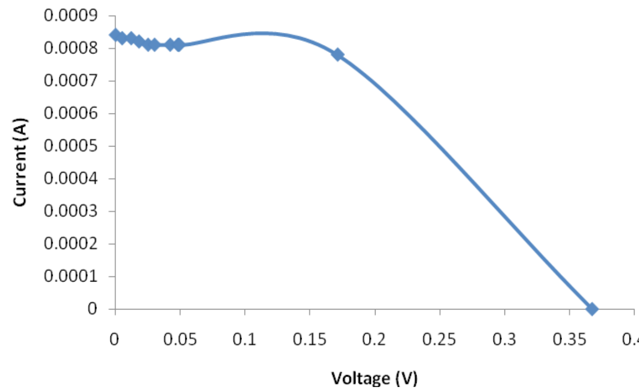


(b) P-V Curve

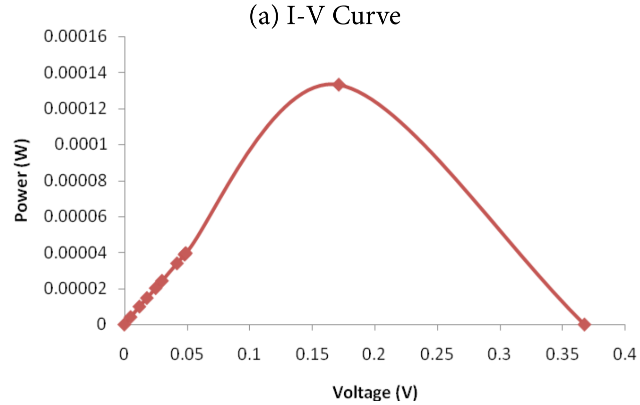


(c) Maximum Power Point Curve

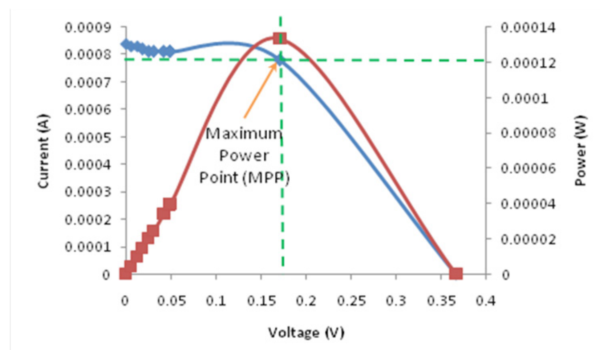
Figure 3. PV Cell Characteristics in direct sun (Weather – Sunny, Temperature – 37.5 ˚C, Tilt Angle - 0˚, Time – 2:45pm, Place – SPSU Campus) (a) I-V Curve; (b) P-V Curve; (C) Maximum Power Point Curve.



(a) I-V Curve



(b) P-V Curve

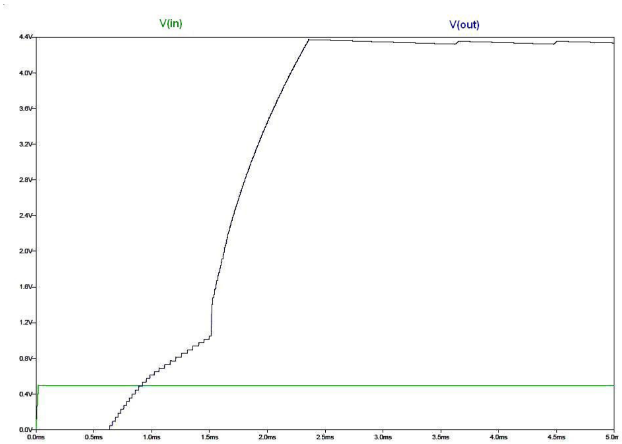


(c) Maximum Power Point Curve

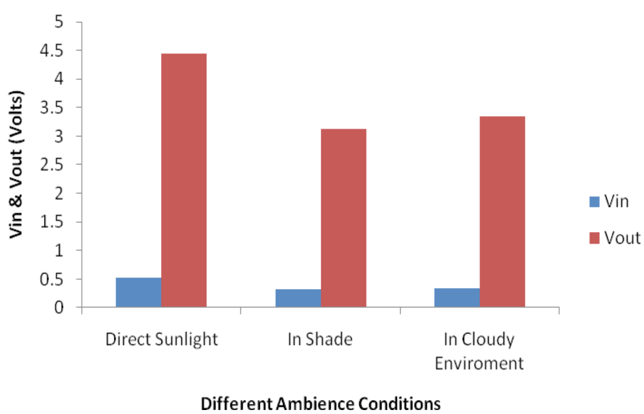
Figure 4. PV Cell Characteristics in shade (Weather – Sunny, Temperature – 33.6 ˚C, Tilt Angle - 0˚, Time – 12:00pm, Place – SPSU uP Lab) (a) I-V Curve; (b) P-V Curve; (C) Maximum Power Point Curve.

A 53.00mm x 18.00mm x 2.50mm PV cell is used as input energy source. The PV cell is having open circuit voltage of 0.565V and short circuit current of 94.4mA observed experimentally. The maximum power the PV cell can develop is 53mW, with fill factor of 0.565 and efficiency around 60%. The characteristics of the PV cell under direct sun and shade with different load resistors are shown in Figure 3 and Figure 4 respectively.

LTC3105 of Linear Technology is an energy scavenging and managing IC with embedded Maximum Power Point Controller (MPPC) and very low startup voltage. The values of R1 and R2 are calculated to set the output voltage at 4.317V. It is used to charge the super capacitor from PV cell to power sensor node. Simulation and experimental Input and output voltage in different ambience conditions is shown in Figure 5. In the presented work only super capacitor is connected in output, it can be used along with rechargeable batteries to power a sensor node.



(a) Simulation Input and Output Voltages



(b) Experimental Input and Output Voltages

Figure 5. (a) Simulation Input and Output Voltages (b) Experimental Input and Output Voltages.

We had taken eZ430-CC2500 platform for calculating the required power needed for sensor node to be supplied by our developed interface circuit. It includes MSP430 microcontroller, CC2500 2.4 GHz ISM band multi channel transceiver and a temperature sensor. MSP430 microcontrollers from Texas Instruments features ultra low power, high performance, low cost, and small foot print. It runs the application properly at an input voltage of 3.3V.

3. Analysis and Results

To ensure the power requirements for presented work life time calculation of the sensor node is provided. The sensor node performs various tasks to read the temperature and transmit it to the target device. During this it consumes current from 10μA to 20mA and takes time of milliseconds as shown in Figure 6 and 7 respectively. The average current for input and output consumed by the node is near about 13.36mA and total time taken to execute the task is 2.8ms to 3ms in continuous operation. The power consumption will be 44.088mW.

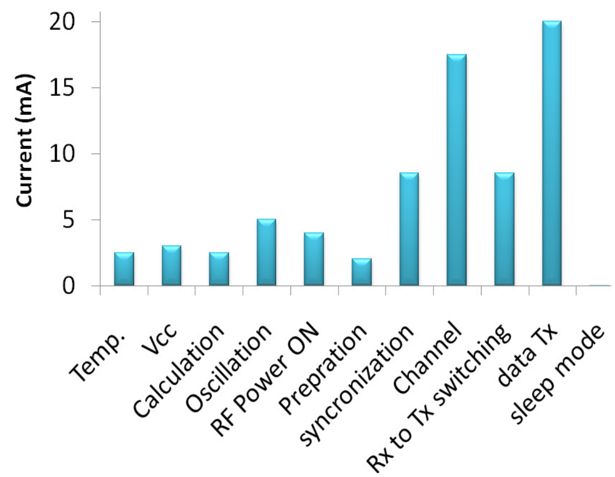


Figure 6. Current Consumption with Different Tasks.

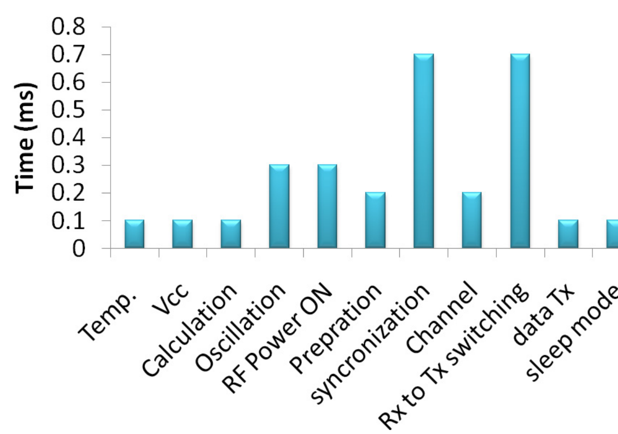
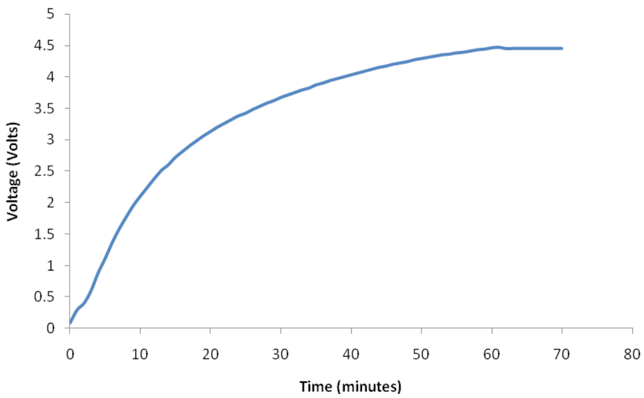


Figure 7. Time Taken to Perform Tasks.

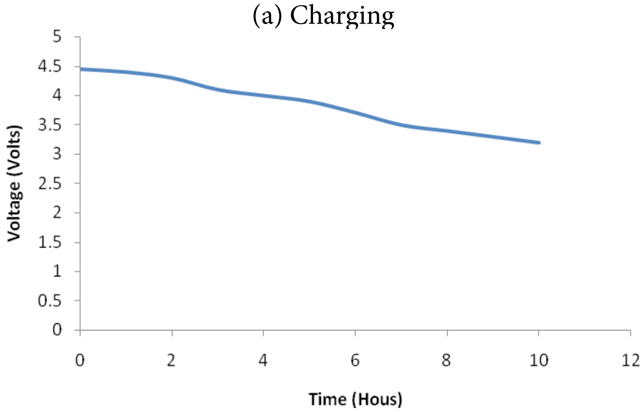
We have considered 3.6V, 300mAh Ni-Cd rechargeable telephone batteries, the lifetime of the application is 22.449 hrs calculated using equation-(1).

$$Lifetime of application node = \frac{Battery current capacity}{Average current consumtion by node application} \quad \ldots(1)$$

The lifetime can be improved by changing the continuous run of sensor node to discrete one at some time interval depending on the application. In current case if we transmit temperature measurement at 1s interval the life time will be improved to 304 days approximately. The power consumption will be 0.136mW. To charge the batteries or super capacitor voltage of 4.4 V is sufficient in the output of the circuit developed.



(a) Charging



(b) Discharging

Figure 8. SupercapacitorCharacterisitics (a) Charging (b) Discharging.

The daylight duration is approximately 12 hours per day in a year. To get 12 hours of power from super capacitor at night, the value of capacitor can be calculated using equation-(2).

$$Capacitance = \Delta t * 2 * \frac{Power}{Vi^2 - Vt^2} \quad (2)$$

$$= 12 * 3600 * 2 * \frac{0.136mW}{4.4^2 - 3.3^2}$$

$$= 1.306 \text{ F}$$

We had experimented with 1F capacitor nearby with the 1.306 F value. Once the capacitor gets charged it will work for 12 hours in the night duration. The larger value can be taken if day time is shorter than 12 hours.

The charging and discharging characteristics of the super capacitor is shown in Figure 8. Capacitor starts charging from 83mV and charged to 4.45V in 60 minutes. It discharges in dark from 4.45V to 3.2V in 10 hours.

4. Conclusion and Future Research Directions

An independent energy scavenging interface circuit for embedded systems in WSN has been developed and experimented in this work. The proposed system will improve the lifetime of the sensor node in WSN and make it working for the full day. All the experiments for the super capacitor charging were done in direct sunlight in sunny day. If the ambient condition changes the input voltage to the capacitor will change and effect the lifetime of the sensor node. It was found that during night in dark hours the super capacitor discharges to 3.2V in ten hours. It will make sensor node not working until it will charge back to 3.3V in sunlight. So to continuous power to a sensor node both super capacitor and rechargeable batteries are required in most of the cases. When the super capacitor voltage drops below node input voltage the supply of the node will be switched to the batteries to improve the working hours. In future studies much higher values of super capacitor can be experimented along with rechargeable battery. More improvements in the energy scavenging interface circuit is required to make it universal for all embedded systems working at 3.3V.

5. Acknowledgments

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6. References

1. Shenck NS, Paradiso JA. Energy scavenging with shoe-mounted piezoelectrics. Micro IEEE. 2001 May/Jun; 21(3):30–42. Crossref

2. Roundy S, Wright PK, Rabaey JM. Energy Scavenging for Wireless Sensor Networks with Special Focus on Vibrations. 1st edition. Springer; US; 2004. p. 87–9.
3. Raghunathan V, Chou PH. Design and Power Management of Energy Harvesting Embedded Systems. Proceedings of ISLPED; Germany; 2006. p. 4–6. Crossref
4. Dondi D, Alessandro B, Brunelli D, Luca L, Luca B. Modeling and Optimization of a Solar Energy Harvester System for Self-Powered Wireless Sensor Networks. IEEE Transactions on industrial electronics. 2008 Jun; 55(7):2759–66.
5. Moser C, Chen J, Thiele L. An Energy Management Framework for Energy Harvesting Embedded Systems. ACM Journal on Emerging Technologies in Computing Systems. 2010 Jun; 6(2):24–8. Crossref
6. Sandal S, Verma K. Power management techniques in Wireless Sensor Network. International Journal of Advances in Computing and Information Technology. 2012 Apr; 1(2):237–44. Crossref
7. Kooti H, Nga D, Mishra D, Bozorgzadeh E. Energy Budget Management for Energy Harvesting Embedded Systems. Proceedings of IEEE 18th International Conference on Embedded and Real-Time Computing Systems and Applications; South Korea; 2012. p. 320–9. Crossref
8. Cammarano A, Petrioli C, Spenza D. Pro-Energy: A novel energy prediction model for solar and wind energy-harvesting wireless sensor networks. Proceedings of IEEE 9th International Conference on Mobile Adhoc and Sensor Systems (MASS); USA; 2012. p. 75–83. Crossref
9. Sarker MR, Sawal A, Othman M, Islam S. Designing a Battery-Less Piezoelectric based Energy Harvesting Interface Circuit with 300 mV Startup Voltage. Journal of Physics: Conference Series. 2013; 431:1–8.
10. Zhou G, Huang L, Wei L, Zhu Z. Harvesting Ambient Environmental Energy for Wireless Sensor Networks: A Survey. Journal of Sensors. 2014 Jun; 14:1–20.
11. Bhaskar A, Champawat R, Bhaskar S. Current Developments of Energy Scavenging, Converting and Storing in WSNs. International Journal of Computer Applications. 2015 Sep; 125(7):6–12. Crossref
12. Nathan B. Harvest Energy from a Single Photovoltaic Cell. LT Journal of Analog Innovation. 2011 Apr; 21(1):1–6.