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Analysis of Energy Harvesters for Powering a Wireless Sensor Node Device

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Abstract

This study analyses energy harvesters used to power a wireless sensor node. The sensor node measures the ambient temperature and transmits the data to a coordinator. Three main energy sources are investigated: solar, radio frequency and thermal. The energy produced by these devices is investigated under various environmental conditions to ensure that it can reliably supply the required amount of power to the wireless sensor node. The results show that these energy sources can provide power to the wireless sensor node at different transmission rates with an average power of 0.16 W during each data transmission.

Keywords

energy harvester, solar, radio frequency, thermal energy, ultra-low power, wireless sensor node

1. Introduction

Wireless sensor nodes will become increasingly important in the future. These devices allow users to monitor and collect data regarding their surrounding environment and use it to improve services, life quality and safety. The devices monitor the environment remotely and transmit the data to a base station. Existing wireless sensor nodes are operated using batteries, which limits the operation of devices to only a few years. For mission-critical applications, these devices must be able to operate continuously with minimal human intervention. Thus, harvesting energy from an ambient source is important to ensure the continuous, long-term operation of these devices.

The power requirement of the sensor nodes must be known beforehand in order for energy harvesting to power the wireless sensor nodes. Once the power requirement is known, the design of the proper energy harvester can be made. This ensures that the peak power requirement of the device can be achieved in any situation.

The work described in this paper forms part of our effort to design a multi-energy harvester to power a wireless sensor node. This study analyses several energy harvesters that have a high potential to power wireless sensor nodes. The harvested energy is investigated in various conditions so that the limit of each energy provider can be known. The generated energy is then used to power a wireless sensor node device.

This paper is organised as follows. Section 2 reviews existing methods used to harvest energy from various sources. Section 3 discusses our approach to analysing energy harvesters and wireless sensor nodes. The results of the experiment are discussed in Section 4, and Section 5 presents the conclusion.

2. Literature Review

This section discusses existing methods used to harvest energy from various energy sources. Since they are abundant in our surroundings, solar, radio frequency and thermal energy sources are reviewed here.

In [1], solar energy is used to power a LPR2430ERA wireless sensor node operated at 3.3 V. The solar panel produces an output of 3 V, which is stored in the Li-Ion battery. Since charging the battery requires 4.5 V, a booster circuit is use to increase the voltage output from 3 V to 4.75 V. In addition, a 1F super capacitor is used in the circuit to ensure that the peak energy requirement during data transmission can be provided sufficiently. The maximum power point tracker (MPPT) discussed in [2] is able to achieve maximum power transfer from a solar panel to a battery. In this method, the maximum energy transfer from the solar cell to the battery can be obtained even in non-optimal weather conditions.

In [3], a thermal energy generator to power a wireless sensor node, ABBRF03, is discussed. Since a temperature difference is necessary for thermal power conversion, a heat sink is connected to a window. The temperature difference is obtained between the outside temperature and the inside temperature. The highest current output of 7 mA is generated by the thermal energy harvester when there is a temperature difference of 38 °C. Since the output of the energy harvester is too low to operate the sensor, a super capacitor is used to power the sensor directly. The sensor transmits the data every hour, and each transmission requires 27 mA. In [4] the

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use of thermal energy to power a wireless sensor network is investigated. For continuous operation, a temperature difference higher than 15 °C is required to power a 60 mW wireless sensor node without interruption.

Paper [5] investigates a multiple wireless sensor network arranged in a multi-hop network powered by a 3 W RF energy transmitter. The RF energy transmitter allows a maximum achievable distance between the RF energy sources and receiver of 12 metres. The sensor node must harvest at least 7 uW before it can operate properly. Once it has enough energy, the node 'wakes up' and communicates with the synchronizer. The farther away the sensor is from the energy transmitter, the longer the node needs to gather enough energy to wake up. In [6] radio frequency energy harvesting is used to power a wireless device without a battery. The device can operate with 3 W of power up to 90 feet from the radio frequency power source.

3. Methodology

This section discusses the work done to evaluate several energy harvesters used to power a wireless sensor node. Three types of energy harvesters are evaluated: solar energy, RF and thermal energy. The first part of this study analyses the output of the energy harvesters, and the second part analyses the behaviour of the wireless sensor node when powered by the energy harvester. The overall block diagram of our experiments is shown in Figure 1.

To evaluate the solar energy harvester, a solar panel 2 cm x 6 cm is used to convert the light energy to electrical energy. A small solar panel is used here to ensure that the panel can be easily integrated into a portable system. The generated energy is converted to a useable power by a power management to ensure a stable voltage at the output. The power management circuit has two 50 uAh solid state batteries that store the harvested energy [7].

Harvesting energy using RF is performed using a RF energy harvester [8]. The RF energy harvester consists of a transmitter and a receiver. The transmitter is powered through USB and emits a RF signal of 13.56 Hz frequency. The receiver converts the RF into useable electric and store the energy into a solid state battery of 50 uAh.

A thermo generator (TEG) is used to convert available waste heat to electric energy [9]. The device can output voltage whenever there is a temperature difference between two surfaces. The electric generated by the TEG is converted to a usable voltage by a power management circuit. The thermo generator used in this experiment can output voltage between 1.8 V to 4.5 V, with a temperature ranging from 0 °C to 105 °C [9].

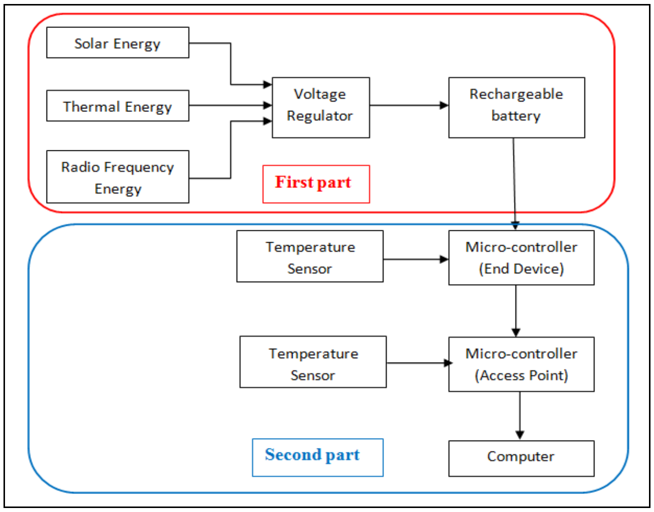

Figure 1: The block diagram of temperature sensor power by rechargeable battery using multi-energy sources.

Once the useable energy has been generated by the energy harvester, the energy is used to power a wireless sensor node. In this work, a wireless sensor node from Texas Instruments [10] was used. The device consists of two sets of devices that work as a coordinator and an end device. Each set consists of microprocessors, temperature sensors and wireless transmitters/receivers. The transmitter behaves as a coordinator that receives and displays the data on a PC. The receiver performs as an end device measuring the ambient temperature and transmitting the data with the current voltage level to the coordinator. The coordinator, which is connected directly to the PC through USB cable, then displays the data on the PC monitor.

4. Results and Discussion

In this section, we perform experiments to analyse the characteristic of the energy harvester from various energy sources. The results of the analysis will be used to power a wireless sensor node.

To analyse the solar energy harvester, the solar panel was first evaluated to determine the amount of electrical energy generated from it. Figure 2 shows various output voltages produced by the solar panel. The measurement was done for various environment conditions: direct sunlight; indoors with a light source; indoors without a light source; with a direct secondary light source. As expected, the solar panel generated maximum power when the solar panel was located under direct sunlight, with 1.5 V produced by the solar panel. 0.3 V was obtained in the condition of indoors without a light source.

Figure 3 shows the output voltage when it is connected to the power management circuit. The power management circuit takes the output voltage from the solar panel and stores it into a solid state battery so that a stable output voltage can be obtained. As shown in Figure 3, a voltage of 3.3 V is produced from the power management circuit regardless of the environment. The power management circuit ensures that stable output voltage can be produced at the output before it is connected to a device. Since the device is equipped with a battery, a stable 3.3 V can be obtained. However, the time it takes for the power management circuit to provide useful energy is affected by the amount of sunlight available.

Figure 4 shows the results of measuring the output voltage using the RF energy harvester. As mentioned in Section 3, the transmitter emits the RF signal, and the receiver converts the signal to electrical energy. The results show that the output from the energy harvester can produce 3.3 V. For the RF energy harvester, a constant voltage output at the receiver can be obtained as long as the RF source is powered by a constant voltage.

Figure 5 shows the results of harvesting energy from thermal energy harvester. In this experiment, several temperatures were applied to the device and the time taken to produce useable energy was recorded. The maximum output voltage for this device was 2.4 V. As shown in Figure 5, at 50 ^{0}C, the device required 15 seconds to generate the maximum output voltage. As the temperature increases, the time it takes to produce the output voltage decreases. At 90 ^{0}C, it requires less than 5 seconds to produce 2.4 V.

To investigate the wireless sensor node operation, the sensor node was first connected to batteries, and the current consumption by the device was then monitored. Figure 7 shows that the device transmitted the data every 1 second. The device required 7 ms to complete each transmission. Figure 8 shows a detailed current profile for each transmission. As shown in the figure, each transmission consisted of a sub-operation that began when the device woke up, communicated with the coordinator, and then returned the device to sleep mode. Table 1 presents a summary of the power required by the sensor node during each transmission. Each transmission required 0.16 W of energy with a peak voltage of 3.2 V and an average voltage of 1.41 V. From the above results showed that the solar, RF and thermal harvesters can reliably provide the voltage required by the wireless sensor node.

Table 2 shows the effectiveness of each energy harvester in powering the wireless sensor node as the transmission rate is increased. Using AA batteries, the wireless sensor node transmits the data every 1 second. The RF and solar energy harvesters can transmit the data up to every 5 seconds and 10 seconds, respectively. The results showed that the RF energy harvester can provide better energy compared to the solar harvester as long as the energy source of the RF harvester is constant. However, in the case where an RF energy source is not available, the solar energy harvester is a better choice although it has a lower transmission rate compared to the RF energy harvester.

In this experiment, the thermal energy harvester was not evaluated to power the wireless sensor node since the output voltage from the device was lower than the required operating voltage of the wireless sensor node. Work is in progress to modify the thermal device to increase the output voltage to 3.3 V.

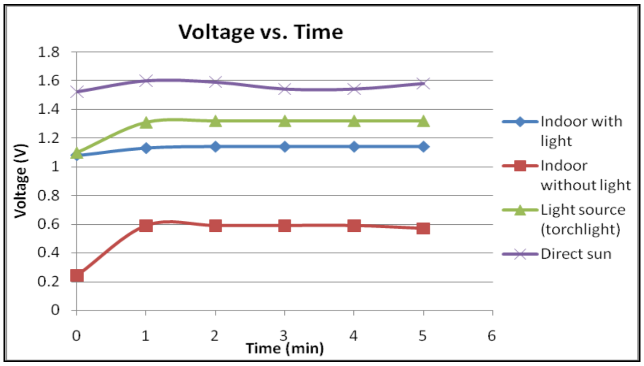

Figure 2: Output voltage for solar panel

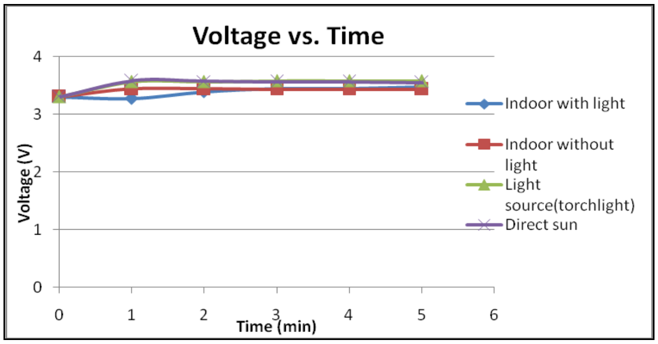

Figure 3: Output voltage of CBC-EVAL-09 with solar panel

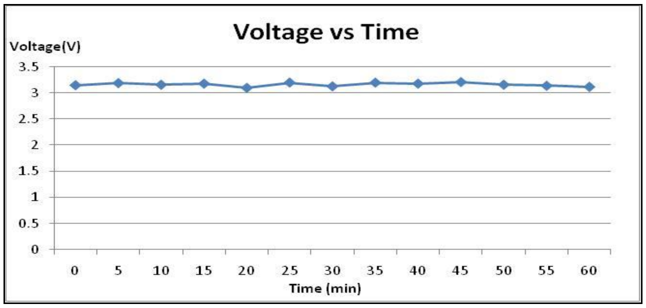

Figure 4: Output voltage of CBC-EVAL-11

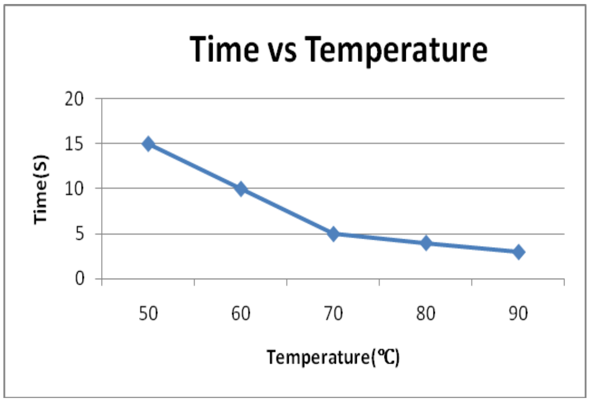

Figure 5: Output voltage of TE-CORE7

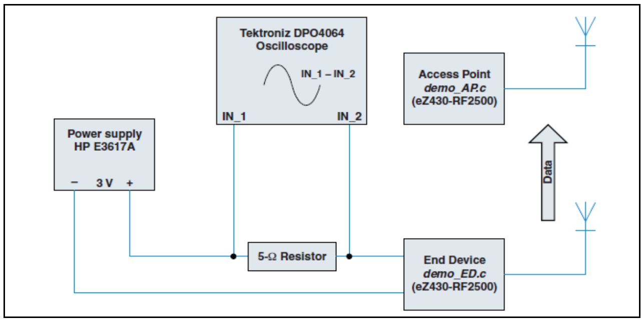

Figure 6: Experimental setup to measure current consumption by the wireless sensor node [11].

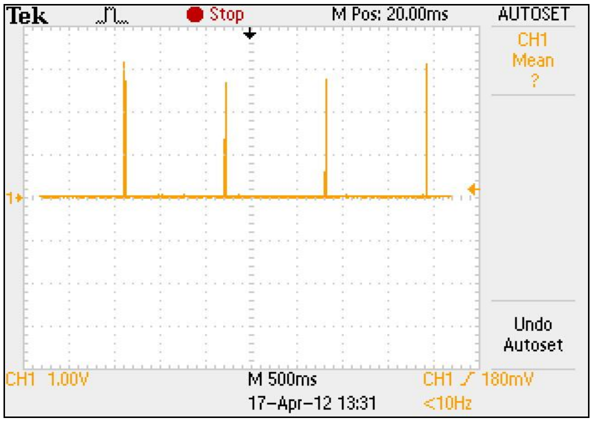

Figure 7: End device current over 5 seconds. (1 second delay)

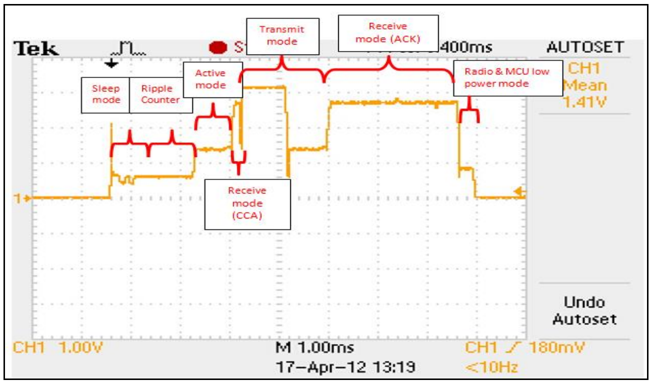

Figure 8: End device transmission current

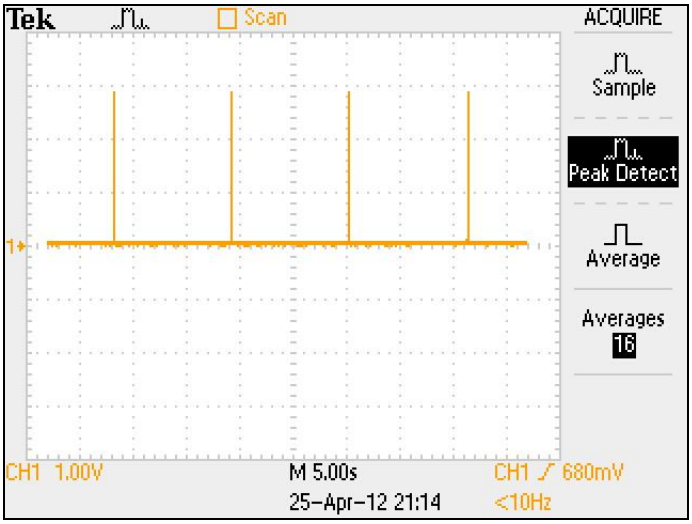

Figure 9: End device current over 50 seconds (10 seconds delay for solar)

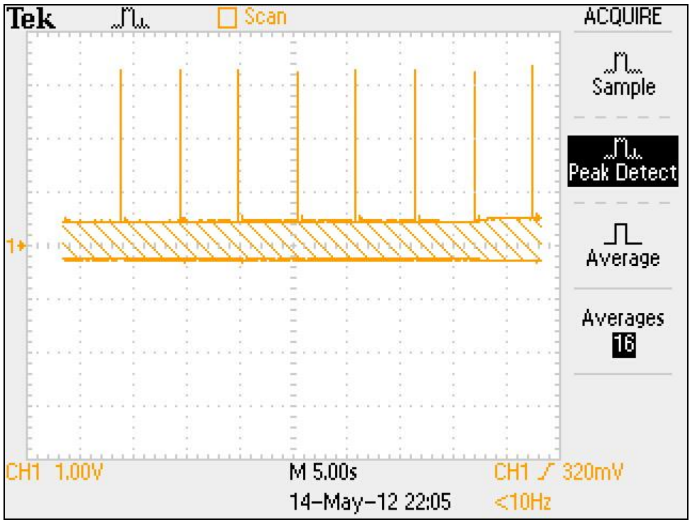

Figure 10: End device current over 50 seconds (5 seconds delay for RF)

	Voltage (V)	Resistor (Ω)	P = V^2/R(W)
Peak	3.2	12.5	853 m
Average	1.41	12.5	160 m

Table 1: Power consumption

	Battery	RF	Solar	Thermal
Time (s)	1 s	5 s	10 s	NA

Table 2: Minimum interval time for the wireless sensor node to operate when powered by different energy harvesters

5. Conclusion

Several energy harvesters were used to power wireless sensor nodes. Energy generated by a solar panel, RF and thermal were evaluated to measure their effectiveness as energy sources for a wireless sensor node. Our experiment showed that these energy sources are potential sources for wireless devices. However, since harvesting the energy from the environment takes some time, the wireless sensor node operation has to be adjusted to match the available energy. Our results showed that for a wireless sensor node that requires average power of 0.16 W, the RF and solar harvesters are reliable sources of energy. In future studies, the integration of these energy sources for powering a single device will be investigated.

6. Reference

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