

Radio Frequency Energy Harvesting with Phase Shift Keying Modulation Technique

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ABSTRACT

In this study, impacts of phase shift keying modulation technique on charging times of Radio Frequency (RF) energy harvesting circuit were measured and evaluated in detail. A measurement system was established for receiving and recording measurement packets. The measurement system was performed by utilizing a signal generator, an RF energy harvesting circuit, patch antennas and the other auxiliary devices. Output power level of the signal generator was adjusted to 14 dBm. The modulated signals were harvested wirelessly at distances from 20 cm to 50 cm at the interval of 5 cm by the RF energy harvesting circuit. For each distance, 100 consecutive measurement packets were obtained and hence, totally 700 measurement packets were analyzed for charging times. According to the measurement results, the shortest charging time was calculated as 7.97 s at a distance of 20 cm. In addition to that, the longest charging time was evaluated as 48.88 s at a distance of 50 cm for the phase shift keying modulated signals.

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Introduction

Many different energy sources such as thermal gradients, solar, mechanical vibrations, and electromagnetic waves are used to provide power for electronic devices. It is possible to utilize multiple combinations of these energy sources as well [1]. Radio Frequency (RF) energy harvesting technology as an alternative energy source has recently attracted considerable attention. This promising technology uses electromagnetic waves in the ambient environment as an alternative energy source.

An RF energy harvesting circuit collects the RF energy in the ambient environment and

stores the harvested RF energy into the capacitor. In order to harvest more RF energy, the most powerful RF bands should be detected. For detecting power levels of the electromagnetic waves, many RF spectral measurements were conducted in different countries [2]–[10]. Therefore, the higher the amount of harvested RF energy, the shorter the charging time of the RF energy harvesting circuit.

RF energy harvesting circuits are utilized in many application fields such as industrial monitoring, building automation, data centers, smart grid, defense and agriculture.

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Recently, the RF energy harvesting technology has been of great interest and there are various studies in the literature on this subject [11]–[15]. An RF energy harvesting circuit can be designed and manufactured as single, dual, triple, quad or broad band for gathering energy.

The waveform of the RF signal in the time domain affects the amount of harvested RF energy and the efficiency as well. In some studies, the efficiency of system was improved by utilizing the signals with various waveforms [16]–[20]. In [21], the nonlinear behavior of diodes in RF energy harvesting was presented for small-signal and large-signal operations. The effect of multi-tone signals on the rectified waveform was illustrated for multi-sine input signal of RF energy harvester. The charging time of an energy storage unit also changes with the input RF signal [22]. In [23], the statistical distributions of charging time were investigated for RF energy harvesting systems. Since modulation techniques directly impact the RF waveforms, they have also an effect on the system performance of RF energy harvesters. In [24], the efficiency of an RF-DC rectifier QPSK and 16-QAM modulation techniques were analyzed for different power levels. The charging time of the RF energy harvesting circuit varies according to the different waveforms. Therefore, the RF signals with different modulation techniques may have different charging times. In [25], an analytical expression for the probability density function of charging time based on the symbols of modulation techniques was expressed.

In this study, it was aimed to measure and evaluate the impacts of Phase Shift Keying (PSK) modulation technique on charging times of an RF energy harvesting circuit. For this purpose, an advanced measurement set up was installed for acquiring measurement packets. Finally, measurement results were analyzed in detail.

Materials and Methods

In this section, the charging times of the RF energy harvesting circuit that collected powers of the PSK modulated signals were measured at different distances. Besides, measurement set up was explained in detail and collection of measurement samples was described.

Measurement set up

As seen in Fig. 1, the measurement set up consists of Universal Software Radio Peripheral (USRP)-2900 Software Defined Radio from National Instruments [26], P2110 Powerharvester module from Powercast Company [27], WSN-Eval-01 Wireless Sensor Board, Microchip 16-bit XLP Development Board [28], PICTail Daughter Card, and PCB Patch antennas as receiver and transmitter antennas.

PSK is a modulation technique that conveys digital data by changing the phase of a carrier signal. Samples per symbol were selected as 8 for PSK modulation technique. Pseudo noise sequence order was chosen as 10 for 8-PSK. Moreover, 8-PSK was used as a modulated signal and it has totally 1 MHz bandwidth.

In this study, USRP-2900 was used as a signal generator and the PSK modulated signals at 915 MHz carrier frequency were generated by the USRP-2900. Output power level of the USRP-2900 was set to 14 dBm. P2110 Powerharvester module was utilized as an RF energy harvesting circuit. The modulated signals generated by the USRP-2900 were collected wirelessly by the P2110 Powerharvester module at distances from 20 cm to 50 cm at the interval of 5 cm. As shown in Fig. 1, two PCB patch antennas were employed. One of the patch antennas was connected to the USRP-2900 as a transmitter antenna and the other one was attached to the P2110 Powerharvester module as a receiver antenna. Each PCB patch antenna has 68° vertical and 122° horizontal pattern. Moreover, it has 6.1 dBi antenna gain and it is vertically polarized and directional antenna. P2110 Powerharvester module can collect power down to -11.5 dBm. This module enables efficient energy harvesting between 902 MHz and 928 MHz frequency band. In addition to that, WSN-Eval-01 Wireless Sensor Board that is plugged into the P2110 Powerharvester module senses temperature, humidity and light. When the P2110 Powerharvester module provides sufficient power for this wireless sensor board, it sends the data such as Received Signal Strength Indicator (RSSI), Node and Transmitter (TX) ID, temperature, humidity and light to the PICTail Daughter Card as an access point.

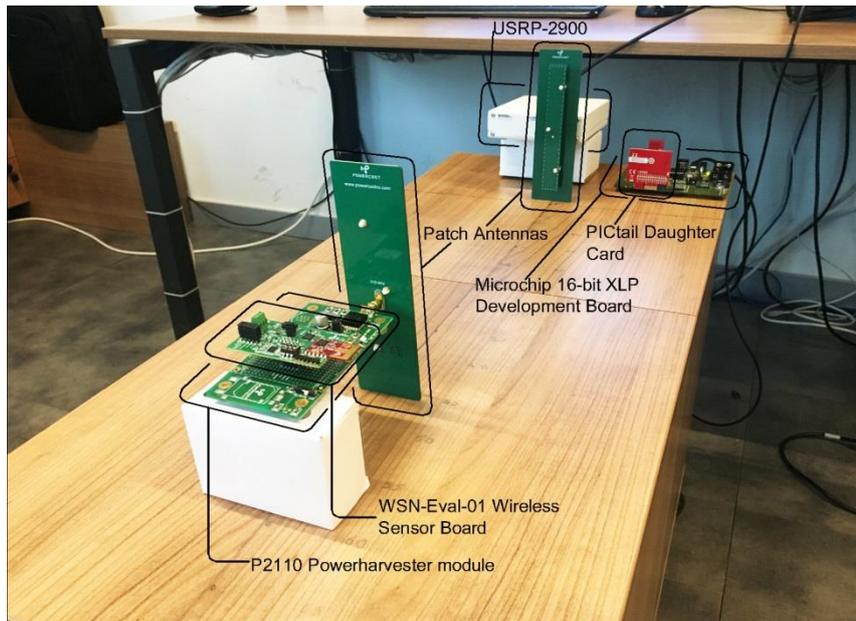


Figure 1. Measurement set up

Microchip 16-bit XLP Development Board includes the Microchip's PIC24F micro controller unit and this development board is able to receive the data sent from the P2110 Powerharvester module up to 8 Node IDs at the same time. Moreover, the development board can manage time counter for each Node ID separately. Furthermore, the PICtail Daughter Card that is plugged into Microchip 16-bit XLP Development Board is used as an access point and it has IEEE 802.15.4 (2.4 GHz) radio module.

Collection of measurement samples

The P2110 Powerharvester module transmits the data such as RSSI, Node ID, TX ID, temperature, humidity and light wirelessly to the PICtail Daughter Card via the WSN-Eval-01 Wireless Sensor Board. In order to receive the measurement samples, the Microchip 16-bit XLP Development Board was attached to a computer with a cable. The Microchip 16-bit XLP Development Board acquires packet numbers and then, calculates time and time difference (ΔT) between sequential packets. The measurement samples were recorded and illustrated via HyperTerminal as shown in Fig. 2. The configuration of the HyperTerminal must be set as baud rate: 19200, data bits: 8 bits, parity and none stop bits: 1 bit and flow control:

hardware to display the measurement samples. The data from the PICtail Daughter Card (access point) and the data from the WSN-Eval-01 Wireless Sensor Board (wireless sensor board) were shown in Fig. 2.

Results and Discussions

The received power levels of the PSK modulated signals vary with the distances. The charging times of the RF energy harvesting circuit depend on the received power levels of the PSK modulated signals. Therefore, the longer the distance, the longer the charging time.

The time difference (ΔT) between two consecutive measurement packets as seen in Fig. 2 was defined as charging time. The charging time for each distance was calculated as mean of the time difference for 100 consecutive measurement packets. For the distance from 20 cm to 50 cm at the interval of 5 cm, 100 measurement packets were obtained and totally 700 measurement packets were evaluated for the PSK modulated signals. In this study, units of distance and charging time as shown in Table 1 are centimeter (cm) and second (s), respectively.

Table 1 indicates the charging times according to the distances for 6.1 dBi antenna gain at 14 dBm output power level. The shortest charging time was evaluated as 7.97 s at a distance of 20 cm.

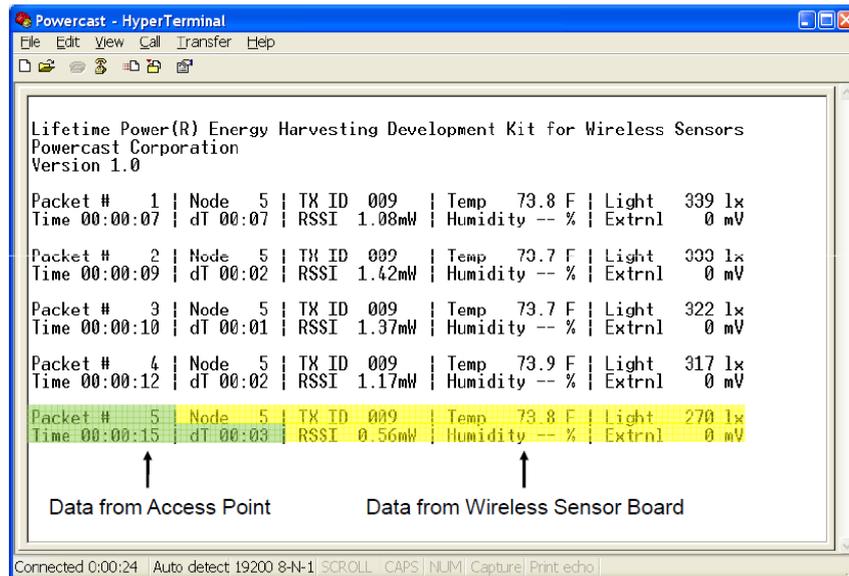


Figure 2. Collection of measurement data via HyperTerminal [27]

Besides, the longest charging time was calculated as 48.88 s at a distance of 50 cm for the PSK modulated signals.

As seen in Fig. 3, the charging times for the PSK modulated signals across the distances were depicted on the graph in order to illustrate the measurement values more obviously. As the distance decreases, the charging time of the RF energy harvesting circuit also reduces. Considering the distances from 20 cm to 50 cm, the best charging time (the shortest charging time) was measured at a distance of 20 cm and the worst charging time (the longest charging time) was measured at a distance of 50 cm for the PSK modulated signals.

Table 1: Charging time versus distance for PSK

Distance (cm)	PSK (s)
20	7.97
25	13.14
30	17.23
35	19.46
40	27.33
45	32.15
50	48.88

Conclusions

In this study, a measurement system was established to receive and record the charging times of the RF energy harvesting circuit for the PSK modulated signals. The measurement system included USRP-2900 as a signal generator, P2110 Powerharvester module as an RF energy harvesting circuit, WSN-Eval-01 Wireless Sensor Board, Microchip 16-bit XLP Development Board, PICtail Daughter Card, and PCB Patch antennas.

Charging times of the RF energy harvesting circuit for the PSK modulated signals were measured at the distances from 20 cm to 50 cm at the interval of 5 cm. Then, the measurement packets were investigated in detail. Considering the measured values, the shortest charging time was obtained as 7.97 s at a distance of 20 cm and the longest charging time was evaluated as 48.88 s at a distance of 50 cm for the PSK modulated signals.

As a consequence, it was determined that the charging time increased while the distance between signal generator and RF energy harvesting circuit increased.

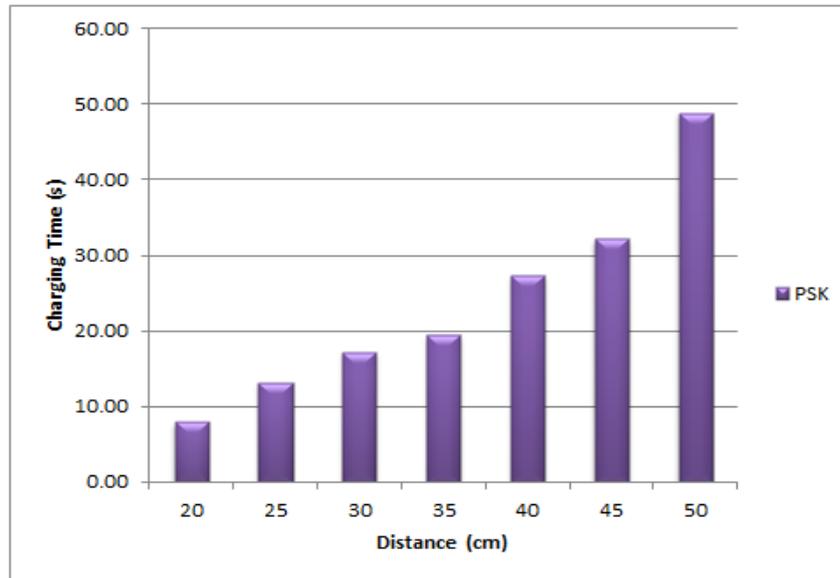


Figure 3. Charging times of RF energy harvesting circuit versus distances for PSK modulated signals

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