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Radio Frequency Energy Harvesting with Frequency Shift Keying Modulation Technique

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ARTICLE INFO	ABSTRACT
	Radio Frequency (RF) energy harvesting is a promising alternative energy source to provide power for low power electronic devices through the air. RF energy harvesting technologies are used in many application fields such as building automation, industrial monitoring, data center, security and defense. In this study, effects of frequency shift keying modulation technique on charging times of RF energy harvesting were measured and investigated in detail. An advanced measurement system was established and this measurement system was performed using an RF energy harvesting circuit, a signal generator, patch antennas and other equipment. The modulated signal at 14 dBm output power was generated by signal generator. Then, the energy produced by the signal generator was obtained from 20 cm to 60 cm at the interval of 5 cm distance by the RF energy harvesting circuit with 6 dBi patch antenna. According to measurement results, the shortest charging time was calculated as 1 s at a distance of 20 cm. In addition to that, the longest charging time was calculated as 7 s at a distance of 60 cm. It was determined that the charging time of the RF energy harvesting decreased as the distance between signal generator and RF energy harvesting circuit reduced.

Introduction

There are many kinds of energy sources such as solar, mechanical vibrations, thermal gradients and electromagnetic waves in nature. A Radio Frequency (RF) energy harvesting technology is a promising alternative energy source to feed low power electronic devices through the air. Due to the increase in the number of low power electronic devices in the ambient environment, it is hoped that this technology will be widely used in future.

Measurement of power densities of the electromagnetic waves is important for efficient RF energy harvesting. There are many studies on this subject in the literature [1]–[9]. The operating frequency of an RF energy harvesting circuit should be designed according to the most powerful frequency band in the environment. Thus, maximum efficiency can be obtained.

Various studies on RF energy harvesting exist in the literature [10]–[23]. An RF energy harvesting circuit generally consists of antenna and matching circuit, rectifier, voltage multiplier and energy storage equipment. RF energy harvesting circuit can be designed and implemented as single band, double band, multi band or broad band. Using

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the multi band RF energy harvesting circuit, more energy may be harvested when it is compared to single band.

The capacitor on the RF energy harvesting circuit can be charged with the power of the modulated signal. The power of the modulated signal varies by the distance between signal generator and RF energy harvesting circuit. For that reason, charging times of the RF energy harvesting change according to the distances.

In this paper, it was aimed to measure and analyze the effects of Frequency Shift Keying (FSK) modulation technique on charging times of the RF energy harvesting. The measurement data such as distance and charging times were shown in a table. Moreover, the effects of FSK on charging times of the RF energy harvesting versus the distances were depicted on the graph.

Materials and Methods

In this section, charging times of RF energy harvesting were measured at different distances. Besides, measurement system and collection of the measurement results were explained in detail.

Measurement system

The measurement system consists of Universal Software Radio Peripheral (USRP) -2900 Software Defined Radio from National Instruments [24], P2110 Powerharvester module from Powercast Company [25], WSN-Eval-01 Wireless Sensor Board, XLP 16-bit Development Board and PICtail Daughter Card and Patch Antennas. In Figure 1, all measurement devices are depicted.

FSK is a modulation technique that represents digital data (binary 1 or 0) as variations in frequency of a carrier signal. In this study, 8-FSK was used as a modulated signal and it has totally 1 MHz bandwidth. In addition to that, Pseudo Noise (PN) sequence order was chosen as 10. NI USRP-2900 was used to generate FSK modulated signals at 915 MHz carrier frequency. Output power of NI USRP-2900 was set to 14 dBm. Then, the modulated signal was transmitted through the air to the RF energy harvesting module. As seen in Figure 1, patch antennas which has two layers and 6 dBi gain were used as both a receiver and a transmitter antenna [26]. Charging times of RF energy harvesting from 20 cm to 60 cm at the interval of 5 cm were measured and recorded, respectively.
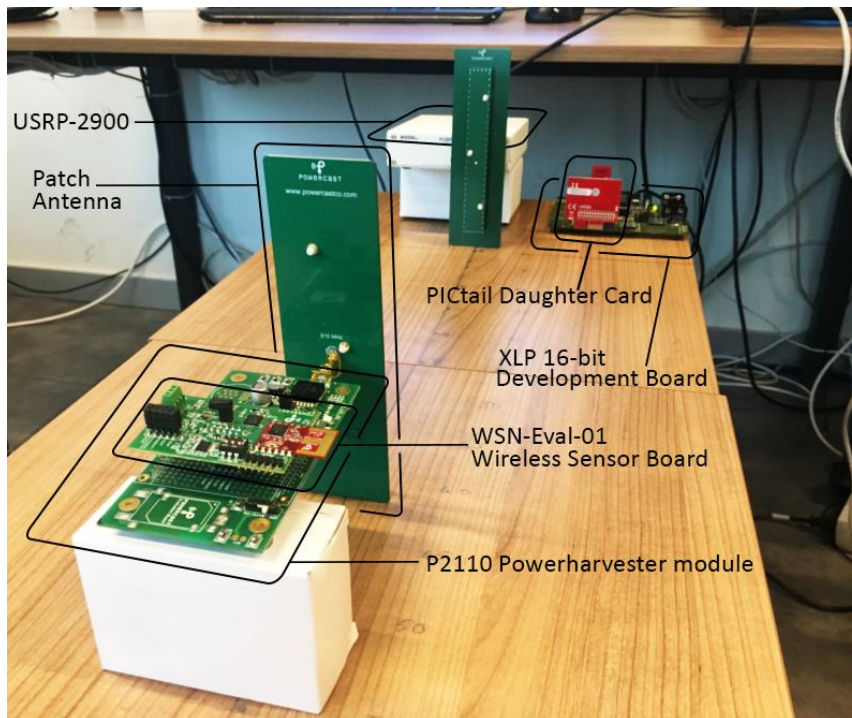

Figure 1. Measurement System

P2110 Powerharvester module allows efficient energy harvesting between 902 MHz and 928 MHz RF band. This energy harvester can collect power down to -11.5 dBm received input power. Furthermore, WSN-Eval-01 Wireless Sensor Board can sense temperature, humidity and light. As seen in Figure 1, WSN-Eval-01 Wireless Sensor Board was plugged into the P2110 Powerharvester module and it sends the data such as temperature, humidity, light, Received Signal Strength Indicator (RSSI), Node and Transmitter (TX) ID to the access point.

XLP 16-bit Development Board contains Microchip's PIC24F Micro Controller Unit (MCU) and it can obtain data wirelessly up to 8 Node IDs at the same time. Moreover, it maintains time counter for each Node ID. As shown in Figure 1, PICtail Daughter Card was attached into the XLP 16-bit Development Board and it was used as an access point which has 2.4 GHz, IEEE 802.15.4 radio module. PICtail Daughter Card obtains the data through the air from WSN-Eval-01 Wireless Sensor Board.

Collection of data

As soon as the P2110 Powerharvester module stores sufficient power, it will provide the required power for the WSN-Eval-01 Wireless Sensor Board. Then, the WSN-Eval-01 Wireless Sensor Board will send the temperature, humidity, light, RSSI, Node and TX ID (data from Wireless Sensor Board as seen in Figure 2) to the access point.

XLP 16-bit Development Board was connected to a computer with a cable. As seen in Figure 2, the data obtained from the XLP 16-bit Development Board was shown via HyperTerminal. HyperTerminal should be set as baud rate: 19200, flow control: hardware, data bits: 8 bits, parity and none stop bits: 1 bit.

Results and Discussions

The NI USRP-2900 generates the FSK modulated signals. The received power levels of the modulated signals vary according to the distance. Therefore, the charging time of the P2110 Powerharvester module varies according to each distance. So, the shorter the distance the faster the charging time will be.
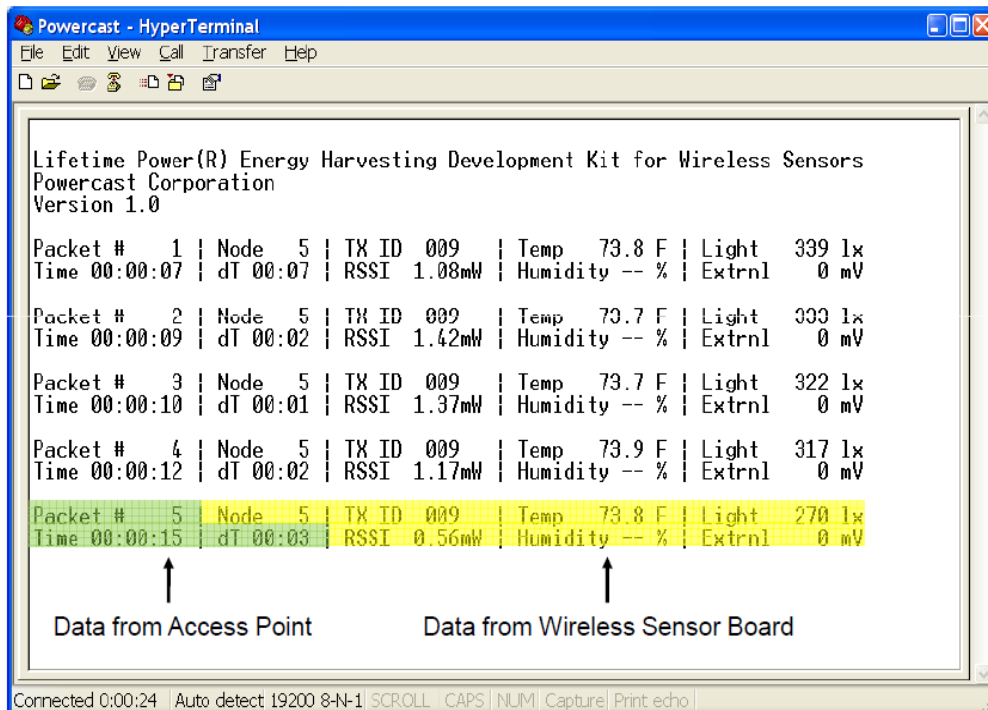

Figure 2. Obtaining data via HyperTerminal [26]

The time difference between the consecutive packets was calculated as charging time for RF energy harvesting. In this study, for each distance from 20 cm to 60 cm at the interval of 5 cm, 100 packets were obtained, recorded and then, evaluated as measurement samples. 100 samples for each distance and totally 900 samples were measured for FSK modulation technique. The unit of distance is centimeter (cm) and the unit of the charging time is second (s) as shown in Table 1.

Table 1: Distance versus charging time for FSK

Distance (cm)	FSK (s)
20	1.00
25	1.57
30	1.95
35	2.30
40	3.12
45	3.79
50	4.47
55	6.05
60	7.00

Table 1 shows the charging times according to the distance. The shortest charging time was measured as 1.00 s at a distance of 20 cm. Besides, the longest charging time was measured as 7.00 s at a distance of 60 cm.

In order to illustrate more clearly, the charging times of the RF energy harvesting with FSK were shown on the graph. As the distance increases, the charging time also increases as depicted in Figure 3. From 20 cm to 60 cm at the interval of 5 cm, the FSK modulation technique performed the best charging time at a distance of 20 cm and the worst charging time at a distance of 60 cm.

Conclusions

Recently, rapid advances in RF energy harvesting technology have been observed. It is estimated that this technology will be used more widely in the future practical applications.

In order to measure the charging times of the RF energy harvesting with FSK modulated signal, an advanced measurement system was established. The advanced measurement system consisted of NI USRP-2900, P2110 Powerharvester module, WSN-Eval-01 Wireless Sensor Board, XLP 16-bit Development Board, PICtail Daughter Card and Patch Antennas.

According to the measurement results, the shortest charging time was measured as 1.00 s at a distance of 20 cm and the longest charging time was measured as 7.00 s at a distance of 60 cm. It was determined that as the distance decreased, the charging time of RF energy harvesting reduced.
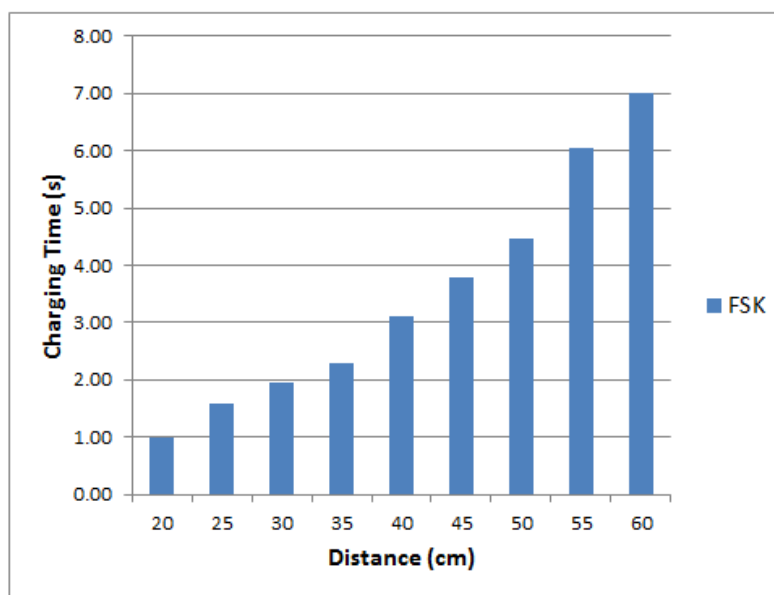

Figure 3. Charging times of RF energy harvesting versus distances for FSK

References

[1] M. Pinuela, P. D. Mitcheson, and S. Lucyszyn, "Ambient RF Energy Harvesting in Urban and Semi-Urban Environments," *IEEE Trans. Microw. Theory Tech.*, vol. 61, no. 7, pp. 2715–2726, Jul. 2013.

[2] M. Cansiz, T. Abbasov, M. B. Kurt, and A. R. Celik, "Mobile measurement of radiofrequency electromagnetic field exposure level and statistical analysis," *Measurement*, vol. 86, pp. 159–164, May 2016.

[3] N. Barroca *et al.*, "Antennas and circuits for ambient RF energy harvesting in wireless body area networks," in *2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2013, pp. 532–537.

[4] F. T. Pachón-García, K. Fernández-Ortiz, and J. M. Paniagua-Sánchez, "Assessment of Wi-Fi radiation in indoor environments characterizing the time & space-varying electromagnetic fields," *Meas. J. Int. Meas. Confed.*, vol. 63, pp. 309–321, 2015.

[5] M. Cansiz, T. Abbasov, M. B. Kurt, and A. R. Celik, "Mapping of radio frequency electromagnetic field exposure levels in outdoor environment and comparing with reference levels for general public health," *J. Expo. Sci. Environ. Epidemiol.*, no. October, pp. 1–5, Nov. 2016.

[6] P. Baltrėnas and R. Buckus, "Measurements and analysis of the electromagnetic fields of mobile communication antennas," *Measurement*, vol. 46, no. 10, pp. 3942–3949, Dec. 2013.

[7] L. Verloock, W. Joseph, F. Goeminne, L. Martens, M. Verlaek, and K. Constandt, "Temporal 24-hour assessment of radio frequency exposure in schools and homes," *Measurement*, vol. 56, pp. 50–57, 2014.

[8] M. Cansiz and M. B. Kurt, "Drive Test Yöntemi ile Elektromanyetik Kirlilik Haritasının Çıkartılması ve Ölçüm Sonuçlarının Değerlendirilmesi," *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Derg.*, vol. 3, no. 2, pp. 101–110, 2012.

[9] P. Ancey, "Ambient functionality in MIMOSA from technology to services," in *Proceedings of the 2005 joint conference on Smart objects and ambient intelligence innovative context-aware services: usages and technologies - sOc-EUSAI '05*, 2005, no. october, p. 35.

[10] S. Kim *et al.*, "Ambient RF Energy-Harvesting Technologies for Self-Sustainable Standalone Wireless Sensor Platforms," *Proc. IEEE*, vol. 102, no. 11, pp. 1649–1666, Nov. 2014.

[11] A. Collado and A. Georgiadis, "Optimal Waveforms for Efficient Wireless Power Transmission," *IEEE Microw. Wirel. Components Lett.*, vol. 24, no. 5, pp. 354–356, May 2014.

[12] A. Collado and A. Georgiadis, "Conformal Hybrid Solar and Electromagnetic (EM) Energy Harvesting Rectenna," *IEEE Trans. Circuits Syst. I Regul. Pap.*, vol. 60, no. 8, pp. 2225–2234, Aug. 2013.

[13] S. Keyrouz, H. Visser, and A. Tijhuis, "Multi-band simultaneous radio frequency energy harvesting," *Antennas Propag.*, no. Eucap, pp. 3058–3061, 2013.

[14] C. Song *et al.*, "Matching Network Elimination in Broadband Rectennas for High-Efficiency Wireless Power Transfer and Energy Harvesting," *IEEE Trans. Ind. Electron.*, vol. 64, no. 5, pp. 3950–3961, May 2017.

[15] C. Song, Y. Huang, S. Member, J. Zhou, J. Zhang, and S. Yuan, "A High-Efficiency Broadband Rectenna for Ambient Wireless Energy Harvesting A High-efficiency Broadband Rectenna for Ambient Wireless Energy Harvesting," vol. 63, no. MAY, pp. 3486–3495, 2015.

[16] M. Cansiz, D. Altinel, and G. K. Kurt, "Efficiency in RF energy harvesting systems: A comprehensive review," *Energy*, vol. 174, pp. 292–309, 2019.

[17] M. S. Trotter, J. D. Griffin, and G. D. Durgin, "Power-optimized waveforms for improving the range and reliability of RFID systems," in *2009 IEEE International Conference on RFID*, 2009, pp. 80–87.

[18] D. Altinel and G. Karabulut Kurt, "Energy Harvesting From Multiple RF Sources in Wireless Fading Channels," *IEEE Trans. Veh. Technol.*, vol. 65, no. 11, pp. 8854–8864, Nov. 2016.

[19] J. F. Ensworth, S. J. Thomas, S. Y. Shin, and M. S. Reynolds, "Waveform-aware ambient RF energy harvesting," in *2014 IEEE International Conference on RFID (IEEE RFID)*, 2014, pp. 67–73.

[20] G. Andia Vera, D. Allane, A. Georgiadis, A. Collado, Y. Duroc, and S. Tedjini, "Cooperative Integration of Harvesting RF Sections for Passive RFID Communication," *IEEE Trans. Microw.*

Theory Tech., vol. 63, no. 12, pp. 4556–4566, Dec. 2015.

[21] V. Kuhn, C. Lahuec, F. Seguin, and C. Person, "A Multi-Band Stacked RF Energy Harvester With RF-to-DC Efficiency Up to 84%," *IEEE Trans. Microw. Theory Tech.*, vol. 63, no. 5, pp. 1768–1778, May 2015.

[22] Hucheng Sun, Yong-xin Guo, Miao He, and Zheng Zhong, "Design of a High-Efficiency 2.45-GHz Rectenna for Low-Input-Power Energy Harvesting," *IEEE Antennas Wirel. Propag. Lett.*, vol. 11, pp. 929–932, 2012.

[23] U. Olgun, C.-C. Chen, and J. L. Volakis, "Wireless power harvesting with planar rectennas for 2.45 GHz RFIDs," in *2010 URSI International Symposium on Electromagnetic Theory*, 2010, pp. 329–331.

[24] National Instruments, "www.ni.com/en-us.html." .

[25] PowercastCorporation, "www.powercastco.com." .

[26] Powercast, "P2110-EVAL-01 User's Manual."