Radio Frequency Energy Harvesting with Different Antennas and Output Powers

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Abstract— **In this study, the effects of antenna types and output powers on charging times of RF energy harvesting circuit were measured and analyzed in detail. A measurement system which consisting of a signal generator, an RF energy harvesting circuit, antennas and other devices was installed for receiving the measurement samples. According to the measurement results, the shortest charging time was obtained as 0.58 s at a distance of 20 cm, when 6.1 dBi antenna was connected to the RF energy harvesting circuit and the output power of the signal generator was set to 17 dBm. In addition to that, the longest charging time was evaluated as 25.01 s at a distance of 60 cm, when 1 dBi antenna was connected to the RF energy harvesting circuit and the output power of the signal generator was adjusted to 14 dBm. As a result, it was determined that increasing of antenna gains and output powers and shortening of distances between signal generator and RF energy harvesting circuit decreased the charging times of the RF energy harvesting circuit in this study.**

Index Terms— **Radio frequency, Energy harvesting, Antenna, Output power.**

I. INTRODUCTION

MANY KINDS of energy sources such as solar [1], mechanical vibrations [2], thermal gradients [3] and electromagnetic waves [4] exist in nature. Electromagnetic waves are energy source for Radio Frequency (RF) energy harvesting technology. Thanks to this technology, the energy required for operation of many low power devices can be provided wirelessly [5].

The harvested energy obtained by the RF energy harvesting technology depends on many parameters such as power levels of RF bands, antenna types, distance between transmitter and receiver, etc. In order to increase the harvested energy, the RF bands in the ambient environment should be measured [6]–[12] and then, the operating frequency of the RF energy harvesting circuit should be adjusted according to the most powerful RF band or bands. Furthermore, suitable antenna types and distances should be chosen for increasing the harvested energy.

Efficiency of an RF energy harvesting circuit is crucial and it directly affects the harvested energy. For that reason, the efficiency should be increased as much as possible when an RF energy harvesting circuit is designed and implemented. The efficiency of the RF energy harvesting system can be improved by using RF power signals with various waveforms [13]–[17]. In addition to that, the efficiency can also be enhanced by optimizing circuit parts such as antenna, rectifier and voltage multiplier forming the RF energy harvesting circuit. All parameters that increase the efficiency of the RF energy harvesting lead to shorter charging times.

In [18], the battery recharging time was analyzed when multiple RF sources were available. A statistical distribution model was proposed for RF energy harvesting systems. Furthermore, it was determined that the theoretical results were consistent with the experimental results.

In this study, it was aimed to measure and analyze the effects of antenna types and output powers on the charging times of the RF energy harvesting. A measurement system was established for obtaining the measurement samples. The measurement results were evaluated and then, charging times versus distances were shown in tables.

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II. MATERIALS AND METHOD

In this section, the charging times of the RF energy harvesting circuit were measured for different antennas and output powers. Measurement system and devices were described in detail. Moreover, the collection of measurement data was explained.

A. Measurement System and Devices

Universal Software Radio Peripheral (USRP)-2900 Software Defined Radio from National Instruments [19], PCB dipole antenna, PCB patch antenna [20], P2110 Powerharvester module from Powercast Company [21], WSN-Eval-01 Wireless Sensor Board, Microchip 16-bit XLP Development Board and PICtail Daughter Card were used as measuring devices. In Fig. 1, measurement system was illustrated.

NI USRP-2900 was used as a signal generator and it produced RF power signals at 915 MHz carrier frequency in continuous wave mode for 14 and 17 dBm output powers. Then, the generated RF power signals were harvested by the RF energy harvesting circuit with different antennas at distances from 20 cm to 60 cm at the interval of 5 cm. On the other hand, between 902 MHz and 928 MHz frequency band, P2110 Powerharvester module as an RF energy harvesting circuit can provide efficient energy harvesting. This module can obtain the received power level down to -11.5 dBm.

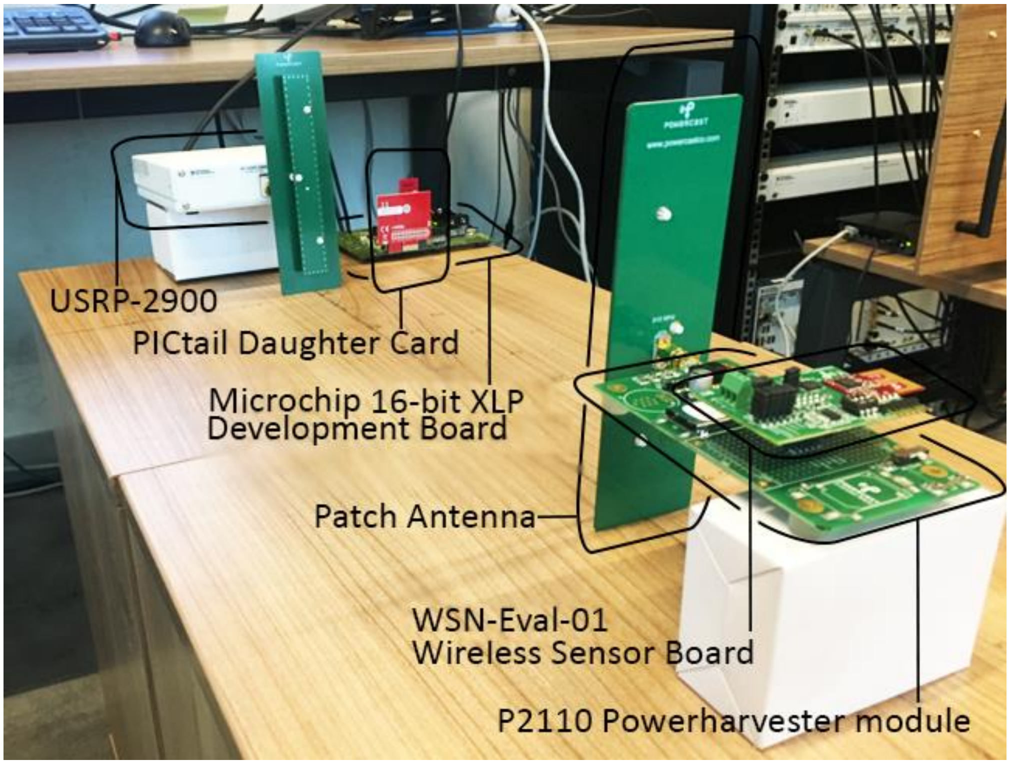

Fig. 1. Measurement system

As shown in Fig. 2, PCB dipole antenna and PCB patch antenna were connected to the RF energy harvesting circuit, respectively. Then, measurements were taken for each antenna at different distances. The PCB dipole antenna has 1.0 dBi antenna gain and it is vertically polarized and omni-directional antenna and it has 360° horizontal pattern [20]. The PCB patch antenna has 6.1 dBi antenna gain and this antenna is vertically polarized and directional antenna. Furthermore, the PCB patch antenna has 122° horizontal and 68° vertical pattern [20]. During the measurements, only the PCB patch antenna was attached to the NI USRP-2900 which used as a signal generator.

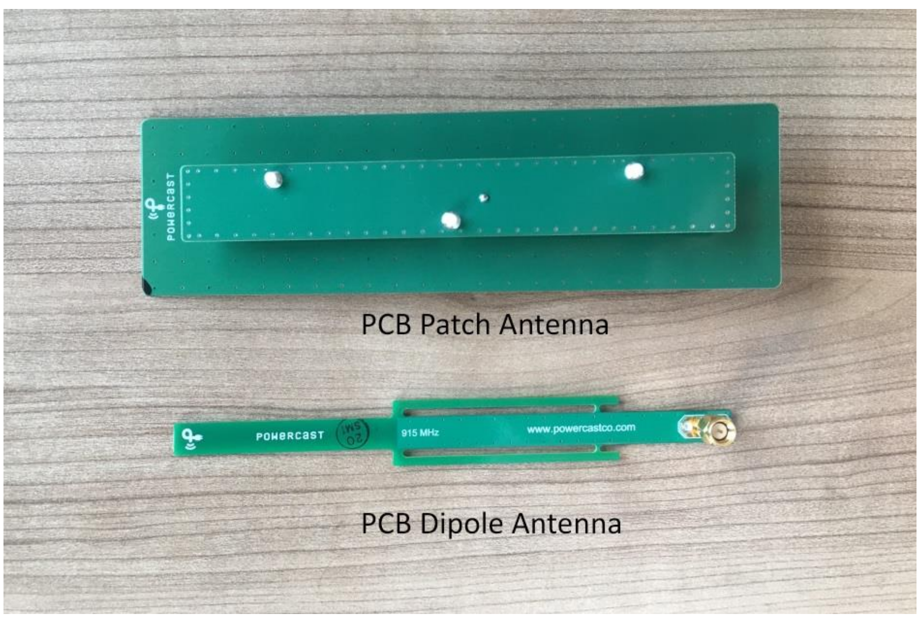

Fig. 2. PCB patch antenna and PCB dipole antenna

As shown in Fig. 1, the WSN-Eval-01 Wireless Sensor Board was plugged into the RF energy harvesting circuit (P2110 Powerharvester module) and this wireless sensor board can sense light, temperature and humidity. The WSN-Eval-01 Wireless Sensor Board transmits the measurement data such as light, temperature, humidity, Node ID, Transmitter (TX) ID and Received Signal Strength Indicator (RSSI) to the access point (PICtail Daughter Card) which is plugged into Microchip 16-bit XLP Development Board. The PICtail Daughter Card was used as an access point which has IEEE 802.15.4 radio module (2.4 GHz). Microchip 16-bit XLP Development Board can take data up to 8 Node IDs simultaneously and manage time counter for each Node ID. This development board has a Microchip's PIC24F micro controller unit.

B. Collection of Measurement Data

When the RF energy harvesting circuit charges the sufficient energy, it will feed the WSN-Eval-01 Wireless Sensor Board for transmitting the measurement data such as light, temperature, humidity, Node ID, TX ID and RSSI wirelessly to the PICtail Daughter Card (access point). Then, the Microchip 16-bit XLP Development Board calculates time and time difference (dT) and also receives packet numbers. Data from the access point and data from the wireless sensor board were shown in Fig. 3.

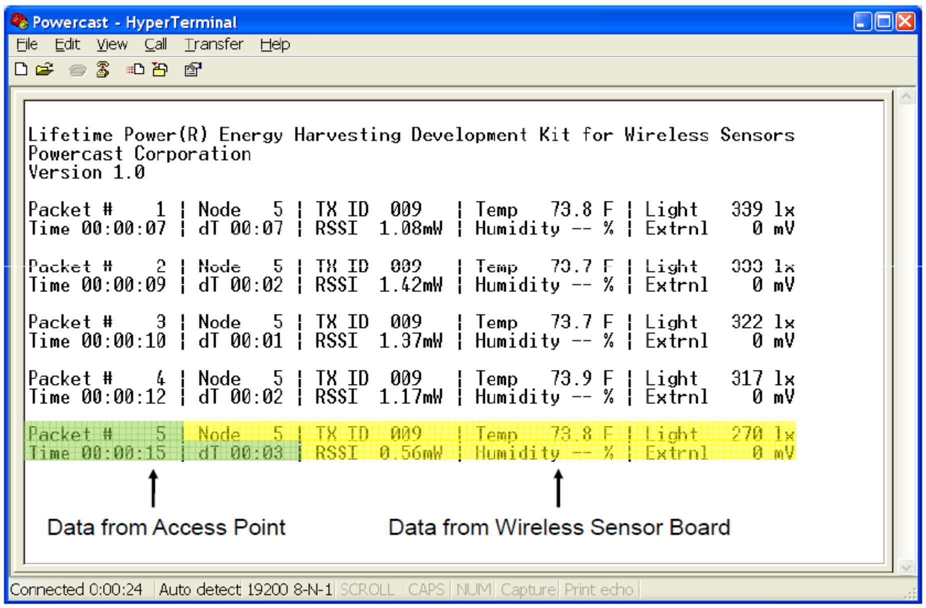

Fig. 3. Collection of measurement data via HyperTerminal [21]

In order to obtain the measurement data, the Microchip 16-bit XLP Development Board was connected to a computer with a cable. Then, the measurement data was shown via HyperTerminal as seen in Figure 3. HyperTerminal must be set as baud rate: 19200, flow control: hardware, parity: none stop bits: 1 bit and data bits: 8 bits for displaying the measurement data correctly. Finally, the measurement data was recorded on a computer via HyperTerminal.

III. RESULTS AND DISCUSSION

Charging times of an RF energy harvesting circuit depend on many parameters such as antenna type, distance and output power, etc. In this study, the charging time was defined as the time difference (dT in Fig. 3) between two consecutive packets. So, the shorter the time difference, the shorter the charging time. After the PCB dipole antenna was connected to the RF energy harvesting circuit and the output power of the signal generator was set to 14 dBm, 100 measurement samples were received for each distance from 20 cm to 60 cm at the interval of 5 cm and totally 900 measurement samples were taken for 14 dBm. In the same way, 900 measurement samples were also taken for 17 dBm output power. On the other hand, after the PCB patch antenna was attached to the RF energy harvesting circuit, 900 measurement samples were obtained for 14 dBm and 17 dBm, respectively. The charging time for each distance was calculated as the average of the time differences for the consecutive 100 packets.

Table I indicates the charging times for PCB dipole antenna (1 dBi antenna gain) and PCB patch antenna (6.1 dBi antenna gain), respectively, while the output power is adjusted to 14 dBm. Units of charging time and distance are second (s) and centimeter (cm), respectively. According to the measurement results in Table I, the shortest charging time was determined as 2.61 s at a distance of 20 cm and the longest charging time was determined as 25.01 s at a distance of 60 cm for 1 dBi antenna gain. In addition to that, the shortest charging time was calculated as 0.93 s at a distance of 20 cm and the longest charging time was determined as 5.92 s at a distance of 60 cm for 6.1 dBi antenna gain.

TABLE I
CHARGING TIMES FOR PCB DIPOLE ANTENNA AND PCB PATCH ANTENNA AT 14 DBM OUTPUT POWER

Distance (cm)	14 dBm USRP	
	1 dBi antenna	6.1 dBi antenna
	Charging Time (s)	Charging Time (s)
20	2.61	0.93
25	4.09	1.38
30	5.63	1.82
35	8.92	2.35
40	11.10	3.18
45	11.43	3.86
50	12.38	4.23
55	18.11	5.00
60	25.01	5.92

TABLE II
CHARGING TIMES FOR PCB DIPOLE ANTENNA AND PCB PATCH ANTENNA AT 17 DBM OUTPUT POWER

Distance (cm)	17 dBm USRP	
	1 dBi antenna	6.1 dBi antenna
	Charging Time (s)	Charging Time (s)
20	1.27	0.58
25	1.77	0.72
30	3.06	0.94
35	3.73	1.28
40	4.94	1.59
45	7.51	1.84
50	7.81	2.17
55	9.09	2.46
60	11.20	2.75

Table II shows the charging times for PCB dipole antenna (1 dBi antenna gain) and PCB patch antenna (6.1 dBi antenna gain), respectively, while the output power is set to 17 dBm. In terms of the measurement results in Table II, the shortest charging time was determined as 1.27 s at a distance of 20 cm and the longest charging time was determined as 11.20 s at a distance of 60 cm for 1 dBi antenna gain. Moreover, the shortest charging time was calculated as 0.58 s at a distance of 20 cm and the longest charging time was calculated as 2.75 s at a distance of 60 cm for 6.1 dBi antenna gain.

The charging times according to the different antenna gains and output powers were clearly shown in Fig. 4. The shortest charging time was obtained for RF energy harvesting when 6.1 dBi antenna (PCB patch antenna) was connected to the circuit and the output power of the signal generator was set to 17 dBm. On the other hand, the longest charging time was determined for RF energy harvesting when 1 dBi antenna (PCB dipole antenna) was connected to the circuit and the output power of the signal generator was adjusted to 14 dBm as seen in Fig. 4.

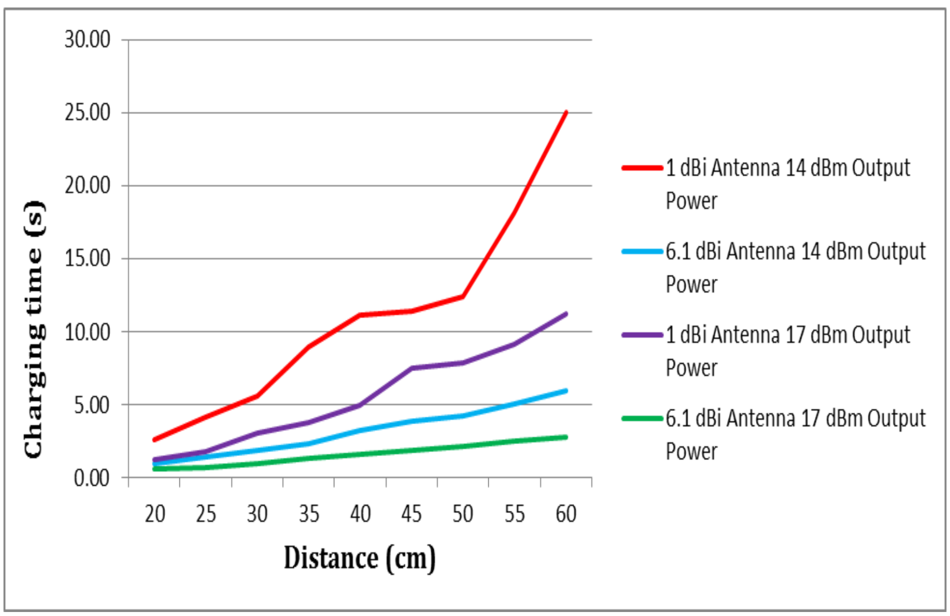

Fig. 4. Charging times versus distance for different antenna gains and output powers

IV. CONCLUSION

The harvested energy obtained by the RF energy harvesting technology is used as an alternative energy source for the operation of many low power devices. With this technology, it is estimated that the number of battery-free devices will increase.

An advanced measurement system was established for analyzing the effects of antenna types and output powers on the charging times of the RF energy harvesting circuit. This measurement system consisted of NI USRP-2900 as a signal generator, PCB dipole antenna, PCB patch antenna, P2110 Powerharvester module as an RF energy harvesting circuit, WSN-Eval-01 Wireless Sensor Board, Microchip 16-bit XLP

Development Board and PICtail Daughter Card as an access point.

When 6.1 dBi antenna was connected to the RF energy harvesting circuit and the output power of the signal generator was adjusted to 17 dBm, the shortest charging time was obtained at the distance of 20 cm. Furthermore, when 1 dBi antenna was connected to the RF energy harvesting circuit and the output power of the signal generator was set to 14 dBm, the longest charging time was received at the distance of 60 cm. As a result, it was determined that shortening of distances and increasing of antenna gains and output powers reduced the charging times of the RF energy harvesting circuit in this study.

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REFERENCES

[1] M. A. Green, K. Emery, Y. Hishikawa, W. Warta, and E. D. Dunlop, "Solar cell efficiency tables (Version 38)," *Prog. Photovoltaics Res. Appl.*, vol. 19, no. 5, pp. 565–572, Aug. 2011.

[2] A. C. Turkmen and C. Celik, "Energy harvesting with the piezoelectric material integrated shoe," *Energy*, vol. 150, pp. 556–564, May 2018.

[3] A. R. M. Siddique, R. Rabari, S. Mahmud, and B. Van Heyst, "Thermal energy harvesting from the human body using flexible thermoelectric generator (FTEG) fabricated by a dispenser printing technique," *Energy*, vol. 115, pp. 1081–1091, Nov. 2016.

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

[5] J. Bito, S. Kim, M. Tentzeris, and S. Nikolaou, "Ambient Energy Harvesting from 2-way Talk-Radio Signals for 'Smart' Meter and Display Applications," in *2014 IEEE Antennas and Propagation Society International Symposium (APSURSI)*, 2014, pp. 1353–1354.

[6] S. Kim, R. Vyas, J. Bito, K. Niotaki, A. Collado, A. Georgiadis, and M. M. Tentzeris, "Ambient RF Energy-Harvesting Technologies for Self-Sustainable Standalone Wireless Sensor Platforms," *Proc. IEEE*, vol. 102, no. 11, pp. 1649–1666, Nov. 2014.

[7] N. Barroca, H. M. Saraiva, P. T. Gouveia, J. Tavares, L. M. Borges, F. J. Velez, C. Loss, R. Salvado, P. Pinho, R. Goncalves, N. Borges Carvalho, R. Chavez-Santiago, and I. Balasingham, "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.

[8] 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.

[9] 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.

[10] 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.

[11] 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.*, vol. 28, no. 2, pp. 161–165, Nov. 2016.

[12] 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.

[13] 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.

[14] 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.

[15] A. Collado and A. Georgiadis, "Improving wireless power transmission efficiency using chaotic waveforms," in *2012 IEEE/MTT-S International Microwave Symposium Digest*, 2012, pp. 1–3.

[16] 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.

[17] 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.

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

[20] Powercast, "P2110-EVB Evaluation Board for P2110 Powerharvester datasheet."

[21] Powercast Corporation, "www.powercastco.com." .

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