

Development of RF Energy Harvesting and Charging Circuits for Low Power Mobile Devices

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Abstract—The electrical power generated by RF energy harvesting techniques is small, depending on techniques it is enough to drive low power consumption devices. Therefore, it is possible to increase the battery life and to reduce the environmental pollution. In this paper, we focus on the RF energy harvesting and design the rectenna with a 4×4 patch antenna of 2.13 GHz for low power mobile devices. The rectenna element is a microstrip patch antenna with PTFT board of 10 dielectric constant and 1.6 mm thick that has a gain of 5.8dBi. A step-up converter is adopted the Texas Instruments TPS61220. The step-up converter is operated with load at 0.7V to 5.5V. If the output current is 1.7mA, the conversion efficiency shows 80.9%. From the evaluated results of RF energy harvesting system, the low power mobile devices such as Zigbee when we set the distance of 12m can be operated.

I. INTRODUCTION

Energy harvesting has been around for centuries in the form of windmills, watermills and passive solar power systems. In recent decades, technologies such as wind turbines, hydroelectric generators and solar panels have turned harvesting into a small but growing contributor to the world's energy needs. This technology offers two significant advantages over battery-powered solutions, virtually inexhaustible sources and little or no adverse environmental effects. Recently, the availability of the free RF energy has increased due to advent of wireless communication and broadcasting systems.

Wireless power transmission technology via microwave was advanced from 1960's [1]. The rectenna, rectifying antenna, is one of the primary components in the application of wireless power transmission system. The rectenna, for receiving and converting the microwave power to direct current (DC) power, has received much attention lately in the development of the wireless power transmission. The application of this technology can be used in low power mobile devices such as radio-frequency identification (RFID) and Zigbee. For environments without or not enough ambient energy, wireless energy supply is a reliable way to power the low power mobile devices. Recently, many rectennas have been reported, including a rectenna using rhombic hula loop antenna [2], a dual-frequency rectenna [3], and a dual-diode rectenna [4]. Until this time, the electrical power generated by RF energy harvesting techniques is small, depending on techniques it is enough to drive low power consumption devices. Therefore,

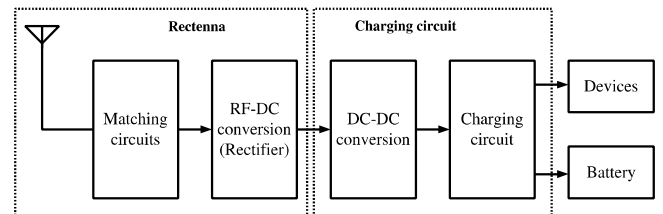


Fig. 1. The diagram of RF energy harvesting devices.

it is possible to increase the battery life and to reduce the environmental pollution.

Radio wave is ubiquitous in our daily lives in form of signals transmission from TV, radio, wireless LAN and mobile phone. Wireless communication devices generally have omni-directional antennas that propagate RF energy in most directions, which maximizes connectivity for mobile applications. The energy transmitted from the wireless sources is much higher, but only a small amount can be scavenged in real environment, rest is dissipated as heat or absorb by other materials. In this paper, we focus on the RF energy harvesting and design the rectenna with a 4×4 patch antenna of 2.13 GHz for low power mobile devices. This paper is organized as follows. The RF energy harvesting devices is described in Section II. In Section III, we show the system experimental results. Finally, the conclusion is given in Section IV.

II. RF ENERGY HARVESTING DEVICES

A. Rectenna Design

The RF energy harvesting devices consist of rectenna and charging circuits as shown in Fig. 1. The rectenna, rectifying antenna, is one of the primary components in the application of RF energy harvesting devices. The rectenna consists of antenna, matching circuit, and rectifying circuit. A high efficient rectenna has been studied assuming the use in solar power station (SPS) [5],[6]. Although wireless communications use UHF waves such as CDMA and WCDMA, the basis is nearly identical. Previously, we have developed the prototype of 5.8 GHz rectenna for electric vehicle system [7]. In this paper, we have developed 2.13 GHz rectenna

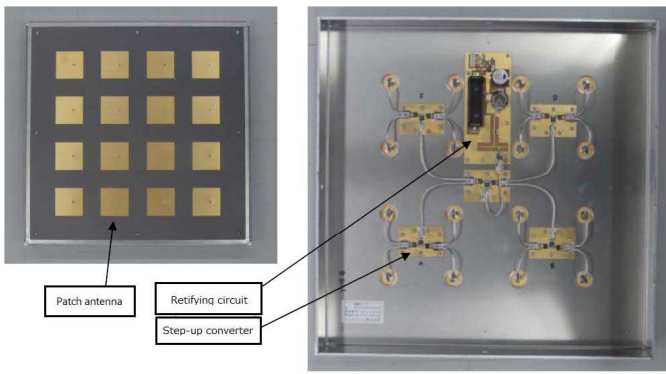


Fig. 2. The manufactured RF harvesting device.

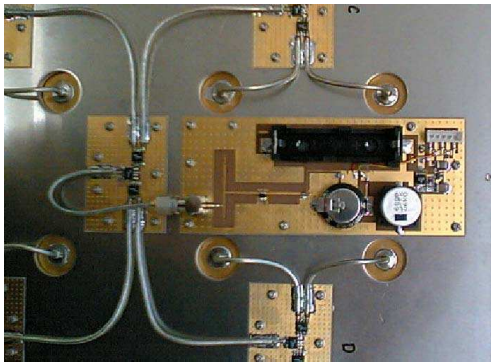


Fig. 3. The manufactured rectifying circuit, step-up converter, and charging circuit.

by using the previous developed rectenna of 5.8 GHz since the frequencies of 2.12 GHz and 2.14GHz are CDMA and WCDMA frequency bands, respectively. In the design of rectenna, microstrip dipole and patch antennas are widely used. Microstrip antenna has the characteristics of light, easy and small-size manufacturing. However, it has demerits due to relatively narrow bandwidth, restricted incident power and low gains. However, in this paper, microstrip patch antenna is adopted due to its big size and no polarization characteristics. Figs. 2 and 3 show the manufactured RF energy harvesting devices. The rectifying circuit is a key element to improve the RF-DC conversion efficiency. An Schottky diode HSMS-2862 is chosen for the rectifying circuit. The measured gain of the manufactured rectenna is shown in Fig. 4. The rectenna shows the maximum gain of 5.8dBi at the frequency of 2.13 GHz with PTFT(Teflon) board of 10 dielectric constant and 1.6 mm thick. The frequencies of 2.12 GHz and 2.14 GHz are within the half power bandwidth of the rectenna.

B. Charging Circuits

In low power mobile devices such as Zigbee, the stepped-up voltage such as 2.5~5V is required to drive transmitter at up to 35 mA. From this reason, we adopted the Texas Instruments TPS61220 as a step-up converter. The step-up converter is operated with load at 0.7V to 5.5V. Adjustable output voltage

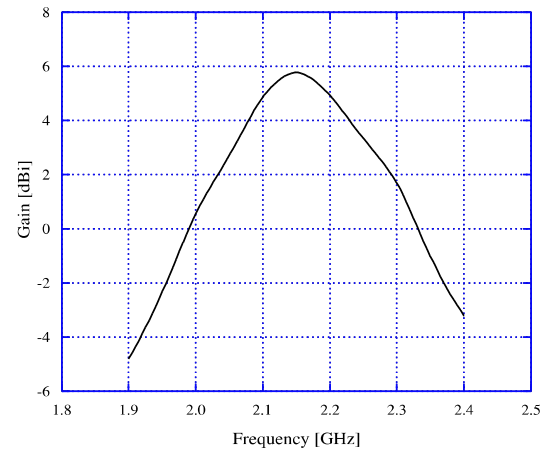


Fig. 4. The measured gain of the rectenna versus various frequency.

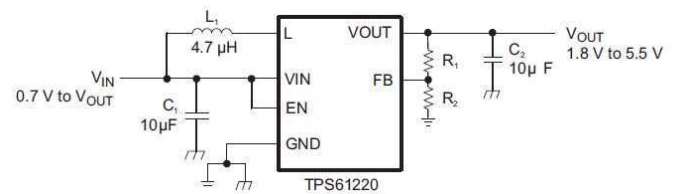


Fig. 5. The simplified schematic of the step-up converter with TPS61220.

is from 1.8V to 5.5V. Fig. 5 shows the simplified schematic of the step-up converter with TPS61220. The TPS61220 provides a power-supply solution for products powered by either a single-cell, two-cell, or three-cell alkaline NiCd or NiMH, or one-cell Li-Ion or Li-polymer battery. In the prototype, we used the one-cell Li-Ion battery as a battery powered application.

III. EXPERIMENTAL RESULTS

Rectenna is designed with the PTFT board of 10 dielectric constant and 1.6 mm thick. The 4×4 rectenna array consists of 16 patch antennas and each patch antenna size is 39mm×31mm. The patch antennas are in front and rectifying and charging circuits are in back of antenna as shown in Fig. 2. We adopted 2.13 GHz rectenna since the frequencies of 2.12 GHz and 2.14GHz are CDMA and WCDMA frequency bands. The 4×4 rectenna array is used and the load resistance is chosen as 50Ω. The RF-DC conversion efficiency is defined as

$$\eta = \frac{P_{dc}}{P_r} \times 100\%, \quad (1)$$

where P_{dc} is the DC output power and P_r is the power received by the array rectenna that is calculated by using the Friss transmission equation [8]. By changing the distance between the transmitting antenna and rectenna array, the efficiencies for different power densities can be determined.

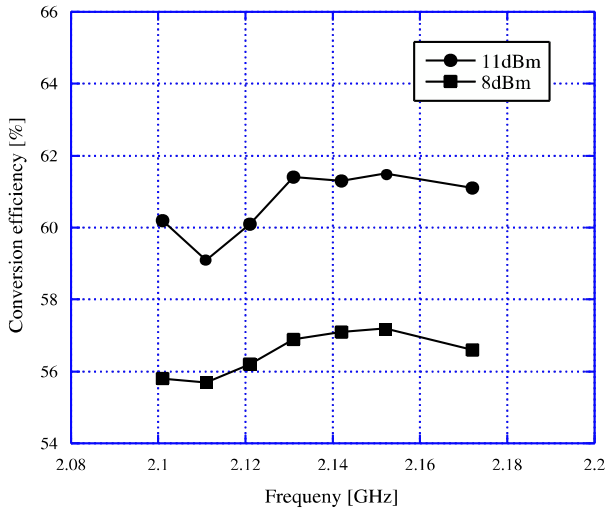


Fig. 6. The RF-DC conversion efficiency of the rectenna versus various input frequency.

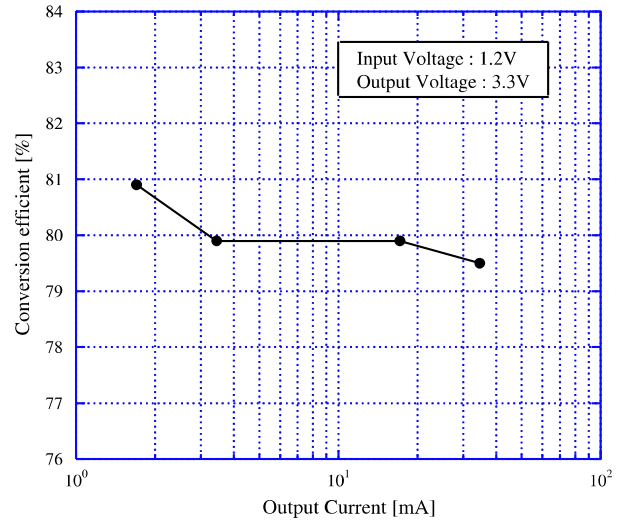


Fig. 7. The conversion efficiency of low input voltage set-up converter.

The power density P_d is given by

$$P_d = \frac{P_t G_t}{4\pi D^2} \quad (2)$$

where P_t is the transmit power, G_t is the transmit antenna gain, and D is the distance between the transmit antenna and the center of the rectenna array, respectively.

Fig. 6 shows the frequency characteristics of the manufactured rectenna. From Fig. 5, the vertical axis represents the conversion efficiency of the manufactured rectenna. It should be noted that the input power is varied from 8dBm to 11dBm, while input frequency is varied from 2.1GHz to 2.171GHz. From the evaluated results, it is found that the weaker the input power shows a low efficiency of the rectenna. Therefore, it is necessary to increase the input power for efficiency of the rectenna.

Fig. 7 shows the conversion efficiency of low input voltage set-up converter. A set-up converter operates when the input voltage is higher than 0.7V. When we set the input voltage of 1.2V, the conversion efficiency is various due to the output current. If the output current is 1.7mA, we can achieve the conversion efficiency of 80.9%. With increasing the output current, the conversion efficiency is also degraded.

Fig. 8 shows the output voltage characteristic and chargeable distance for input power. The estimated and calculated output voltages are 21mV and 21.4mV at the distance of 180m between the transmit antenna and the center of the rectenna. Moreover, when we set the distance of 100m, the estimated and calculated output voltages are 92.6mV and 92.8mV. From these results, it is found that the estimated and calculated results show the same values. Therefore, we can realize the output voltage to operate the low power mobile devices such as Zigbee when we set the distance of 12m.

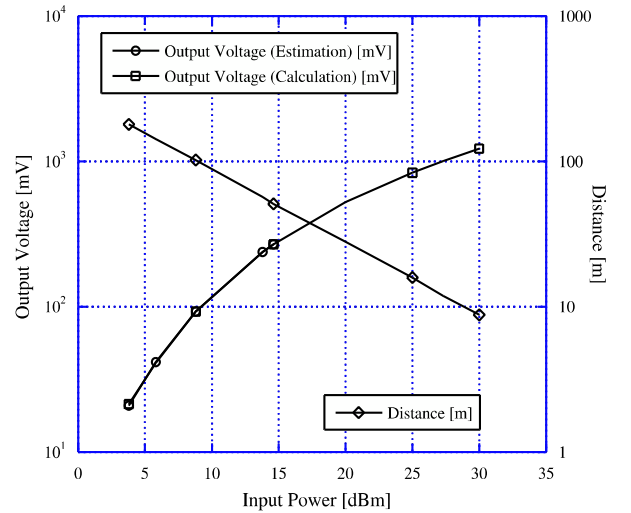


Fig. 8. The output voltage characteristic and chargeable distance for input power.

IV. CONCLUSION

In this paper, a 4×4 rectenna of 2.13 GHz has been developed for low power mobile devices. The rectenna element is a microstrip patch antenna with PTFT board of 10 dielectric constant and 1.6 mm thick that has a gain of 5.8dBi. A step-up converter is adopted the Texas Instruments TPS61220. The step-up converter is operated with load at 0.7V to 5.5V. If the output current is 1.7mA, the conversion efficiency shows 80.9%. From the evaluated results of RF energy harvesting system, the low power mobile devices such as Zigbee when we set the distance of 12m can be operated.

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REFERENCES

- [1] W.C. Brown, "The history of power transmission by radio waves," *IEEE Trans. on Microwave Theory and Techniques*, vol.32, no.9, pp.1230-1242, September 1984.
- [2] B. Strassner, and K. Chang, "5.8GHz circularly polarized rectifying antenna for wireless microwave power transmission," *IEEE Trans. on Microwave Theory and Techniques*, vol.50, no.8, pp.1870-1876, August 2003.
- [3] J. Heikkinen, and M. Kivikoski, "A novel dual-frequency circularly polarized rectennas," *IEEE Antennas and Wireless Propagation Letter*, vol.2, no.1, pp.330-333, February 2003.
- [4] Y. Ren, and K. Chang, "5.8GHz circularly polarized dual-diode rectenna and rectenna array for microwave power transmission," *IEEE Trans. on Microwave Theory and Techniques*, vol.54, no.4, pp.1495-1502, April 2006.
- [5] G. Landis, M. Stavnes, S. Oleson and J. Bozek, "Space transfer with ground-based laser/electric Propulsion," (*ALAA-92-3213*) *NASA Technical Memorandum TM-106060*, 1992.
- [6] N. Shinohara, and H. Matsumoto, "Microwave power transmission system with phase and amplitude controlled magnetrons," *Proc. of RAST2005*, pp.28-33, Istanbul, Turkey, 2005.
- [7] C. Ahn, T. Kamio, H. Fujisaka and K. Haeiwa, "Prototype of 5.8GHz Wireless Power Transmission System for Electric Vehicle System," *Proc. of IEEE International Conference on Environmental Science and Technology (ICEST 2011)*, Singapore, vol.1 pp.128-131, February 2011.
- [8] C. Ahn, "OFDM technology and its applications," *Corona Publishing Co., LTD.*, ISBN978-4-339-00815-9, September 2010 (in Japanese).