Simple Self-Driven Synchronous Rectifier for Resonant Inductive Coupling Wireless Power Transfer

Takahiro Koyama, Toru Honjo, Masataka Ishihara, Kazuhiro Umetani, Eiji Hiraki
Graduate School of Natural Science and Technology
Okayama University
Okayama, Japan

Published in: 2017 IEEE International Telecommunications Energy Conference (INTELEC)

DOI: 10.1109/INTLEC.2017.8214163

Simple Self-Driven Synchronous Rectifier for Resonant Inductive Coupling Wireless Power Transfer

Takahiro Koyama, Toru Honjo, Masataka Ishihara, Kazuhiro Umetani, Eiji Hiraki
Graduate School of Natural Science and Technology
Okayama University
Okayama, Japan
pk430kpd@s.okayama-u.ac.jp

***Abstract*—Resonant inductive coupling wireless power transfer (RIC-WPT) is attracting attention as a convenient power supply method to small mobile apparatus. The efficiency and the power transfer capability of RIC-WPT has been known to be profoundly dependent on the quality factor of the receiving resonator. However, the quality factor of the receiving resonator tends to be deteriorated because of the conduction loss at the diode rectifier, particularly for low output voltage applications. In order to improve the efficiency and the power transfer capability, this paper propose a novel simple synchronous rectifier, which can reduce the conduction loss. The proposed rectifier has simple circuit configuration, which contributes to straightforward application to the wireless power transfer to small mobile apparatus with limited installation space. Experiment was carried out to verify the operation principle of the proposed rectifier. As a result, the proposed rectifier revealed successful suppression of the conduction loss. In addition, the experimental wireless power transfer system verified successful improvement in the rectification efficiency, supporting usefulness of the proposed rectifier for practical applications of the RIC-WPT for small mobile apparatus.**

Keywords—wireless power transfer; resonant inductive coupling; self-driven synchronous rectifier

I. Introduction

Recently, resonant inductive coupling wireless power transfer [1]–[9] (RIC-WPT) is attracting growing attention as a wireless power transfer technique to small mobile apparatus. The RIC-WPT can supply the power without the wire connection to the power source. Because RIC-WPT can ensure high mobility of the apparatus to be supplied with power, this technique can be promising for the future wireless communication system. Owing to this attractive feature, a number of preceding studies [10]–[14] have investigated application of RIC-WPT not only to mobile phones but also biomedical implants, which needs wireless communication of the medical information.

A typical RIC-WPT system consists of the magnetically coupled transmitting and receiving LC resonators, the AC power source, the rectifier, and the power load, as shown in Fig.1. The RIC-WPT system transfers the power using the magnetic coupling between the transmitting and receiving resonators. In RIC-WPT, comparatively small magnetic induction by the transmitting resonator suffice to excite large resonance in receiving resonator even under small magnetic coupling. Therefore, the RIC-WPT is effective to transfer comparatively large power to the receiving resonator, which commonly have limited size of the receiving coil for the applications of small mobile apparatus.

The efficiency of the RIC-WPT is widely known to be dependent on the figure-of-merit [14]–[16], defined as

$$F = k^2 Q_T Q_R , \tag{1}$$

where k is the magnetic coupling coefficient, Q_T and Q_R are the quality factor of the transmitting and receiving resonator, respectively. (Hereafter, we refer to it as the Q factor.) These Q factors are defined as

$$Q_T = \frac{1}{r_T}\sqrt{\frac{L_T}{C_T}}, \quad Q_R = \frac{1}{r_R}\sqrt{\frac{L_R}{C_R}} , \tag{2}$$

where, L_T, C_T and r_T are the inductance, capacitance and parasitic AC resistance of the transmitting resonator, respectively. Similarity, L_R C_R and r_R are the inductance, capacitance and parasitic AC resistance of the receiving resonator, respectively.

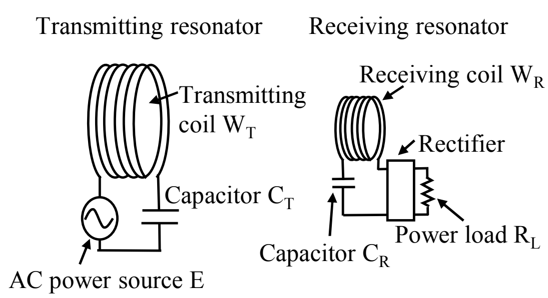


Fig. 1. Basic structure of resonant inductive coupling wireless power transfer (RIC-WPT).

As can be seen in (1), designing high Q factor is essential for each resonator. However, compared with Q_T, i.e. the Q factor of the transmitting resonator, Q_R tends to have small value in practical circuit design, because a diode rectifier is commonly connected to convert the AC power of the resonating current into the DC power, as exemplified in Fig. 2. The voltage drop of the diodes often generates far larger conduction loss than the parasitic resistance of the coil. Therefore, this voltage drop can add significant resistance to r_R, thus lowering Q_R and leading to deterioration of the efficiency.

Similarly, the output power may often be limited by the parasitic resistance added by the voltage drop of the diode rectifiers. As discussed in [17], the maximum output power of the RIC-WPT is dependent on the factor M^2/r_R, where M is the mutual inductance between the transmitting and receiving coil. Therefore, larger r_R results in reduction in the output power.

As we have seen above, the voltage drop of the diode rectifiers reduces not only the efficiency but also the output power. This indicates that elimination of the voltage drop will contribute to improvement in both the efficiency and the output power.

One of the effective methods to eliminate the voltage drop is the synchronous rectifiers using the MOSFETs [18]–[20]. As for the typical synchronous rectifiers utilized for the secondary winding of the isolated transformers of the forward and flyback DC-DC converters, the rectifiers are driven in synchronization with the polarity of the voltage applied to the primary winding of the transformer. However, in the RIC-WPT systems, this approach, i.e. synchronization with the phase of the AC voltage source of the transmitting resonator, is not practically applicable because of the following reason.

Certainly, the voltage induced in the receiving coil has the same phase angle as the primary winding according to Faraday's law. However, the voltage drop at the capacitance and the leakage inductance of the receiving resonator is generally far larger than the voltage induction. As a result, the voltage appearing at the AC input of the rectifier is not necessarily has the same phase angle as the primary winding; and therefore, the rectification in synchronization with the AC voltage source does not leads to effective power conversion to the DC power output.

In order to overcome the difficulty, a number of synchronous rectifiers have been proposed in literature [21]–[25]. Contrarily to the typical synchronous rectifiers, these synchronous rectifiers are self-driven. In other words, they can operate without the external signal for synchronization. Hence, they can be applied to the rectifiers of the RIC-WPT. However, many of the self-driven synchronous rectifiers may suffer from large-sized circuit elements or complicated circuit topology.

For example, some self-driven synchronous rectifiers [21]–[23] utilizes the auxiliary coil to operate the rectifier. As for [21], the auxiliary coil is utilized to detect the polarity of the AC voltage applied to the input of the rectifier. On the other hand, the auxiliary coil is utilized to detect the direction of the AC current at the input of the rectifier in [22]. Although these preceding studies have verified the effective operation of these techniques, these rectifiers may suffer from large size of the auxiliary coil, which may often be a severe drawback for

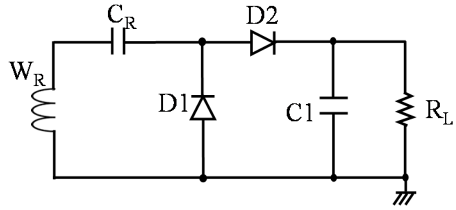


Fig. 2. Circuit diagram of the receiving resonator with the diode rectifier.

applications of the small mobile apparatus with limited installation space. According to the same reason, the synchronous rectifier with the center tap system [23] may also be difficult to be applied to the RIC-WPT systems for the small mobile apparatus.

Certainly, there have also been proposed synchronous rectifiers that are free from the auxiliary coil [24][25]. These rectifiers are proposed to improve the efficiency of the rectification in high voltage applications. However, these rectifiers may not be conveniently applicable to small mobile apparatus because these rectifiers still tend suffer from complicated circuit topology, which may result in large circuit size. Hence, small-sized synchronous rectifiers are required for practical applications of the RIC-WPT to small mobile apparatus.

The purpose of this study is to propose a novel self-driven synchronous rectifier with simple circuit configuration. The proposed rectifier is free from the auxiliary coil. Furthermore, only 4 basic elements suffice to implement the whole rectifier including the control circuit for the synchronous rectifier.

The following discussion consists of four sections. Section 2 presents the circuit configuration and the operation principle of the proposed synchronous rectifier. Section 3 presents the experiment to verify the effectiveness of the proposed rectifier. Finally, section 4 gives the conclusions.

II. PROPOSED SYNCHRONOUS RECTIFIER

A. Circuit Configuration

This subsection presents the circuit configuration of the proposed synchronous rectifier. Figure 3 depicts the proposed self-driven synchronous rectifier attached to the receiving resonator. The proposed rectifier and the power load R_L is marked by the dashed box. Diode D1, P-ch MOSFET S1, and decoupling capacitor C1 form the basic structure of the

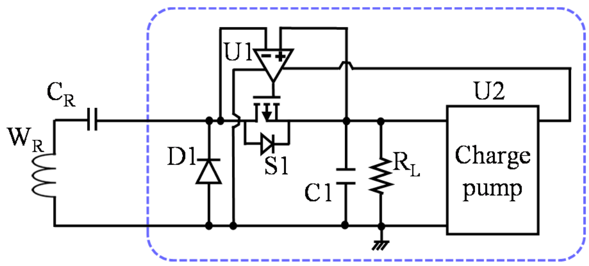


Fig. 3. Circuit diagram of the proposed self-driven synchronous rectifier attached to the receiving resonator.

synchronous rectifier. Comparator U1 is employed to detect the voltage difference between the drain and source of S1. Comparator U1 works as the controller of S1, as discussed in the next subsection in detail. Charge pump U2 is employed for the power supply to U1 by generating the DC voltage source with twice as large voltage as the output voltage. W_R and C_R are the receiving coil and the capacitor, respectively, which compose the receiving resonator.

As can be seen in Fig.3, the proposed rectifier replaces diode D2 in the conventional rectifier, i.e. Fig.2, by MOSFET S1. This results in elimination of the voltage drop at D2. In order to effectively reduce the voltage drop, S1 is designed to have small on-resistance so that the drain-source voltage of S1 during the on-state is far smaller than the voltage drop at D2. As a result, the parasitic resistance r_R can be reduced to improve the efficiency and the output power.

Certainly, diode D1 is not replaced by a MOSFET in the proposed rectifier unlike other conventional self-driven synchronous rectifier topologies. Hence, diode D1 still generates the conduction loss. In the proposed rectifier, D1 remains unchanged in order to simplify the whole circuit configuration, which tends to have more priority in small mobile applications with limited installation space.

B. Operation Principle

In the RIC-WPT system, the AC current in the receiving coil is induced by AC magnetization of the transmitting coil. According to the direction of the AC current, the operation of the proposed rectifier can be divided in two modes. Current patterns of these modes are shown in Fig. 4. In addition, Fig.5 depicts the timing diagram of the proposed rectifier, where v_{com} and v_c are the output voltage of the comparator and the charge pump, respectively; v_{gs} is the voltage difference between the gate and source of MOSFET S1; r_{on} and i_d are the on-resistance and the drain current of S1, respectively.

In mode 1, the AC current flows from the receiving coil W_R to the power load R_L. This current generates small voltage drop

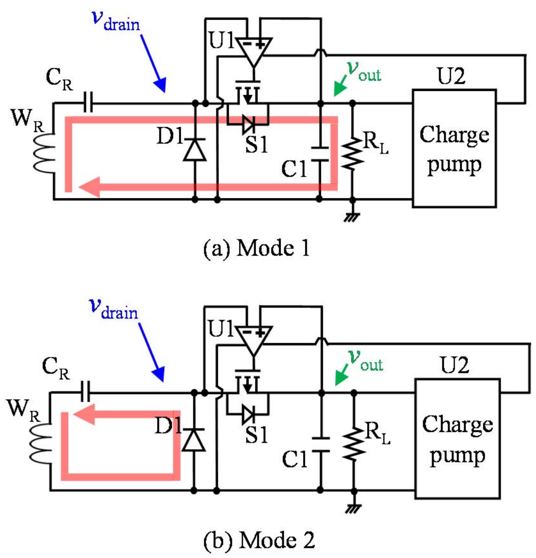


Fig. 4. Operation modes of the proposed synchronous rectifier.

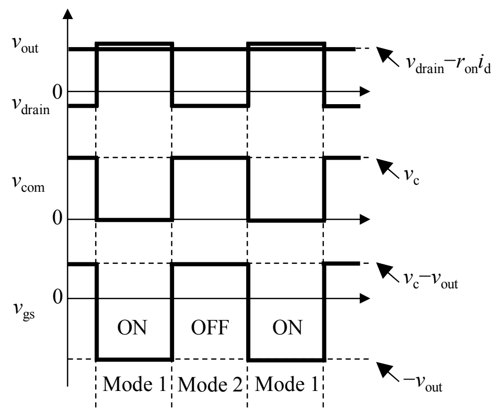


Fig. 5. Timing diagram of the proposed synchronous rectifier.

at S1 due to the on-resistance r_{on}. Hence, v_{drain} is slightly larger than v_{out}. Comparator U1 compares v_{drain} and v_{out}. As a result, U1 outputs the ground level voltage. Therefore, S1 is kept at the on-state because the voltage level of the gate is far lower than that of the source. Because S1 is in the on-state, the voltage drop at S1 is $r_{on}i_d$, which is designed to be far smaller than the voltage drop of the diode. Therefore, the conduction loss can be suppressed in this mode and the figure-of-merit can be improved compared with the diodes rectifier.

In mode 2, the receiving coil current flows through D1 to form the circulating current path. Therefore, v_{drain} is far lower than v_{out}. Hence, U1 outputs the high voltage level. This voltage level is equal to the voltage level of the power supply to U1, i.e. the twice as high voltage as the output voltage. As a result, S1 is kept at the off-state, preventing the reverse current from flowing from the source to the drain of S1. Therefore, the operation of this mode is similar to that of the conventional diodes rectifier.

C. Design of the Proposed Synchronous Rectifier

This subsection discuss design considerations for the proposed rectifier. As for D1, C1 and R_L, design is the same as the diodes rectifiers. Therefore, design considerations for U2, U1, and S1 are discussed below.

Charge pump U2: Generally, the output voltage of the RIC-WPT system is greatly dependent on the magnetic coupling between the transmitting and receiving coils. Therefore, the output voltage may have large variation in the RIC-WPT system for the mobile apparatus. Charge pump U2 is required to have wide operating voltage range to tolerate this large variation of the output voltage. Particularly, low under-voltage-lockout voltage and high maximum operating voltage is preferable for the charge pump for the proposed rectifier.

Comparator U1: Similarly as U2, Comparator U1 is also required to have wide supply voltage range because the output voltage of U2 tends to have large variation according to the magnetic coupling. In addition, U1 is required to detect small voltage difference caused by the on-resistance at S1, which may take the order of 1mV. Therefore, U1 should be enough sensitive and should not have Schmitt-trigger input. Besides, U1 is required to have far smaller rise and fall time as well as propagation delay time than the frequency of the AC voltage of the transmitting resonator.

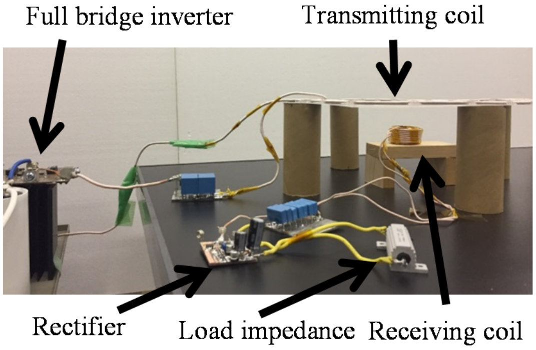
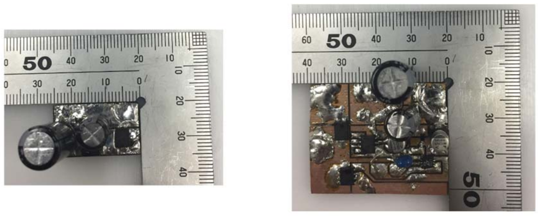


Fig. 6. Photograph of the experimental RIC-WPT system.



(a) diodes rectifier (b) proposed rectifier

Fig. 7. Photographs of the prototypes of the diode rectifier and the proposed rectifier.

MOSFET S1: P channel MOSFET S1 should have large voltage tolerance of the gate-source voltage because the output voltage of the rectifier tends to have large variation. The gate-source voltage is approximately v_{out} in mode 1, whereas the voltage is $-v_{out}$ in mode 2. Therefore, S1 should have the gate-source voltage tolerance greater than the maximum possible output voltage of the rectifier. At the same time, S1 is required to have small threshold voltage in order to operate the proposed rectifier under weak magnetic coupling between the transmitting and receiving coils. The threshold voltage should be smaller than the minimum allowable output voltage v_{out} with sufficient margin.

Charge pump U2 is installed in order to supply sufficient voltage to U1 so that the input of U1 is sufficiently below the power supply voltage of U1. Comparator U1 is required to have sufficient sensitivity to detect small voltage drop at S1. Therefore, U2 is utilized so that the input has the suitable voltage level for U1 for sensitivity. However, if U1 is a rail-to-rail comparator and has sufficient sensitivity near the power supply voltage, U2 may be eliminated to further simplify the circuit.

III. EXPERIMENT

Experiment was carried out to verify the operating principle and the rectification efficiency improvement of the proposed rectifier. Improvement in the rectification efficiency indicates reduction in the power loss at the rectifier. Therefore, the rectification efficiency is an important factor that reflects the parasitic resistance added by the rectifier.

The operation and the rectification efficiency was evaluated in comparison with the conventional diode rectifier with the circuit topology shown in Fig. 2. A full bridge inverter was employed for the AC voltage source. This inverter operated at 100kHz. Although this inverter generates the square-wave voltage instead of the sinusoidal voltage, the transmitting resonator is excited only by the fundamental wave because the resonance frequency of the transmitting and receiving resonators are set at 100kHz. The transmitting current was adjusted by changing the DC power supply voltage to the inverter.

TABLE I. SPECIFICATIONS OF EXPERIMENTAL RIC-WPT SYSTEM

	Transmitting resonator	Receiving resonator
Coil diameter	Inner 230mm Outer 290mm	32mm
Number of turns	10T	20T
Parasitic Resistance	0.10Ω	63mΩ
Self-inductance	50μH	13μH
Capacitance	51.0nF	200nF

Mutual inductance : 0.36μH

TABLE II. SPECIFICATIONS OF THE PROTOTYPE RECTIFIERS

Diodes rectifier		Proposed rectifier	
D1	SBRT15U50SP5-13	D1	SBRT15U50SP5-13
D2	SBRT15U50SP5-13	U1	LT1711CMS8
		U2	ICL7660CSA
		S1	FDS4435BZ

650μF is utilized for C1 in both rectifiers.

Figure 6 shows the photograph of the experimental RIC-WPT system; and Fig. 7 shows the photographs of the prototypes of the conventional diode rectifier and the proposed synchronous rectifier, respectively. In the prototype, we utilized Si Schottky barrier diodes, which is known to show smaller forward voltage than the PN diodes. In addition, Table 1 and Table 2 present specifications of the experimental RIC-WPT system and the prototypes, respectively. In the experimental RIC-WPT system, a small coil was employed for the receiving coil because small mobile apparatus is assumed as application of the proposed synchronous rectifier. The distance between the transmitting and receiving resonators was set at 40mm.

A. Operating Principle

First, operation of the proposed synchronous rectifier was evaluated. In this experiment, the receiving coil current was set at 4.0Arms. At the same time, the load resistance of 3.0 Ω is connected to the output of the prototype rectifiers.

Figure 8 shows the experimental result. Fig. 8(a) shows the voltage of v_{out} and v_{drain} as well as the current of the receiving coil i_d, whereas Fig. 8(b) and Fig. 8(c) show the voltage

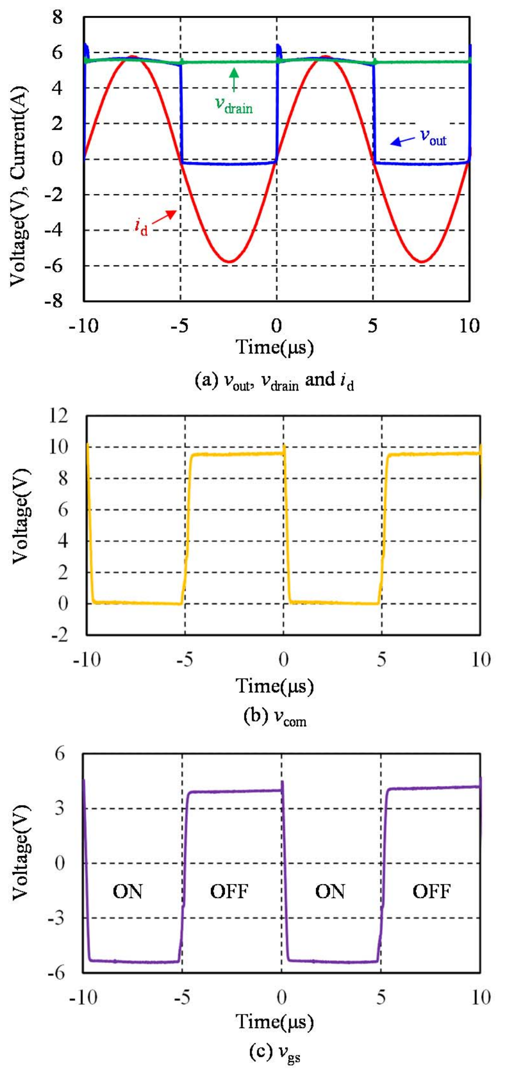


Fig. 8. Voltage and current waveforms of the proposed synchronous rectifier.

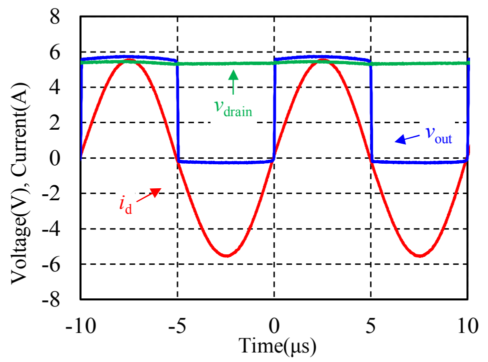


Fig. 9. Voltage and current waveforms of the diode rectifier.

waveforms of v_{com} and v_{gs}, respectively. On the other hand, Fig. 9 shows the voltage waveforms of the conventional diode rectifier. As can be seen in Fig. 8, the gate-source voltage v_{gs} of S1 was operated in accordance with the input voltage v_{drain} and

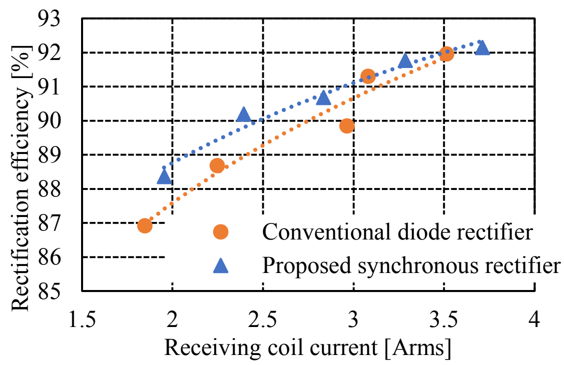


Fig. 10. Experimental result of the rectification efficiency.

the receiving coil current i_d of the proposed synchronous rectifier, as is consistent with the theory. Therefore, S1 worked as the synchronous rectifier.

During the on-state of S1, i.e. the period in which v_{gs} is kept at the low voltage level, the voltage difference between v_{out} and v_{drain} was found to be kept smaller than that of the conventional diode rectifier. This indicates suppression of the conduction loss in mode 1 by the synchronous rectifier. Certainly, there is a slight spike in v_{drain} at the beginning of the on-state of S1, i.e. mode 1. This spike generates the voltage drop close to the forward voltage drop of the body diode of S1, which is generally far larger than that of the Si Schottky barrier diodes. Therefore, this spike is consistently explained as the result of the fall time of v_{gs}, during which S1 still remains in the off-state and the AC current flows through the body diode of S1.

B. *Rectification Efficiency*

Next, the rectification efficiency was evaluated and compared between the proposed synchronous rectifier and the conventional diode rectifier. In this experiment, the rectification efficiency was measured by dividing the output power to the load resistance by the input AC power to the rectifiers. In this experiment, the load resistance was also set at 3Ω. The rectification efficiency was evaluated at various AC current of the receiving coil current to compare the dependence of the rectification efficiency on the receiving coil current. In order to change the receiving coil current, we adjusted the DC voltage supply of the full-bridge inverter in the experimental RIC-WPT system.

Figure 10 shows the result. As can be seen in the figure, the proposed synchronous rectifier showed better rectification efficiency regardless to the load resistance. Figure 10 also showed that the rectification efficiency of the proposed rectifier is approaching close to that of the diode rectifier, as the receiving coil current becomes larger. This may be caused by the increase of the voltage drop at S1 of the proposed synchronous rectifier according to the increase of the receiving coil current. Therefore, the rectification efficiency improvement of the proposed synchronous rectifier may be deteriorated at extremely large AC current induction in the receiving coil. Thence, the effectiveness of the proposed rectifier may be prominent in low power applications, such as the RIC-WPT to small mobile apparatus.

Consequently, this experiment supported the operating principle of the proposed synchronous rectifier as well as suppression of the conduction loss and the resultant improvement in the rectification efficiency.

IV. CONCLUSION

The RIC-WPT is attracting growing attention as the convenient power supply method to the small mobile apparatus. However, The RIC-WPT to small mobile apparatus tends to suffer from large parasitic resistance of the receiving resonator added by the conduction loss of the diode in the rectifier. This may result in low efficiency and weak output power, particularly in comparatively small power applications with low output voltage, resulting in low efficiency.

In order to overcome this issue, this paper proposed a novel simple self-driven synchronous rectifier for the RIC-WPT to the small mobile apparatus. The proposed synchronous rectifier has a simple circuit configuration because this circuit can be implemented only by a charge pump, a comparator, a P-MOSFET and a diode. This simple configuration is effective for saving installation space, as is often required in the small mobile apparatus.

The experiment verified suppression of the conduction loss and improvement in the rectification efficiency, supporting effectiveness of the proposed synchronous rectifier. Consequently, this rectifier can be a promising technique for practical application of the RIC-WPT to small mobile apparatus.

REFERENCES

[1] Z. N. Low, R. A. Chinga, and R. Tseng, "Design and test of a high-power high-efficiency loosely coupled planar wireless power transfer system," IEEE Trans. Ind. Electron., vol.56, no.5, pp1801–1812, 2009.

[2] T. Imura and Y. Hori, "Maximizing air gap and efficiency of magnetic resonant coupling for wireless power transfer using equivalent circuit and Neumann formula," IEEE Trans. Ind. Electron., vol.58, no.10, pp. 4746–4752, 2011.

[3] R. Bosshard, J. Muhlethaler, J. W. Kolar, and I. Stevanovic, "optimized magnetic design for inductive power transfer coils," Proc. IEEE Appl. Power Electron. Conf. Expo. (APEC), pp.1812–1819, 2013.

[4] I. Awai, "Basic characteristics of "Magnetic resonance" wireless power transfer system excited by a 0 ohm power source," IEICE Electron. Express, vol.10, no.21, pp. 1–13, 2013.

[5] R. Huang, B. Zhang, D. Qiu, and Y. Zhang, "Frequency splitting phenomena of magnetic resonant coupling wireless power transfer," IEEE Trans. Magn., vol.50, no.11, 8600204, 2014.

[6] D. Ahn and S. Hong, "Wireless power transfer resonance coupling amplification by load-modulation switching controller," IEEE Trans. Ind. Electron., vol.62, no.2, pp. 898–909, 2015.

[7] V. Jiwariyavej, T. Imura, and Y. Hori, "Coupling coefficients estimation of wireless power transfer system via magnetic resonance coupling using information from either side of the system," IEEE J. Emerg. Sel. Topics Power Electron., vol.3, no.1, pp. 191–200, 2015.

[8] H. Li, J. Li, K. Wang, W. Chen, and X. Yang, "A maximum efficiency point tracking control scheme for wireless power transfer systems using magnetic resonant coupling," IEEE Trans. Power Electron., vol.30, no.7, pp. 3998–4008, 2015.

[9] M. R. V. Moghadam and R. Zhang, "Multiuser wireless power transfer via magnetic resonant coupling: performance analysis, charging control, and power region characterization," IEEE Trans. Signal Inform. Process. Over Networks, vol.2, no.1, pp. 72–82, 2016.

[10] H. Jiang, J. Zhang, D. Lan, K. K. Chao, S. Liou, H. Shahnasser, R. Fechter, S. Hirose, M. Harrison, and S. Roy, "A low-frequency versatile wireless power transfer technology for biomedical implants," IEEE Trans. Biomed. Circuits Syst., vol.7, no.4, pp.526–535, 2013.

[11] R. Xue, K. Cheng, and M. Je, "High-efficiency wireless power transfer for biomedical implants by optimal resonant load transformation," IEEE Trans. Circuits Syst. I, Reg. Papers, vol.60, no.4, pp.867–874, 2013.

[12] T. Koyama, T. Honjo, K. Umetani, and E. Hiraki, "Lagrangian derivation and analysis of a simple equivalent circuit model of wireless power transfer system with dual transmitting resonators," in Proc. European Conf. Power Electron. Appl. (EPE2016), Karlsruhe, Germany, Sept. 2016, pp. P1–P10.

[13] H. Liu, Q. Shao, and X. Fang, "Modeling and optimization of class-E amplifier at subnominal condition in a wireless power transfer system for biomedical implants," IEEE Trans. Biomed. Circuits Syst., vol.PP, no.99, pp.1–9, 2016.

[14] A. K. RamRakhyani and G. Lazzi, "On the design of efficient multi-coil telemetry system for biomedical implants," IEEE Trans. Biomed. Circuits Syst., vol.7, no.1, pp.11–23, 2013.

[15] M. Pinuela, D. C. Yates, S. Lucyszyn, and P. D. Mitcheson, "Maximising DC to load efficiency for inductive power transfer," IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2437–2447, 2012.

[16] M. W. Baker and R. Sarpeshkar, "Feedback analysis and design of RF power links for low-power bionic systems," IEEE Trans. Biomed. Circuits Syst., vol. 1, pp. 28–38, 2007.

[17] T. Honjo, T. Koyama, K. Umetani, and E. Hiraki, "Novel receiving coil structure for improving efficiency and power transfer capability of resonant inductive coupling wireless power transfer," in Proc. IEEE Intl. Conf. Elect. Mach. Syst. (ICEMS2016), Chiba, Japan, Nov. 2016, pp. 1–6.

[18] P. Hurtuk, R. Radvan, M. Frivaldsky, "Full bridge converter with synchronous rectifiers for low output voltage application" Proc. Applied Electronics (AE), 2011

[19] K. Murata, K. Harada, and T. Harimoto, "Self turn-on loss of MOSFET as synchronous rectifier in dc/dc buck converter—In case of a low driving impedance," Proc. IEEE Power Electron. Spec. Conf., pp. 3348–3353, Jun. 2008.

[20] B.-H. Kwon, J.-H. Youm, and J.-W. Lim, "A line-voltage-sensorlesssynchronous rectifier," IEEE Trans. Power Electron., vol. 14, no. 5, pp. 966–972, Sep. 1999.

[21] P. Alou, J. A. Cobos, O. Garcia, R. Prieto and J. Uceda, "A new driving scheme for synchronous rectifiers: single winding self-driven synchronous rectification" IEEE Trans. Power Electron., vol. 16, no. 6, pp. 803–811, Nov. 2001.

[22] X. Xie, J. C. P. Liu, F. N. K. Poon, and M. H. Pong, "A novel high frequency current-driven synchronous rectifier for low voltage high current applications", Proc. Applied Power Electronics Conference and Exposition (APEC), vol. 1, pp469–475, Mar. 2001.

[23] G.-Y. Jeong, "High efficiency asymmetrical half-bridge converter using a self-driven synchronous rectifier," IET Power Electron., vol. 1, no. 1, pp. 62–71, Mar.2008.

[24] W. X. Zhong, S. Y. Hui, W. C. Ho and Xun Liu, "Using self-driven AC-DC synchronous rectifier as a direct replacement for tradirional power diode rectifier" IEEE Trans. Ind. Electron., vol. 59, no. 1, pp. 392–401, Jan. 2012.

[25] W. X. Zhong, W. P. Choi, Wing W. C. Ho and S. Y. Hui, "Generalized self-driven AC-DC synchronous rectification tecniques for single- and multiple systems" IEEE Trans. Ind. Electron., Vol. 58, no. 8, pp. 3287–3297, Aug. 2011.