Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp821-822

PS-5-10 (Late News)

A High-Efficiency Wide-Input-Voltage-Range CMOS Voltage Doubler Rectifier for RF Wireless Power Transfer Systems

Yu-Lung Lo[1], Teng-Huei Tsai[1], Wei-Ming Cheng[1], and Wei-Bin Yang[2]

[1] Department of Electronic Engineering, National Kaohsiung Normal University,
No. 62, Shenzhong Rd., Yanchao Dist., Kaohsiung City, Taiwan
[2] Department of Electrical Engineering, Tamkang University,
No. 151, Yingzhuan Rd., Tamsui Dist., New Taipei City, Taiwan
Phone: +886-7-7172930#7917 Email: yllo@nknu.edu.tw

Abstract

The voltage doubler rectifier (VDR) is designed for wireless power transfer (WPT) systems. This work featured with wide input voltage range, high voltage conversion ratio (VCR), and high power conversion efficiency (PCE) by active diodes to reduce threshold voltage (V_T) and low voltage assist rectifier (LVAR) to extend working voltage range. The experimental results for a 0.18μm standard CMOS process with a 1.8V power supply voltage demonstrate that the proposed VDR can operate from a low voltage (0.7$V_{AC.peak}$) to a high voltage (2$V_{AC.peak}$) while maintaining high PCE. When input voltage is 1.2$V_{AC.peak}$, the PCE is up to 84% and the VCR is over 1.73. When input voltage is 0.7$V_{AC.peak}$, the PCE can maintain to 65% and the VCR is 1.34.

1. Introduction

The RF wireless power transfer (WPT) system is a fundamental enabling technology of the Internet of Things (IoT) concept, since it minimizes the use of batteries and eliminates wired power connections. Besides, in terms of health-related applications, implantable biomedical devices play emerging and promising roles in a variety of monitoring, diagnostic, therapeutic and interventional applications. Such devices require real-time power transfer in the range of 10 to 100mW [1], and as human tissue specific absorption rate (SAR) increases with frequency, inductively-coupled power links that operate at 13.56MHz or lower in ISM bands are commonly used [2].

The boost rectifier have better PCE in different peak alternating current (AC) input voltage [3], [4]. In other words, the boost rectifier have characteristic of wide input voltage so it has advantages for WPT application. The most of previous boost rectifiers adopted multistage gate cross-coupled rectifier (MGCCR) [5]. Though the rectifier was feature high speed, low voltage, reverse current occurred when voltage was little higher and had narrow working range. To improve the performance at high voltage, the active voltage doubler rectifier (AVDR) was presented in [2]. Though the problem of high voltage was solved and the threshold-voltage of diodes was reduced. However, the PCE couldn't be optimization.

In this paper, the comparator-controlled power switches with dynamic base bias (DBB) circuit and LVAR with adaptive voltage control circuit (AVCC) were used to design a voltage doubler rectifier to achieve better PCE under various input voltages.

2. Proposed Voltage Doubler Rectifier

The proposed voltage doubler rectifier (VDR) consists of comparator-controlled power switches with dynamic base bias (DBB) circuit and the low voltage assist rectifier (LVAR), as shown in Fig. 1. In the VDR unit, the four active diodes were used to replace diodes so that the rectifier could work at a lower $V_{AC.Peak}$. The active-rectifier suffered from reverse current caused by the comparators that turned off the power switches with delay. Therefore, the unbalanced-based comparators were used to set an artificial input offset voltage to compensate for the delay and to turn the power switches on and off properly [2]. In high voltage operation, there were two steps in this work without LVAR, charging and boosting. When V_{AC+} was high and V_{AC-} was low, the capacitor C_{F1} was charged to $V_{AC.peak}$. Meanwhile, the capacitor C_{F2} is boosting the output voltage to $2\times V_{AC.peak}$.

Though the active rectifier has better VCR and PCE, however, it couldn't work well at low voltage operation. To improve the performance in low voltage operation, the rectifier with bootstrapping circuit (RBC) was used as the energy harvesting circuit at low voltage situation. Therefore, the low voltage assist rectifier (LVAR) is proposed to achieve high VCR and PCE at voltage operation. Figure 2 shows the proposed LVAR with adaptive voltage control circuit (AVCC) in this work. When the input voltage was lower than 1.2$V_{AC.peak}$, the input voltage of AVCC (V_{IN}) would lower than a transition voltage, the LVAR transferred 'high' to power MOS (M_{P1} and M_{P3} in Fig. 1) of the active rectifier and the active rectifier stop working. The RBC of LVAR would take charge of charging and boosting the flying capacitances.

3. Experimental Results

The layout of the proposed VDR is shown in Fig. 3. The proposed VDR was design in a 0.18μm standard CMOS process with a 1.8V power supply voltage. Figure 4 shows the simulation waveforms of the proposed VDR with V_{OUT} values of 0.94 and 3.68V at 0.7 and 2V $V_{AC.Peak}$, respectively. Under the same condition of 300Ω load resistance, the proposed circuit was compared with AVDR [2] and MGCCR [5], as shown in Fig. 5. Compared with the AVDR, the proposed VDR achieves a better PCE in low voltage operation; moreover, the proposed VDR achieves a better PCE than MGCCR in high voltage operation. Table I shows the simulation and comparison results with previous works. The comparison indicates that the proposed VDR has a wider input voltage range and a better performance on PCE and VCR.

4. Conclusions

This paper proposes a VDR, which features wide input voltage range, high PCE, and high VCR. Using the LVAR with AVCC to dynamically detect output voltage to enable switching to different circuit modes, thereby achieving high PCE. The proposed VDR has up to 84% PCE and 1.84 VCR. Moreover, the proposed rectifier is its ability to maintain high PCE in both low voltage operation ($V_{AC.peak}$=0.7V) and high voltage operation ($V_{AC.peak}$=2V). With these advantages, the proposed VDR is suitable for RF wireless power transfer systems, such as IoT and biomedical applications.

References

[1] K. Chen, et al., "An integrated 256-channel epiretinal prosthesis," *IEEE J. Solid-State Circuits*, vol. 45, no. 9, pp. 1946–1956, Sept. 2010.

[2] Y. Lu, et al., "A 13.56 MHz fully integrated 1X/2X active rectifier with compensated bias current for inductively powered devices," in Proc. *IEEE Int. Solid-State Circuits Conf. Dig. Tech. Papers*, Feb. 2013, pp. 288–289.

[3] H. Lee, et al., "An adaptive reconfigurable active voltage doubler/rectifier for extended-range inductive power transmission," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 59, no. 8, pp. 481–485, July. 2012.

[4] K. Eguchi, et al., "Design of a charge-pump type AC-DC converter for RF-ID tags," in *Proc. Int. Symp. Commun. Inf. Technologies*, Oct. 2006, pp. 1203–1206.

[5] A. Moghaddam, et al., "A 73.9%-efficiency CMOS rectifier using a lower dc feeding (LDCF) self-body-biasing technique for far-field RF energy-harvesting Systems," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 64, no. 4, pp. 992–1002, Apr. 2017.

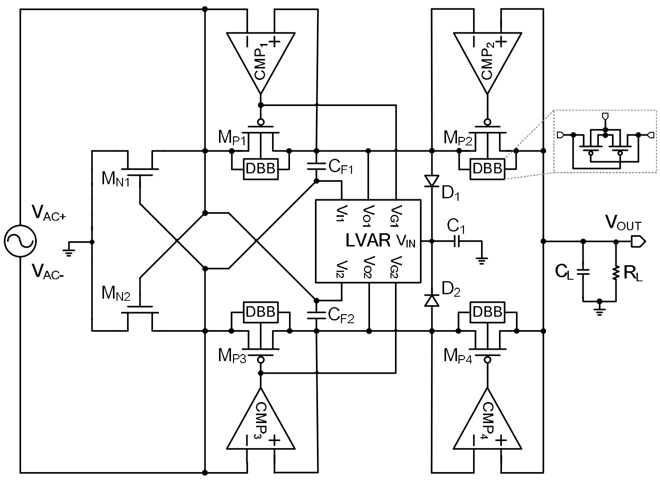

Fig. 1. Proposed voltage doubler rectifier.

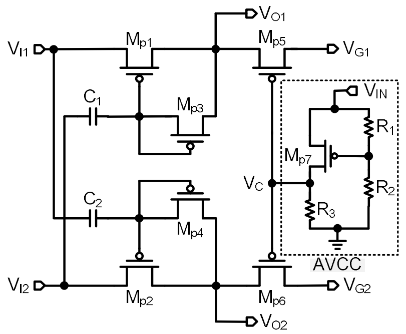

Fig. 2. LVAR circuit.

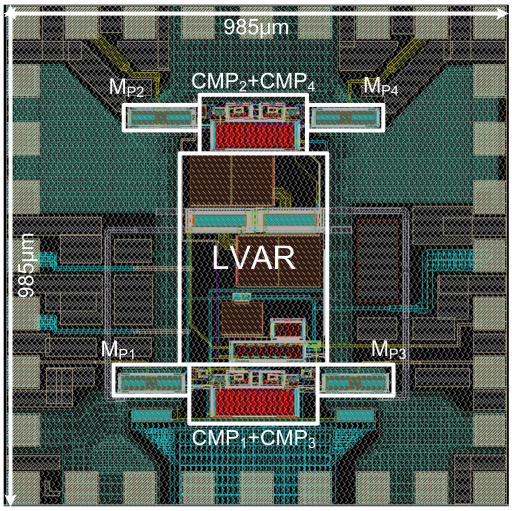

Fig. 3. Layout of the proposed voltage doubler rectifier.

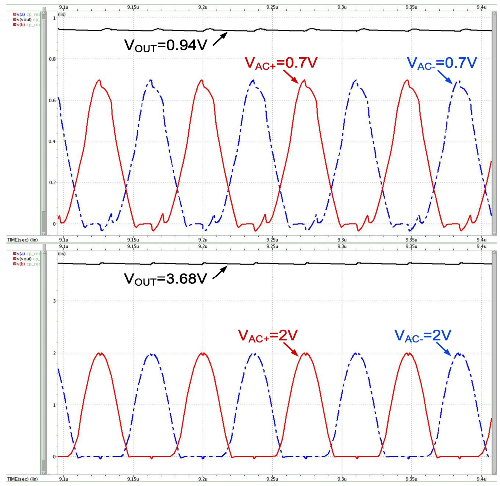

Fig. 4. Simulation results of 0.7V $_{AC.Peak}$ and 2V $_{AC.Peak}$ input voltages.

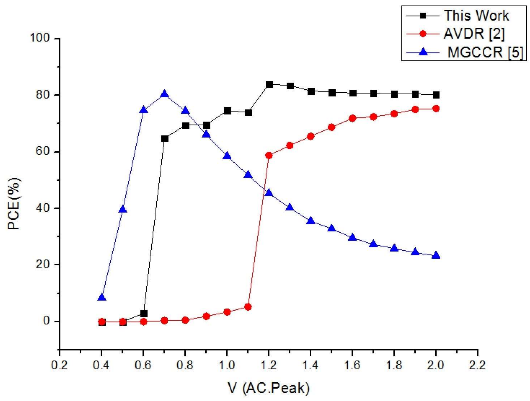

Fig. 5. Comparison results of previous works.

Table I. Comparison results of voltage doubler rectifiers.

Parameter	[2]	[3]	[4]	This work
Tech. (μm)	0.35	0.5	0.35	0.18
Freq. (MHz)	13.56	13.56	200	13.56
$V_{AC.Peak}$ (V)	1.25~2.5	0.9~2	1	0.7~2
V_{OUT} (V)	1.27~4	2.5~4.3	N/A	0.94~3.68
P_{OUT} (mW)	32	3.2	<5	4.3~32.4
VCR	1.3~1.61	<1.41	N/A	1.34~1.84
PCE (%)	61~76	64~70	<85	65~84