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The Designs of Low Power AC-DC Converter for Power Electronics System Applications

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Abstract— **This paper reviews low power AC-DC converter in different techniques capable of developing high efficiency of energy consumption in many applications. By using low power AC-DC converter, the size of whole system integrated circuit could be reduced. However, the requirements of CMOS converter that required low input voltage and low voltage drop of MOS transistors is discussed. Different techniques in different application are implemented to overcome those problems. In this paper, the reviews of low power AC-DC converters have been focused for energy harvesting systems and wireless power devices only. These AC-DC converters consume several micro-watts from small ac or rf signal voltage and achieve excellent performance in terms of power efficiency. However, the power efficiency of AC-DC converter system is actually highly correlated to the relationship between voltage and the alternating current in ac source. It is because, an in-phase voltage and current in alternating current source is causing in good power factor performance. Power factor correction, PFC is important in many single-phase AC-DC converter circuits to reduce harmonic distortion, hence increase power efficiency of electric appliances. Therefore, the low power AC-DC converter with PFC is proposed. The post-layout of low power AC-DC converter is designed by using the Silterra 0.18 µm technology. The whole post-layout AC-DC converter circuit consumes only 50 µW and works in low voltage, 1V. The power efficiency of whole system also improved to 93%. The proposed low power AC-DC converter with PFC is suitable for future power electronics systems such as battery charger and energy conversion devices.**

Keywords- low power, AC-DC converter, low-voltage drop, power efficiency, CMOS technology, power factor correction (PFC)

I. INTRODUCTION

The demand for AC-DC converter circuits that can efficiently operate at very low voltages is increasing as a consequence of the growing interest for the miniaturization of portable devices in communications and microelectronics system. It is because low supply voltage allows a device to be powered from a single cell of battery thus reducing power consumption [1, 2]. By using low input voltage AC-DC converter with low power consumption, then the size of integrated low power AC-DC converter circuit could be reduced. However, there are many challenges associated with reducing size of integrated AC-DC converter circuits. Among these problems are low voltage (around 1 V) required as source of AC-DC converter circuit and high voltage drop of diode in bridge-AC-DC converter. These problems cause low power efficiency of low power AC-DC converter integrated circuits are developed.

As a step toward low power AC-DC converter with high power efficiency, the development of CMOS converter using latest IC technology is needed. There are many techniques of proposed circuit to realize the low power AC-DC converter requirements in many different applications. In many energy harvesting devices, a AC-DC converter circuit generates the dc voltage from a received ac or rf voltage [3]. An ac or rf voltage comes from vibrations or even from the body motions which are classified as kinetic energy to generate energy source. Usually, piezoelectric (PE) transducer parallel with switch controller is used to convert kinetic energy as power supply of low power AC-DC converter to generate electrical power [4-6]. The power extracted from PE in energy harvesting is improved by technique of bias-flip AC-DC converter compared with existing full-bridge AC-DC converter [7].

However, if the energy source is not from vibration or rf signal, it would be a sinusoidal wave, therefore AC-DC converter charge pump is required to transfer the AC signal to DC source. The multi-stage AC-DC converter charge pump circuit is designed to improved efficiency better than conventional AC-DC converter charge pump's especially for an energy harvesting system [8]. The use of energy harvesting as energy source has also been applied for biomedical devices. Implantable biomedical devices have been developed for different applications such as retinal prosthesis, cochlear implant, arm rehabilitation, etc [9].

Furthermore, low power AC-DC converter in energy harvesting system also has problems with threshold voltage drop of diodes [10]. The introducing of a cross-coupled active switch only AC-DC converter in energy harvesting systems is important to overcome the limitation of the voltage drop [11].

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This topology replaced diodes with MOS transistors as switch in low power AC-DC converter circuit. Another technique is used to overcome the problem of threshold voltage drop by applying bootstrapped circuit in AC-DC converter circuit. This technique usually employed in RFID tag where high efficient of low power AC-DC converter is much required [12, 13].

Differ for wirelessly power devices, a simple low voltage active diode combined with negative voltage converter is more popular technique to improve efficiency. By using this technique, the low power AC-DC converter is achieved by reduction of input voltage using wireless inductively coupled link as power source and suitable for RFID tag and biomedical implants [14-16]. Conversely, an implement of comparator-controller switches in low power AC-DC converter is innovative used to minimize the voltage drop and usually used in high-current biomedical implants [17]. The development of low power AC-DC converters with low voltage drop over the MOSFETs and high performance in terms of power efficiency is discussed. Implementation several technique which discussed above are further explained in Section II. While, section III describes a proposed low power AC-DC converter for power electronics system with power factor correction (PFC).

II. STATE OF THE ART OF LOW POWER AC-DC CONVERTERS

In this chapter the designs of low power AC-DC converter is classified by different applications. Usually, low power AC-DC converter is used in energy harvesting systems and wireless power devices. The different design is developed for different purpose in order to meet low power AC-DC converter requirements. Therefore, in this chapter state of the art of low power AC-DC converter in energy harvesting systems and wireless power devices are reviewed.

A. Low power AC-DC converter in energy harvesting systems.

There are two popular techniques of low power AC/DC converter in energy harvesting systems. The techniques are active AC-DC converter with piezoelectric, PE transducer and bias-flip AC-DC converter with shared inductor.

The active AC-DC converter shown in Figure 1(a) introduced a cross-coupled active switch-only AC-DC converter adds on switch S1 in parallel with piezoelectric, PE transducer. PE transducer is one of the most important parts in energy harvesting system to convert kinetic energy from small motions and vibrations to electrical power. The AC-DC converter shows both good performances in power extraction and conversion ability. Based on TSMC 0.18 µm CMOS technology, simulation result for this technique is achieved with 91 % power efficiency and consumed 144 µW at 95 kΩ load. The AC-DC converter improve upon the efficiency by 1.5 times better compared with passive switch AC-DC converter in energy harvesting applications [11].

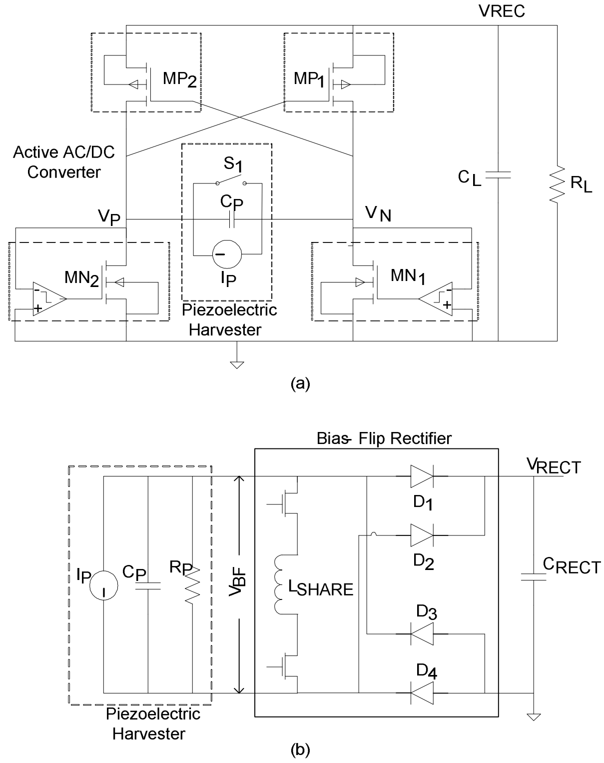


Figure 1 (a) Active AC-DC converter for vibration energy harvesting systems with PE transducer, (b) Bias-flip AC-DC converter and shared inductor in order to improve efficiency of energy harvesting interface circuit.

Another technique is employed in energy harvesting system is shown in Figure 1 (b). The paper introduced new design of bias-flip AC-DC converter and shared inductor in order to improve efficiency of piezoelectric energy harvesting interface circuit. The bias-flip AC-DC converter is used to improve the power extracted from piezoelectric harvesters compared with commonly used in conventional full-bridge AC-DC converter and voltage doublers. However, this technique required the inductor to minimize the number of off-chip components and improve cost-efficient of the system. Based on 0.35 µm CMOS process, the piezoelectric energy harvester interface circuit is implemented. This technique achieved 85 % power efficiency and contributed 32.5 µW at the storage capacitor. The input voltage of bias-flip AC-DC converter is set to 2.4 V with voltage drop of CMOS diode used is 380 mV [7].

B. Low power AC-DC converter in wireless power devices

Low power AC-DC converter also is implemented in integrated circuit of wireless power devices in order to reduce the input voltage and produce small voltage drop, thus increase power efficiency of the devices. Therefore, two techniques which commonly used are negative voltage converter with active diode and gate cross-coupled AC-DC converter with bootstrap capacitor, shown in Figure 2.

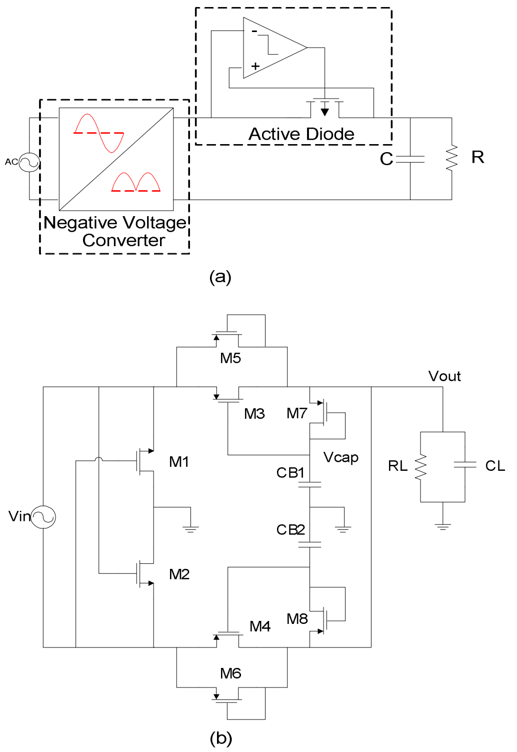


Figure 2. (a) Negative voltage converter with active diode, (b) Gate cross-coupled AC-DC converter with bootstrap capacitor in order to improve efficiency of wireless power devices integrated circuit.

The main goals of the AC-DC converter design for wireless power devices are the reduction of the input voltage and achievement of high power efficiency is shown in Figure 2(a). The low power AC-DC converter introduced two stages of low voltage processes; the negative voltage converter and the simple low-voltage active diode. The negative voltage converter converts the negative half-wave of the input sinusoidal wave to full-wave rectification, which is done by two PMOS and two NMOS transistors. Additionally, the low operation voltage active diode is used to control the current direction of transistors; therefore it is necessary to block the reverse leak current. Based on 0.18 µm CMOS technology, the low-voltage AC-DC converter is achieved by simulated result with 81 % power efficiency at 500Ω load. The AC-DC converter is improved upon the efficiency and suited for a low input voltage, 0.7 V by using a simple low-voltage operation comparator-controlled switch.

Low power AC-DC converter with different technique is presented for wireless power devices as shown in Figure 2(b). The gate cross-coupled AC-DC converter is combined with the bootstrap technique to produce smaller voltage drop and increase power efficiency. The gate cross-coupled AC-DC converter improved voltage drop of diode-connected by replace it with effective voltage drop across a MOS switch. The technique also reduced switch leakages and improved the switch conductivity. However, the gate cross-coupled AC-DC converter requires additional circuit to reduce the effect of threshold voltage, Vth in the CMOS integrated circuit. Therefore, the bootstrapped capacitor is proposed to solve the drawback is occurring. In addition, the bootstrapped capacitor increase the output voltage range for a given input source voltage, thus increase power efficiency. The design has been implemented in TSMC 0.18 um CMOS technology and achieved 86 % power efficiency with input amplitude voltage is set to 3.3 V. The gate cross-coupled AC-DC converter combined with the bootstrap technique is more suitable for wireless power devices and RFID tags [13, 18].

III. PROPOSED LOW POWER AC-DC CONVERTER WITH POWER FACTOR CORRECTION (PFC) FOR POWER ELECTRONICS SYSTEM

The low power AC-DC converters which discussed above have been designed for energy harvesting systems and wireless power devices, these AC-DC converters consume several micro-watts from small ac or rf signal voltage and achieve excellent performance in terms of power efficiency. However, the power efficiency of AC-DC converter system is actually highly correlated to the relationship between voltage and the alternating current in ac source. It is because, an in-phase voltage and current in alternating current source is causing in good power factor performance. Therefore, power factor correction, PFC is important in many single-phase AC-DC converter circuits to reduce harmonic distortion, hence increase power efficiency of electric appliances.

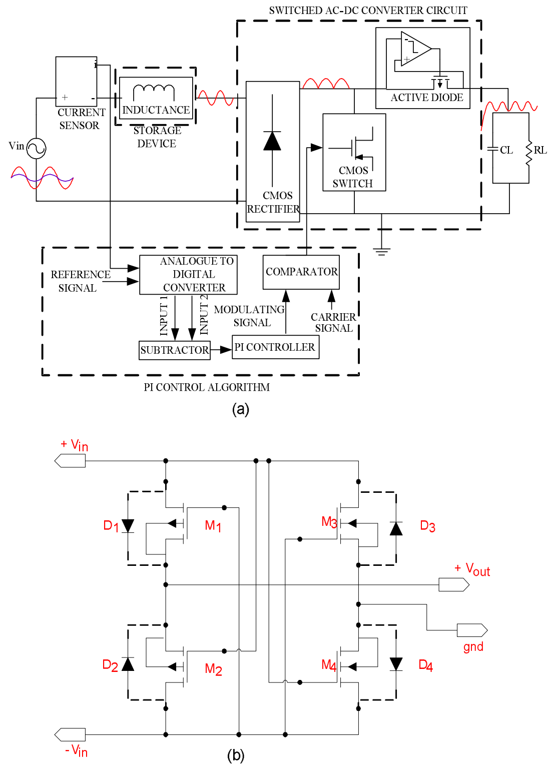


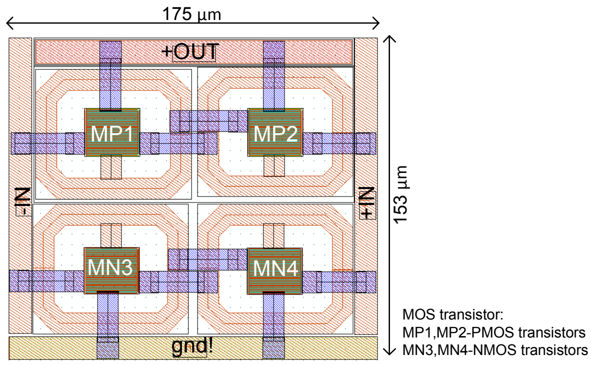
Figure 3. (a) Architecture of low power AC-DC converter with power factor correction, PFC, (b) Operation of low power AC-DC converter with diode.

The main goals of the proposed low power AC-DC switch converter with PFC scheme are the reduction of the input voltage, achievement of nearly unity power factor and improve system efficiency, shown in Figure 3(a). The proposed converter can be divided into four stages; CMOS converter; low voltage active diode; switch boost topology and PI controller.

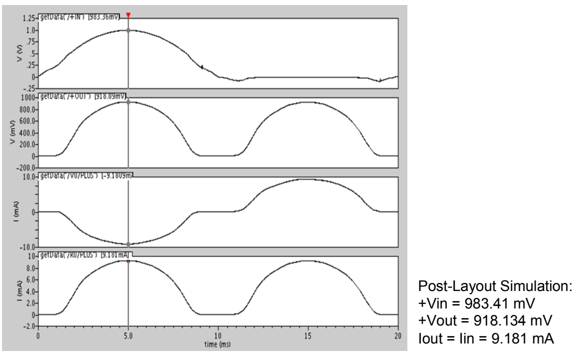
The CMOS converter used in this study consists of two PMOS transistors and two NMOS transistors, shown in Figure 3(b). In this case, the large transistor size is used to decrease the resistance and maximize the voltage drop. However, when CMOS converter with almost no voltage drop is used, it cannot control the current direction; therefore an active diode as blocking diode is required.

IV. Post-Layout Simulation Results

The post-layout of the low power AC-DC converter is shown in Figure 4(a). It is designed by using Silterra 0.18 µm CMOS technology with layout area of 0.0268mm^2. This work provides high power efficiency of low power converter with a low input voltage, 1V and save more power.



(a)



(b)

Figure 4. (a) Post-layout of low power AC-DC converter with area of 0.0268mm^2, (b) Post-layout simulation of low power AC-DC converter

The post-layout simulations have been done to verify the proposed ideas design against conceptual schematic model, shown in Figure 4(b). Table 1 below shows the performance of Low power AC-DC converter compared with other designs in literature. The proposed of low power AC-DC converter improved upon the power efficiency of 93% compare to others designs in literature. A low power AC-DC converter for power electronics system is presented.

V. Conclusion

The post-layout of low power AC-DC converter is designed by using the Silterra 0.18 µm technology, which is cost effective technology for the highly competitive consumer electronics market. The whole post-layout AC-DC converter circuit consumes only 50 µW and works in low voltage, 1V. The power efficiency of whole system also improved to 93%. The proposed low power AC-DC converter is suitable for future power electronics systems such as battery charger and energy conversion devices.

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TABLE I. PERFORMANCE COMPARISONS WITH PREVIOUSLY LITERATURE OF LOW POWER AC-DC CONVERTERS

Design Technique of CMOS converters	**Performance**				
	CMOS Technology	***Input Voltage, Vin***	***Output Voltage, Vout***	***Power Efficiency, Peff***	***Application***
Negative Voltage Converter with Active Diode [10]	0.35 µm	2.75 V	2.735 V, (RL=20 kΩ)	90%	RFID tags
A Cross-Coupled Active Switch-Only AC-DC converter with PE transducer [11]	0.18 µm	-	3.7 V, (RL=95 kΩ)	91%	Energy Harvesting Systems
Gate Cross-Coupled AC-DC converter with Bootstrapped Capacitor [13]	0.18 µm	3.3 V	2.8 V, (RL=2 kΩ)	86%	Wirelessly Powered Devices
Negative Voltage Converter with Low Voltage Active Diode [14]	0.18 µm	0.7 V	0.575 V, (RL=500 Ω)	82%	Wirelessly Powered Devices
Negative Voltage Converter with Active Diode [16]	0.18 µm	0.3 V	- (RL=40 kΩ)	87%	Energy Harvesting Systems
Comparator-Controlled Switches with Unbalanced-Biasing AC-DC converter [17]	0.35 µm	1.2 V	0.98 V, (RL=100 Ω)	82%	High-Current Biomedical Implants
Proposed-Low-Voltage CMOS converter with Power Factor Correction (PFC)	0.18 µm	1 V	0.918 V. (RL=100 Ω)	93%	Power Electronics System

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