A Parellel-SSHI Rectifier for Piezoelectric Energy Harvesting

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Abstract— **In energy-harvesting circuits, the traditional rectifier circuits use the full-bridge diode rectifier, but the loss of efficiency is large. In order to improve the efficiency, this paper presents a Parallel-SSHI piezoelectric energy harvesting system in a 0.18um CMOS process. The implemented interface is based on the Parallel-SSHI technique and can harvest from periodic and shock excitations. The device is capable of cold startup and provides a stable output voltage for powering an application.**

Index Terms—Bias-flip rectifier, common-gate comparator, energy harvesting, inductor sharing, piezoelectric, Parallel-SSHI

I. INTRODUCTION

Energy is everywhere in the environment surrounding in the form of thermal energy, light (solar) energy, wind energy, and mechanical energy. We can use advanced technical developments to increase the efficiency of devices in capturing amounts of energy from environment and transforming them into electrical energy. The most popular energy harvesting are the kinds of magnetic, piezoelectric and capacitive. Using piezoelectric elements is a popular way, because cantilever geometry is one of the most widely used architectures in piezoelectric energy harvesters (PEHs). Especially for mechanical energy harvesting form vibrations, a large mechanical strain can be produced within the piezoelectric material during vibration. Additionally, the fundamental bending mode of a cantilever is much lower than the other vibration modes of the piezoelectric elements.

In this paper, a rectifier with Synchronized Switch Harvesting Inductor (SSHI) is proposed for piezoelectric energy (PE) harvesting system. The serial inductor help to flip the voltage across the internal capacitor of PE transducer instead of wasting the capacitor voltage by discharge. Active diodes are used for the switches to further improve the extraction efficiency.

II. CIRCUIT DESCRIPTIONS

This section introduces and analysis of the Full-Bridge Diode Rectifier and the parallel-SSHI interface as alternatives for AC/DC conversion.

A. Full-Bridge Rectifier

A full-bridge rectifier is one of the most commonly used rectifier circuits to convert the AC output of a piezoelectric harvester into a DC voltage. A typical implementation of the full-bridge rectifier circuit shown in Fig 1. [1] During positive half cycle of the supply, diodes D1 and D4 conduct while diodes D2 and D3 turn OFF; however, during negative half cycle diodes D2 and D3 conduct while diodes D1 and D4 turn OFF.

Every half-cycle of the input current waveform can split into two regions. In the interval between $t = t_O$ and $t = t_{OFF}$ the piezoelectric current flows into C_P to charge it. In this interval, all the diodes are reverse-biased and no current flows into the output capacitor C_{buf}. Fig. 2 the shaded areas of the plot, represented by the loss [1].

In the previous concept, adding an inductor to form C_P-L_F resonance can achieve high efficient, but it requires a large inductor. As a result, this is not a good idea. Thus, we can adopt Parallel-SSHI or Switch-Only architecture to improve this problem.

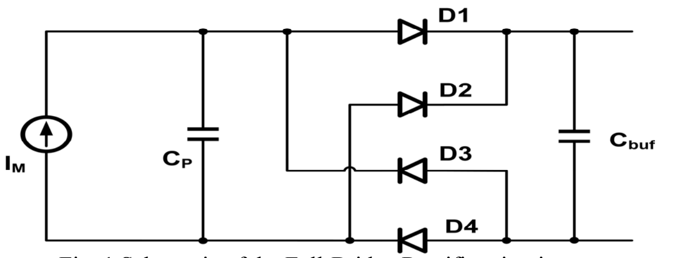


Fig. 1 Schematic of the Full-Bridge Rectifier circuit.

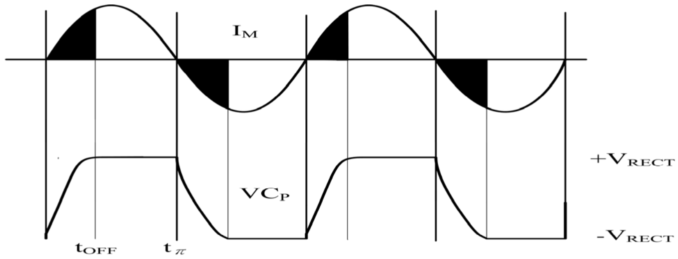


Fig. 2 Simulated of the voltage and current waveforms for a full-bridge rectifier connected to a piezoelectric energy harvester.

B. Parallel-SSHI

The Switch-Only rectifier can improve the effect from the full-bridge rectifier. However, there was still significant amount of charge lost in the switch-only rectifier due to charging C_P up from zero to $\pm V_{RECT}$ every half-cycle. To further increase the energy efficiency, the Parallel-SSHI rectifiers delivering charge to a constant voltage can make every half-cycle the voltage in front of the diodes to flip from $+V_{RECT}$ to $-V_{RECT}$ less loss than the Switch-Only rectifier.

Fig. 3 shows the circuit of the Parallel-SSHI [2], compared to Switch-Only [3]. The Parallel-SSHI circuit architecture adds an inductor (L_F) in series with the switch (SW_F). Fig. 4 shows the schematic of the common-gate comparator of the active diode. The AD activation signal SW_{AD} drives the PMOS switch, which controls the energy flow to the buffer capacitor C_{buf}.

Fig. 5 shows the circuit used to control the switch. This circuit can detect during the periods. When no current is flowing to C_{buf}, the switch turns ON. The inductor helps flipping in an efficient manner of the voltage across C_P. Ideally, the switch needs to be turn OFF exactly when the inductor current reaches zero to achieve maximal flipping of the voltage across C_P. Assuming ideal diode for simple analysis, the voltage and current waveforms associated with this circuit shown in Fig. 6(a) [1], compared with the Switch-Only one shown in Fig. 6(b) [3].

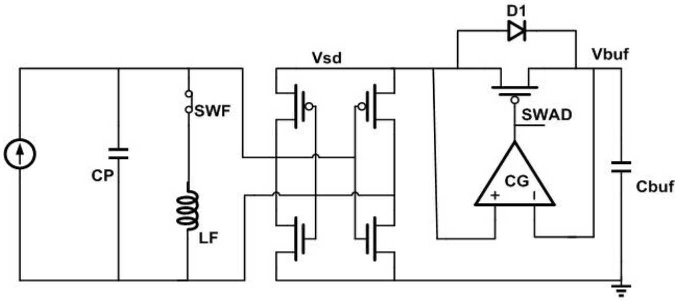


Fig. 3. Schematic of the Parallel-SSHI interface together with the active rectifier.

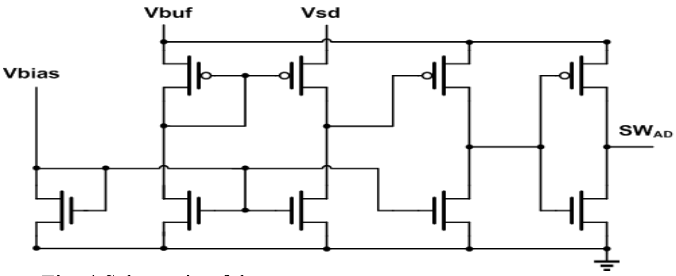


Fig. 4 Schematic of the common-gate comparator.

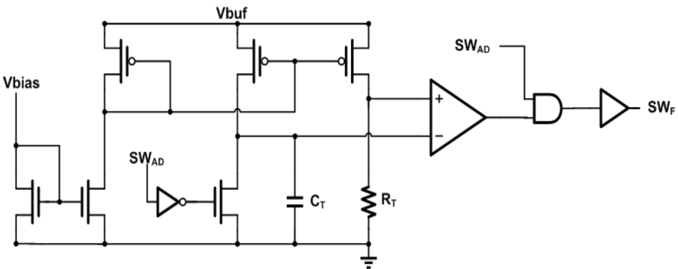
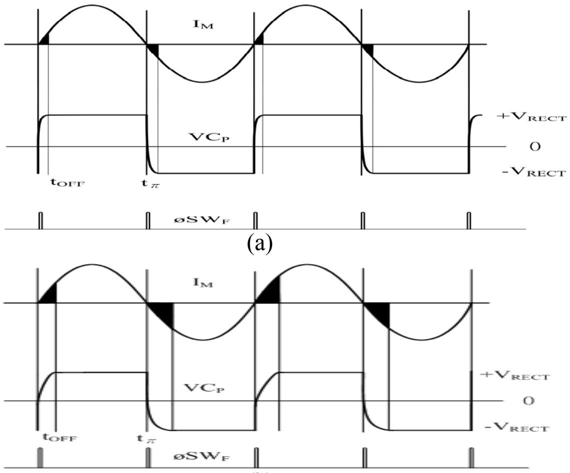


Fig. 5 Schematic of the precision timer control of the flip switch.



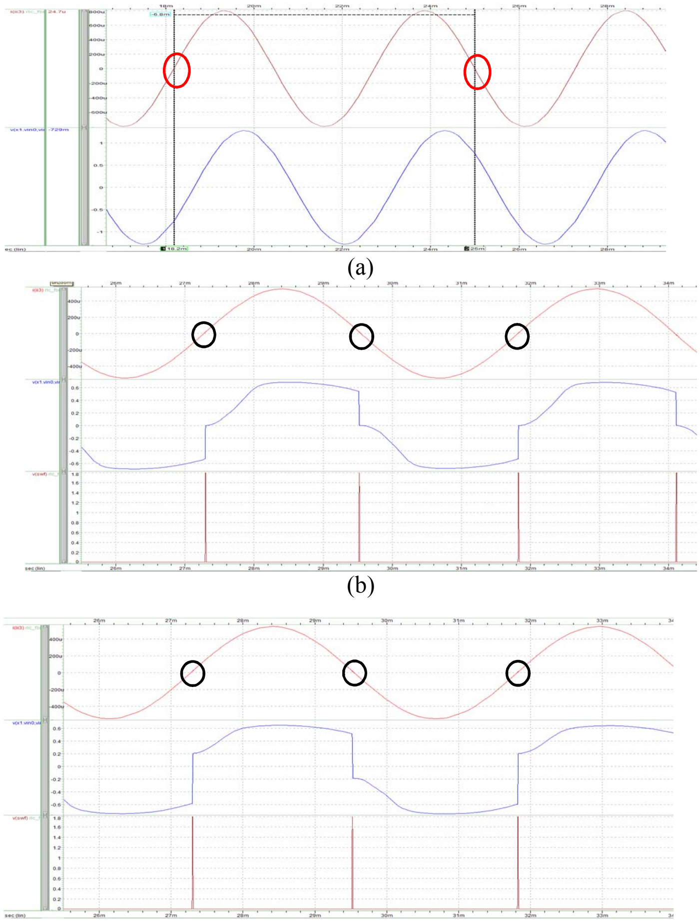
(a)

(b)

Fig. 6 Simulated voltage and current waveforms: (a) Parallel-SSHI rectifier and (b) Switch-Only rectifier connected to a piezoelectric energy harvester.

III. EXPERIMENTAL RESULTS

Fig. 7(a) shows the simulated of the Full-Bridge Rectifier FBR is the most common rectifier, but this method have energy loss (red circle is energy lose) in order to decrease the energy loss can substituted by Parallel-SSHI or Switch-Only. Parallel-SSHI be compared with the Switch-Only, an additional inductor (LF) has been added in series with the switch (SWF). The method can use switch to decrease the energy lose. An inductor can passively flip the voltage across a capacitor and the waveforms are shown in Fig. 7(b) and Fig. 7(c), respectively. Note that the black circles are zero-current cross point to verify the improvement for energy loss.



(a)

(b)

(c)

Fig. 7 Simulated waveforms for (a) the Full-Bridge Rectifier, (b) the Switch-Only Rectifier, and (c) the Parallel-SSHI Rectifier.

IV. REFERENCES

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