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Energy harvesting dc offset and self-powered symmetrical slew rate class-abs op-amp rectifier

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Abstract
This paper contains a self-powered rectifier in piezoelectric energy harvesting applications, and the main idea of the proposed system is to reset the transducer capacitance at optimal instants of time to maximize the extracted output power. Here the rectifier contains two switches and two active diodes. The active diodes used here decreases the voltage drop, leakage current and also avoids instability because the diodes used here are based on op-amps with a preset dc offset. And also in addition the controller used for the proposed rectifier is simple so reduces complexity and power dissipation .In order to decrease the power dissipation more and to obtain good skew rate here we replacing the Op-amp's with preset offset voltage with Class-AB Op-amp's. This rectifier is fabricated by 0.18µm technology of CMOS.

Keywords: Piezo electric; energy harvesting; dc offset; symmetrical slew rate; class-ab op-amp; self-powered rectifier.

1. Introduction

In the recent past years many researchers have been working on the energy harvesting. Removal of batteries is very useful in many applications such as wireless sensor networks where changing of batteries is difficult and costly. Energy harvesting has given a solution for these applications where replacement of batteries is impractical. Piezoelectric energy (PE) harvesting systems offer effective high energy ranging from 10 to several 100's of µw/cm3 [1]. There are several full bridge (FB) rectifiers proposed for PE harvesting systems to maximize the extracted power[6] and these are divided into three types – Conventional Process, Synchronized Switch Process, and Synchronized Switch Harvesting on Inductor (SSHI) [2] as shown in Fig. 1. The main aim of the Conventional process (Fig. 1(a)) is to reduce the voltage drop across the diodes of the rectifier. The most commonly used scheme for this approach uses active diodes based on cross-coupled MOSFETs. The main drawback of this method is that the offset of the comparators which causes leakage and oscillations results in increased loss of power. Op-Amp based active diodes can avoid this problem. Synchronized Switch process is based on switching that discharges the internal capacitance at optimal instances of time. This method uses a synchronized switch to discharge the capacitor or reset the capacitor voltage at required time. As shown in Fig. 1(b), the Switch is in parallel with

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the internal capacitor and placed across the terminal of the transducer. SSHI method recycles the stored energy across the capacitor by reversing the polarity of the capacitor at zero crossing points of the transducer current by the addition of an inductor in series with a synchronized switch as shown in fig1(c). The voltage across the capacitor changes the polarity when the synchronized switch is closed due to the resonance of the LC network formed by the internal capacitor and the inductor that added in series with the synchronized switch. The drawback with this method is the need of large inductor (>20µH) occupies large place which makes the circuit complex and also increases the cost of the circuit [3].

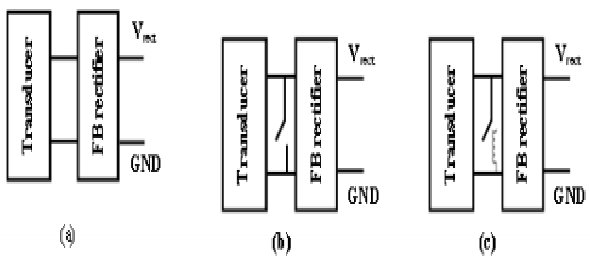

Fig 1: Rectifiers for PE harvesting systems: (a) Conventional process, (b) Synchronized switch process, and (c) SSHI process.

The main drawback of both the synchronized switch and SSHI processes is the need for the zero crossing point detection which is sensitive to the efficiency of the circuit and also, the detection process needs complex circuit which needs dual power supply externally[4]. Therefore, the conventional process with active diodes approach is used frequently because the usage of power supplies is completely prohibited as it is a self powered rectifier. PE energy harvesting circuit with conventional full bridge rectifier is shown in Fig. 2. The above shown full bridge rectifier is composed of a current source in parallel with internal capacitor and resistor [5].The capacitor CL and resistor RL together act as a storage battery and load also. But this Conventional full Bridge rectifier has low efficiency because of the voltage drop across the diodes. This paper discusses on a method for improving slow rate and reducing the power dissipation of a rectifier using conventional process.

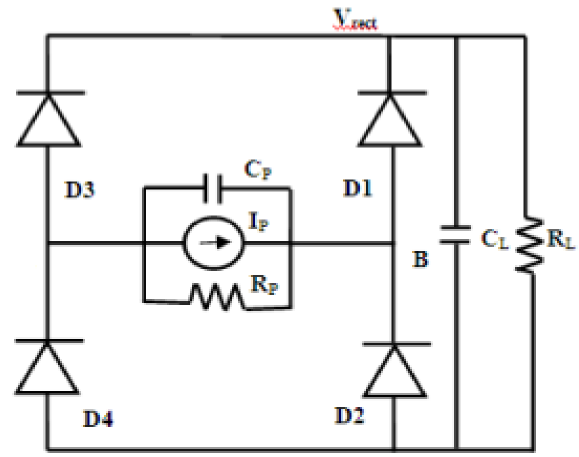

Fig 2: Piezo electric energy harvesting circuit with conventional full bridge rectifier.

The rest of the paper is organized as follows. Section 2 describes the existing full bridge rectifier with Op-amp based active diodes. Proposed rectifier using Class-AB Op-amp is presented in section 3. Measurement results of different types of Op-amp based rectifiers are discussed in section 4. Section 5 concludes the paper.

2. Related Work

2.1 Existing fb rectifier with op-amp based active diodes:

The diodes D1 and D2 in the conventional full bridge rectifier are replaced by two switches M1, M2 and two Op-amp based active diodes as shown in Fig. 3. This method decreases the voltage drop across the diodes.

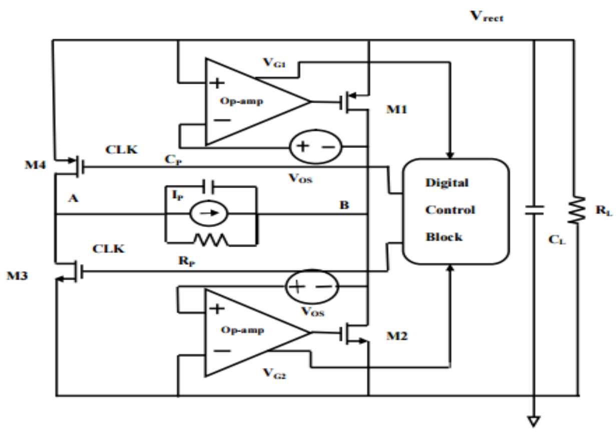

Fig 3: Existing Rectifier with op-amp based active diodes.

In the above Fig. 3, the CL and RL form a storage battery. The transducer current IP flows through the circuit and charges the load for both positive and negative pulses of the current by the operation of op-amps and input switches, which are controlled by the digital control block, thereby continuously charges the load and then load acts as a battery. These Op-amp based active diodes have three main blocks: digital control block, Op-amp compatible with VDD and Opamp compatible with GND.

A. Digital Control Block

The Digital Control Block consists of two blocks Clock Generator and Dead time control block as shown in Fig. 4. The Clock generator consists of two D- flip flops. The Clock generator generates the clock by using outputs from VDD and GND Compatible Op-amps. Clock from the clock generator activates dead time control block which generates two clock signals PCLK and NCLK. These clock signals in turn used to control M3 and M4 switches and make them to turn on one at a time but not the both.

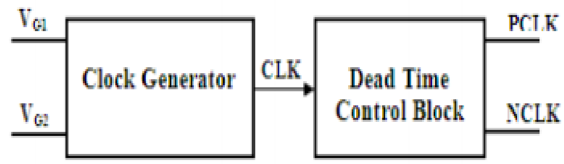

Fig. 4 Digital control block

The Digital Control Block consists of two blocks Clock Generator and Dead time control block as shown in Fig. 4. The Clock generator consists of two D- flip flops. The Clock generator generates the clock by using outputs from VDD and GND Compatible Op-amps. Clock from the clock generator activates dead time control block which generates two clock signals PCLK and NCLK. These clock signals in turn used to control M3 and M4 switches and make them to turn on one at a time but not the both. The output waveforms of the clock generator and dead time control block are shown n Fig. 5 and Fig. 6 respectively.

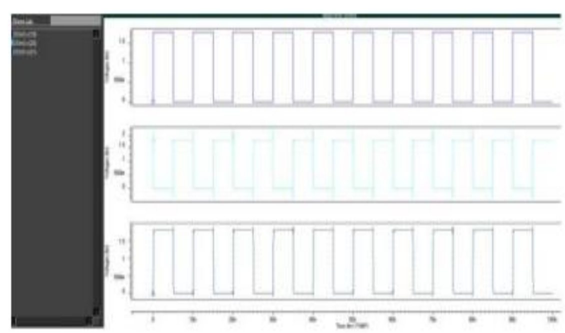

Fig 5: Output waveforms of Clock generator block of Digital control block.

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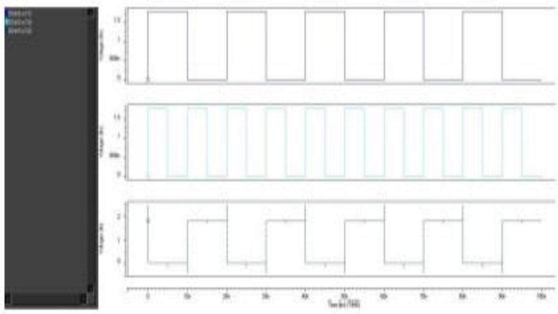

Fig 6: Output waveforms of Dead time control block of Digital control block.

B. VDD and GND compatible Op-amps

Generally in transistor implementation of comparators or op-amps the inputs are connected to the gate terminals of the input transistors, resulting in the requirement of the external supply voltage for an input signal. And the input signal from the external power supply swings between GND to VthN for NMOS transistor and VDD-|VthP| to VDD for PMOS transistor. In order to avoid this problem the input is connected to the source terminal of the input transistor rather than the gate terminal[4] as shown in Fig. 7 and 8. The output of these op-amp's are obtained as the common-source amplifier followed by an inverter. The output signals are represented by G1 and G2 respectively which are given as input to Digital control block. Preset offset voltage, Vos is developed in the FB rectifier based on active diodes due to mismatch in the size of the input transistors M1 and M2. And the simulated results of these Op-amps are shown in Fig. 9 and Fig. 10 respectively.

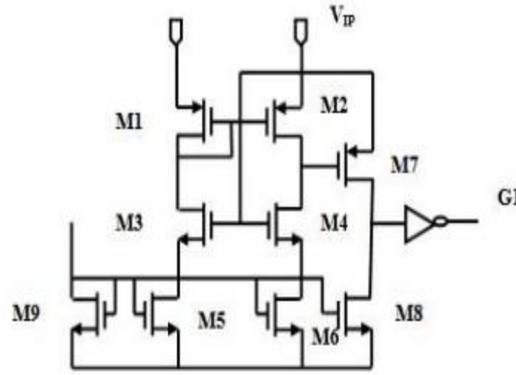

Fig 7: VDD Compatible Op-amp

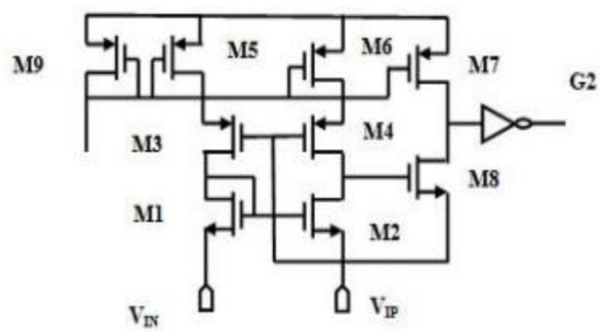

Fig 8: GND Compatible Op-amp.

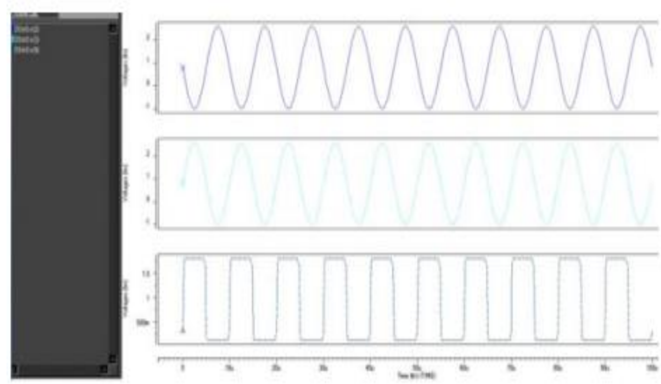

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Fig 9: Simulation result of VDD Compatible Op-amp

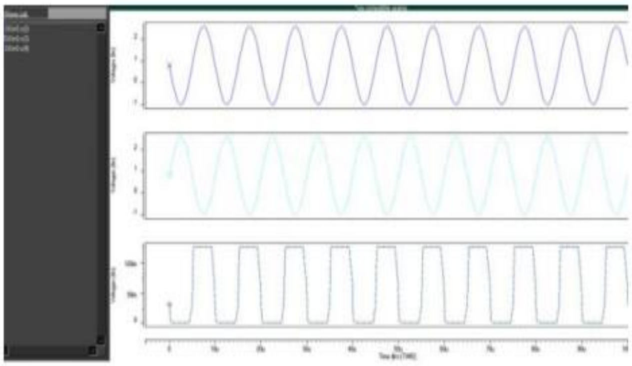

Fig 10: Simulation result of GND Compatible Op-amp

Here now we will consider the Slew rate which is defined as rate of change of output with respect to input. The slew rate calculation of the VDD compatible and GND Compatible Op-amps are shown in is shown in Fig. 11 and Fig. 12 respectively.

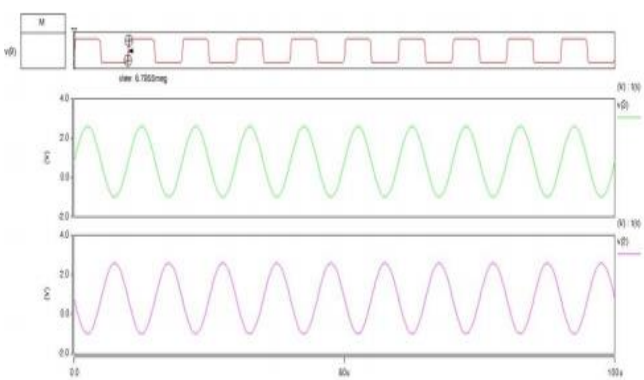

Fig 11: Slew rate calculation of VDD Compatible Op-amp

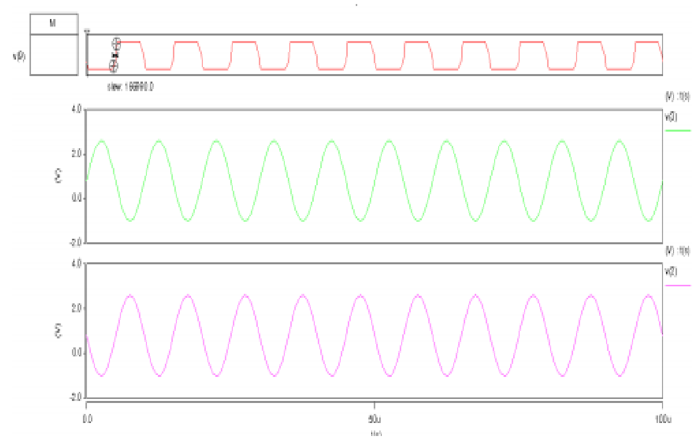

Fig 12: Slew rate calculation of GND Compatible Op-amp.

3. Implementation

3.1 Proposed full Bridge rectifier with class ab op-amps:

We have different types of Op-amps that can be used in FB rectifier. In this section we have described different types of op-amps and also the proposed Class-AB Op-amp with high symmetrical slew rate and less power dissipation. This proposed Op-amp is compared in slew rate and power dissipation with different existing Op-amps in this section. The different Op-amps are shown below

C. Conventional two stage Miller Op-amp:

The Conventional two stage Miller Op-amp has large negative Slew rate and small negative Slew rate, because NMOS transistor acts as a dc current source. The conventional two stage miller op-amp and its simulation results are shown in Fig. 13 and Fig. 14 respectively.

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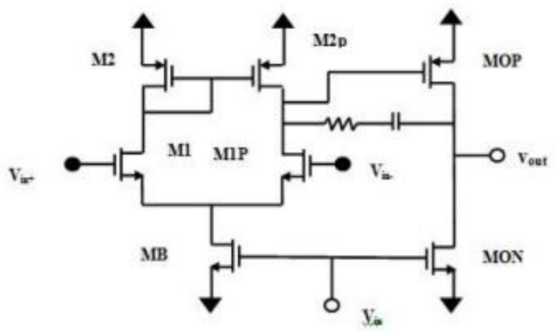

Fig 13: Conventional two stage miller op-amp

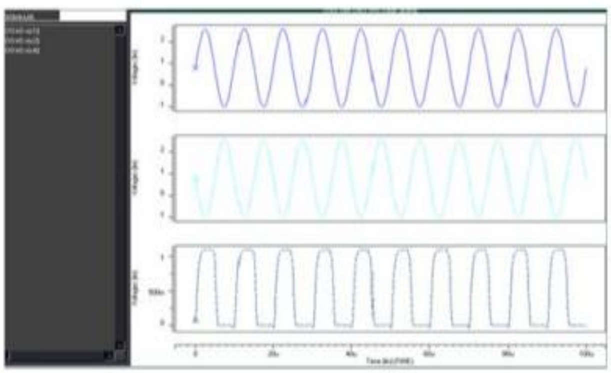

Fig 14: simulation result of Conventional two stage miller op-amp

D. Free Class-AB Op-amp

The Free Class-AB Op-amp have less hardware and it consists of both high negative and positive Slew rate but it works during only dynamic changes of frequency and it decreases power dissipation. The free class-AB Op-amp and its simulation results are shown in Fig. 15 and Fig. 16 respectively.

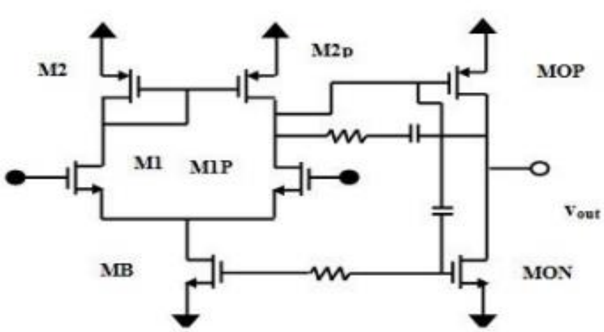

Fig 15: Free Class-AB Op-amp

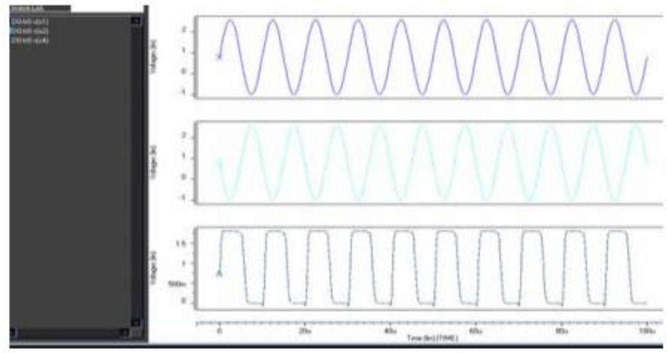

Fig 16: Simulation result of Free Class-AB Op-amp

E. Push-Pull Op-amp with current replicating branch

This Push-pull Op-amp transfers current variations to the output transistors, by which output positive current increases by twice. The circuit and simulation result are shown in Fig. 17 respectively.

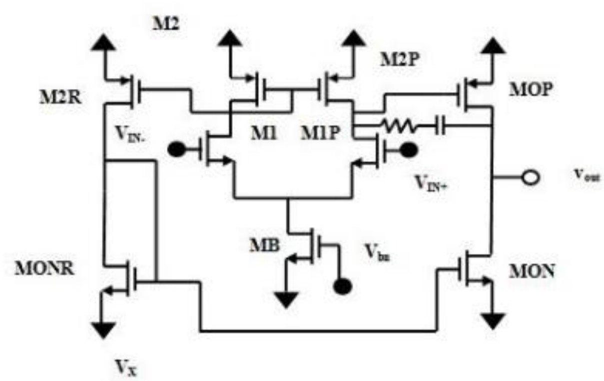

Fig 17: Push-Pull Op-amp with Current Replicating Branch.

4. Conclusion

In this paper, we proposed conventional FB rectifier using class-AB Op-amps for PE energy harvesting system. The slew rate of the proposed FB rectifier is 8.0296v/µs and it is high as compared to all existing FB rectifiers. Similarly, the power dissipation of proposed FB rectifier is 1.163mW and it is the minimum as compared to all existing FB rectifiers. We conclude that the proposed FB rectifier using power efficient high symmetrical slew rate class-AB Op-amps is more suitable for conventional PE energy harvesting systems

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