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An Active Efficiency Rectifier with Automatic Adjust of Transducer Capacitance in Energy Harvesting Systems

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ABSTRACT:

Energy harvesting is the process by which energy is derived from external sources (e.g., solar power, thermal energy, wind energy), captured, and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks. Energy harvesters provide a very small amount of power for low-energy electronics. While the input fuel to some large-scale generation costs resources (oil, coal, etc.), the energy source for energy harvesters is present as ambient background and is free. This paper presents a rectifier with automatic adjust of transducer capacitance for Piezo electric energy harvesting applications, and the key idea of the proposed system is to adjust of transducer capacitance maximize the extracted power.

The proposed-rectifier consists of active diodes based on op-amps with a preset dc offset, which reduces the voltage drop and the leakage current and avoids instability. In addition, the controller for the proposed rectifier is simple to reduce the circuit complexity and the power dissipation. The proposed rectifier was designed and fabricated in 0.12-µm CMOS technology. Measured results indicate that it achieves power efficiency of 90%, and the amount of power extracted by the proposed rectifier is 3 times larger when compared with the conventional rectifiers. The proposed rectifier does not require any off-chip components to enable a full chip integration, and the die area of the proposed circuit is 0.07 × 0.18 mm2.

INTRODUCTION:

Nowadays, the demand of using green energy harvested from ambient environment to supply applications like wireless sensor nodes is rapidly growing. Harvesting vibration energy through piezoelectric transducer is a popular method which can supply up from 10’s to 100’s of µW available power. An interfacing circuit, a rectifier normally, is needed to efficiently convert the AC current at the output of PE device into a DC signal that can be used for circuits as well as to store in power storage elements. The role of interfacing circuit is very critical because it directly decides the amount of energy that can be extracted from PE devices. The full-bridge rectifier is widely used piezoelectric energy harvesting system; however, the main limitation is the poor efficiency.

Many rectifier circuits have been proposed for the PE energy harvesting systems. There are two main approaches of research directions, improving the power conversion and the extraction efficiencies. In the first approach, to reduce the diode forward voltage drop, active diode replaces the passive diodes. The active diode is implemented by comparator, or op-amp based active diodes. In the second approach, to reduce the power loss due to the internal capacitor of transducer, several rectifier architectures are proposed. To reduce the discharge process in each half cycle of transducer power can be doubled. However, the charging process still wastes power. To reduce the power loss during the charge process, the capacitor voltage flipping technique is proposed using an off-chip inductor in parallel with the PE transducer.

In the bias flipping technique, the inductor is connected in parallel with PE transducer only when the current from the PE crosses zero. Then a resonant loop that includes the inductor and internal capacitor of the PE transducer is formed to flip the voltage across the internal capacitor which eliminates the charging process. In each half cycle of the operation, the inductor should be disconnected immediately after all the energy from inductor is transferred back to the internal capacitor. Therefore, the timing of connecting and disconnecting the inductor is very important; affecting extraction efficiency. To precisely control the inductor ON- time, [4] uses a complex circuit with external tuning and needs external voltage for control of switches. By inserting a passive diode in the resonant loop to prevent the inverse current, [2] simplifies the inductor ON-time control. However, two passives diodes are needed for the two flipping processes of plus to minus and vice versa. In [3] a derivative circuit is needed to detect the zero-crossing point of the current increasing the complexity. This paper presents a rectifier that adopts a series synchronized switch harvesting inductor where the flipping inductor is connected not parallel but in series with the PE transducer. The serial configuration helps to simplify the control circuit and reduce the number of passive diodes while achieving the same extracted power as the rectifiers reported in [2-4]. Moreover, in the proposed rectifier, all the passive diodes are replaced by active diodes to reduce the voltage drop for further improvement of extraction efficiency.

PROPOSED RECTIFIER:

Fig. 1 shows the circuit diagram of the proposed rectifier, which consists of two active diodes, D1 and D2, and two switches, SW1 and SW2. The topology of the proposed rectifier is identical to the conventional FB rectifier shown in Fig. 1 except replacement of two diodes on the left branch by two switches. The two switches reset (discharge) transducer capacitor CP at the zero crossing point of the transducer current. During the time interval t1 < t < t2, the source current is positive, and VBA starts to increase from zero with SW1 open and SW2 close. The two diodes are turned off,). The capacitor voltage VBA reaches Vrect at t2, causing D1 to conduct, and the source current starts to flow to the load,. During the time period, +diode D2 remains turned off, and Vrect practically remains constant due to a large CL . Thus, the transducer delivers power to the load. As the current crosses the zero point and becomes negative at t = t3 ± t, the capacitor starts to discharge, and VBA decreases to turn D1 off. Once D1 stops conducting current, SW1 closes and SW2 opens, Node A voltage VA, instantaneously becomes Vrect (due to the activation of SW1) and node B voltage 2Vrect, thereby activating diode D1. Since both SW1 and D1 are activated, the capacitor is instantly discharged, i.e., automatically resets. After the capacitor is fully discharged, node voltage VB becomes lower than VA (due to the negative transducer current) to turn D1 off. The negative transducer current charges the capacitor during t3 < t < t4. When VBA becomes slightly less than −Vrect at t = t4, diode D2 conducts, and the transducer current flows into the load. This status is maintained for t4 < t < t5 and terminates when the transducer current reaches a slightly positive value at t5. The operation of the proposed circuit is similar to the conventional voltage doubler during the positive (negative) cycle of the current. However, the reset of the internal capacitor at beginning of the negative (positive) half cycle enables the proposed circuit to extract more power than the conventional voltage doubler. For the proposed rectifier, as we can be seen from the waveform VBA , the transducer current charges (discharges) CP from 0 to +Vrect (0 to −Vrect) every cycle. Therefore, the amount of charge lost per cycle for the proposed rectifier is given as

Qloss=2CPVrect. (1)

The maximum output power of the proposed rectifier is given by

$$P(\max) = \frac{I_P^2}{4\pi^2 C_P f_P (1-\eta_F)} \qquad (2)$$

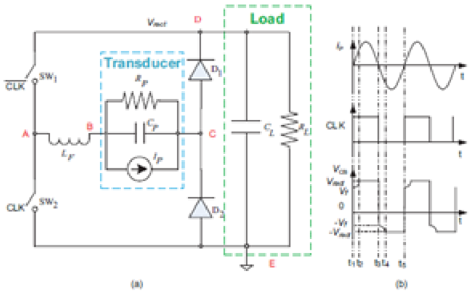

Fig. 1: (a) The proposed op-amp circuit. (b) Current and voltage waveforms

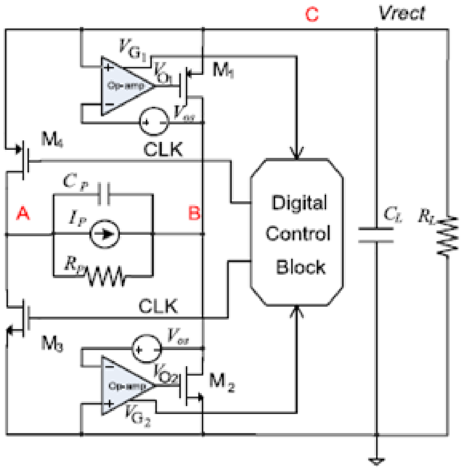

Fig. 2 The proposed op-amp rectifier

Circuit implementation – Fig. 2 shows the rectifier circuit detail, in which the passive diodes are replaced by active diodes. Diode D_1 is replaced with ground compatiblecomparator COM_1 and a transistor M_1; the other diode is replaced supply compatible comparator COM_2 and transistor M_2. As mention before, in each cycle of the rectifier operation, each diode is turned on in two times: when current from transducer flows to load, and when the resonant loop is created. Therefore, the waveform of comparator's output, G_1 and G_2, are as the way shown in Fig. 2(b). In Fig. 2(b)

SIMULATION AND MEASUREMENT RESULTS:

The simulation and measurement are carried out for the proposed rectifier shown in Fig.3 with transducer model values of I_P= 70µA, f_P=200Hz, C_P=25nF and R_P=1MΩ, and the inductor value of 390µH is used and load is varied from 50KΩ to 200KΩ with a 5KΩ step. From the simulation the maximum extracted power of proposed rectifier occurs at 160KΩ resistor at the load. Fig. 4 shows the comparison between the active FB rectifier and proposed rectifier on V_{CB} and V_{rect} with the same load of 160KΩ. The simulation shows that, the flipping efficiency of conventional rectifier is 0 while, the proposed rectifier $\eta_F = 0.7$. Theoretically, by using (2), with $\eta_F = 0.7$, the maximum extraction power is 82.7µW at V_{rect}=3.71V, however, because of power consumption of the system, simulation results shows that the maximum extracted power of proposed rectifier is 75µW with V_{rect}=3.63V. Under the same conditional, the active full bridge rectifier extract 18.1 µW when V_{rect}=1.7V

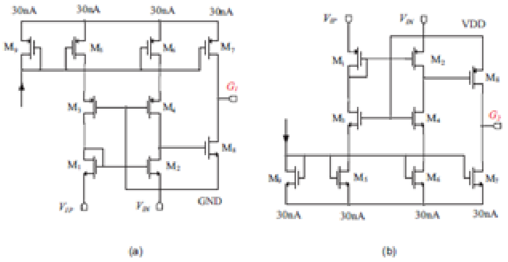

Fig. 3 Circuit schematics of (a) Ground comparator; (b) VDD comparator

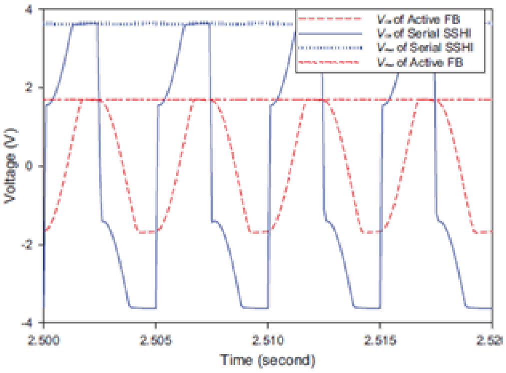

Fig. 4. Simulated waveform of active FB rectifier and proposed rectifier in V_{CB} and V_{rect}

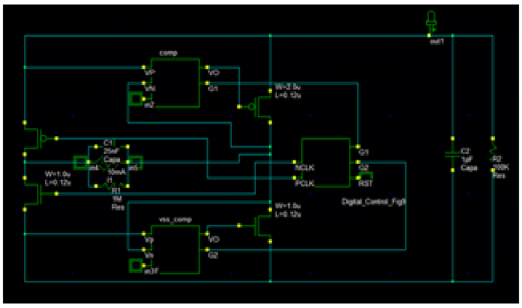

Fig.5. Schematic of proposed rectifier with op-amp based active diodes

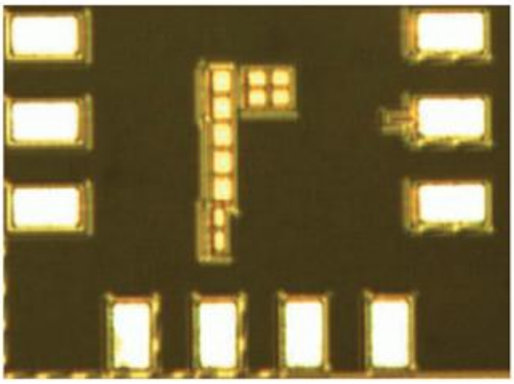

Fig. 6 The micrograph of the proposed rectifier

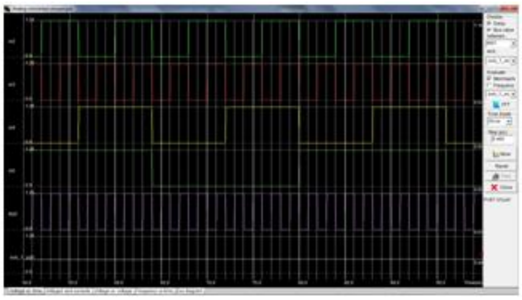

Fig.7. Measurement wave form of output voltage across the piezoelectric harvesting VCB, control signal CLK and output voltage (Vrect)

Table.1 Proposed rectifier with op-amp based active diode results

S.No.	Parameters	Proposed Design
1	Power(µW)	88.98
2	Area(mm^2)	0.079 X 0.014

Table.2Comparison of comparator based active diode results and op-amp based active diode results

S.No.	Parameters	Comparator based active diodes	Op-amp based active diodes
1	Power(µW)	77	88.98
2	Area(mm^2)	0.078 X 0.017	0.079 X 0.014

CONCLUSION:

This paper has identified problems that exist with the rectifiers that are used in piezoelectric energy harvesting systems. The proposed rectifier overcomes the drawback of previous rectifiers. By using op-amp based rectifier, the voltage across the internal capacitor of PE transducer is flipped to extract more power; simultaneously, diodes are replaced by active diodes to reduce the voltage drop. Furthermore, a new effective control scheme is proposed to control switches. The measurement result show that the extracted power of proposed rectifier 88.98µW with flipping efficiency 0.68 and shown that more than 90% of the power conversion efficiency can be achieved.

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