A Voltage-Boost Rectifier Circuit for Energy Harvesting from Environmental Vibrations

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Abstract. We propose a VBR (voltage-boost rectifier) circuit based on the 0.18-μm Si CMOS (complementary metal oxide semiconductor) technology, which is designed for vibrational energy harvesters utilizing environmental vibrations. The VBR employs a single-end Dickson type charge-pump topology, and the circuit would be realized as a monolithic chip. The evaluation results obtained by multi-physics simulations on a circuit simulator reveal that the proposed circuit can deliver boosted DC voltage from the input of sub-threshold AC voltage.

1. Introduction
VEH (vibrational energy harvesters) are considered as a future power source of IoT (Internet-of-Things) sensor nodes. The output voltage of vibrational energy harvester is AC voltage, and thus rectifiers are essential for driving subsequent circuitry in the sensor node. Environmental vibration is generally non-

![Figure 1. VBR for vibrational energy harvester utilizing environmental vibration.](image-url)
stationary, whose intensity and spectrum randomly change. The output voltage of VEH therefore changes likewise and may become smaller than the threshold voltages of conventional diode rectifiers [1].

Low-threshold diode, such as Schottky barrier diodes, are not usually included in the standard CMOS (complementary metal oxide semiconductor) processes, although CMOS technology is useful for miniaturization, low power, low parasitic capacitance and monolithic integration of large-scale circuitry. Harvested energy would be wasted, if the rectified voltages of energy harvesters are smaller than the threshold voltage of latter circuitry. Use of off-chip inductors is not preferable in voltage booster circuits, as it would increase the total package size.

In this work, we propose a CMOS-based VBR (voltage-boost rectifier) circuit for VEH working under environmental vibrations. The VBR admits input voltage below the threshold voltage of diodes, and delivers boosted voltages, as shown in Fig. 1. The behavior of the VBR with an electrostatic vibrational energy harvester excited by environmental vibrations is evaluated by multi-physics simulations on a circuit simulator.

2. Design of VBR
Figure 2 describes a schematic of the VBR that employs a single-end Dickson-type charge pump topology with the threshold voltage compensation [2]. The input signal $V_{in}$ and the ground node are alternately connected to the pumping nodes through a 1-pF coupling capacitor. In the first twenty n-MOSFETs, the gate and backgate terminals are connected with the latter stage outputs, which provide a biased signal for compensation. The last two n-MOSFETs adopt diode connections to prevent leak
3. Simulation Results

3.1. Transient analysis of VBR

Figure 3 shows the transient analysis results of the VBR with the sinusoidal voltage input at 100 Hz. For comparison, analysis results with a diode-connected n-MOSFET instead of the VBR are included. In Fig. 3(a), the amplitude of the input voltage is higher than the n-MOSFET threshold voltage ($V_{TH} \approx 0.6$ V), and the DC voltage delivered by both the VBR and the diode rectifier are above $V_{TH}$. Figure 3(b)
suggests that the VBR could convert the input voltage of sub-threshold (0.2 V) AC amplitude to a DC voltage above $V_{TH}$.

3.2. Multi-physics transient simulation

To evaluate the effectiveness of VBR with vibrational energy harvesters, we performed multi-physics simulations [3] on a circuit simulator (LTspice, Analog Devices, Inc.) with an equivalent circuit model of a MEMS vibration energy harvester. Figure 4 shows the multi-physics simulation environment, where electrical and mechanical behaviors are analyzed simultaneously. We employed a model of an electret-based MEMS vibrational energy harvester whose structure was documented in Ref [4]. Besides, arbitrary acceleration can be used as the input vibration of energy harvester [5]. In this analysis, we used the environmental vibration that was experimentally obtained from an expressway. The data of vibration were imported to the simulation model as velocity and displacement waveform which was obtained from the numerical integration of the measured time-series data of acceleration.

Figure 5 presents multi-physics transient simulation results of $V_{in}$ and $V_{out}$. Analysis results using a diode-connected n-MOSFET instead of the VBR are also included in Fig. 5. The evaluation results confirmed that the proposed circuit successfully deliver boosted voltages from the input of sub-threshold voltages from a MEMS energy harvester.

4. Conclusion

We presented a VBR circuit based on CMOS technology. The evaluation results revealed that the proposed circuit was able to deliver boosted DC voltage at the input of sub-threshold AC voltage. The circuit would be useful to increase the operation range of vibrational energy harvesters, especially when excited by environmental vibrations.

References

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