A Power Management Interface IC Using low voltage self-startup and ZCS controller for thermoelectric energy harvesting

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요 약

Power conservation and clean energy harvesting for wireless and low-cost devices (e.g., medical implants, IoT applications, or sensor nodes,) have lately become popular research subjects. With this in mind, the study focuses on the most critical component of the energy conversion system chain: the power management system (PMS). This paper presents a core of such a unit Boost DC-DC converter IC energy harvesting system for thermoelectric generator (TEG) using an off-chip inductor. Fabricated in a 28-nm CMOS process, a fractional open circuit voltage (FOCV) based maximum power point tracking (MPPT) circuit is introduced to get maximum extract power from TEG, and a zero current Sensing (ZCS) circuit is to prevent the backflow inductor current. The proposed converter operates at the TEG input voltage of 150 mV and delivers the output voltage of 1.3 V to the load.

I. Introduction

Powering ultra-low power devices using energy harvesting is becoming a hot topic for researchers. From anybody or structure where a temperature deviation between two levels is present there thermoelectric energy can be reaped such as the human body, aircraft, or a steam engine. The thermocouple is used by thermoelectric harvesters for the production of voltage proportionate to the temperature difference across the two surfaces of the system. The main principle of thermoelectric energy harvesters is the Seebeck phenomena [1- Kanno T]. For the obtaining of thermal energy from the human body one side of the thermocouple shall be kept on warm skin and the other one on cold closed air. Harvesting thermal energy is more consistent than other energy sources in environments with unpredictable conditions. It can also reduce the demand for the rectifier circuit as well as reliable d.c output. TEG is suitable for energy harvesting applications due to these two mentioned characteristics. Wearable devices that are powered by the body's energy are presented in [2- Hoang D.C].

However, in the case of low-power electronic design circuits operate at a significantly 1 V or more than 1 V [3- Elham K]. The tens of mV d.c must be converted into 1 V or more d.c voltage to operate these low-power devices.

Focusing on the TEG's low power, the researchers face the challenges of designing chips with a small area and high efficiency of the boost converter for these insufficient power harvesting systems. for the improvement of efficiency, there are different topologies were implemented for low-power energy harvesting applications, like switch capacitors mode charge pump circuits, and DC-DC converters based on inductors with pulse width control feedback in both modes (CCM and DCM) [4- S. Tokuda],[5- Q. Peng].

In this work, we present the single inductor DC-DC boost converter with a special design self-startup circuit implementation, FOCV-based adaptive MPPT, and ZCS with an off-chip inductor, which is capable of harvesting energy efficiently, self-staring at low voltage TEG and works in DCM mode. The harvester's efficiency and output power are increased because the MPPT assures maximum power transfer (MPT) from the source to the converter's input.

Ⅱ. Design

The overall system of the proposed design of the power management interface IC is shown in Fig.1.The system consists of a sub-block the main converter, the start-up circuit, the MPPT controller circuit, and the ZCS controller circuit. All the sub-block and main converter except the inductor are on-chip as marked by the blue dotted line. This article mainly focuses on the boost converter for thermal energy harvesting applications that can self-start at input voltages lower than those of conventional off-chip systems.

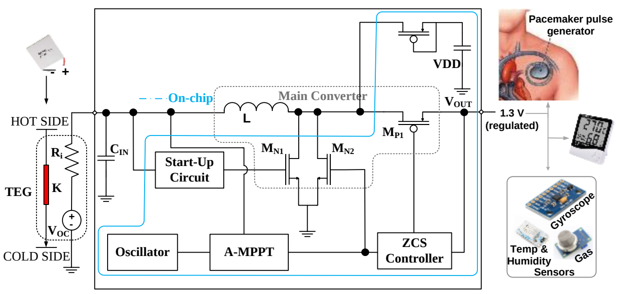
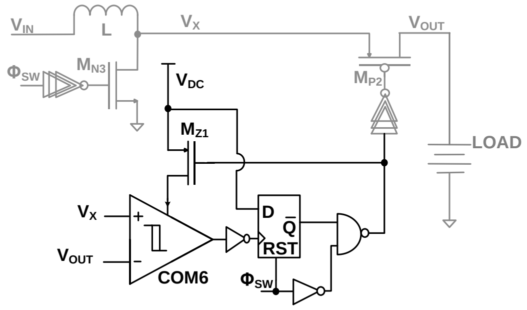


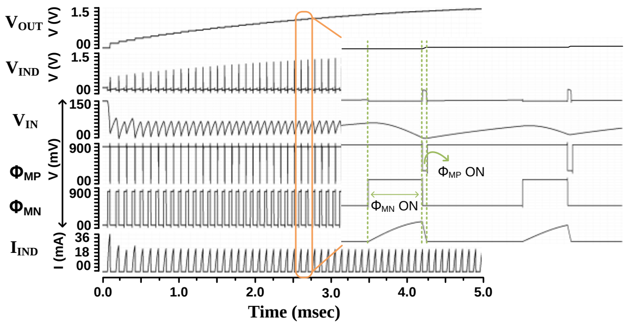
Fig 1. Block diagram of the proposed system architecture

Fig. 2 (a) shows the schematic diagram of the zero current sensing (ZCS) which prevents the backflow current through the inductor. Fig. 2 (b) shows the simulated time Waveform of the converter. The accurate switching of the P-MOS which is controlled by

ZCS, and N-MOS which is controlled by MPPT. The charging and discharging of the inductor are fine and no backflow current.



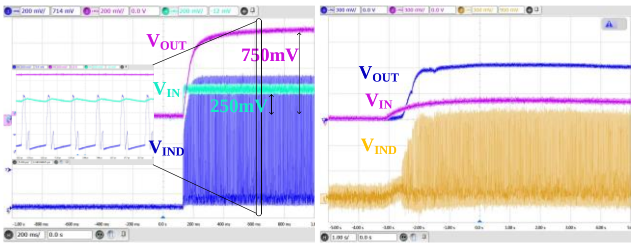
(a)



(b)

Fig 2. (a) Schematic diagram of the zero current sensing (ZCS). (b) The simulated waveform of the proposed system.

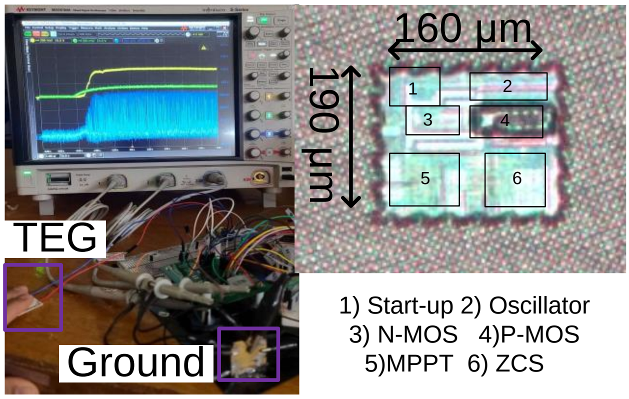
Fig.3 (a) Shows the measured results of the self-startup circuit using a power supply as the source, the input voltage V_{IN} is 250 mV which gives the V_{OUT} of the converter 750 mV 3 times the V_{IN}. Using the TEG source as the input we get the same result as we get from the power supply as in shown in Fig.3 (b).



(a) (b)

Fig 3. The measured waveform of the start-up circuit using (a) power supply as a source and (b) TEG as a source.

Fig.4 (a) shows the measurement setup result to operate the clock using a power supply as input of 250 mV. The proposed converter was implemented in 28-nm CMOS technology. A chip micrograph is shown in Fig.4 (b).



(a) (b)

Fig 4. (a) Measurement setup. (b) Chip micrograph.

Ⅲ. Conclusion

In this work, the proposed boost converter for TEG energy harvesting operates in the range of VIN 100-300 mV of TEG source, and the output VOUT can be boosted up to 3 times the input. The proposed MPPT ensures that the converter achieves the maximum power transfer (MPT) from the source, and the ZCS is accurately switching when the inductor current reaches zero.

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