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A Thermoelectric Energy Harvesting Circuit For a Wearable Application

Khoa Van Pham*, Son Ngoc Truong*, Wonsun Yang* and Kyeong-Sik Min*★

Abstract

In recent year, energy harvesting technologies from the ambient environments such as light, motion, wireless waves, and temperature again a lot of attraction form research community [1-5] due to its efficient solution in order to substitute for conventional power delivery methods, especially in wearable together with on-body applications. The drawbacks of battery-powered characteristic used in commodity applications lead to self-powered, long-lifetime circuit design. Thermoelectric generator, a solid-state sensor, is useful compared to the harvesting devices in order to enable self-sustained low-power applications. TEG based on the Seebeck effect is utilized to transfer thermal energy which is available with a temperature gradient into useful electrical energy. Depending on the temperature difference between two sides, amount of output power will be proportionally delivered. In this work, we illustrated a low-input voltage energy harvesting circuit applied discontinuous conduction mode (DCM) method for getting an adequate amount of energy from thermoelectric generator (TEG) for a specific wearable application. With a small temperature gradient harvested from human skin, the input voltage from the transducer is as low as 60mV, the proposed circuit, fabricated in a 0.6μm CMOS process, is capable of generating a regulated output voltage of 4.2V with an output power reaching to 40μW. The proposed circuit is useful for powering energy to battery-less systems, such as wearable application devices.

Key words: thermoelectric generator (TEG), dc-dc booster, charge pump circuit, discontinuous conduction mode, low voltage startup circuit

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* Dept. of Electronics Engineering, Kookmin University
★ Corresponding author
e-mail: mks@kookmin.ac.kr tel: 02-910-4634

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I. Introduction

For conventional CMOS technology perspective, the low voltage level harvested from TEG typically less than CMOS threshold voltage can not be directly provided to any digital circuitry [1,2,]. Dc-Dc boost converter, a potential device, is implemented to boost up the low input voltage from transducers to a useful voltage for powering CMOS operation.

II. Architecture

As depicted in Fig. 1, the circuit block diagram consists of 2 stages dc-dc boost converter integrated with a digital controller to govern as well as monitor control signals.

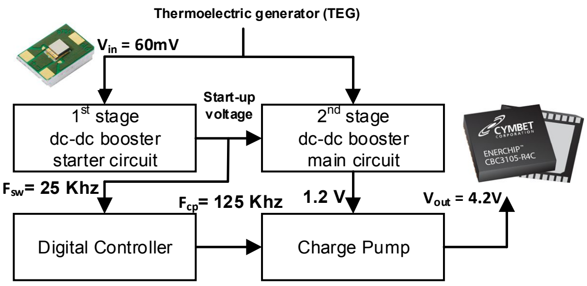

Fig.1.Circuit block diagram

In order to obtain the control voltage level at the first time, there are some kinds of the method to start-up circuit such as using a tiny battery, remote RF kick-start, integrated cold-start circuit, pre-charged capacitor and so on. Among this approaches, for a wearable application like worn harvesting wristbands using human motion actions [6], a mechanical switch seems to be a potential choice due to its simple. Fig.2 illustrates the proposed architecture. The first-stage dc-dc boost converter is connected in parallel to the second-stage booster.

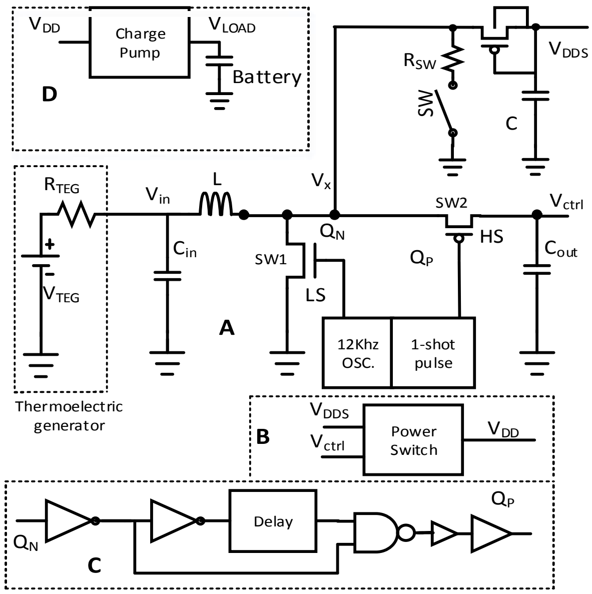

Fig.2: Circuit submodules

By using a manual switch, the VDDS level, kick-start voltage, can be achieved. This voltage at the startup time is provided to the digital controller for generating control signals as high side, low side switches. According to Eq. 2 from [1], a 10μH inductor along with 330pF output capacitor are used to generate a voltage level of 1.2V corresponding to a thermoelectric resistance of 2Ω (Laird 430857-500). A small size inductor is employed for reducing parasitic resistance and fitting on on-skin designs [7]. A half-duty cycle switchingpulse (f_s) is pre-defined frequency based on the values of TEG interna lresistance, and a given inductor size to regular Vin closed to the open voltage of TEG for extracting maximum power fromTEG[8].

$$P_{\max} = UI = \left(\frac{V_{oc}}{2}\right)^2 \frac{1}{R_{TEG}} = \frac{V_{oc}^2}{4R_{TEG}}$$

The results from [] showed that the switching frequency for LS switch is properly defined as the followed equation

$$f_s = \frac{T_{TEG}}{8L}$$

After several switching cycles, when V_{ctrl} at the second-stagereaches 1.2V. The digital controller performs using power from V_{ctrl} instead of V_{DDS} line.T*his results in activating charge pump block. Based on V_{ctrl} voltage combined with a 125kHz charge-pump frequency the output voltage of 4.2V for providing to load or charging a tiny battery can be obtained. Also, with a small generated power from TEG, it will become critical to reduce the converter losses including conduction loss, switching loss, and synchronization loss. DCM, a switching control approach, is more efficient compared with CCM control method in order to overcome synchronization loss during a switching cycle. For dealing with such loss, a simple circuit used to produce a pulse with accurate opening time for HS switch with respect to a LS pulse. Based on the voltage second product of the inductor for the charge and discharge cycles, the on-time for HS signal is computed.

$$T_{LS}V_{IN} = T_{HS}(V_{OUT} - V_{IN})$$

For the targeted input voltage level, the on-time for HS pulse is around 1.2μS in order to perform zero current switching functionality. The circuit to create 1-shot HS pulse with open time defined by delay block is demonstrated in Fig. 2C. Due to the small temperature difference, the mismatching of HS pulse width can be negligible.

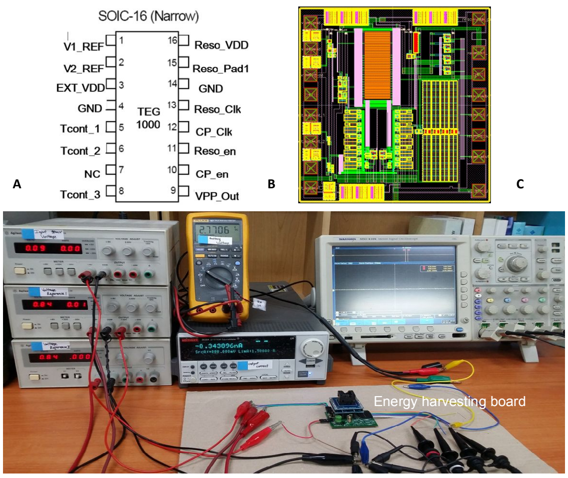

Fig.3: The chip package. B Die photo of the C Test-chip measurement environment

Fig.3: The chip package. B Die photo of the chip. C Test-chip measurement environment

Table 1. Parameters of the proposed circuit

Technology	CMOS 0.6μm	Sw. Freq.	25kHz, 50% duty cycle
Supply	1.2V	CP. Freq.	125kHz
Input range	60 - 70mV	R_{TEG}	2Ω
Output voltage	4.2V	Package	SOIC 16 pins

III. Conclusion

A thermoelectric energy harvesting architecture is proposed in this paper. With a targeted input voltage level by using discontinuous conduction mode combined with a predefined switching frequency for extracting maximum harvested power from TEG along with a simple circuit for reducing power loss caused by the time for opening PMOS, the output voltage of 4.2V can be obtained.

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