

Multiplexed Power Management Circuit for Low-Power Thermoelectric Generators

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Summary:

In the field of autonomous sensors powered by energy harvesters, this work proposes and experimentally characterizes a power management circuit (PMC) for low-power thermoelectric generators (TEG). The proposed circuit combines and interconnects, in a multiplexed approach, two off-the-shelf PMCs so as to achieve the benefits of both. Thanks to this interconnection, the resulting circuit is able to start operating from a low input voltage (40 mV) with a satisfactory efficiency (up to 78 %), features that are difficult to achieve exclusively using one of these PMC alternatives.

Keywords: Autonomous sensors, energy harvesting, maximum power point tracker, power management circuit, thermoelectric generator.

Introduction

A large-scale deployment of autonomous sensors (including sensor nodes related to Internet of Things) is no exempt from limitations, and probably the most critical issue is their power supply. The most viable and sustainable alternative seems to be the use of an energy harvester, which converts "free" environment energy to electrical energy. Energy harvesters can rely on different types of input energy [1]: optical, thermal, mechanical, and radio frequency. This work is focused on thermal energy harvesters based on a thermoelectric generator (TEG). The output power of a low-area TEG (say, with a few tens of cm²) is usually in the range of units or tens of milliwatt [2], but this highly depends on the available thermal gradient.

The DC voltage obtained at the TEG output is generally quite low (i.e., tens or hundreds of millivolts), which is not valid to directly power the electronics of a sensor node. Consequently, an intermediate power management circuit (PMC) performing a DC/DC conversion is required. Among other tasks, this PMC is in charge of ensuring that the TEG operates around its maximum power point (MPP), which corresponds to an operating voltage equal to half of the open-circuit voltage. Therefore, an MPP tracking (MPPT) technique, such as the fractional open-circuit voltage (FOCV) [3], must be automatically applied to adapt the operating point of the TEG to the varying thermal operating conditions.

The semiconductor market offers two alternatives of PMC for TEGs: 1) PMCs able to operate from a very low input voltage but without the ability to apply any MPPT method; and 2) PMCs able to apply an MPPT method but operating from higher values of input voltage. Off-the-shelf PMCs for TEGs offering both abilities (i.e., low-input voltage operation and MPPT) are not available, although these have been suggested with application specific integrated circuits.

This work aims to propose and experimentally characterize a circuit for TEGs that combines the two off-the-shelf PMC alternatives indicated before so as to achieve the benefits of both.

Preliminary characterization of a TEG

For the ensuing characterization of the circuit, the data corresponding to a commercial TEG was used as a reference: GM250-241-10-12 (European Thermodynamics) with an active area of 40×40 mm². This TEG was attached to a heatsink (TDEX6015/TH with 60×60×47 mm³) and then characterized under thermal gradients (ΔT) from 5 to 40 °C, which are expected indoors [4], generated by a thermal plate (QInstruments ColdPlate 2016-0110). Table 1 summarizes the main experimental results, including the open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), and power at the MPP (P_{MPP}) for different ΔT . The power was in the range of units of mW for $\Delta T \geq 20^\circ\text{C}$, which is appropriate for sensor nodes, but the DC output voltage was in the mV range, which is too low for a direct supply voltage connection.

Tab. 1: Experimental results for the TEG.

ΔT (°C)	V_{OC} (mV)	I_{SC} (mA)	P_{MPP} (mW)
5	38.0	6.2	0.06
10	91.1	12.5	0.29
20	212.6	27.7	1.51
30	345.7	43.1	3.81
40	482.9	57.8	7.18

Multiplexed PMC for a TEG

A block diagram of the proposed circuit to handle the power coming from a TEG is represented in Fig. 1. The circuit has three main blocks: 1) PMC1 that operates from a very low input voltage, but without the ability to apply any MPPT method; 2) PMC2 that is able to apply an MPPT method but operating from higher values of input voltage; and 3) a switching stage that selects one of the two potential paths depending on the voltage level of the TEG output signal. In the prototype designed, PMC1 and PMC2 were implemented with LTC3108 and ADP5092 (both from Analog Devices), respectively. In addition, PMC2 was set to apply the FOCV with a fraction of 0.5. The switching stage was implemented by ADG839, which is a solid-state switch with an ultra-low on-resistance.

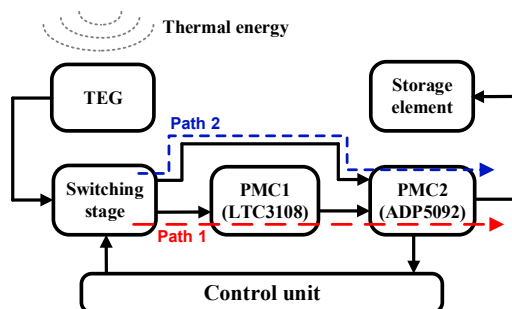


Fig. 1. Block diagram of the proposed circuit combining two PMCs in a multiplexed approach.

When the voltage provided by the TEG is low, path 1 (highlighted in red in Fig. 1) is selected so that the TEG is mainly handled by PMC1 and, then, connected to the storage element using an auxiliary input (BACKUP) of PMC2. On the other hand, when the TEG voltage is high enough, path 2 (shown in blue in Fig. 2) is chosen so that the TEG is directly connected to the main input of PMC2. Note that using always path 1 is not advisable since PMC1 efficiency is low, whereas path 2 cannot be always selected because the minimum operating voltage of PMC2 can be higher than that provided by the TEG. For this reason, this multiplexed solution combining both alternatives is proposed herein.

Experimental Results

The power efficiency of the circuit in Fig. 1 was experimentally evaluated. In order to have a characterization independent of potential drifts affecting the TEG, this was emulated by a source and measurement unit (Keysight B2961A) with a resistor ($7\ \Omega$) connected in series to mimic its internal resistance. On the other hand, the output was connected to another source and measurement unit (Agilent B2901A) behaving as a voltage source (3 V) to emulate an energy storage element, such as a supercapacitor or a rechargeable battery.

The efficiency results are represented in Fig. 2. While $40\text{ mV} \leq V_{OC} < 200\text{ mV}$, path 1 in Fig. 1 was selected and the efficiency was between 25 and 30 % in most of the range. However, when $200\text{ mV} \leq V_{OC} < 500\text{ mV}$, path 2 was chosen and the efficiency increased up to 78 %. Accordingly, the circuit in Fig. 1 is able to start operating from a low input voltage (i.e., 40 mV, which almost corresponds to $\Delta T = 5\text{ }^\circ\text{C}$) with a satisfactory efficiency (78%) at high values of input voltage, features that will not be achievable in a non-multiplexed topology.

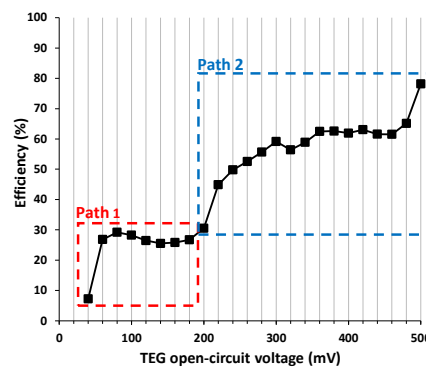


Fig. 2. Experimental results of circuit efficiency.

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