Thermoelectric Energy Harvesting Circuit for Variable Temperature Gradients

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***Abstract*—In this paper, a thermoelectric energy harvesting circuit that starts up at very low input voltages and harvests the very little energy of a variable temperature gradient is presented. It is based on a commercially available step-up converter Integrated Circuit (IC), with an adopted wiring scheme and some additional components to guarantee a stable operation for a sensor unit over a certain time. As a result, it turns out that load matching is suboptimal for the start up of the Thermo-Electric Generator (TEG) system in the case of small temperature gradients.**

Keywords-energy harvesting; small temperature gradient; step-up converter; thermoelectric generator.

I. INTRODUCTION

One main resource used for generating electrical power is thermal energy. There are many applications, which focus on the usage of thermoelectric devices exploiting temperature differences, but there are rarely any of them dealing with harvesting energy from temperature gradients [1]-[3]. There are two main reasons for that: on one hand, the little energy potential within a gradient does not seem to be attractive and, on the other hand, it is a reliability issue for stable operations of autonomous systems. Nevertheless, there are a plenty of applications that show small temperature gradients, for example in wearable systems and in systems for environmental and infrastructure monitoring.

The presented paper describes in Section 1, a thermal harvesting circuit that is capable to start up at very low voltage levels and to harvest all disposable energy within a thermal gradient to supply a sensor node in an oven application. In Section 2, the main results are briefly discussed and an outlook for future work is given.

II. DEVELOPMENT OF THE HARVESTER CIRCUIT

A commonly used IC to build up a thermal energy harvesting device is the LTC3108 from Linear Technology Corp. [4]. It is intended for low power wireless sensor nodes and other low power applications and, therefore, contains additional to the power management unit, several output voltage regulators that can either be switched on independently, on demand or sequentially, to supply a controller core and a transmitter or sensor unit. The power-up sequence of the circuit is fixed and hard coded, if thermal energy is applied to the TEG and will be described next.

After some energy is collected, the voltage at the low voltage regulator starts to increase until it reaches a level of 2.2 V. This regulator is intended to supply a controller unit. As the thermal energy is still available at the input, the voltage at the output VOUT still increases to 3.3 V. If this level is reached, the Power-Good (PGD) indicator pin activates, indicating the controller that a valid voltage level is available for other components. Due to the still applied energy at the input, now a transistor in the LTC3108 activates another output to charge an additional external storage capacitor.

Based on this short functional description, it can be recognized that the power up sequence is only useful if a constant energy is present at the input. If working with thermal gradients, in worst case also limited in time and additionally at varying rates, some problems will occur with this setup. One major problem is that the thermal energy within such gradients is very limited. In the case of constant heat transfer in the TEG, load matching is targeted to guarantee maximal power transfer. This configuration is suboptimal for the start up of a TEG system from small temperature gradients. The reason is that, if a load like a Microcontroller (MCU) core is already present at the Low-Dropout Regulator (LDO) output, the current flow will lead to a decrease of voltage level at the input. Tests showed that even for very low power MCUs, a valid start up of the controller core is impossible. Therefore, another strategy must be implemented; meaning, first to harvest all available energy within the thermal gradient and just at a certain point where enough power is available to initially activate the controller circuit.

If investigating in the different units implemented in the LTC3108, [3], all necessary building blocks can be found that are suitable to change the originally intended sequence, by just adding a few external components and adopting the connection scheme shown in Figure 1. The presented circuit just considers temperature gradients, which result in a positive voltage on the TEG system.

The start up procedure, for example of an oven, results in a temperature gradient, which proportionally increases the generated voltage of the TEG in the self-sustaining sensor system. If a level of 20 mV is reached, the dc-dc converter of the LTC3108 starts, leading to a corresponding voltage at the pin VOUT. To avoid a constant current flow and perform voltage matching, just a capacitor as load is connected to this pin. The reason is that it is slowly charged and, therefore,

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harvests all the available power at the input. The value of this capacitance must be matched to the slope of the thermal gradient, because if it continues to heat up the system, the voltage at the TEG will decrease at a certain time and will deactivate the dc-dc converter again if turning below 20 mV. In the case of a too high value, even the expected output voltage level at VOUT will not be reached anymore. The stored energy in this capacitor can then be used to supply the sensor electronics. The IC internally generates a PGD signal if the programmed output level at VOUT reaches 2.235 V. In the presented application, the load formed by a MCU is connected to the pin VOUT2. The reason for that is that this pin is switchable by an internal low leakage transistor. For enabling VOUT2, the PGD signal is used and connected to the respective input pin with a low voltage Schottky diode D1. This diode D1 represents another key aspect of the presented circuit, because it forms together with the second one an OR-gate controlled by an output of the MCU. This method is necessary due to the load case at output VOUT2. The MCU current at start up, refer to Figure 2 a.) (A), leads to a voltage drop at VOUT (B), where the energy flows from the capacitor C7 over the internal transistor of IC1 to the MCU. The PGD condition is tied to an internal not access- and adjustable hysteresis setting, which leads to switch off again if the voltage level decreases by 7.5% of the nominal set value (B). This happens quite rapidly, because the start up current even of a low power MCU is quite high. If the voltage is switched off by the PGD signal again, the electronics would never be supplied sufficiently. After switching off (B) again, the current is almost zero again, causing an increase in voltage at VOUT and switching on the voltage regulator once more (C). So, this effect of switching on and off the load leads to some kind of ringing, refer to Figure 2 a.), which has to be prohibited. Therefore, the energy stored in the capacitor C7 must be high enough to hold the voltage level during start up, configuration and switching on the diode D1 over the rated voltage minus 7.5% (internally fixed hysteresis value). After that, a further decrease in voltage level is not critical anymore, due to the lock of the high level of the MCU pin, resulting in Figure 2 b.). In the presented application, the output level is 2.235 V, therefore, the start up procedure including the output pin set is not allowed to decrease beyond 2.174 V. As an MCU with a supply rating of 1.8 V is used, still a margin for a further approximately 0.4 V voltage drop is guaranteed for valid operation. Depending on the stored energy, the permitted voltage drop and the current demand of the electronic circuit for the active operation time of the system, can be calculated.

III. RESULTS AND CONCLUSION

This paper describes a thermal harvesting circuit that can start up at very low input voltages, generated by thermal gradients and supply a circuit over a certain time. As a result, it must be mentioned that the presented solution is just meant for applications where the temperature gradient is exploited in one direction. Furthermore, if harvesting energy from small thermal gradients load matching of the TEG is not suitable, then additional changes to the standard circuitry, provided by the manufacturer, are presented and evaluated to proof the concept. Future work will focus on the improvement of the matching of the used components to increase the efficiency of the circuit and to extend the active time for the sensor application.

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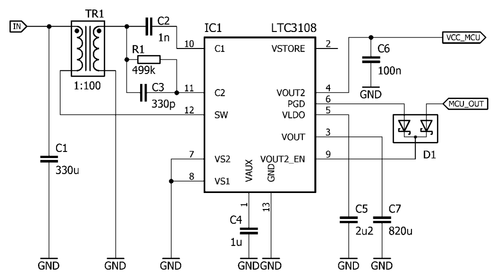

Figure 1. Developed circuit of the thermal harvester unit.

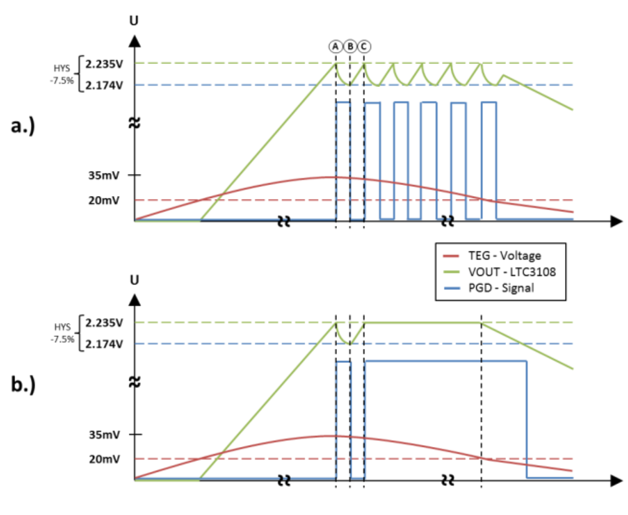

Figure 2. a.) Ringing phenomena due to different load conditions at VOUT, b.) Avoidance of the effect through self locking circuitry