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Universal Energy Harvesting Topology Used for Small Variable Temperature Gradients

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Summary:

This paper presents a thermo-electric energy harvesting circuit that starts up at very low input voltages, harvests the very little energy contained in small variable temperature gradients and bases on a commercially available converter chip. To guarantee a safe system start and stable operation over a certain time, external components are added that realize the topology developed within a modified block diagram. As a result, it turns out that beside optimal load matching also the power distribution and sequencing within the system is essential to deal with such low energy levels.

Keywords: harvester topology, harvesting circuit, thermo-electric generator, LTC3108

Introduction

Due to the rapid growing number of wireless sensor systems favored by the IoT and industry 4.0 applications also the demand for low power electronics increases. Many systems are powered by battery, but their drawbacks are an increase in dimensions and costs. Additionally, there is a need for replacement or recharging. To overcome these problems and to develop systems that are even able to be used in harsh environments, methods are introduced to harvest energy from present energy sources in the environment of the sensor. Since their quantities are quite small, sophisticated circuits must be developed to convert this low energy into useful supply levels for electronic circuits. Possible energy sources to be converted are - light emissions, radio frequency transmissions, vibrations and heat as it is used in the presented work. There are many publications dealing with harvesting circuits working under stable conditions, but there are rarely few dealing with temperature gradients [1], [2].

Modified Block Diagram for an Energy Harvesting System

Generally an energy harvesting system is built up by a detector unit that converts the physical quantity into an electrical signal, an energy converter, to boost the signal amplitude to a proper one for supplying an electronic circuit, an energy storage module for charging up with not instantly used energy and at last the energy consumption module represented by the electronic circuit of the sensor, refer to Fig. 1.

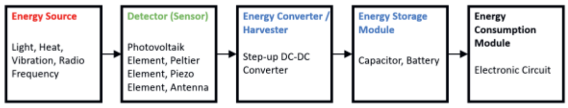

Fig. 1. General valid block diagram for a harvester unit working under stable environmental conditions.

If dealing with temperature gradients, which may additionally vary in time, this simple block diagram must be modified and extended to a configuration shown in Fig. 2.

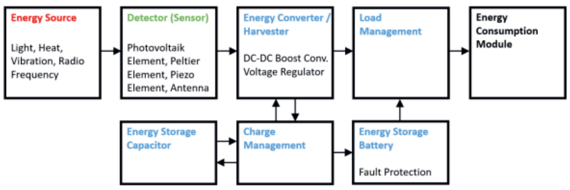

Fig. 2. Modified block diagram for a general harvester unit, dealing with not stable environmental conditions.

There are two main differences between the block diagram in Fig. 1 and the modified one in Fig. 2. First, the energy storage block is separated and split for both storage technologies - a capacitor and a battery, which additionally may need a fault protection. Furthermore, the constant voltage level enables a direct connection to the so important load management block, which represents the second main modification. This block is essential, especially if dealing with very low energy of temperature gradients. In this case first the energy must be harvested, before switching on the power supply for the electronics, which requires, even if using low power components a few milli amperes to start-up and run for a certain time.

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Thermal Harvester Circuit Development

Thermal energy harvesting systems require optimizations on the thermal and on the electrical circuit level. In particular, the thermo-electric device must be sized appropriately for the available heat and the electrical load. To maximize the converted power a perfect matching condition of the thermo-electric generator (TEG) and the input impedance of the DC-DC converter circuit is aimed. In the presented use case of exploiting the energy from thermal gradients the LTC3108 from Linear Technologies seemed to be the best fitting one. As it is already pointed out, also the suggested circuit schematic in the datasheet of the chip (see Fig. 3, [3]) bases on the simple block diagram shown in Fig. 1.

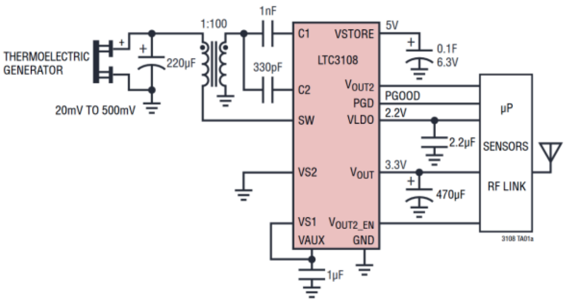

Fig. 3. Wireless remote sensor application powered from a Peltier cell recommended in the datasheet.

The implemented start-up sequence in the LTC3108 requires constant input levels. As this is not given with transient gradients, the switching scheme must be influenced, which is just possible by applying external components. Fig. 4 illustrates the developed circuit and its modifications realizing a circuit based on the adopted block diagram shown in Fig. 2.

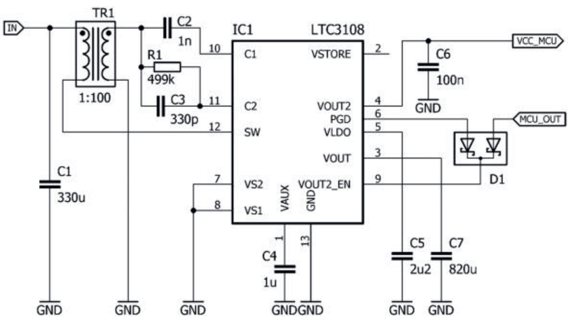

Fig. 4. Developed circuit with improved power-up sequence influenced by external components.

The first key modification is the connection of just a capacitor C7 to VOUT of the LTC3108, which represents a high impedance load. Therefore, all available energy at the input is stored in C7, right after start-up of the DC-DC converter. If the programmed output level of 2.35 V, set via VS1 and VS2, is reached, the power good PGD signal enables VOUT2, where the low power microcontroller is connected. However quite a high start-up current is necessary, leading to a voltage drop at VOUT, because the current flows from the input and additionally from C7 via VOUT2 to the MCU. Due to the fixed internal hysteresis, this drop causes the chip to deactivate PGD again, resulting in a shutdown of VOUT2 and therefore deactivation of the electronics again. Now just C7 represents the load again, and after reaching the valid level PGD is activated once more. To overcome this kind of ringing phenomena, which would never allow the circuit to start-up properly, an external OR-gate is realized by D1. If PGD is deactivated again by the LTC3108, one output of the controller switches on in the meantime, which leads the power supply to remain at the desired level. So, this configuration represents a self-locking circuit mechanism, which is the second important feature of the circuit. The value of C7 must be carefully chosen according to either provide enough stored energy to start-up the electronics or to charge up in time to reach the valid output level at VOUT according to the given thermal gradient at the input.

Results

Measurements show the functionality of the circuit and demonstrate how the switching sequence of the LT3108 is influenced by external components to deal with the little energy of thermal gradients.

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