A Fully Integrated Adaptive Energy Harvesting System for Ultra-low Power Applications

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The goal of this project is to implement a fully integrated platform with minimum external components for a PV cell energy harvester and a sub-threshold voltage microprocessor for ultra-low power applications. It can harvest the light energy in both indoor and outdoor environments with the input power ranging from uW to mW level with optimal efficiency.

Nowadays, for many systems, the power source is a bottleneck that limits the system lifetime and performance, adds manufacturing cost, and increases the system bulk and maintenance costs. A smart solution that could tackle this problem is using energy harvesting technology. To reduce system cost and volume it is desirable to integrate energy harvesting circuits with data acquisition, data processing, and communication circuits on the same chip for ultra-low power applications. This work focuses on a fully integrated photovoltaic (PV) energy harvester design optimized for both indoor and outdoor light intensity. As PV cells exhibit a strong non-linear electrical characteristic and must work in a variety of environments, they require the development of an adaptive solution to transfer the energy generated by the PV cells into a storage medium, such as a capacitor or a battery, while maintaining the working point of the cell around the optimal region (for which the transferred power is maximized) under changing illumination conditions. The design exhibits three main features:

- It minimizes the external components for cost-effectiveness and compactness
- It minimizes the power consumed by the power management unit (PMU) by using advanced nano-power circuits and a sub-threshold digital controller
- It maximizes the converting efficiency and automatically adapts to the environment changes for an optimized operation of the whole energy transfer path

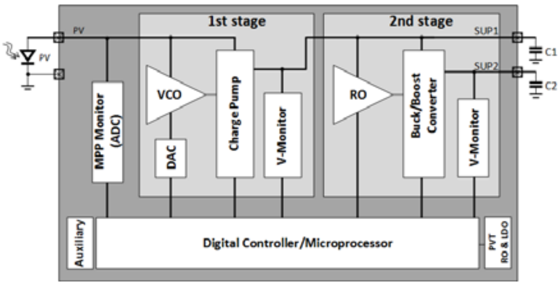

Figure 1: System block diagram.

The architecture of the system is illustrated in Figure 1. Only 2 external capacitors are needed. They act as the energy storage medium connected to the output of each DC-DC converter stage. The power converting efficiency is optimized for both the PV cell and the 2 stage DC-DC circuits (Efficiency simulation results are shown in Figure 2 and Figure 3 for 1st and 2nd stages, respectively). This is achieved by combining:

- A maximum power point tracker (MPPT) based on fractional open circuit voltage with self-adjustment to the input light and linearized PV cell voltage controlling algorithm
- A 2-stage switched-capacitor DC-DC converter with on-chip MIM capacitor placed on top of the digital core
- An advanced self-oscillating charge pump structure [1] for the 1st stage, working with PV cell voltages down to 0.35 V
- A combination of staircase and PWM control schemes for the DC-DC converter

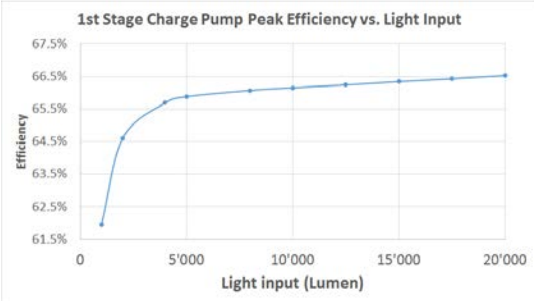

Figure 2: The simulated peak efficiency of the 1st stage as a function of illumination.

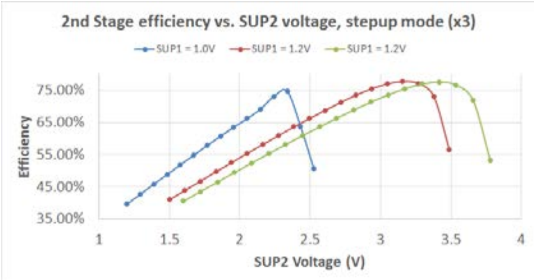

Figure 3: Simulated efficiency of the 2nd stage.

The energy transfer paths of the system with the voltage and peak efficiency is indicated in Figure 4.

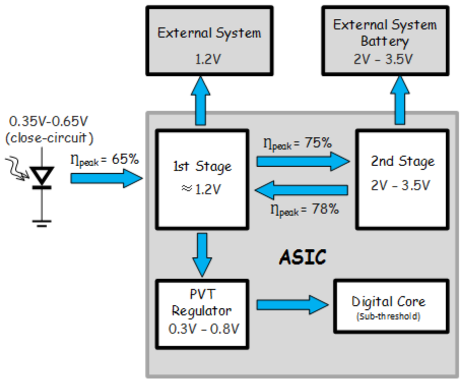

Figure 4: Energy conversion paths of the system.

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[1] W. Jung, *et al.*, “A 3 nW fully integrated energy harvester based on self-oscillating switched-capacitor DC-DC converter", ISSCC IEEE Int. Solid-State Circuits Conf. Digest of Technical Papers (2014) 398.