An Harvesting System with Adaptive Power Management Algorithm for Energy Autonomous Devices

L. Zahnd, J. Deng, Y. Zha, J.-L. Nagel, C. Arm, M. Pons Solé, P. Persechini, D. Ruffieux, C. Monneron, R. Godinho Caseiro, Y. Liechti, S. Emery

A fully-integrated energy harvesting and transfer unit controlled by a sub-VT MCU has been implemented. The system is able to seamlessly transfer power between a solar cell and a 2.5-3 V battery while energizing external chips at 1.2 V. It manages the available energy optimally thanks to control algorithms such as hill-climbing, hysteresis regulation, Pulse Width Modulation for Maximum Power Point Tracking (MPPT) and output regulation.

Many modern electronic systems (i.e. wearable devices, connected sensors for the IoT) would greatly benefit from being able to harvest their own energy so as to eliminate wiring, daily recharge, maintenance or the need for oversized batteries. Energy autonomous operation for such devices requires combining in a low cost, compact system: 1) energy harvesting, 2) power conversion, and 3) storage functions. In addition, the awareness of the energy available at any time is a must for an optimum management of the application which could switch between different power modes contextually.

The smart fully-integrated powering unit, whose layout is pictured in Figure 1, is a System-on-Chip (SoC) that has been designed in 65-nm CMOS to provide an effective such solution for energy-autonomous connected nodes. It features two icyflex2-MCUs operating in sub-threshold and whose frequency can be changed dynamically for both minimum and scalable energy consumption. The MCUs control on the one hand an integrated energy harvester/transfer unit in the way described above and are able thanks to standard digital interfaces to interact with off-the-shelf components (COTS), process and manage related data to be transmitted wirelessly.

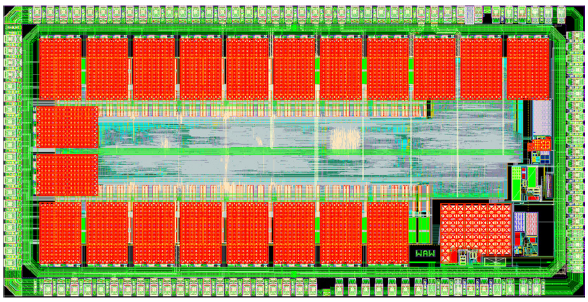

Figure 1: Smart powering unit SoC layout comprising a fully-integrated switched-capacitor based harvester, two MCU cores, 32 KB SRAM, 8 KB ROM, standard peripherals and interfaces.

The block diagram of the proposed adaptive energy harvesting system used with a photovoltaic (PV) cell is shown in Figure 2.

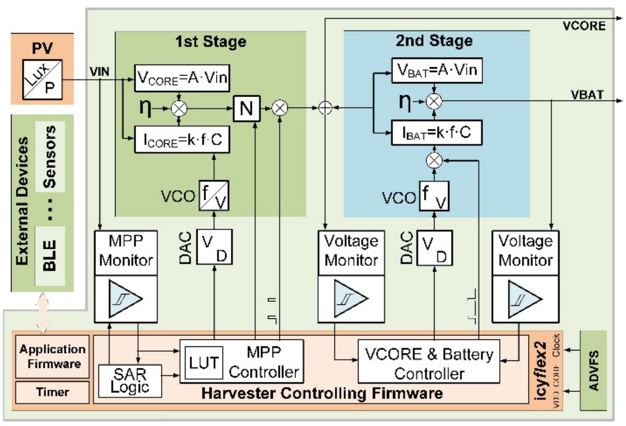

Figure 2: Block diagram of the dual stage energy harvesting unit.

The system consists of a dual stage energy conversion path and three control loops: one for MPPT and two for output voltages regulation. The 1st stage boosts the PV output voltage to a VCORE of ~1.2 V, suitable to power the SoC and an external wireless transmitter. The surplus (or missing) energy is transferred to (or taken from) a 2.5-3 V LiMn battery (or supercap) via the bidirectional 2nd stage charge pump. The higher standard voltage is used to power and interface COTS. To achieve maximum power transfer, a dynamic MPPT algorithm was implemented. It is able to:

- Detect changes of illumination via the level-crossing ADC.
- Search the PV-cell maximum power point with a SAR ADC.
- Control the 1st stage configuration to tune the current load.

To minimize the hardware complexity and power consumption, the MPP monitor is power-cycled and reconfigurable as either level-crossing ADC or SAR ADC. MPP open-circuit voltage method is used for calculating the optimized PV-cell voltage. Then, an energy-efficient hill-climbing algorithm is executed on the MCU to reach the targeted PV-cell voltage after configuring the 2D charge pump (CP) network (1×1 to 4×21) and its operating frequency for voltage gain and load setting. When illumination is weak, a PWM scheme (periodically turning on and off part of CP units) is applied to the 1st stage. With this approach a wide range of input currents spanning several decades (µW-mW) can be harvested with >50% efficiency.

To set the 1st stage output voltage, a control loop based hysteresis regulation is applied. By comparing VCORE using the voltage monitor, the regulation scheme turns off and on the 2nd stage. Thus the 1st stage is over or under loaded for a limited period, which creates a saw-tooth shape waveform within a predefined range (i.e. ±50 mV) around the target voltage. The hysteresis regulation is also applied to the output of the 2nd stage to prevent over-charging or over-draining the battery.

Figure 3 shows a measurement of the powering SoC when the illumination is changed (between indoor and outdoor). It demonstrates that the system can adapt the PV-cell voltage to the MPP and maintain VCORE within a predefined range.

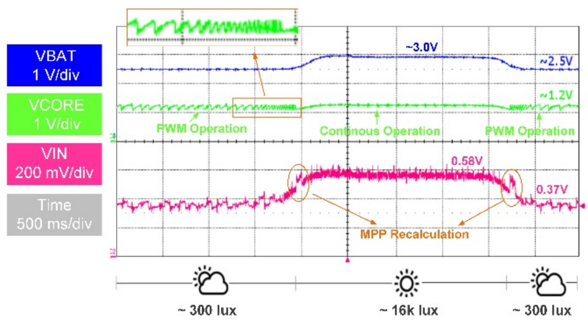

Figure 3: SoC measurement when varying the illumination condition.