PROBIOTICS —a Pressure Monitoring Robust Unobtrusive Batteryless IoT Integrated Circuit & System

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PROBIOTICS aims at realizing the first robust, extremely miniaturized, pin-sized, energy autonomous Internet-of-Things node combining energy harvesting, storage and management, sensing (e.g., pressure, temperature), on-chip digital signal processing and wireless data transfer. It addresses the booming IoT market by leveraging CSEM multidisciplinary skills to solve both the power and size bottlenecks currently preventing ubiquitous WSN deployment.

The Internet-of-things (IoT) holds the promises to connect wirelessly almost any sensor node (WSN) to the cloud accelerating the digitalization of our society. Wide and ubiquitous deployment is however currently facing a critical bottleneck. How to energize the foreseen billions of nodes in a maintenance-free way? IoT market penetration is hindered by the reliance on technologies that fuel the smartphone revolution: These off-the-shelf parts (COTS), targeting high performances, high complexity applications, are too energy-greedy to ensure the kind of autonomy requested by the envisioned tiny nodes. In order to overcome this challenge, the missing components required to build an extremely low power, unobtrusive, energy autonomous WSN capable of interacting with the mobile infrastructure via the Bluetooth Low Energy standard are being developed.

As a representative sensing element, an SOI-based, ultra-compact, piezo-resistive, chip scale packaged pressure sensor is being designed. Through-silicon via are used to connect the top sensing face of the device to the electrical pads on the bottom, easing assembly. It is associated to a system-on-chip (SoC) integrated circuit that is capable of acquiring and processing locally the signal in order to reduce the payload to be transmitted wirelessly, since each byte is associated to a high energy penalty. Such an energy-efficient computing scheme performed at the edge, coupled with a smarter data management approach yields tremendous power savings despite the added complexity.

This approach makes possible for the SoC to harvest its own energy from a miniature PV-cell, provided an efficient Power Management Unit (PMU) is used to optimize the energy distribution, usage and storage. Precise time and frequency references are obtained with two crystal oscillators (XO) running at 32 kHz for timekeeping and scheduling and 48 MHz for ADC/radio operation. Complementing the two XOs, a programmable on-chip ring oscillator whose frequency can be locked to one of the references is used to clock the sub/near threshold microcontroller (MCU) operated at 0.5 V at various speeds from a few kHz up to 20 MHz, for maximum flexibility.

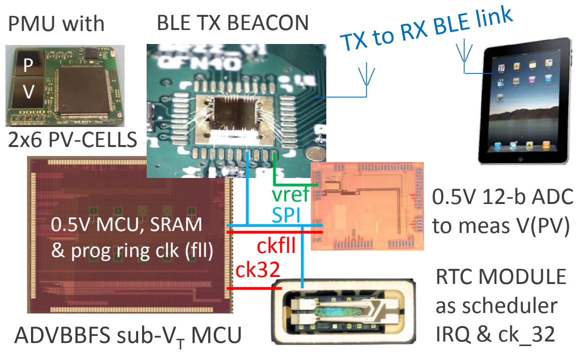

Figure 1: Preliminary WSN demonstrator made with test-chips.

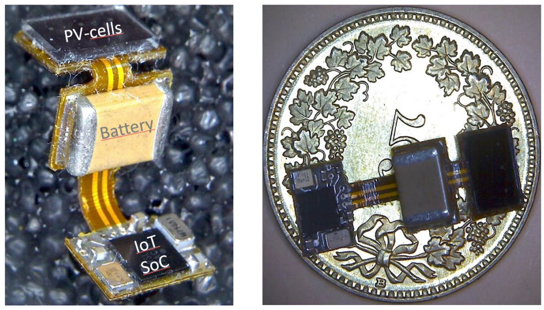

Figure 2: Photographs of the energy autonomous miniature IoT WSN.

Running the MCU at 0.5 V rather than 1 V trades maximum speed off for a large quadratic power gain (4x) but also amplifies the sensitivity to PVT variations. Unchecked, the latter, yields to a frequency variations of 100x. However, it can be mostly eliminated (±10% residue) thanks to a simple patent-pending current servo loop that adjusts individually the substrate voltage of N and PMOS transistors. Most of the speed penalty can be cancelled without any additional circuitry by forward-biasing the MOS transistors, at the expense of an increased leakage. With bulk voltages spanning -1 V (REV) to 0.6 V (FWD) referred to the N & PMOS supply rails, PVT compensation and 100x frequency scaling is obtained when using MIE Fujitsu 55 nm DDC CMOS technology. The robust control scheme allows to dynamically and adaptively scale the MCU performances and its associated system clock at run time, guaranteeing minimum energy dissipation over a wide range of frequencies. With this approach, a record low dynamic power of 3 uW/MHz was measured for the 32 b-MCU. The combined 0.9/0.5 V 1 Msps 12-b ADC digitizing the sensor data makes use of the same principle, consuming merely 20 uA. Compared to the 6 mW, 1-2 Mbps BLE TRX running at 0.95 V, it allows data acquisition and computing operation with 1 pW/bit and 0.1 pW/bit respectively, or between 3 and 4 orders of magnitudes less than communication.

Figure 1 shows the intermediate WSN demonstrator that was built with the three MCU, ADC and BLE test-chips and a COTS RTC. As a simple PMU replacement, two homemade 1.5 cm^2 six-segments, SMT compatible PV-cells, delivering 30 uW at 500 lux, are used to supply -1 V, 0.5 V, 1 V and 3 V. Capacitors absorb peak currents such as when the ADC measures the PV-cells voltages and as BLE beacons encoding that information are transmitted to a tablet. The MCU operates at various speed and in retention to optimize the overall consumption at runtime.

As an outlook, Figure 2 shows the miniature WSN implemented with a COTS IoT SoC incorporating CSEM BLE IP. After folding, the WSN, supplied by a 100 uAh 1.5 V SMT battery recharged by a 3-segments miniature PV-cell delivering 3 uW at 500 lux, is about the size of the inner digit of Swiss 5 cts coin!