ASIC-driven Miniature Atomic Clock

S. Karlen, J. Haesler, Y. J. Regamey, D. Ruffieux, S. Lecomte

Chip-scale atomic clocks (CSACs) currently achieve the high level of frequency stability required for today communication systems and localization devices. Thanks to the combination of a dedicated application specific integrated circuit (ASIC) with a microcontroller and a MEMS atomic vapor cell-based physics package, a small, low power and highly integrated solution was demonstrated at CSEM. These results pave the way for the power reduction of CSACs in a near future.

Miniature atomic clocks play an important role in the fields of telecom and navigation. Upon further miniaturization and cost reduction, they are poised to play an ever-increasing role in modern portable and autonomous applications. Several compact and miniature atomic clocks are today available on the market with different levels of miniaturization. All of them make use of discrete electronic components to drive the physics package. Moving electronics to an application specific integrated circuit (ASIC) opens new perspective for further miniaturization, high volume production as well as power and cost reduction.

In the past several years CSEM has developed Rubidium filled MEMS atomic vapor cells with a process compatible with low-cost and large-volume production [1] (see Figure 1-right), and a flat physics package (PP) was developed for height sensitive applications [2] (see Figure 1-left). The physics package consists of an LTCC (Low Temperature Co-fired Ceramics) package which includes a proprietary MEMS cell, a 795 nm emitting VCSEL (Vertical-Cavity Surface-Emitting Laser), and a propriety planar waveguide used to route the laser light to the cell and the photodiodes.

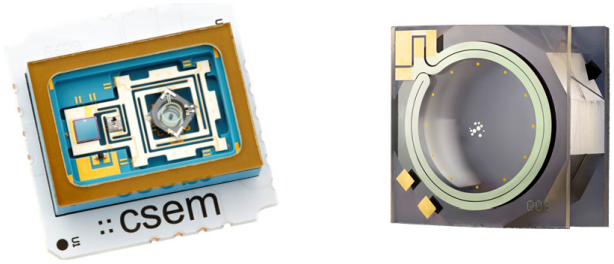

Figure 1: LTCC flat-form factor atomic clock physics package, PP (left); Rubidium filled MEMS atomic vapor cell (right).

To tend towards the ultimate clock miniaturization, a proprietary ASIC was developed as well [3] (see Figure 2). Coupled to a microcontroller, this integrated circuit offers the required functionalities to fully and autonomously operate a CPT atomic clock: RF synthesizer, transimpedance amplifiers, current sources, and lock-in detection. This ASIC was implemented in a standard digital 0.18 µm CMOS. Its total power consumption was estimated to be in the order of 26 mW (without current sources).

A clock prototype which takes advantage of the three elements was assembled as a single compact system. The cell was heated up to 90°C using the ASIC current sources. The system was operated under vacuum in order to reach this cell temperature as the vacuum encapsulation of the physics is not yet realized.

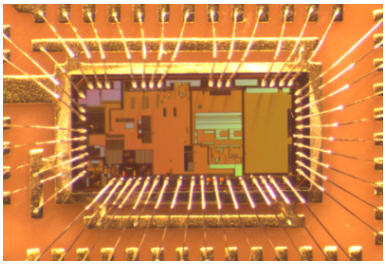

Figure 2: Clock ASIC (3 × 6 mm).

A coherent population trapping (CPT) signal with a full width at half maximum of 1.7 kHz was measured by locking the laser to the rubidium D^1 atomic transition and modulating its frequency at 3.417 GHz using the ASIC RF generator. The measured CPT contrast was 0.6%. After locking the local oscillator (quartz) to the atomic clock transition, a short-term frequency stability of 10^{-10} at 1s integration time (see Figure 3) was measured. The long-term stability was not optimized and was limited to 10^{-11} in this measurement.

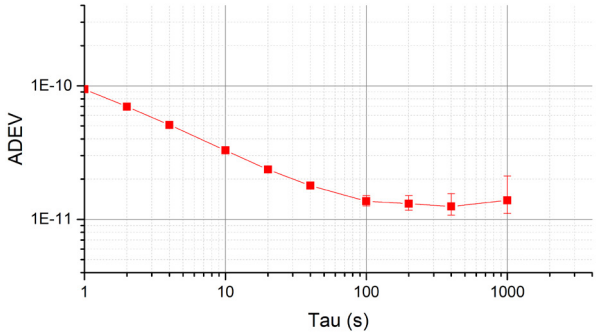

Figure 3: Allan deviation of the ASIC-driven chip-scale atomic clock system.

The measured short-term frequency stability is comparable to the stability of a clock operated with discrete electronics in the same experimental conditions This verifies the functionality and the operability of the ASIC. Coupled with a low consumption physics package, a full clock draining less than 50 mW of electrical power can thus be reached in a near future.

[1] S. Karlen, *et al.*, "Lifetime assessment of RbN3-filled MEMS atomic vapor cells with Al_2O_3 coating", Optics Express, 25(3), 2187 (2017).

[2] J. Haesler, *et al.*, "Ceramic based flat form factor miniature atomic clock physics package (C-MAC)", 6th International Colloquium on Scientific and Fundamental Aspects of GNSS / Galileo (2017)
J. Haesler, *et al.*, "Low-Power and Low-Profile Miniature Atomic Clock Ceramic based flat form factor miniature atomic clock physics package C-MAC)", European Frequency and Time Forum & International Frequency Control Symposium (EFTF-IFCS) (2017).

[3] D. Ruffieux, *et al.*, "Towards Portable Miniature Atomic Clocks" In A. Baschirotto, *et al.*, "Frequency References, Power Management for SoC, and Smart Wireless Interfaces" (pp. 83–99), Springer International Publishing (2014).