

# A HBAR-oscillator-based 4.596 GHz frequency source: design, characterization and application to a Cs microcell atomic clock

Rodolphe Boudot<sup>1</sup>, Gilles Martin<sup>1</sup> and Jean-Michel Friedt<sup>1</sup>

<sup>1</sup>FEMTO-ST, CNRS, UFC, ENSMM, Besançon, France.

Email: [rodolphe.boudot@femto-st.fr](mailto:rodolphe.boudot@femto-st.fr)

The most common technological approach for the development of a local oscillator in miniature atomic clocks (MACs) application consists of a frequency synthesizer using a LC voltage-controlled oscillator (VCO) phase-locked to a 10 MHz quartz oscillator through a fractional-N phase-locked loop (PLL) [1,2]. However, in such systems, the frequency multiplication degrades the phase noise and can consume up to 50% of the MAC total power budget [1]. In that domain, a promising alternative solution is the development of microwave MEMS oscillators based on bulk acoustic wave (BAW) resonators, exhibiting small size, low power consumption and high Q-f products.

This work reports on the design and characterization of a high-overtone bulk acoustic wave resonator (HBAR)-oscillator-based 4.596 GHz frequency source. A 2.298 GHz signal, generated by an oscillator constructed around a thermally-controlled two-port AlN-sapphire HBAR resonator with a Q-factor of 24000 at 68°C, is frequency multiplied by 2 to 4.596 GHz, half of the Cs atom clock frequency. The temperature coefficient of frequency (TCF) of the HBAR is measured to be -23 ppm/°C at 2.298 GHz. The measured phase noise of the 4.596 GHz source is -105 dBrad<sup>2</sup>/Hz at 1 kHz offset and -150 dBrad<sup>2</sup>/Hz at 100 kHz offset. These phase noise performances are significantly better than those achieved with usual technologies [1,2].

The 4.596 GHz output signal is used as a local oscillator (LO) in a laboratory-prototype Cs microcell-based coherent population trapping (CPT) atomic clock [3]. The HBAR-based source signal is frequency-stabilized onto the atomic transition frequency in two steps: a coarse frequency tuning by adjusting the HBAR resonator temperature and a fine tuning by using a voltage-controlled phase shifter (VCPS) implemented in the 2.298 GHz HBAR-oscillator loop, preventing the need for a high-power-consuming direct digital synthesis (DDS).

The short-term fractional frequency stability of the free-running oscillator is  $1.8 \cdot 10^{-9}$  at one second integration time. In locked regime, the latter is improved in a preliminary proof-of-concept experiment at the level of  $6.6 \cdot 10^{-11} \tau^{-1/2}$  up to a few seconds and found to be limited by the signal-to-noise ratio of the detected CPT resonance. The potential of this technology to be embedded in viable miniature atomic clocks will be discussed.

## References

- [1] R. Lutwak, A. Rashed, M. Varghese, G. Tepolt, J. Leblanc, M. Mescher, D. K. Serkland, K. M. Geig and S. Romisch, 39<sup>th</sup> Annual Precise Time and Time Interval (PTTI) Meeting, Long Beach, CA, p. 269-281, 2007.
- [2] Y. Zhao, S. Tanner, A. Casagrande, C. Affolderbach, L. Schneller, G. Mileti and P. A. Farine, "CPT cesium cell atomic clock operation with a 12-mW frequency synthesizer ASIC", IEEE Trans. Instr. Meas., vol. 64, p. 263, 2015.
- [3] T. Daugey, J. M. Friedt, G. Martin and R. Boudot, A high-overtone bulk acoustic wave resonator-oscillator-based 4.596 GHz frequency source: Application to a coherent population trapping Cs vapor cell atomic clock. Rev. Sci. Instr. 86, 114703 (2015).