Characterization of the phase-noise induced by an optical frequency doubler

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***Abstract*— We report on the characterization, including residual phase noise and fractional frequency instability, of second harmonic generation fiber-coupled periodically poled LiNbO3 (PPLN) waveguides. We observe a residual phase noise as low as -35 dBrad^2/Hz at 1 Hz, which makes them compatible with the best up-to-date optical clocks and ultra-stable cavities.**

***Keywords*— optical atomic clocks; second harmonic generation; phase noise; frequency metrology**

State-of-the-art optical atomic clocks have attained short-term fractional frequency stabilities in the low 10^{-16} range [1,2]. This has been made possible thanks to improved performances of the clock lasers, which are pre-stabilized using ultra-stable Fabry-Perot (FP) resonators [3]. Many of the last-generation optical atomic clocks rely on frequency doubling via second harmonic generation (SHG) to produce the laser clock frequency [4,5], where the pump laser used for SHG is stabilized to the ultra-stable FP resonator. It is therefore necessary to ensure that the SHG setup does not degrade the beam fractional frequency stability.

Bulk crystals and periodically poled (PP) crystals have been used and characterized, and it has been shown that they introduce very low phase noise, at the price of a poor SHG efficiency [6-8].

In this study, we employ fiber-coupled PPLN waveguides to perform the frequency doubling from an extended cavity diode laser at a wavelength λ = 871 nm to the electric quadrupole transition clock frequency of Yb^+ at λ = 435.5 nm. These modules are both compact, highly-efficient, and avoid the use of an enhancement cavity. We report SHG efficiencies up to 117.5 % /W.

We measure the phase noise induced by the SHG with a Mach-Zehnder interferometer and a novel noise rejection technique and observe a residual phase noise as low as -35 dBrad^2/Hz at 1 Hz (see Fig. 1), which makes them compatible with the best up-to-date optical clocks and ultra-stable cavities.

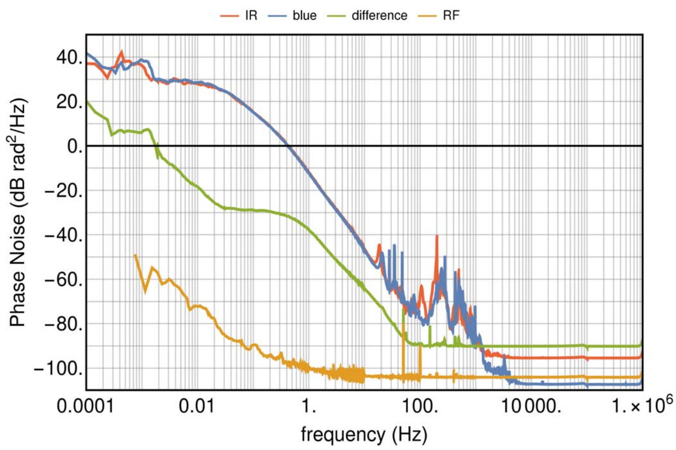

Fig. 1. Optical phase noise measured using a Mach-Zehnder interferometer. Red: pump laser phase noise at 871 nm. Blue: second harmonic phase noise at 435.5 nm , scaled to 871 nm. Green: phase noise obtained when mixing the pump and second harmonic signals, allowing an estimation of the residual phase noise of the second harmonic beam. Orange: noise floor of the electronic measurement setup.

REFERENCES

[1] B. J. Bloom, T. L. Nicholson, J. R. Williams, S. L. Campbell, M. Bishof, X. Zhang, W. Zhang, S. L. Bromley, and J. Ye, "An Optical Lattice Clock with Accuracy and Stability at the 10^{-18} Level", Nature, vol. 506, pp. 71-75, 2014.

[2] I. Ushijima, M. Takamoto, M. Das, T. Ohkubo, and H. Katori, "Cryogenic Optical Lattice Clocks", Nat. Phot., vol. 9, pp. 185-189, 2015.

[3] Y. Y. Jiang, A. D. Ludlow, N. D. Lemke, R. W. Fox, J. A. Sherman, L.-S. Ma, and C. W. Oates, "Making Optical Atomic Clocks more stable with 10^{-16}-Level Laser Stabilization", Nat. Phot., vol. 5, pp. 158-161, 2011.

[4] C. W. Chou, D. B. Hume, J. C. J. Koelemeij, D. J. Wineland, and T. Rosenband, "Frequency Comparison of Two High-Accuracy Al^+ Optical Clocks", Phys. Rev. Lett., vol. 104, pp. 070802, 2010.

[5] R. Tyumenev, M. Favier, S. Bilicki, E. Bookjans, R. Le Targat, J. Lodewyck, D. Nicolodi, Y. Le Coq, M. Abgrall, J Guéna, L. De Sarlo, and S. Bize, "Comparing a Mercury Optical Lattice Clock with Microwave and Optical Frequency Standards", New Jour. Phys., vol. 18, pp. 113002, 2016.

[6] R. Wynands, O. Coste, C. Rembe, and D. Meschede, "How Accurate is Optical Second-Harmonic Generation?", Opt. Lett., vol. 20, pp. 1095–1097, 1995.

[7] Jörn Stenger, Harald Schnatz, Christian Tamm, and Harald R. Telle, "Ultraprecise Measurement of Optical Frequency Ratios", Phys. Rev. Lett., vol. 88, pp. 073601, 2002.

[8] D. Yeaton-Massey and R. X. Adhikari, "A New Bound on Excess Frequency Noise in Second Harmonic Generation in PPKTP at the 10^{-19} Level", Opt. Expr., vol. 20, pp. 21019–21024, 2012.