# A Commercial Acetylene-based Optical Clock with an ADEV $<3\times10^{-13}/\sqrt{\tau}$ and TDEV <1 ns for $\tau$=100,000 s

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Advanced clocks exhibiting sub-picosecond timing instabilities are enabling advancements in diverse application spaces like positioning, navigation, and timing (PNT), time and frequency transfer (TFT), distributed radar networks, and timing for financial and commercial interests. Most state-of-the-art optical atomic clocks are constrained to laboratory settings due to the low technology readiness level (TRL) of many, if not all, of their subsystems, including: optical frequency combs (OFCs), narrow-linewidth and high-power lasers, low-noise electronics, and atomic physics packages. Recent developments at Vescent Technologies, Inc. (Vescent) and the Danish National Metrology Institute (DFM) have produced commercial-off-the-shelf (COTS) solutions that combine to form an optical molecular clock, whose performance rivals that of hydrogen masers but with drastically reduced environmental susceptibility and footprint.

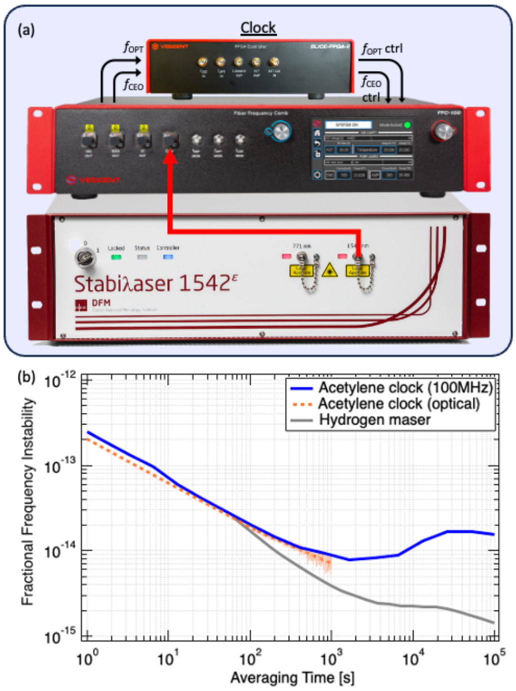


Figure 1 (a) COTS components required for the $C_2H_2$ optical clock demonstration. (b) Fractional frequency instability of the $C_2H_2$ clock measured from the 100 MHz comb output against a hydrogen maser.

DFM's Stabiλaser 1542ϵ [1] is a turnkey optical frequency reference (OFR) system based on frequency-stabilizing a laser to an overtone transition in acetylene ($C_2H_2$) near 1542 nm. The laser, spectroscopy cell, electro-optic actuators, and control electronics occupy a 3U rack-mount chassis with a volume of ≈30 L. Vescent's FFC-100 OFC system [2] is based on robust telecom fiber technologies and is enclosed in a 10 L, 2U rack-mount chassis. The fully phase-stabilized comb shows a fractional frequency instability of $<5\times10^{-17}/\tau^{3/2}$ [modified Allan deviation, in-loop] indicating the amount of noise the comb would contribute to any optical clock measurement. Vescent's OFCs have been designed and tested to operate reliably over large temperature ranges and have been proven to maintain continuous, glitch-free operation over several months; long-term testing of this optical clock kit are ongoing.

By combining the OFR with the OFC system (Fig. 1a), a high-performance microwave clock output is generated in less than 30 minutes of set-up time, leveraging the high TRL of each subsystem. The measured Allan deviation of the acetylene clock was $<3\times10^{-13}/\sqrt{\tau}$ (Fig. 1b) for $\tau$<100 s and reaching a fractional instability of $8\times10^{-15}$ around $\tau$=2,000 s. The comb faithfully divided the $C_2H_2$ reference's optical stability into the radio-frequency domain without adding any observable noise. Measurements were collected over 5 days, resulting in a fractional frequency instability of $<2\times10^{-14}$ and a timing deviation of <1 nanosecond at $\tau$=1 day. Measurements of clock phase noise and performance at longer timescales will be discussed.

[1] "Stabilaser product page," [Online]. Available: https://stabilaser.dk/stabilized-laser
[2] "FFC-100 Fiber Frequency Comb product page," [Online]. Available: https://vescent.com/us/ffc-100-frequency-comb.html