Absolute frequency measurements with a stabilized near-infrared optical frequency comb from a Cr:forsterite laser*

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Abstract: A Cr:forsterite laser-based frequency comb is stabilized simultaneously to two NIST frequency references. Several optical frequency references frequencies are then measured from 1315 nm – 1620 nm, including methane lines near 1330 nm.

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We report the frequency stabilization of a near infrared frequency comb based on a high repetition rate, short pulse Cr:forsterite laser[1] and its use for optical frequency metrology. The laser output was broadened in 10 m of highly nonlinear dispersion-shifted optical fiber (HNLF), made from Ge and F –doped silica [2] with a dispersions of -13 ps/(nm km) at 1280 nm. The resulting comb was stabilized by phase-locking one mode of the comb to one half of the frequency of the NIST neutral Ca optical frequency reference [3], and simultaneously phase-locking the repetition rate to a hydrogen maser that is calibrated by the NIST-F1 Cs fountain clock.[4]. The details of the stabilization are shown in Fig. 1.

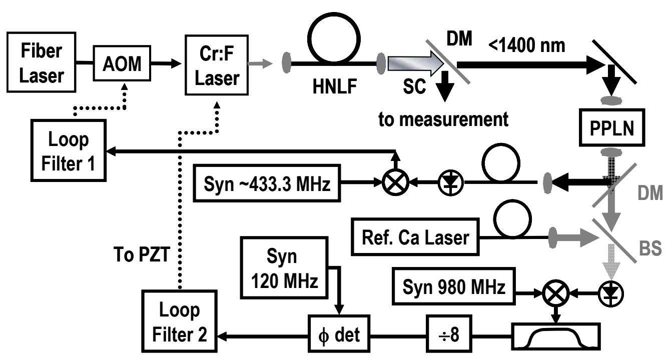

Figure 1: Schematic. SC, supercontinuum; DM, dichroic mirror; Syn. Synthesizer; BS, beamsplitter; ϕ det, phase detector; Loop Filter, electronic servo filter.

The two phase-locked electrical signals are shown in Fig. 2, as measured with an rf spectrum analyzer. Both the locked repetition rate of the laser and the beat of the doubled comb against the Ca reference show a narrow carrier, with a width of < 10 Hz, which is the resolution of the spectrum analyzer employed. Given the fractional frequency uncertainty and instability of both frequency references, the result is a stabilized frequency comb spanning 1100 – 1800 nm, spaced by 433 MHz, and known to better than 11 Hz with an instability smaller than 10 Hz in 1 s.

We have used to comb to measure several frequency standards, including Rb and a stable optical cavity. We have also remeasured the NIST methane wavelength standard near 1300 nm.[5] This spectrometer consists of an extended cavity diode laser locked to a Doppler-broadened transition in methane at 8.21± 0.76 kPa. The new measurement of the R(8) transition feature gives 228 050 482.8 ± 2.3 MHz, which agrees with the previous

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measurement within its quoted uncertainty. The clean single features labeled R(1) and R(2) in Ref. [5] were also measured for the first time to this level of accuracy and are reported in Table 1. No attempt was made to reassess the systematic errors in the spectrometer, and therefore the uncertainty of our new measurement is not reduced.

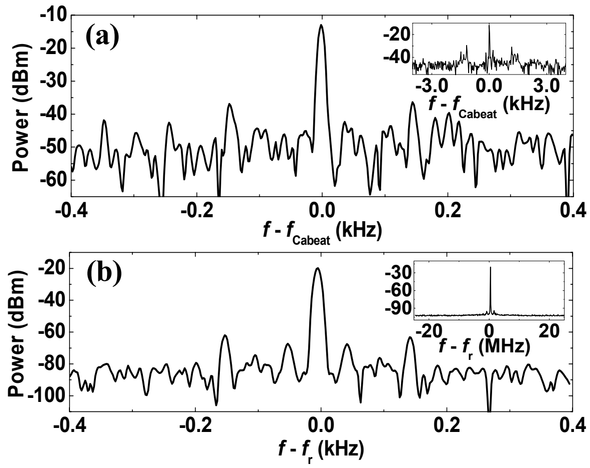

Figure 2: Electrical signals used for locking, shown while comb is phase-locked. a) Ca beat with doubled comb, centered on f_{Cabeat} = 20.6 kHz. b) Repetition rate, centered on fr = 433.435 2 MHz.

Table 1. Measured optical frequencies of ro-vibrational transitions at two pressures in THz, with an expanded uncertainty of 2.3 MHz. Also, the resulting pressure shift in MHz/kPa and MHz/torr. Cell 1 has a pressure of 1.44 ±0.13 kPa (10.8 ± 1.0 torr), and Cell 2 a pressure of 8.21 ±0.76 kPa (61.6 ± 5.8 torr).

CH_3 $\nu_2 + 2\nu_3$	Cell 1 (1.44 kPa)	Cell 2 (8.21 kPa)	Pressure shift	
	(± 2.6 MHz)	(± 2.6 MHz)	MHz/kPa	MHz/torr
R(1)	225 786 217.3 MHz	225 786 175.5 MHz	-6.17	-0.822
R(2)	226 105 467.1 MHz	226 105 466.7 MHz	-0.059 0	-0.007 86
R(8)	228 050 528.7 MHz	228 050 482.8 MHz	-6.773	-0.903

1. I. Thomann, A. Bartels, K. L. Corwin, N. R. Newbury, L. Hollberg, S. A. Diddams, J. W. Nicholson, M. F. Yan, "420-MHz Cr:forsterite femtosecond ring laser and continuum generation in the 1-2 µm range," Opt. Lett., **28**, 1368 (2003).
2. J. W. Nicholson, M. F. Yan, P. Wisk, J. Fleming, F. DiMarcello, E. Monberg, A. Yablon, C. Jorgensen, T. Veng,"All-fiber, octave-spanning supercontinuum," Opt. Lett., **28**, 643 (2003).
3. T. Udem, S. A. Diddams, K. R. Vogel, C. W. Oates, E. A. Curtis, W. D. Lee, W. M. Itano, R. E. Drullinger, J. C. Bergquist, L. Hollberg, "Absolute frequency measurements of the Hg+ and Ca optical clock transitions with a femtosecond laser," Phys. Rev. Lett., **86**, 4996 (2001).
4. S. R. Jefferts, J. Shirley, T. E. Parker, T. P. Heavner, D. M. Meekhof, C. Nelson, F. Levi, G. Costanzo, A. D. Marchi, R. Drullinger, L. Hollberg, W. D. Lee, F. L. Walls, "Accuracy evaluation of NIST-F1," Metrologia, **39**, 321 (2002).
5. T. Dennis, E. A. Curtis, C. W. Oates, L. Hollberg, S. L. Gilbert, "Wavelength references for 1300-nm wavelength-division multiplexing," J. Lightwave Tech., **20**, 804 (2002).