Application Note
METROLOGY

Czech Metrology Institute (CMI), Prague

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Absolute frequency measurement of wavelength standards

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The main application of the femtosecond comb at the Chech Metrology Institute (CMI) is the absolute frequency measurement of frequency stabilized lasers. These lasers are used for the realization of the SI definition of the meter according to method b) or c) of the *Mise en Pratique* http://www.bipm.org/en/publications/mises-en-pratique/standard-frequencies.html. Menlo Systems' frequency comb FC8004 is referenced to GPS disciplined rubidium clock. This reference limits the uncertainty to 2 x 10^{-13} for 1-day averages (Calibration and Measurement Capabilities (CMC) for the comb measurement recognized for CMI within CIPM Mutual Recognition Arrangement), but we have done several tests approving far better uncertainty if a better reference was available. The tracking capability of the comb when used as the "clockwork" was tested in the following way: the repetition rate was stabilized such that the 532 nm output of YAG laser has constant frequency difference (F_{beat1}) from the nearest comb line. The other beat of the 1064 nm output of the same YAG laser and the comb was measured simultaneously and it was found that it equals (F_{beat1} + F_{ofs})/2 with an uncertainty and stability corresponding to the tracking capability 1.3 x 10^{-15} rel. for 1 second (one standard deviation) and 4.7 x 10^{-17} rel. for 100 seconds [1].

We have developed a program for online processing of the absolute frequency of the laser under investigation. The quality of the beat counting is tested by two counters with shifted band pass filters and its uncertainty is also evaluated online, together with Allan standard deviation, uncertainty and histograms. The measurement including software was validated by comparison with frequency comb data from the Bureau International des Poids et Mesures (BIPM), the Max-Planck-Institut of Quantum Optics (MPQ), and the Bundesamt für Eich- und Vermessungswesen (BEV) via travelling wavelength standards at 633 nm, 543 nm, 532 nm and 1542 nm [1] – and directly by comparison with a touring fibre frequency comb of the BEV [2].

Since the installation of the comb in 2005 we periodically measure the wavelength standards developed in house: iodine stabilized lasers at 532 nm, 543.5 nm, 633 nm, and acetylene stabilized laser at 1542

nm (second harmonic at 771 nm is measured by the Ti:Sapphire comb). These lasers, together with the comb, the interferometric comparator, and the interferometer for gauge blocks do form the Czech national standard of length.

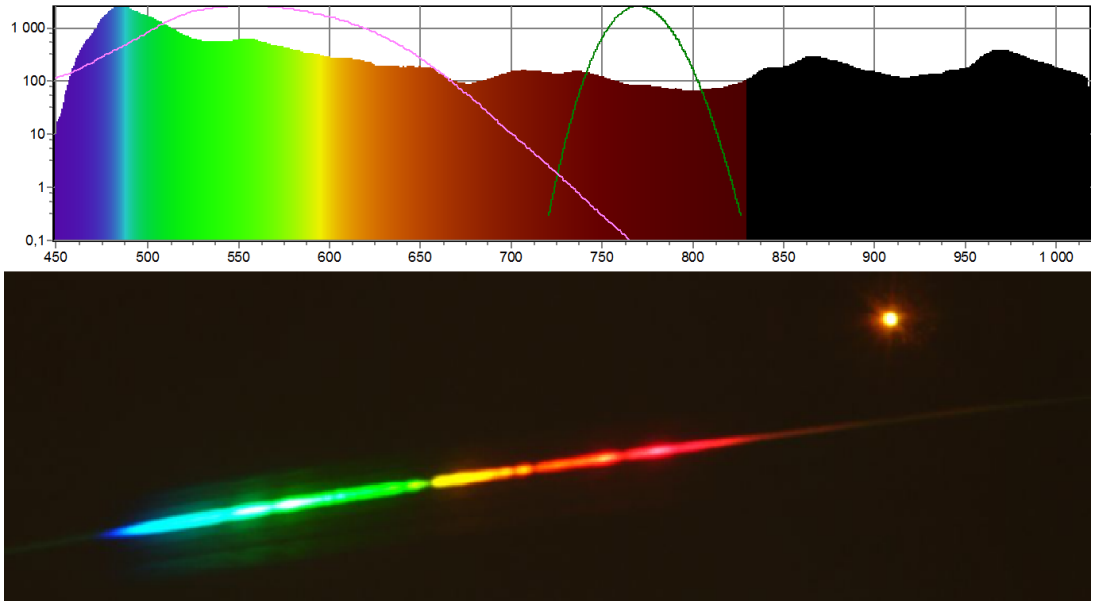

Figure 1: Spectrum of the first PCF of measured by solid state spectrometer (top)

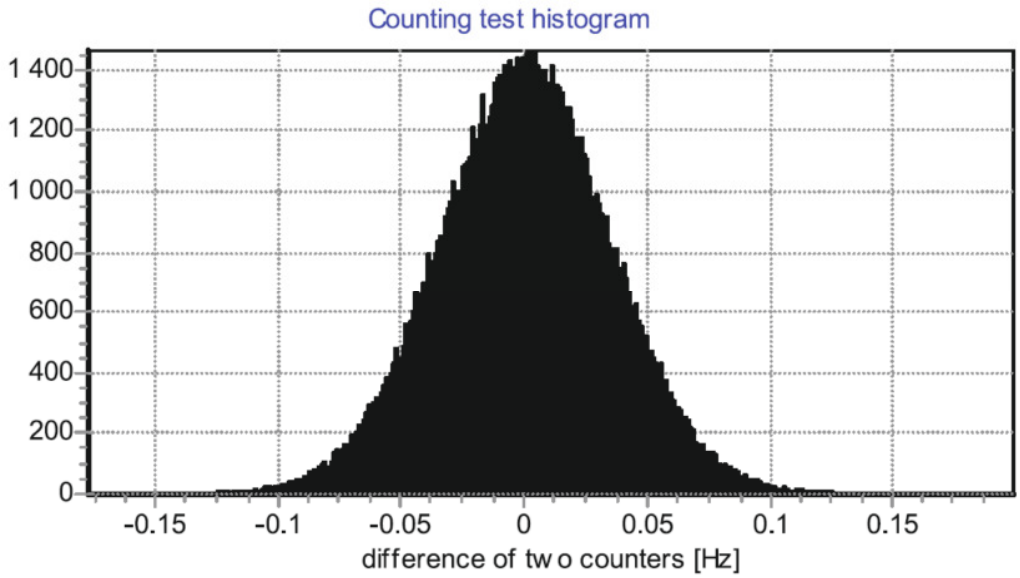

Figure 2: The histogram of residual difference of two counters. Only the valid samples are shown (the samples for which this difference is ≥0.5Hz are removed from further processing due to cycle slip. Typically ≥99% of samples are valid)

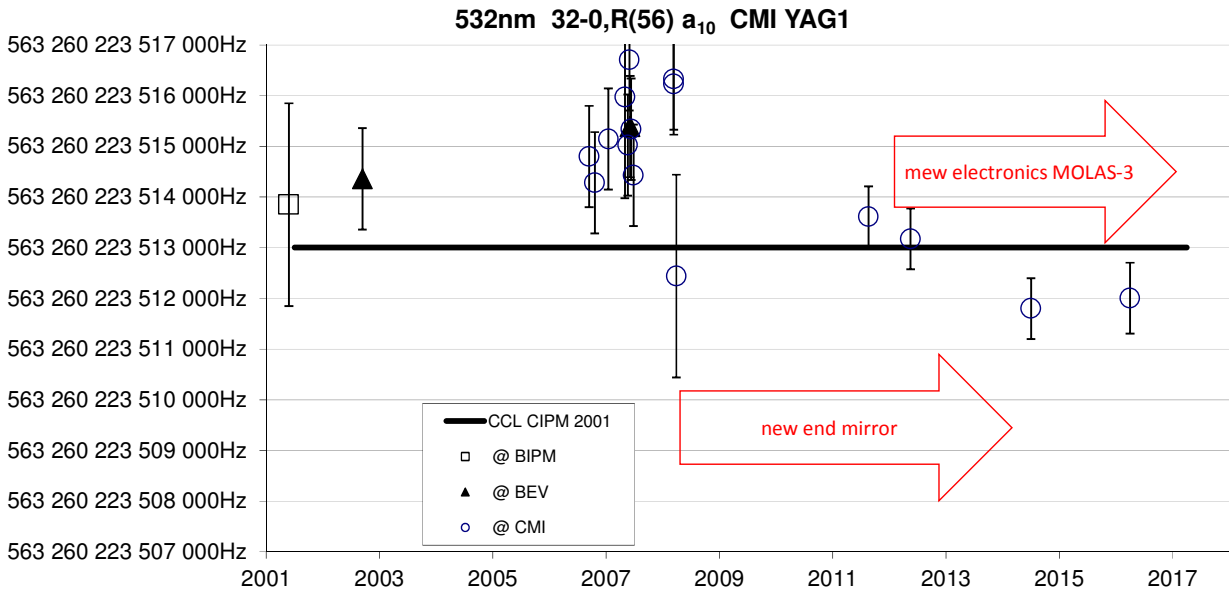

Figure 3: History of absolute frequency measurements of wavelength standard CMI YAG-1 (iodine-stabilized Nd:YAG laser 532nm/1064nm). It was measured at BIPM, at BEV and at CMI.

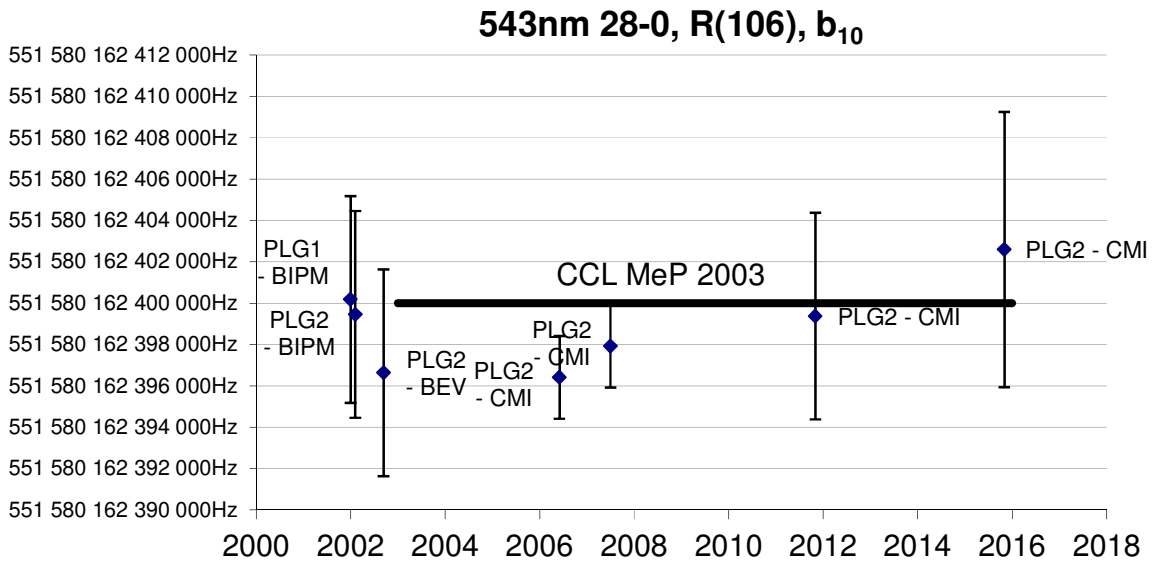

Figure 4: History of absolute frequency measurements of CMI 543,5 nm wavelength standards PLG1 (iodine-stabilized green He-Ne lasers) and PLG2 at BIPM, BEV and CMI.

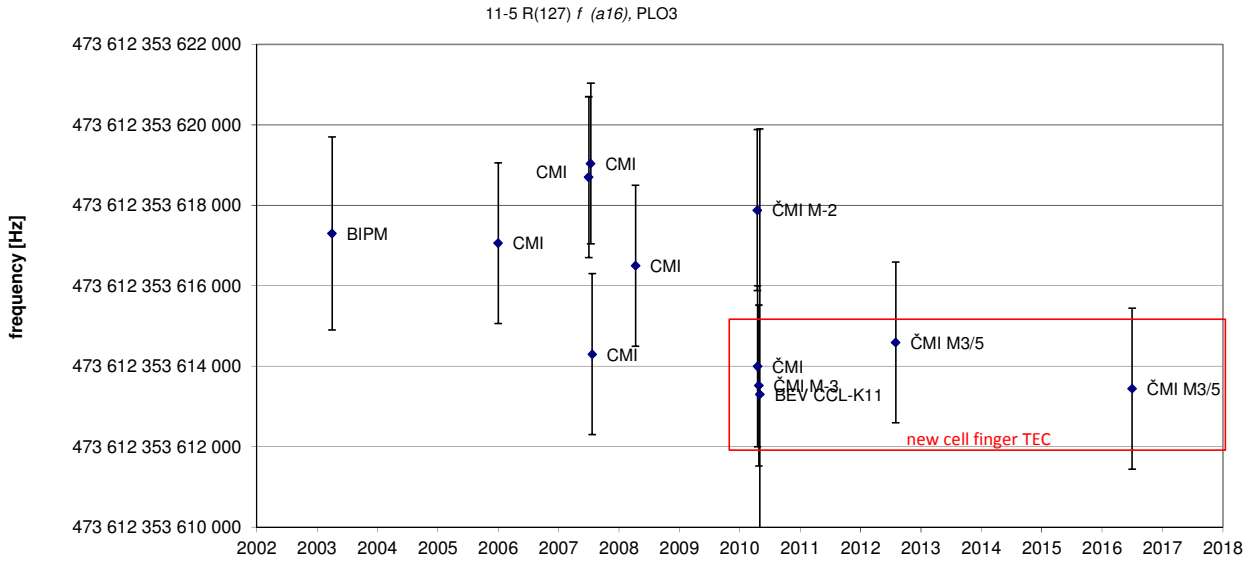

Figure 5: History of absolute frequency measurements of CMI 633 nm wavelength standard PLO3 (iodine-stabilized red He-Ne laser) at BIPM, BEV and CMI.

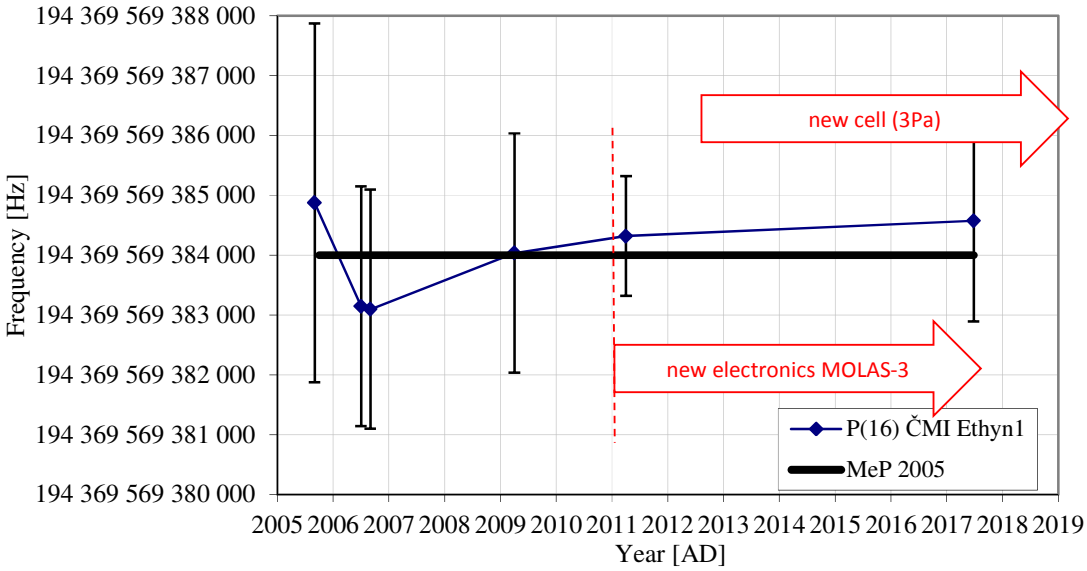

Figure 6: History of absolute frequency measurements of 1542 nm wavelength standard CMI Ethyn-1 (PLO3 (acetylene-$^{13}C_2H_2$-stabilized DFB laser) at IPQ and CMI.

Publications:

[1] P. Balling, P. Kren: Absolute frequency measurement of wavelength standards 532 nm, 543 nm, 633 nm, and 1540 nm; Eur. Phys. J. D 48, 3-10 (2008)

[2] Conference proceedings: M. Matus, P. Balling, W. Mache, A. Nießner, and P. Kren: Uncertainty estimation for comb based laser calibrations by direct comparison of 3 different combs; Macroscale 2011, Recent developments in traceable dimensional measurement

P. Balling, P. Masika, P. Kren, and M. Dolezal: Length and refractive index measurement by Fourier transform interferometry and frequency comb spectroscopy; Meas. Sci. Technol. 23, 094001 (2012)

P. Balling, P. Kren, P. Masika, and S.A. van den Berg: Femtosecond frequency comb based distance measurement in air; Opt. Express 17, 9300-9313 (2009)

Weblinks:

Institute website:
www.cmi.cz

BIPM Mise en Pratique recommended values of standard frequencies:
http://www.bipm.org/en/publications/mises-en-pratique/standard-frequencies.html

BIPM Calibration and Measurement Capabilities:
CIPM MRA

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