

Frequency evaluation of Maser 1401104 by IT-Yb1 for the period MJD 60049 to 60064

During the period MJD 60049 – 60064 (15 April 2023–30 April 2023) INRIM evaluated the frequency of the hydrogen maser IT-HM4 (BIPM code 1401104) using the Yb optical lattice frequency standard IT-Yb1 and an optical frequency comb. The evaluation is based on the CCTF2021 recommended frequency for ^{171}Yb as a secondary representation of the second, $f(^{171}\text{Yb}) = 518\,295\,836\,590\,863.63\text{ Hz}$ with a relative standard uncertainty of $u_{\text{Srep}} = 1.9 \times 10^{-16}$ [1, 2]. The results of the evaluation are summarized in Tab. 1. Details of IT-Yb1 operation and uncertainty budget are given in Refs. [3, 4] and summarized below.

1 Frequency measurement

The clock laser of IT-Yb1 is stabilized on an ultrastable cavity and probes ^{171}Yb atoms trapped in an optical lattice at the magic frequency. A digital control loop acting on an acousto-optic modulator keeps the clock laser frequency in resonance with the atoms. The cavity-stabilized laser is sent to a fibre frequency comb referenced to IT-HM4. The frequency ratio between the ^{171}Yb transition and IT-HM4 is calculated from the comb measurements and the corrections used for steering the acousto-optic modulator.

Table 1: Final evaluation using IT-Yb1.

Period of es- timation	$y(\text{HM1401104}$ $/\text{ITYb1})$ $/10^{-15}$	u_{A} $/10^{-15}$	u_{B} $/10^{-15}$	$u_{\text{A/lab}}$ $/10^{-15}$	$u_{\text{B/lab}}$ $/10^{-15}$	u_{Srep} $/10^{-15}$	Uptime
60049–60064	176.60	0.00	0.02	0.24	0.02	0.19	15.6%

Table 2: Uncertainty budget for IT-Yb1 for the reported period.

Effect	Rel. Shift/ 10^{-17}	Rel. Unc./ 10^{-17}
Density shift	-1.0	0.5
Lattice shift	0.4	1.1
Zeeman shift	-3.21	0.03
Blackbody radiation shift (room)	-235.3	1.5
Blackbody radiation shift (oven)	-1.4	0.7
Static Stark shift	-1.5	0.9
Probe light shift	0.04	0.03
Background gas shift	-0.5	0.2
Servo error	0.0	0.3
Other shifts	0.0	0.1
Grav. redshift (static)	2599.5	0.3
Grav. redshift (tides)	0.0	0.2
Total	2357.0	2.3

Table 3: Uncertainty budget for the link between IT-Yb1 and IT-HM4 for the reported period.

Effect	Uncertainty/ 10^{-15}
Comb statistic	0.01
Extrapolation (dead time)	0.23
Extrapolation (drift)	0.04
Total $u_{A/\text{lab}}$	0.24
Optical/microwave comp. (type B)	0.02
Total $u_{B/\text{lab}}$	0.02

2 IT-Yb1 evaluation

The uncertainty u_A is the statistical contribution from the instability of IT-Yb1. The uncertainty u_B is the systematic uncertainty of IT-Yb1 [4]. The systematic frequency shift and uncertainty budget of IT-Yb1 for the reported period are given in Tab. 2. IT-Yb1 now operates with a vertical optical lattice and the lattice light shift calculations have been updated following Ref. [5]. The table includes the gravitational redshift relative to the conventional potential $W_0 = 62\,636\,856.0\text{ m}^2\text{s}^{-2}$ [4].

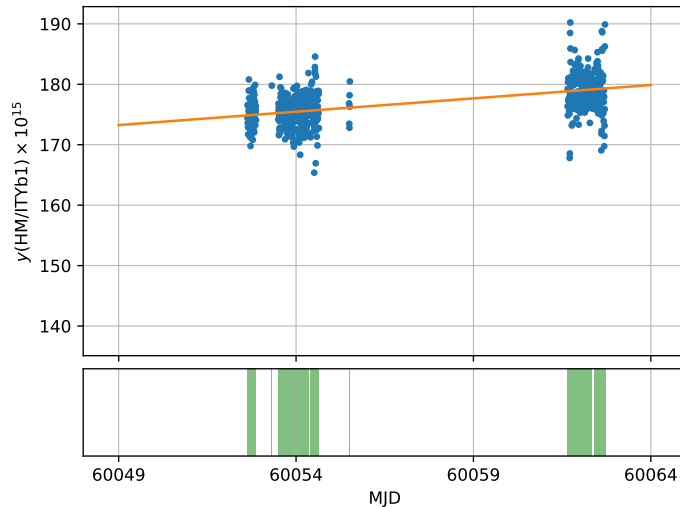


Figure 1: Fractional frequency deviation $y(\text{HM1401104}/\text{ITYb1})$ measured in the period MJD 60049 - 60064. Green shaded regions in the bottom plot represent the uptime of IT-Yb1.

3 Link evaluation

The uncertainty $u_{1/\text{lab}}$ is due to the link between IT-Yb1 and IT-HM4, including the optical to microwave comparison at the comb. Table 3 summarizes the contributions to this uncertainty.

The comparison uncertainty between optical and microwave signals at the comb has been evaluated from comparison with a second optical frequency comb.

IT-Yb1 and the comb were operated for 202 306s (uptime 15.6% of the evaluation period). The data collected and the distribution of the uptimes of IT-Yb1 are shown in Fig. 1. Extrapolation using the maser as a flywheel is needed given the intermittent operation of IT-Yb1. Its evaluation is separated in an uncertainty from dead times and a correction for the maser drift. The maser drift of $4.4(4) \times 10^{-16}/\text{d}$ has been calculated from IT-Yb1 data collected in the period. The contribution from dead times has been evaluated following the approach in Ref. [6]. For this measurement we considered the IT-HM4 noise to be a power-law model described by the Allan deviation: white phase noise $3 \times 10^{-13}(\tau/\text{s})^{-1}$; white frequency noise $4 \times 10^{-14}(\tau/\text{s})^{-1/2}$; flicker frequency noise 3×10^{-16} ; random walk frequency noise $2 \times 10^{-19}(\tau/\text{s})^{1/2}$.

Contributors

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References

- [1] Consultative Committee for Time and Frequency (CCTF), “Recommendation CCTF PSFS 2: Updates to the CIPM list of standard frequencies,” 2021. Online: https://www.bipm.org/en/committees/cc/cctf/22-_2-2021
- [2] Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the definition of the second. Online: <https://www.bipm.org/en/publications/mises-en-pratique/standard-frequencies.html>
- [3] M. Pizzocaro, P. Thoumany, B. Rauf, F. Bregolin, G. Milani, C. Clivati, G. A. Costanzo, F. Levi, and D. Calonico, “Absolute frequency measurement of the $^1S_0 - ^3P_0$ transition of ^{171}Yb ,” *Metrologia*, vol. 54, no. 1, pp. 102–112, 2017. Online: <http://stacks.iop.org/0026-1394/54/i=1/a=102>
- [4] M. Pizzocaro, F. Bregolin, P. Barbieri, B. Rauf, F. Levi, and D. Calonico, “Absolute frequency measurement of the $^1S_0 - ^3P_0$ transition of ^{171}Yb with a link to international atomic time,” *Metrologia*, vol. 57, no. 3, p. 035007, may 2020. Online: <https://doi.org/10.1088%2F1681-7575%2Fab50e8>
- [5] K. Beloy, W. F. McGrew, X. Zhang, D. Nicolodi, R. J. Fasano, Y. S. Hassan, R. C. Brown, and A. D. Ludlow, “Modeling motional energy spectra and lattice light shifts in optical lattice clocks,” *Phys. Rev. A*, vol. 101, p. 053416, May 2020. Online: <https://link.aps.org/doi/10.1103/PhysRevA.101.053416>
- [6] C. Grebing, A. Al-Masoudi, S. Dörscher, S. Häfner, V. Gerginov, S. Weyers, B. Lipphardt, F. Riehle, U. Sterr, and C. Lisdat, “Realization of a timescale with an accurate optical lattice clock,” *Optica*, vol. 3, no. 6, pp. 563–569, Jun 2016. Online: <http://www.osapublishing.org/optica/abstract.cfm?URI=optica-3-6-563>