Frequency evaluation of Maser 1401103 by IT-Yb1 for the period MJD 58459 to 58469

During the period MJD 58459 – 58469 (07 December 2018–17 December 2018) INRIM evaluated the frequency of the hydrogen maser IT-HM3 (BIPM code 1401103) using the Yb optical lattice frequency standard IT-Yb1 and an optical frequency comb. The evaluation is based on the recommended frequency for ^{171}Yb as a secondary representation of the second, $f(^{171}\text{Yb}) = 518\,295\,836\,590\,863.6$ Hz with a relative standard uncertainty of $u_{\text{Srep}} = 5 \times 10^{-16}$ [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-HM3. The frequency ratio between the ^{171}Yb transition and IT-HM3 is calculated from the comb measurement and from the corrections used for steering the acousto-optic modulator.

Table 1: Final evaluation using IT-Yb1

Period of estimation	y(HM1401103 /ITYb1)$/10^{-16}$	$u_{\text{A}}/10^{-16}$	$u_{\text{B}}/10^{-16}$	$u_{\text{l/lab}}/10^{-16}$	$u_{\text{Srep}}/10^{-16}$
58459–58469	-9074.4	<0.1	0.3	5.9	5

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

Effect	Rel. Shift/10^{-17}	Rel. Unc./10^{-17}
Density shift	-2.7	0.2
Lattice shift	5.7	1.8
Zeeman shift	-0.698	0.017
Blackbody radiation shift	-236.5	1.4
Static Stark shift	-2.0	1.1
Background gas shift	-0.5	0.2
Probe light shift	0.10	0.06
Others	0.0	0.6
Gravitational redshift	2599.5	0.3
Total	2362.8	2.6

Table 3: Uncertainty budget for the link between IT-Yb1 and IT-HM3 for the reported period.

Effect	$u_{\mathrm{l/lab}}/10^{-16}$
Optical/microwave comp. (type B)	0.8
Comb statistic	0.5
Extrapolation (dead time)	5.8
Extrapolation (drift)	0.7
Total	5.9

2 IT-Yb1 evaluation

The uncertainty u_{A} is the statistical contribution from the instability of IT-Yb1. It has been evaluated by interleaved measurements [4].

The uncertainty u_{B} is the systematic uncertainty of IT-Yb1. The systematic frequency shift and uncertainty budget of IT-Yb1 for the reported period are given in Tab. 2. The table includes the gravitational redshift relative to the conventional potential $W_0 = 62\,636\,856.0\,\mathrm{m^2 s^{-2}}$ [4].

3 Link evaluation

The uncertainty $u_{\mathrm{l/lab}}$ is due to the link between IT-Yb1 and IT-HM3, including the optical to microwave comparison at the comb. Table 3 summarizes the contributions to this uncertainty.

The comparison between optical and microwave signals at the comb has a Type B uncertainty evaluated from comparison with a second comb. The statistical contribution from the comb is conservatively estimated from the

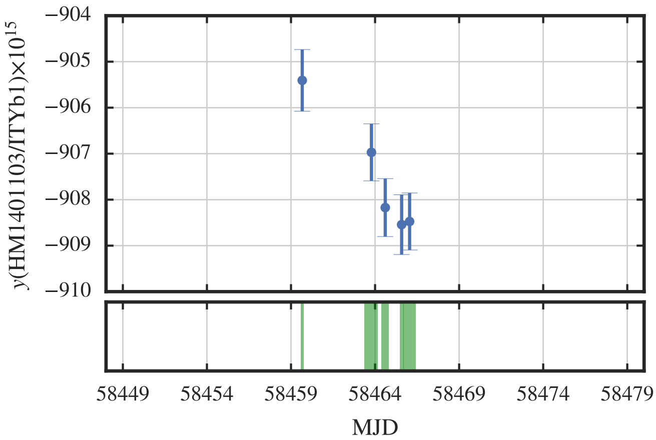

Figure 1: Fractional frequency deviation y(HM1401103/ITYb1) measured in the period MJD 58459 - 58469. Green shaded regions in the bottom plot represent the uptime of IT-Yb1.

instability of the observed noise and it includes the instability of the microwave frequency chain from the maser to the comb. The uncertainty from this instability is used to assign a weight to each frequency measurement.

IT-Yb1 and the comb were operated for a total of 188 040 s, with an uptime 22% 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 [4]. The drift of the maser has been calculated from a linear fit of IT-Yb1 data over the reported period and used to extrapolate the frequency to the center point. The contribution from dead times has been evaluated from simulations of the maser noise [4–6]. For this measurement the instability of IT-HM3 has been conservatively modelled as the quadrature sum of: white phase noise $1.5 \times 10^{-13}(\tau/\mathrm{s})^{-1}$; white frequency noise $3.5 \times 10^{-14}(\tau/\mathrm{s})^{-1/2}$; flicker frequency noise 6×10^{-16}; random walk frequency noise $<1 \times 10^{-18}(\tau/\mathrm{s})^{1/2}$.

References

[1] Consultative Committee for Time and Frequency (CCTF), "Report of the 21st meeting (8-9 June 2017) to the International Committee for Weights and Measures," 2017. Online: https://www.bipm.org/utils/common/pdf/CC/CCTF/CCTF21.pdf

[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, p. 102, 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," *Accepted on Metrologia*, Oct 2019. Online: https://doi.org/10.1088/1681-7575/ab50e8

[5] H. Hachisu and T. Ido, "Intermittent optical frequency measurements to reduce the dead time uncertainty of frequency link," *Japanese Journal of Applied Physics*, vol. 54, no. 11, p. 112401, 2015. Online: http://stacks.iop.org/1347-4065/54/i=11/a=112401

[6] D.-H. Yu, M. Weiss, and T. E. Parker, "Uncertainty of a frequency comparison with distributed dead time and measurement interval offset," *Metrologia*, vol. 44, no. 1, p. 91, 2007. Online: http://stacks.iop.org/0026-1394/44/i=1/a=014