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Frequency evaluation of UTC(NMIJ) by NMIJ-Yb1 for the period MJD 59169 to MJD 59179

The secondary frequency standard NMIJ-Yb1 has been compared to UTC(NMIJ), during a measurement campaign between MJD 59169 and MJD 59179 (16th November 2020 – 26th November 2020). The Yb optical lattice clock operation covers 78.9 % of the total measurement period.

1. Results

Table 1. (a) Results of the comparison in 1×10^{-16}

Period (MJD)	**y(UTC(NMIJ) – NMIJ-Yb1)**	**Total u_A**	**Total u_B**	$u_{A/\mathrm{Lab}}$	$u_{B/\mathrm{Lab}}$	u_{SecRep}	**Uptime (%)**
59169 - 59179	-20.3	0.12	2.22	4.2	1.0	5	78.9

(b) Budget of uncertainties in 1×10^{-16}

u_A : Type A uncertainty	
Yb statistics	0.12
Total	0.12
u_B : Type B uncertainty	
Yb systematics	2.14
Gravitational	0.6
Total	2.22
$u_{A/\mathrm{Lab}}$: Type A uncertainty	
Dead time in UTC(NMIJ) – Yb	4.2
Total	4.2
$u_{B/\mathrm{Lab}}$: Type B uncertainty	
Microwave-optical frequency link	1.0
Total	1.0

The calibration is made using the most recently recommended value for the $6s^2\ ^1S_0 - 6s6p\ ^3P_0$ unperturbed optical transition in the ^{171}Yb neutral atom: 518 295 836 590 863.6 Hz [1]. u_{SecRep} is the recommended uncertainty of the secondary representation [1]

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2. Systematic effects and uncertainties

Table 2. Budget of systematic effects and uncertainties for NMIJ-Yb1 [2,3] in 1×10^{-17}

Effect	**Shift**	**Uncertainty**
Lattice light	5.9	4.5
Blackbody radiation	-266.9	20.8
Density	-1.2	0.7
Second order Zeeman	-5.1	0.3
Probe light	0.5	0.3
Servo error	-8.6	1.6
AOM switching	-	1
Line pulling	-	1
Total	-275.5	21.4
Gravitational redshift	229.4	6
Total (with gravitational redshift)	-46.1	22.2

For the reports submitted in November 2020 and after that, the total systematic uncertainty of NMIJ-Yb1 was improved to 2×10^{-16} compared with an uncertainty of 4×10^{-16} described in previous reports and Ref. [3]. A major improvement was made in the uncertainty of the lattice light shift ($3 \times 10^{-16} \rightarrow 5 \times 10^{-17}$). Here we reduced the uncertainty of the magic frequency by a factor of ~1/3, and operated NMIJ-Yb1 with a lower trap potential depth of ~200Er, where Er denotes the recoil energy from a lattice photon.

3. Frequency comparison

The frequency of NMIJ-Yb1 was compared with UTC(NMIJ) using an optical frequency comb. A beat frequency between a laser locked to an ultra-stable cavity and the comb was counted. The frequency of the ultra-stable laser was shifted by an acousto-optic modulator (AOM) and stabilized to the clock transition in ^{171}Yb atoms trapped in an optical lattice. The frequency of the AOM was then combined with the beat frequency to compute y(UTC(NMIJ) – NMIJ-Yb1).

The uncertainty $u_{\mathrm{B/Lab}}$ arose from a microwave-optical frequency link. For the reports submitted in November 2020 and after that, this uncertainty was improved to 1.0×10^{-16} compared with an uncertainty of 2.2×10^{-16} described in previous reports and Ref. [3]. The previous uncertainty was mainly caused by frequency multiplication of a 10 MHz signal from UTC(NMIJ).

Here we reduced this uncertainty to low 10^{-17} by carefully stabilizing the temperature of a frequency multiplier. The present $u_{\mathrm{B/Lab}}$ uncertainty was limited by phase variations of the 10 MHz signal that occurred during its transmission through a coaxial cable.

The uncertainty $u_{\mathrm{A/Lab}}$ arose from the dead time in the comparison between NMIJ-Yb1 and UTC(NMIJ). This uncertainty was estimated using a method described in Ref. [4]. For this estimation, we derived a maser noise model from the measured stability of UTC(NMIJ) against NMIJ-Yb1. The model includes a white phase modulation of $1\times10^{-12}/(\tau/\mathrm{s})$, a white frequency modulation (FM) of $7\times10^{-14}/(\tau/\mathrm{s})^{1/2}$, a flicker FM of 2×10^{-15}, a random walk FM of $4\times10^{-24}(\tau/\mathrm{s})^{1/2}$. $u_{\mathrm{A/Lab}}$ also includes the uncertainty of a frequency correction resulting from the dead time when the frequency steering of UTC(NMIJ) is carried out.

The gravitational redshift was calculated with respect to the conventionally adopted reference potential $W_0 = 62\,636\,856.0\ \mathrm{m}^2/\mathrm{s}^2$.

References

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