UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
325 Broadway
Boulder, Colorado 80305-3328

Frequency Evaluation of UTC(NIST) by NIST-Yb1 for the period MJD 59249 to 59269

I. Results

Period (MJD)	y(UTC(NIST) - Yb1) (10^{-16})	u_A (10^{-16})	u_B (10^{-16})	$u_{A/Lab}$ (10^{-16})	$u_{B/Lab}$ (10^{-16})
59249-59269	8.2	<0.1	0.062	4.1	0.3

u_A, Type A uncertainty (10^{-16})	
Yb stability	<0.1
Total	<0.1

u_B, Type B Uncertainty (10^{-16})	
Yb total systematic	0.014
Gravitational redshift	0.06
Total	0.062

$u_{A/Lab}$, local link Type A uncertainty (10^{-16})	
Dead time	3.9
Yb-Maser comparison	1.4
Time scale measurement	<0.1
Total	4.1

$u_{B/Lab}$, local link Type B uncertainty (10^{-16})	
Frequency comb + counting	0.3
Microwave transmission	<0.1
Total	0.3

II. NIST-Yb1 operation

During the indicated period, NIST-Yb1 and an optical frequency comb were operated intermittently with a combined uptime of 4.93%. The measured frequency difference assumes the Yb absolute frequency equal to the most recently published CCTF recommendation: 518,295,836,590,863.6 Hz [1]. The frequency shift and uncertainty budget of Yb1 over this period is given in the table below. More details on NIST-Yb1 clock operation and its uncertainty budget can be found in Ref. 2 and 3.

NIST-Yb1 systematic biases and uncertainties

Effect	Shift (10^{-18})	Uncertainty(10^{-18})
Background gas collisions	-5.5	0.5
Spin polarization	0	<0.3
Cold collisions	-0.21	0.07
Doppler	0	<0.02
Blackbody radiation	-2,361.2	0.9
Lattice light (model)	0	0.3
Travelling wave contamination	0	<0.1
Lattice light (experimental)	-1.5	0.8
Second-order Zeeman	-118.1	0.2
DC Stark	0	<0.07
Probe Stark	0.02	0.01
Line pulling	0	<0.1
Tunneling	0	<0.001
Servo error	0.03	0.05
Optical frequency synthesis	0	<0.1
Yb1 Total	**-2,486.5**	**1.4**
Grav. redshift from geoid [4]	180,819	6
Yb + gravitational redshift	**178,333**	**6.2**

III. Frequency measurement

The frequency measurement was carried out with an optical frequency comb that was phase-locked to NIST-Yb1, and the resulting comb frequencies were subsequently counted relative to a hydrogen maser, 412014. For this analysis, one-second gated counting data (measured with a software-defined-radio-based frequency counter) were binned into twelve minute intervals, and related to internal NIST timescales. A final average value was calculated over the indicated period. A breakdown of the Type A and Type B uncertainties for this measurement are listed in the results section. Dead time uncertainty associated with the less-than-unit uptime of the NIST-Yb1 measurement during the indicated period is calculated following the method of [5] and as outlined in [3]. The reported frequency offset, y(UTC(NIST)-Yb1), is computed with NIST-Yb1 frequency corrections from the geoid [4,2].

[1] "Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the definition of the second," BIPM publication, approved by CCTF June 2017, https://www.bipm.org/utils/common/pdf/mep/171Yb_518THz_2018.pdf.

[2] W. McGrew, et al., "Atomic clock performance enabling geodesy below the centimetre level," Nature **564,** 87–90 (2018).

[3] W. McGrew, et al., "Towards Adoption of an Optical Second: Verifying Optical Clocks at the SI Limit," Optica **6,** 448-454 (2019).

[4] N. K. Pavlis and M. A. Weiss, "A re-evaluation of the relativistic redshift on frequency standards at NIST, Boulder, Colorado, USA," Metrologia **54**, 535-548 (2017).

[5] D.-H. Yu, M. Weiss, and T. E. Parker, "Uncertainty of a frequency comparison with distributed dead time and measurement interval offset," Metrologia 44, 91–96 (2007).