Optical Frequency Combs at NPL: TAI Calibrations and Planned Improvements

Xi Zhang, Jacob Tunesi, Marco Schioppo, Chen-Hao Feng, Ian R. Hill, Matthew Y. H. Johnson, Helen S. Margolis

Time & Frequency Department, National Physical Laboratory, Teddington, UK

Email: xi.zhang@npl.co.uk

We will present how optical frequency combs at NPL are used in the comparison between UTC(NPL) and our Sr-lattice optical clock (NPL-Sr1), as required for the steering of International Atomic Time (TAI). Following approval for TAI steering, NPL-Sr1[1] has been used to produce six on-time calibrations of TAI as outlined in table 1. We will discuss these in detail, showing our data analysis method and how we determine the relevant uncertainties $u_{A/Lab}$ and $u_{B/Lab}$.

Measurement Period (MJD)	Uptime	y[UTC(NPL) – NPL-Sr1) /10^{-16}	u_A /10^{-16}	u_B /10^{-16}	$u_{A/Lab}$ /10^{-16}	$u_{B/Lab}$ /10^{-16}
60034 - 60064	88.0%	-0.57	0.003	0.102	1.73	1.29
60064 - 60094	84.4%	-3.04	0.003	0.104	2.85	1.04
60129 - 60154	46.9%	-1.91	0.004	0.120	3.33	1.97
60214 - 60224	28.5%	+7.06	0.009	0.318	11.98	2.20
60234 - 60239	54.4%	+6.47	0.009	0.373	8.07	3.00
60294 - 60309	46.3%	+0.57	0.006	0.375	5.82	3.34
60309 - 60324	60.9%	-2.29	0.005	0.399	4.25	3.19

Table 1: On-time measurement reports of UTC(NPL) as compared against NPL-Sr1 and used in the computation of TAI. Note that MJD periods 60214-60224 and 60234-60239 fall within the same TAI reporting period (October 2023).

We will then discuss areas for improvement in order to reduce the overall measurement uncertainty to below 2×10^{-16}, the criterion given in the roadmap towards the redefinition of the SI second[2]. The first area for improvement lies in the extrapolation of data over dead times[3]. The instability of the hydrogen maser flywheel introduces an uncertainty at the mid to high 10^{-16} level unless an exceptionally high optical clock uptime can be maintained (>80%). The second issue lies in the distribution of radiofrequency (RF) reference signals around NPL, the current setup for which introduces 10^{-16} level uncertainties. These issues may be addressed through the use of alternative masers and the implementation of RF distribution over optical fibres.

To conclude, we will also present our plans for further upgrading the frequency comb infrastructure at NPL by building a second "universal synthesizer" based on a single-branch supercontinuum module (Menlo Systems SCM) phase-locked directly to the ultrastable optical reference. This will provide an improved frequency comb stability while greatly reducing the setup complexity and supplements our previous transfer-oscillator multi-branch comb system. Finally, the addition of a second comb system will improve the measurement confidence and robustness via continuous cross-checks and data backups.

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[1] R. Hobson *et al.* "A strontium optical lattice clock with 1×10^{-17} uncertainty and measurement of its absolute frequency," Metrologia, vol. 57, pp. 065026, 2020.

[2] N Dimarcq *et al.* "Roadmap towards the redefinition of the second" Metrologia vol. 61, pp. 012001, 2024

[3] 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, pp. 91, 2007.