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Is frequency transfer uncertainty limiting the comparison of atomic fountains?

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Close to twenty atomic fountains have contributed in some way to the elaboration of International Atomic Time (TAI) over recent years. Among them are a dozen of Cs fountains operated as primary frequency standards (PFS), one Rb fountain operated as a secondary frequency standard (SFS) and four Rb fountains continuously operated as clocks. The frequency instability of the best atomic fountains is reported of order $1\text{-}3\times10^{-16}$ for averaging times of 15-30 days, which is the typical duration of a PFS or SFS evaluation contributing to the accuracy of TAI. Rb fountains operated as clocks have a similar instability [1]. Fountains operated as PFS or SFS are designed to provide an accurate frequency, with an uncertainty budget of all systematic effects also in the low 10^{-16}, the best published performance being of order $1\text{-}2\times10^{-16}$. A summary of the performance of fountains contributing to TAI each year is presented in the BIPM annual report on Time activities [2].

When contributing to TAI, fountains are compared using the time and frequency transfer techniques used in TAI, namely Two Way satellite time and frequency transfer (TWSTFT) and GPS Precise Point Positioning (PPP). As given in Circular T, the uncertainty of such frequency links is of order 3×10^{-16} for an averaging duration of 15 days to 1.5×10^{-16} for an averaging duration of 30 days. Furthermore, if compared using their contribution to TAI, some fountains may be connected by a combination of two links with two different techniques. Therefore the frequency transfer uncertainty between two fountains is of the same order of magnitude as the uncertainties of the compared fountains and, in some cases, may be suspected to be a dominant factor. In this paper, we study whether improving frequency transfer may yield visible effects in fountains comparisons.

The technique of Precise Point Positioning with integer ambiguities (IPPP) has been developed [3] and provides a frequency transfer uncertainty of 1×10^{-16} for an averaging time of a few days, decreasing with longer averaging. If used to compare two fountains over intervals of 15-30 days, it provides frequency transfer uncertainty well below the intrinsic instability of the compared fountains. We have used IPPP to compute frequency transfer for all intervals of common operation, since 2012, for the PFS and SFS at the PTB and the LNE-SYRTE, and the Rb fountain clocks continuously operated at the USNO. We show that the differences between IPPP and TAI frequency links have a standard deviation of order $2\text{-}2.5\times10^{-16}$, in line with TAI uncertainties. We study the impact of using IPPP on the fountain comparisons based on several tens of links between PFS-SFS and Rb clocks, and a few links between PFSs or between PFS and SFS. We show some evidence of an improvement in the fountain comparisons, specifically over 2016-2017 that may be associated to better fountains uncertainty budgets.

1. S. Peil et al. "The USNO rubidium fountains" J. Phys.: Conf. Ser. 723 012004, 2016.

2. available at ftp://ftp2.bipm.org/pub/tai/annual-reports/bipm-annual-report/

3. G. Petit et al., "1×10^{-16} frequency transfer by GPS PPP with integer ambiguity resolution," Metrologia 52, 301-309, 2015.