Systèmes de Référence Temps-Espace

FREQUENCY COMPARISON (H_MASER 140 0810) - (LNE-SYRTE-FOM)
For the period MJD 58664 to MJD 58694

The primary frequency standard LNE-SYRTE-FOM has been compared to the hydrogen maser 140 0810 of the laboratory, during a measurement campaign between MJD 58664 and 58694 (30th June 2019 – 30th July 2019). The fountain operation covered 92.7 % of the estimation period.

The mean frequency difference at the middle date of the period is given in the following table:

Period (MJD)	**Date of the estimation**	**y(HMaser$_{140\ 0810}$ – FOM)**	u_A	u_B	$u_{link/maser}$
58664 – 58694	**58679**	**-6819.6**	**2.5**	**6.1**	**0.6**

Table 1: Results of the comparison in 1 × 10^{-16}.

The FOM fountain was operated in the same mode during all the period: the interrogating signal synthesis is based on the multiplication of a 1 GHz signal provided by a cryogenic oscillator phase locked to the maser 140 0810. It uses a synthesizer to lock the microwave signal to the atomic resonance. The frequency difference between the maser and the fountain is deduced from the average correction applied to the synthesizer.

Average value and statistical uncertainty

The frequency data are averaged over 0.2 day intervals. We then perform a linear unweighted fit to the average data points to determine the average frequency at the middle date of the interval, as given in Table 1. The statistical uncertainty u_A is estimated using the Allan variance of the frequency residuals, after removing the drift. We estimate a conservative statistical uncertainty u_A of 2.5 × 10^{-16}.

We verified the result by applying a second method. We calculated the accumulated phase by integrating the data points, assuming a constant frequency during each segment, and during the dead times of the fountain operation. The average frequency is then obtained by dividing the total accumulated phase by the calibration period duration. The processing has been performed with segments of 0.01, 0.1 and 1 day durations. The results are in agreement with the values given in Table 1 within 1.3 × 10^{-16}.

Accuracy

The frequency is corrected from the quadratic Zeeman, the black body radiation, the cold collision (+ cavity pulling), the distributed cavity phase shift and the microwave lensing shifts, and at last the redshift. The cold collision (+ cavity pulling) correction is based on alternating measurements at full and half atomic density every 100 cycles, by changing the state selection frequency and readjusting the microwave power to keep the selection transition probability at maximum. We estimate a conservative uncertainty of 15% of the average frequency shift.
The following table summarizes the budget of the systematic corrections and their associated uncertainties. The accuracy is the quadratic sum of all the systematic uncertainties.

	Correction (10^{-16})	**Uncertainty (10^{-16})**
Quadratic Zeeman effect	-320.50	1.90
Black body radiation	166.73	2.30
Cold collisions + cavity pulling	26.85	4.03
Distributed cavity phase shift	-0.70	2.75
Microwave lensing	-0.90	0.90
Microwave spectral purity&leakage	0	1.50
Ramsey & Rabi pulling	0	0.10
Second order Doppler effect	0	0.10
Background gas collisions	0	1.00
Total	-129.52	6.06
Redshift	- 68.26	0.25
Total with redshift	**-196.78**	**6.07**

Table 2: Budget of systematic corrections and uncertainties for SYRTE-FOM fountain for the MJD 58664 – 58694 period

$$\boxed{u_B = \mathbf{6.1 \times 10^{-16}}}$$

Uncertainty of the link

The uncertainty of the link is the quadratic sum of 2 terms:
-A possible effect of phase fluctuations introduced by the cables that connect the primary standard to the maser. A new characterization of the signal distribution leads to a still conservative value of 0.5×10^{-16}.
-The uncertainty due to the dead times of the frequency comparison.
We have updated the estimation of this contribution, applying the method described in *Metrologia*, vol. 44, pp 91-96, 2007, as we did for the initial calibration reports of the LNE-SYRTE Strontium SFS. The maser noise model includes a white frequency noise component of 5×10^{-16} at 1 d and a flicker frequency noise component of 5×10^{-16} at 1 d, which is pessimistic especially for short averaging periods. We applied the method to the dead times longer than 600 s and obtained a stability degradation of 0.4×10^{-16}.