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FREQUENCY COMPARISON (H_MASER 140 0889) - (LNE-SYRTE-FO2)
For the period MJD 57904 to MJD 57924

The primary frequency standard LNE-SYRTE-FO2 has been compared to the hydrogen Maser 140 0889 of the laboratory, during a measurement campaign between MJD 57904 and 57924 (31st May 2017 – 20th June 2017). The fountain operation covers ~ 89.3 % of the total measurement duration.

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$_{140\ 0889}$ – FO2)	u_B	u_A	$u_{link\ /\ maser}$
57904 – 57924	**57914**	**-3787.6**	**2.4**	**2.5**	**1.1**

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

The FO2 fountain was operated in the same mode during all the period: the interrogating signal is based on the down conversion to 9.192 GHz of a 11.98 GHz signal provided by a cryogenic oscillator phase locked to the maser 140 0889. A synthesizer is used to lock the microwave signal on the atomic resonance. The frequency difference between this 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 $u_A = 2.5 \times 10^{-16}$.

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 value given in Table 1 within 1.2×10^{-16}, which is consistent with the estimation of the statistical uncertainty u_A and the uncertainty due to the link.

Accuracy

The frequency is corrected from the quadratic Zeeman, the Black Body radiation, the cold collisions and cavity pulling, the first order Doppler, the microwave lensing, and the red shift effects. Here the uncertainty in the cold collisions correction accounts for both a statistical uncertainty and a systematic uncertainty taken as 0.5% of the correction for high density measurements. The following table summarizes the budget of systematic effects and their associated uncertainties. The accuracy is the quadratic sum of all the systematic uncertainties.

	Correction (10^{-16})	**Uncertainty (10^{-16})**
Quadratic Zeeman effect	-1919.3	0.3
Black body radiation	168.4	0.6
Cold collisions and cavity pulling	93.7	1.2
Distributed cavity phase shift	-0.9	1.0
Microwave spectral purity&leakage	0	< 0.5
Ramsey & Rabi pulling	0	< 0.1
Microwave lensing	-0.7	0.7
Second order Doppler effect	0	< 0.1
Background gas collisions	0	<1.0
Total	-1658.9	2.2
Red shift	- 65.5	1.0
Total with red shift	**-1724.4**	**2.4**

Table 2: Budget of systematic effects and uncertainties for SYRTE-FO2 fountain for the MJD 57904 – 57924 period

$$\boxed{u_B = \mathbf{2.4 \times 10^{-16}}}$$

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. It is estimated to be 10^{-16}.
-The uncertainty due to the dead times of the frequency comparison.
To estimate this contribution, we use the comparison between the reference Maser and Maser 140 0809. We calculate the time deviation of the normalized phase differences with the linear frequency drift removed. The uncertainty is given by:

$$\sigma_{y_{Dead\ Time}} = \frac{\sqrt{\sum_i \sigma_{x_i}^2}}{T}$$

where σ_{xi} are the extrapolated TVar for each dead times. We applied the method to the dead times longer than 600 s and obtained a stability degradation of 0.4×10^{-16}.