FREQUENCY COMPARISON (H_MASER 140 0889) - (LNE-SYRTE-FO2Rb)
For the period MJD 57629 to MJD 57659

The secondary frequency standard LNE-SYRTE-FO2Rb has been compared to the hydrogen Maser 140 0889 of the laboratory, during a measurement campaign between MJD 57629 and 57659 (29th August 2016 – 28th September 2016). The fountain operation covers ~ 66.0 % of the total measurement duration.

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

Period (MJD)	Date of the estimation	$y(HMaser_{140\ 0889} – FO2Rb)$	u_B	u_A	$u_{link/maser}$	u_{SecRep}
57629 – 57659	57644	-3449.5	3.1	2.0	1.1	7

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

The calibration is made using the recommended value for the [87]Rb secondary representation: 6 834 682 610.904 310 Hz (20th CCTF in 2015).
u_B is the [87]Rb fountain type B uncertainty.
u_{SecRep} is the recommended uncertainty of the secondary representation (20th CCTF in 2015).

The FO2-Rb 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 on the maser 140 0889. It uses a synthesizer 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 calculate with the average points, a linear unweighted fit to determine the average frequency given in Table 1. The statistical uncertainty is estimated with the Allan variance of the frequency residuals, after removing the drift. We estimate a conservative statistical uncertainty $u_A = 2.0 \times 10^{-16}$.

We verified the results 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 0.2 $\times 10^{-16}$ which is consistent with the estimations 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. 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	-3471.2	0.7
Black body radiation	125.2	1.4
Cold collisions and cavity pulling	1.7	1.8
Distributed cavity phase shift	-0.35	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	-3345.3	2.9
Red shift	- 65.4	1.0
Total with red shift	-3410.7	3.1

Table 2: Budget of systematic effects and uncertainties for SYRTE-FO2Rb fountain
for the MJD 57629 -57659

$$u_B = 3.1 \times 10^{-16}$$

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 fountain 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 stability degradation of 0.4×10^{-16}.