

**FREQUENCY COMPARISON (H\_MASER 140 0889) - (LNE-SYRTE-FO1)  
For the period MJD 57169 to MJD 57199**

The primary frequency standard LNE-SYRTE-FO1 has been compared to the hydrogen Maser 140 0889 of the laboratory, during a measurement campaign between MJD 57169 and 57199 (27<sup>th</sup> May 2015 – 26<sup>th</sup> June 2015). The fountain operation covers ~ 80.5 % 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 <sub>140 0889</sub> – FO1)	$u_B$	$u_A$	$u_{link / maser}$
57169 – 57199	57184	-2833.1	3.8	3.0	1.1

*Table 1: Results of the comparison in  $1 \times 10^{-16}$ .*

The FO1 fountain was compared to the hydrogen Maser 140 0889 of the laboratory during the measurement period. The FO1 fountain was operated in the same mode during all the period: the interrogating signal synthesis is based on the multiplication of a 100 MHz 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 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 calculate with the average points, a linear unweighted fit to determine the average frequency given in Table 1, at the middle date of the interval. The statistical uncertainty is estimated with the Allan variance of the frequency residuals, after removing the drift. We estimate a conservative statistical uncertainty  $u_A = 3.0 \times 10^{-16}$ .

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 values given in Table 1 within  $0.5 \times 10^{-16}$ , 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 distributed cavity phase, the microwave lensing, and the gravitational 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.

	<b>Correction (10<sup>-16</sup>)</b>	<b>Uncertainty (10<sup>-16</sup>)</b>
Quadratic Zeeman effect	-1224.3	0.2
Black body radiation	171.4	0.6
Cold collisions and cavity pulling	43.4	1.7
Distributed cavity phase shift	-1.0	2.7
Microwave spectral purity&leakage	0	< 1
Ramsey & Rabi pulling	0	< 1
Microwave lensing	-0.7	0.7
Second order Doppler effect	0	< 0.1
Background gas collisions	0	<0.3
<b>Total</b>	<b>-1011.2</b>	<b>3.6</b>
Red shift	- 69.3	1.0
<b>Total with red shift</b>	<b>-1080.5</b>	<b>3.8</b>

Table 3: Budget of systematic effects and uncertainties for SYRTE-FO1 fountain for the MJD 57169 – 57199 period

$$u_B = 3.8 \times 10^{-16}$$

## 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<sup>-16</sup>.

-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  $\sigma_{x_i}$  are the extrapolated TVar for each dead times. We applied the method to the dead times longer than 600 s and obtained stability degradations of  $0.4 \times 10^{-16}$ .