

**FREQUENCY COMPARISON (H\_MASER 140 0889) - (LNE-SYRTE-FOM)  
For the period MJD 56154 to MJD 56169**

The primary frequency standard LNE-SYRTE-FOM has been compared to the hydrogen Maser 140 0889 of the laboratory, during a measurement campaign between MJD 56154 and 56169 (15<sup>th</sup> August 2012 - 30<sup>th</sup> August 2012). The fountain operation covers ~ 58.3 % of the total measurement duration.

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

Period (MJD)	Date of the estimation	$y(\text{HMaser}_{140\ 0889} - \text{FOM})$	$u_B$	$u_A$	$u_{\text{link} / \text{maser}}$
<b>56154 – 56169</b>	<b>56161.5</b>	<b>-1544.4</b>	<b>6.0</b>	<b>3</b>	<b>2.2</b>

*Table 1: Results of the comparisons  $\text{HMaser}_{140\ 0889}$ -FOM in  $1 \times 10^{-16}$ .*

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 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. The statistical uncertainty is estimated with the Allan variance of the frequency residuals, after removing the drift. We estimate a conservative statistical uncertainty  $u_A = 3 \times 10^{-16}$ .

We verified the result by applying a second method. We calculated the accumulated phase by integrating the data points, assuming a linear frequency drift 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 differences between the results and the value given in table 1 are in agreement within  $1.0 \times 10^{-16}$ , which is consistent with the estimations of the statistical uncertainties  $u_A$  and the uncertainty due to the link.

## Accuracy

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 (<math>10^{-16}</math>)</b>	<b>Uncertainty (<math>10^{-16}</math>)</b>
Quadratic Zeeman effect	-305.6	1.2
Black body radiation	165.6	0.6
Cold collisions and cavity pulling	28.6	5.0
Distributed Cavity Phase Shift	-0.7	1.6
Microwave Spectral Purity	0	1.5
Microwave Leakage	0	1.0
Ramsey & Rabi pulling	0	< 0.1
Microwave lensing	-0.9	0.9
Second order Doppler effect	0	< 0.1
Background gas collisions	0	<1.0
<b>Total</b>	<b>-113.0</b>	<b>5.9</b>
Red shift	- 68.7	1.0
<b>Total with red shift</b>	<b>-181.7</b>	<b>6.0</b>

Table 3: Budget of systematic effects and uncertainties for SYRTE-FOM fountain

$$u_B = 6.0 \times 10^{-16}$$

## 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 0816.

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 degradation of  $1.9 \times 10^{-16}$ .