

**FREQUENCY COMPARISON (H\_MASER 140 0890) - (LNE-SYRTE-FOM)  
For the period MJD 55924 to MJD 55949**

The primary frequency standard LNE-SYRTE-FOM has been compared to the hydrogen Maser 140 0890 of the laboratory, during 1 measurement campaign between MJD 55924 and 55949 (29<sup>th</sup> December 2011 – 23<sup>rd</sup> January 2012). The fountain operation covers ~ 87 % 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	$y(\text{HMaser}_{140\ 0890} - \text{FOM})$	$u_B$	$u_A$	$u_{\text{link} / \text{maser}}$
55924 – 55949	55936.5	-826.2	6.0	3	2

Table 1: Results of the comparisons  $\text{HMaser}_{140\ 0890}$ -FOM in  $1 \times 10^{-16}$ .

The FOM fountain was compared to the hydrogen Maser 140 0890 of the laboratory during the measurement period. 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 0890. 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 details of the calculations are given in figure 1:

The frequency data averaged over 0.2 day are plotted on the upper graph (blue points) together with a linear unweighted fit (red line).

The parameters of the fit  $y=a + b(x-x_{\text{middle\_date}})$  are respectively:

Period (MJD)	a	B
55924 – 55949	$(-826.2 \pm 0.9) 10^{-16}$	$(-1.1 \pm 0.2) 10^{-16}/\text{day}$

Table 2: Coefficients of the linear fit of  $\text{HMaser}_{140\ 0890}$ -FOM

These coefficients are used to remove the drift (data plotted in the graph in the middle, red points) and to calculate the average value at middle date, given in table 1. The lower graph gives the variance of the frequency residual. We estimate a conservative statistical uncertainties  $u_A = 3.0 \times 10^{-16}$ .

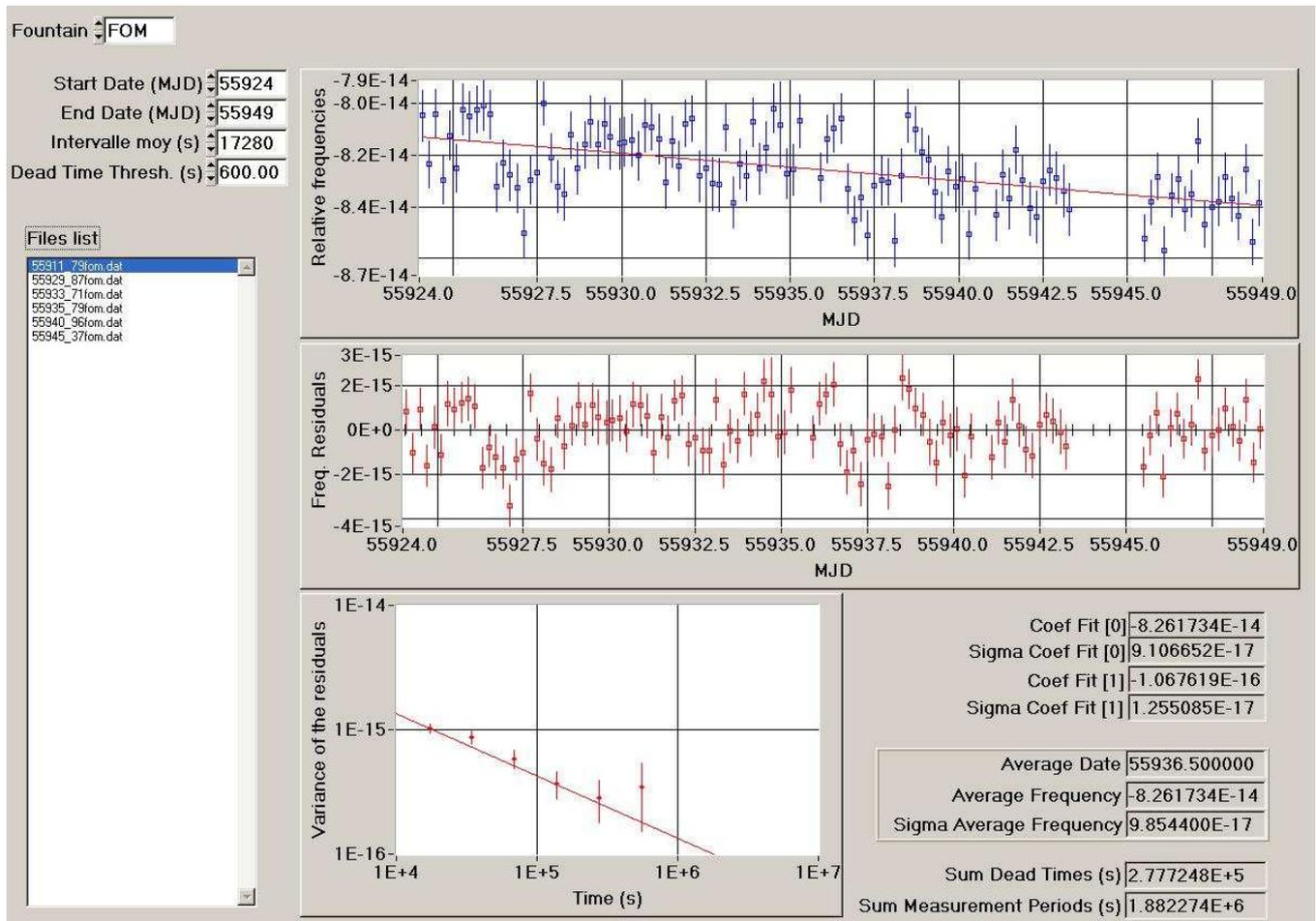


Figure 1: Data processing for the period MJD 55924-55949

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  $0.7 \times 10^{-16}$ , 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

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

The accuracy budget has been updated taking account extensive measurements on the microwave power dependent shifts (pulsed operation tests for microwave leakage, phase transient analysis for spectral purity and to search possible synchronous perturbations, tilted operation to evaluate the distributed cavity phase shift) [1].

[1] Accepted paper in IEEE Trans. on Ultrason. Ferr. Freq. Contr

## 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:

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

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  $1.7 \times 10^{-16}$ .