FREQUENCY COMPARISON (H_MASER 140 0890) - (LNE-SYRTE-FO1)
For the period MJD 55709 to MJD 55729

The primary frequency standard LNE-SYRTE-FO1 has been compared to the hydrogen Maser 140 0890 of the laboratory, during 1 measurement campaign between MJD 55709 and 55729 (28th May 2011 - 17th June 2011). The fountain operation covers ~ 73 % 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$_{140\ 0890}$ – FO1)**	u_B	u_A	$u_{link\ /\ maser}$
55709 – 55729	**55719**	**-499.4**	**4.3**	**3**	**1.3**

Table 1: Results of the comparisons HMaser$_{140\ 0890}$-FO1 in 1 x 10^{-16}.

The FO1 fountain was compared to the hydrogen Maser 140 0890 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 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_middle_date) are respectively:

Period (MJD)	**a**	**b**
55709 – 55729	**(-499.4 +/-1.1) 10^{-16}**	**(-2.0+/-0.2) 10^{-16}/day**

Table 2: Coefficients of the linear fit of HMaser$_{140\ 0890}$-FO1

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 $u_A = 3 \times 10^{-16}$.

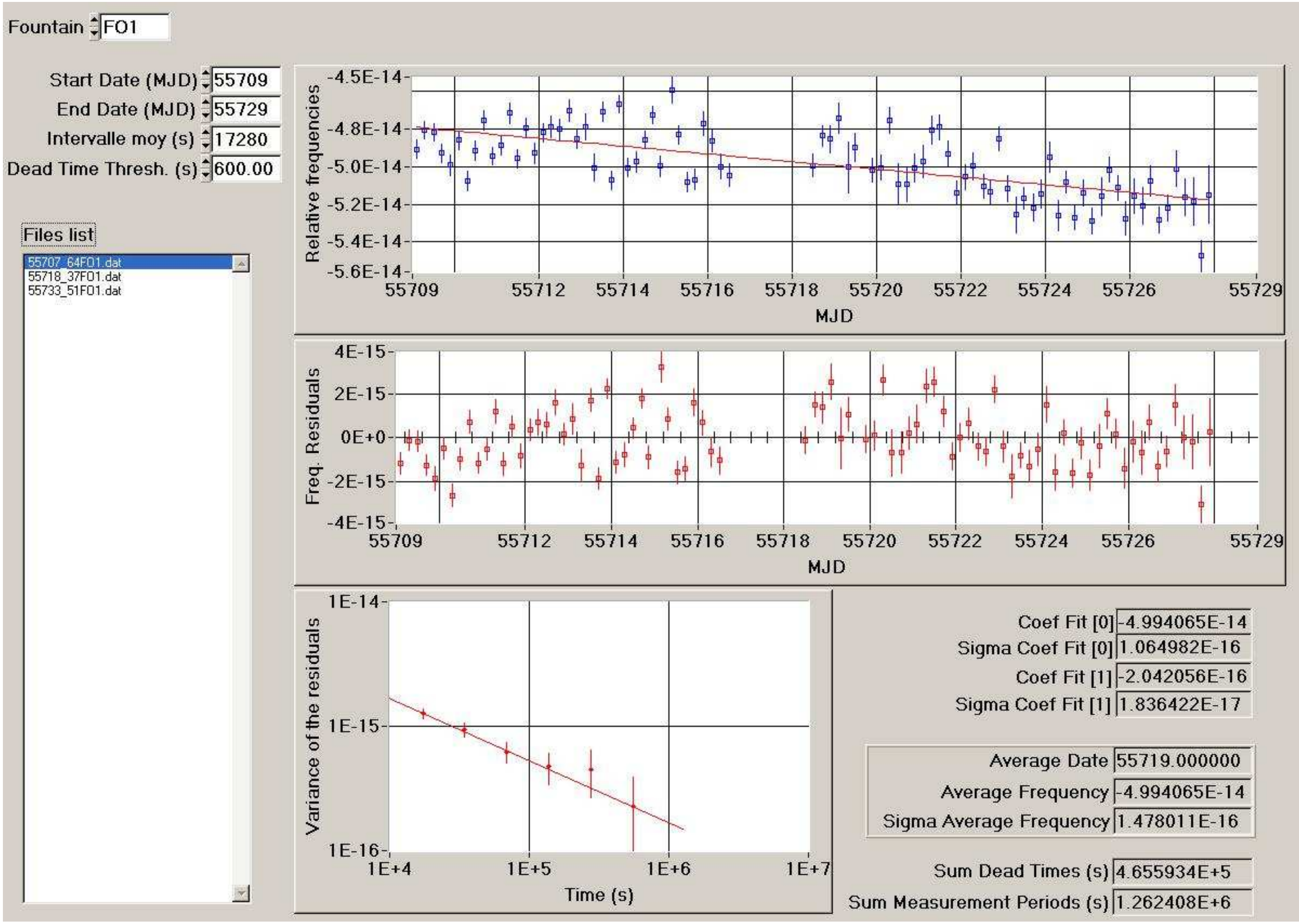

Figure 1: Data processing for the period MJD 55709-55729

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 2×10^{-16}, which is consistent with the estimations of the statistical uncertainties 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, 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	-1273.3	0.4
Black body radiation	172.0	0.6
Cold collisions and cavity pulling	77.0	1.7
First order Doppler	0	3.2
Microwave spectral purity&leakage	0	< 1
Ramsey & Rabi pulling	0	< 1
Microwave lensing	0	< 1.4
Second order Doppler effect	0	< 0.1
Background gas collisions	0	<0.3
Total	**-1024.3**	**4.2**
Red shift	- 69.3	1.0
Total with red shift	**-1093.6**	**4.3**

Table 3: Budget of systematic effects and uncertainties for SYRTE-FO1 fountain

$$u_B = 4.3 \times 10^{-16}$$

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 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 degradations of 0.9×10^{-16}.