FREQUENCY COMPARISON (H_MASER 140 0816) - (LNE-SYRTE-FO2)
For the period MJD 54714 to MJD 54729

The primary frequency standard LNE-SYRTE-FO2 has been compared to the hydrogen Maser 140 0816 of the laboratory, during a measurement campaign between MJD 54714 and 54729 (5th September 2008-20th September 2008). The fountain operation covers ~ 83 % 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$_{140\ 0816}$ – FO2)	u_B	u_A	$u_{link\ /\ maser}$
54714 – 54729	**54721.5**	**+5531.3**	**4**	**6**	**2.4**

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

Details of the estimation

The estimation proceeds in 2 steps. First the FO2 fountain was compared to the hydrogen Maser 140 0890 of the laboratory during the measurement period. The FO2 fountain was operated in the same mode during all the period: the interrogating signal synthesis is based on the down conversion to 9.192 GHz of a 11.98 GHz signal provided by a cryogenic oscillator phase locked to the maser 140 0890. 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. The result is summarized in the following table:

Period (MJD)	Date of the estimation	y(HMaser$_{140\ 0890}$ – FO2)	u_B	u_A	$u_{link\ /\ maser}$
54714 – 54729	**54721.5**	**-525.3**	**4.0**	**6**	**1.4**

In addition, we measure with a time counter the phase departure of the masers 140 0890 and 140 0816 to UTC(OP). This allows us to calculate the average frequency difference between the two masers over the measurement period.

Average value and statistical uncertainty

This paragraph describes the calculation of the average frequency of HMaser$_{140\ 0890}$-FO2. The details of the calculation 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 + bx are respectively:

Period (MJD)	a	b
54714 – 54729	**(17.4 +/- 2.3) 10^{-12}**	**(-4.1 +/- 0.3) 10^{-16}/day**

Table 2: coefficients of the linear fit of HMaser$_{140\ 0890}$-FO2

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 residuals. We estimate a statistical uncertainty u_A = 6 10^{-16}.

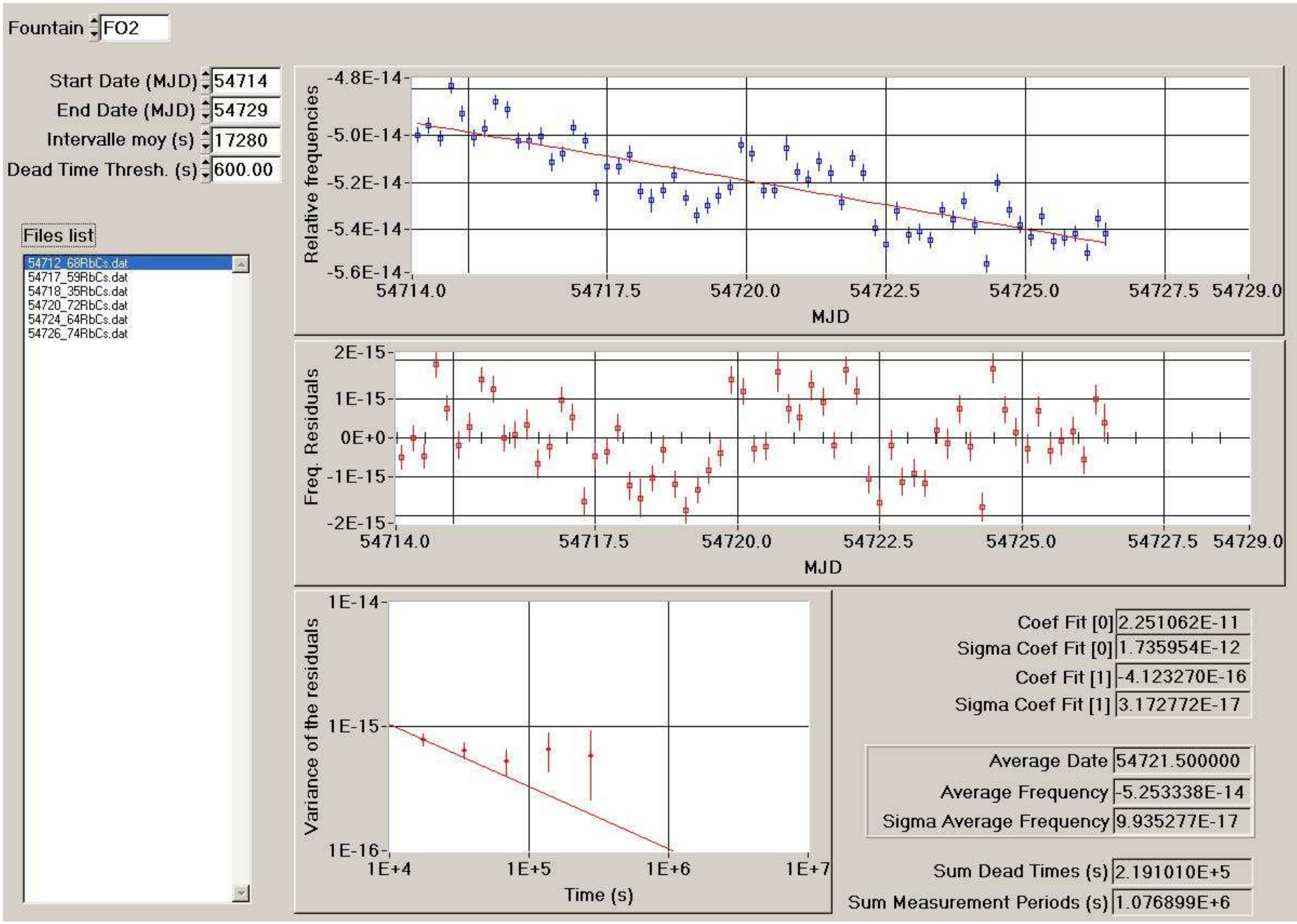

Figure 1: Processing of the data HMaser$_{140\ 0890}$-FO2 for the period MJD 54714-54729

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 6 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, and the red shift effects. Here the uncertainty in the cold collisions correction is taken as 0.5% of the correction for high density measurements. It accounts for at most 1% residual population in F=3, non zero mF Zeeman states which cause a collisional shift that is a fraction of the cold collision shift associated with the clock F=3, mF=0 state.
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	-1917.5	0.3
Black body radiation	166.6	0.6
Cold collisions and cavity pulling	250.0	1.5
First order Doppler	0	< 3.0
Microwave spectral purity&leakage	0	<0.5
Ramsey & Rabi pulling	0	< 0.1
Microwave recoil	0	< 1.4
Second order Doppler effect	0	< 0.1
Background gas collisions	0	<1.0
Total	**-1501**	**3.9**
Red shift	- 65.4	1.0
Total with red shift	**-1566.4**	**4.0**

Table 2: budget of systematic effects and uncertainties for SYRTE-FO2 fountain For the MJD 54714-54729 period

$$u_B = 4.0 \times 10^{-16}$$

Uncertainty of the link

The uncertainty of the link is the quadratic sum of 3 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 0889. 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 1 10^{-16}.

-The uncertainty of the phase measurements UTC(OP)- $HMaser_{140\ 0890}$ and UTC(OP)- $HMaser_{140\ 0816}$. It is estimated to be below 2 10^{-16}.