l'Observatoire de Paris — SYRTE
Systèmes de Référence Temps-Espace
LNE
Le progrès, une passion à partager
CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

FREQUENCY COMPARISON (H_MASER 140 0889) - (LNE-SYRTE-FO2)
From MJD 54334 to MJD 54349

The primary frequency standard LNE-SYRTE-FO2 was compared to the hydrogen Maser (140 0889) of the laboratory during the 21st of August to 6th of September 2007 period corresponding to MJD 54334 and MJD 54349.

Period (MJD)	y(HMaser$_{140\ 0889}$ - FO2)	u_B	u_A	$u_{link\ /\ maser}$
54334 – 54349	**-13430.0**	**4.7**	**3.0**	**1.1**

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

Figure 1 collects the fractional frequency differences averaged over continuous intervals during this period. Error bars represent the statistical and systematic uncertainties. The measurements are corrected for the systematic frequency shifts listed below (table 3). A linear fit with respect to the middle date 54341.5 is plotted with the low and high confidence bounds at 1σ.

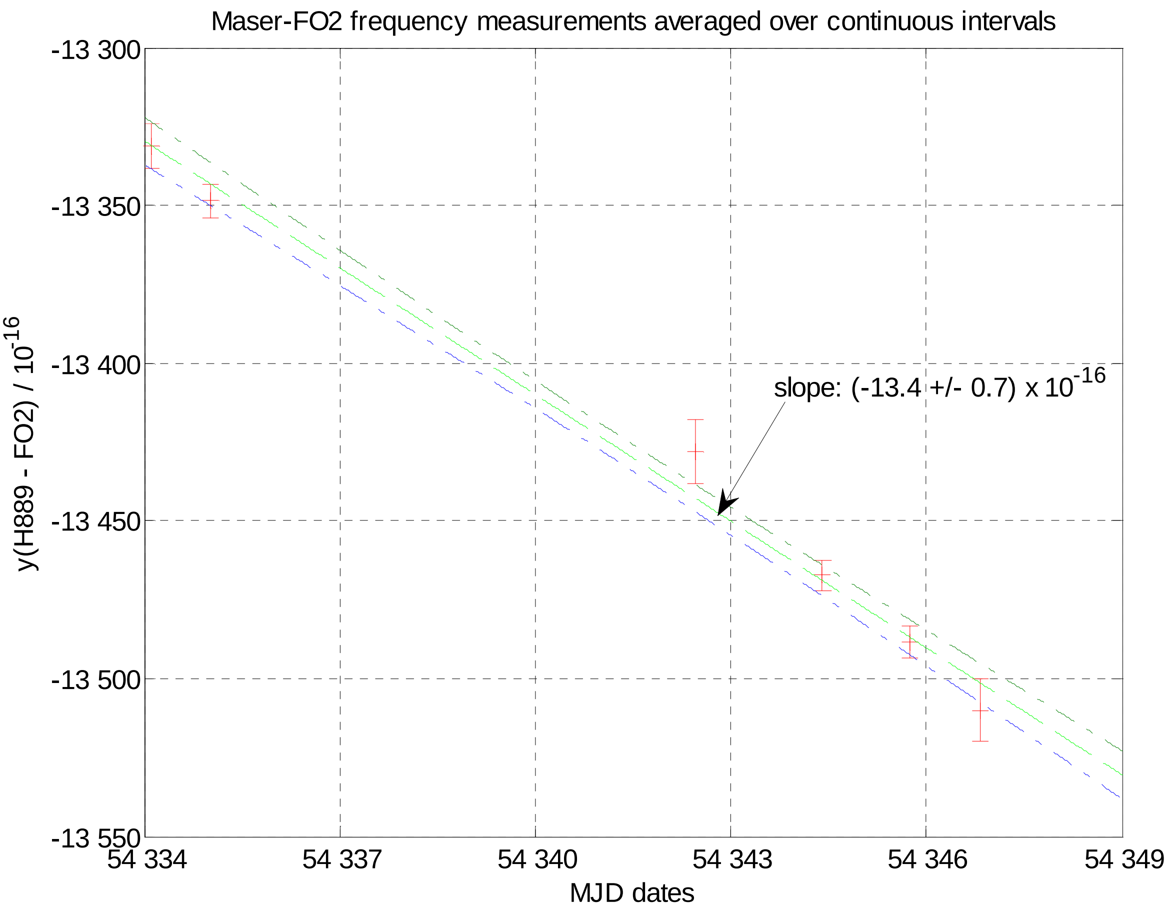

Figure 1: frequency differences between H_Maser 140 0889 & FO2 from MJD 54334 to MJD 54349

Figure 2 shows the shot by shot data measurements during the period MJD 54334 to MJD 54349.

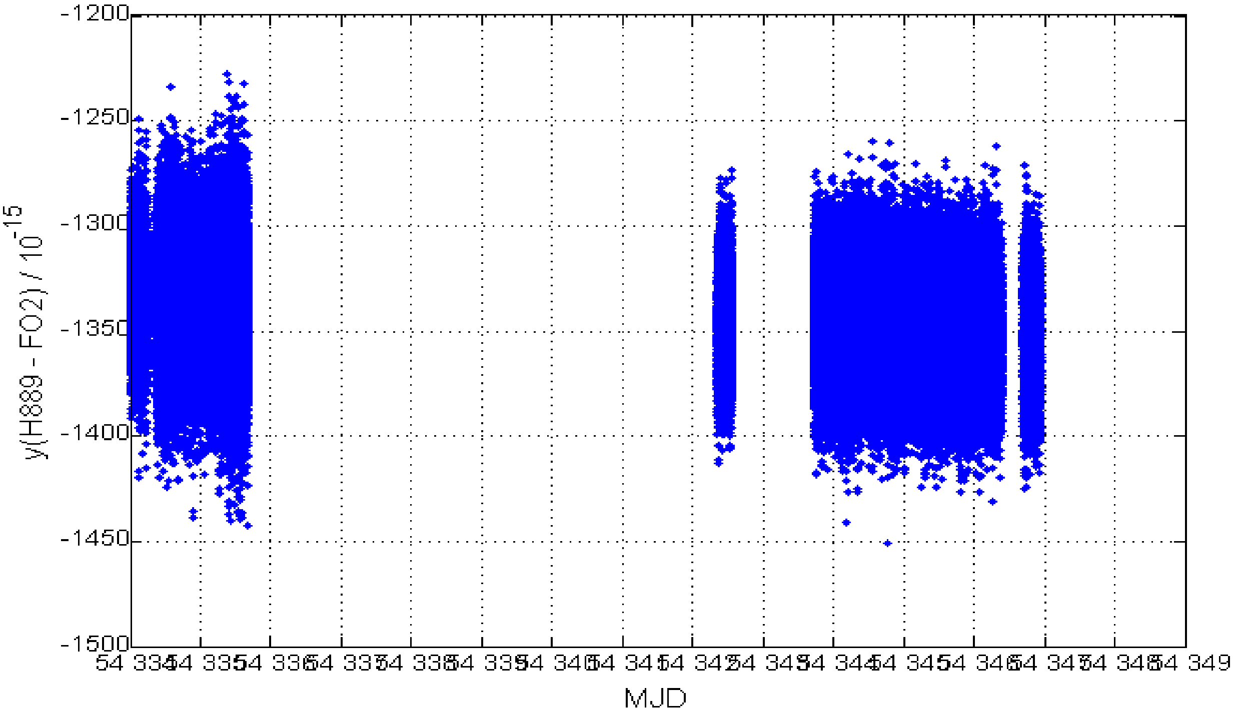

Figure 2: shot by shot data measurements during the period MJD 54334 to MJD 54349

Table 2 gives the results of the frequency estimated at the middle date of the period, and the associated statistical uncertainty, using either a linear or a polynomial fit to the data. Here we have chosen the linear fit, shown in Figure1, to estimate the frequency average.

Dates of measurements Duration & Measurement Rate	Mean normalized frequency difference $y_{Maser} - y_{FO2}$	type A uncertainty σ_{Stat}	Uncertainty due to the dead times $\sigma_{deadTime}$
Start meas. date MJD **54334.0** End meas. date MJD **54346.9** Length of interval T = **15** d Effective interval of measurements **4.67** d **403907** s Measurement Rate: **31.2** % Mean date of BIPM interval: MJD **54341.5**	Frequencies averaged over continuous intervals of measurements: Mean by linear fit at middle date 54341.5 $\overline{y}$ = **-13429.86 x 10^{-16}** Frequencies averaged over intervals of 12H Mean by weighted linear fit at middle date 54341.5 $\overline{y}$ = **-13430.97 x 10^{-16}** Mean by polynomial fit order 5: $\overline{y}$ = **-13428.94 x 10^{-16}**	Uncertainty of linear fit at 1σ **2.98** x **10^{-16}** Uncertainty of weighted linear fit at 1σ **1.65** x **10^{-16}** Allan Deviation at T with assumption of White Frequency Noise σ_y = **2.6 x 10^{-16}**	$\sigma_{deadTime}$ = **0.45 10^{-16}**

Table 2: Statistics of measurements

Uncertainties budget of systematic effects in the FO2 fountain

Summary of the systematic corrections and uncertainties:

	Correction (10^{-16})	**Uncertainty (10^{-16})**
Cold collisions and cavity pulling	**220**	2.9
Quadratic Zeeman effect	**-1919.2**	0.2
Black body radiation	**167.5**	0.6
Microwave spectral purity & leakage		0.5
First order Doppler effect		3.0
Ramsey & Rabi pulling		< 1.0
Microwave recoil		< 1.4
Second order Doppler effect		<0.1
Background gas collisions		<1.0
Total		**4.6**
Red shift	-65.4	1.0
Total with red shift		**4.7**

Table 3: Budget of systematic effects and associated uncertainties in the FO2 fountain.

Systematic effects taken into account are listed in Table 3. The correction and estimated uncertainty for each of them is given. Here the collisional shift correction is the average correction over all measurements, which are taken alternatively at high and low densities. The uncertainty on this correction is taken as 1% of the collisional shift correction at high density to account for 1% spurious population in non-zero m_F states which affect the measurements equally at both densities. Finally, including also an uncertainty for the red shift effect, this gives the type B total uncertainty:

$$\sigma_B = \left(\sigma_{Zeeman2}{}^2 + \sigma_{BlackBody}{}^2 + \sigma_{Collision_{Syst}}{}^2 + \sigma_{Microwave\_Spectrum\_Leakage}{}^2 + \sigma_{first\_Doppler}{}^2 + \sigma_{Ramsey\_Rabi}{}^2 + \sigma_{Recoil}{}^2 + \sigma_{second\_Doppler}{}^2 + \sigma_{Background\_collisions}{}^2 + \sigma_{Redshift}{}^2 \right)^{(1/2)}$$

For the whole period we obtained

$$\boxed{\sigma_B = 4.7 \times 10^{-16}}$$

SYRTE 61, avenue de l'Observatoire 75014 Paris - France tél 33 (0)1 40 51 22 04 fax 33 (0)1 40 51 22 91 e-mail direction.syrte@obspm.fr
Unité de recherche du CNRS 8630 site syrte.obspm.fr Jean-Yves Richard 05/10/2007

Uncertainty due to the dead times

During the period MJD 54334 to 54349, the hydrogen Maser 140 0890 was compared with the hydrogen Maser 140 0889. Figure 3 shows the frequency measurements averaged over 100 seconds. After removing the frequency drift the time deviation was evaluated taking into account the dead times in the measurements of phase differences Maser 140 0889 – Maser 140 0890. Figure 4 shows this time deviation of the normalized phase differences, linear frequency drift removed.

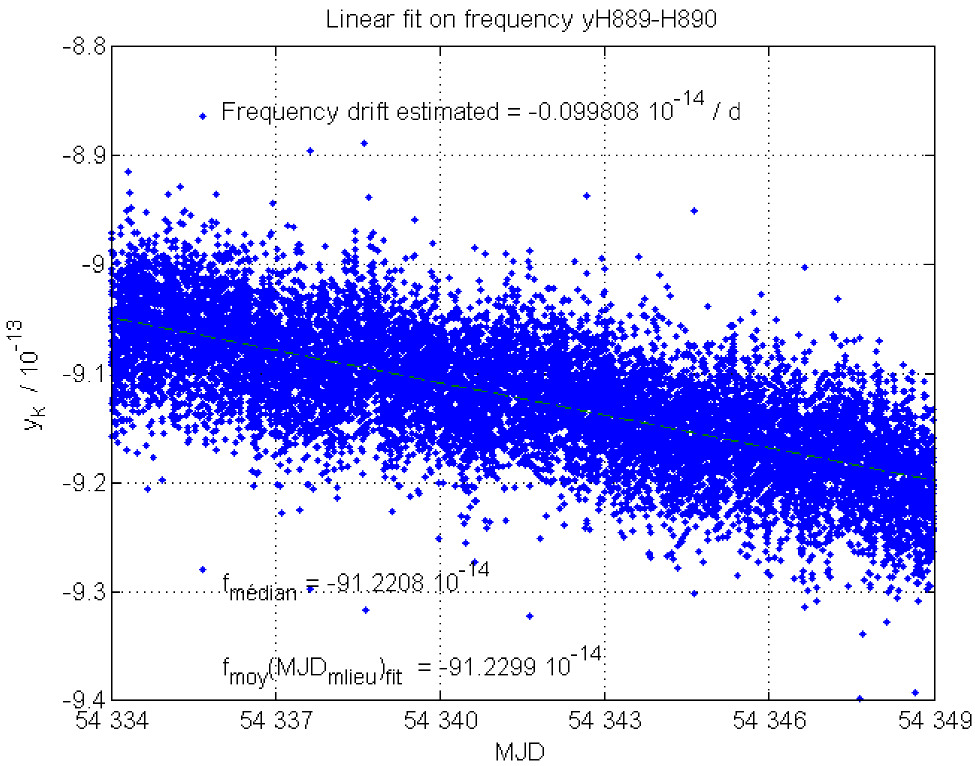

Figure 3: Frequency differences between Maser 140 0889 – Maser 140 0 890 obtained by first phase differences of phases averaged over 100s and estimation of the linear drift, August to September 2007, MJD 54334 to MJD 54349, outliers above +/-5σ removed

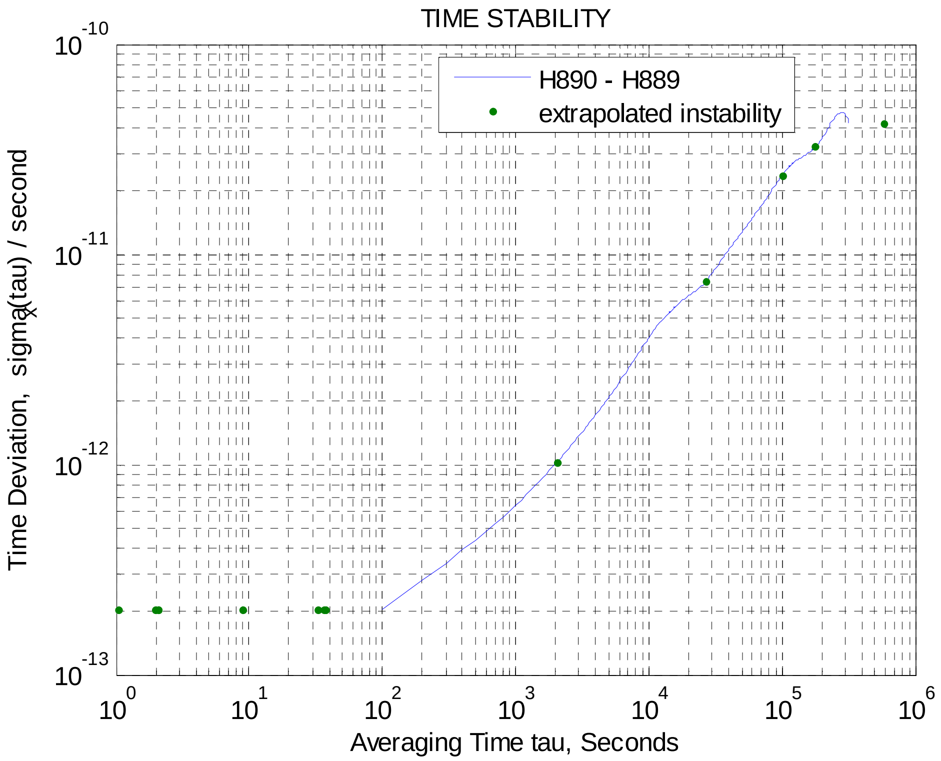

Figure 4: Time stability on normalized phase differences between Masers 140 0889 and 140 0890 linear frequency drift removed for MJD 54334 to MJD 54349

Table 4 gives the measurements by joint intervals of duration 12 hours, the frequency mean and statistical uncertainty estimated by Allan deviation over time of measurements during each interval of 12H, the duration of dead times and the associated uncertainty. The square of quadratic sum of the uncertainties for each dead times divided by the total duration (T = **15** d) of this integration gives the uncertainty due to the dead times. The effect is weak due to the good stability of Maser 140 0889 and so doesn't modify the uncertainty due to the link lab.

MJD start	MJD middle	MJD end	Duration of half interval / d	Frequency average over interval of 12H	Statistical uncertainty	Dead times duration / d	Uncertainty of dead times / s
54334	54334	54334	6,9444E-11	-1,3333E-12	3,2552E-16	1,2E-05	2,0301E-13
54334	54334,25	54334,5	0,25000353	-1,3333E-12	2,8951E-16	0,000429	2,0301E-13
54334,5004	54334,7502	54335	0,24979687	-1,3347E-12	2,6329E-16	2,4E-05	2,0301E-13
54335	54335,2411	54335,4821	0,24105848	-1,3347E-12	2,939E-16	0,023669	1,029E-12
54335,5058	54335,5924	54335,6791	0,08666697	-1,3365E-12	5,1691E-16	6,666076	4,2324E-11
54342,3452	54342,4226	54342,5	0,07741399	-1,3419E-12	4,0163E-16	0,000104	2,0301E-13
54342,5001	54342,5296	54342,5591	0,02952536	-1,3449E-12	6,6627E-16	1,160452	2,3869E-11
54343,7195	54343,8598	54344	0,14023112	-1,3461E-12	3,182E-16	2,4E-05	2,0301E-13
54344	54344,2499	54344,4999	0,2499474	-1,3466E-12	2,2703E-16	0,000382	2,0301E-13
54344,5003	54344,75	54344,9997	0,24971038	-1,347E-12	2,4163E-16	0,000417	2,0301E-13
54345,0001	54345,25	54345,5	0,24995951	-1,3481E-12	2,4355E-16	2,3E-05	2,0301E-13
54345,5	54345,75	54346	0,24999989	-1,3496E-12	2,3641E-16	2,3E-05	2,0301E-13
54346	54346,1963	54346,3927	0,19634884	-1,3486E-12	2,6393E-16	0,309953	7,4216E-12
54346,7026	54346,8241	54346,9455	0,12143535	-1,351E-12	3,3254E-16	2,054525	3,2491E-11
54349	54349	54349	1,189E-05	-1,3529E-12	2,8134E-16	0	2,0301E-13

Table 4: measurements by joint intervals of duration 12 hours with dead times between intervals & associated time deviation

The standard deviation of the fluctuations of frequency due to the dead times in measurements is estimated by the ratio

$$\frac{\sqrt{\sum_{i=1}^{15}\sigma_{x_i}^2(\tau)}}{T} = \sigma_{Dead\_Time} = 0.45 \text{ x } 10^{-16}$$

The uncertainty on the link Maser is obtained by the quadratic sum of the link lab uncertainty and the uncertainty due to the dead times calculated above:

$\sigma_{Link\_Lab} = 1 \text{ x } 10^{-16}$ and $\sigma_{Link\_Maser} = \sqrt{(\sigma_{Dead\_Time})^2 + (\sigma_{Link\_Lab})^2} = 1.1 \text{ x } 10^{-16}$