Dr. E. Felicitas Arias

Head of Time Section

BIPM

Paris

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Dear Dr. Arias,

Attached is the report of our most recent evaluation of SU-CsFO2, a cesium fountain primary frequency standard. The report period is for the 30 day interval from MJD 56684 to 56714. We have used data from previous evaluations to determine the spin exchange shift.

Sincerely,

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FREQUENCY COMPARISON (H-MASER 40 3818) - (SU-CsFO2) For the period MJD 56684 to MJD 56714.

The primary frequency standard SU-CsFO2 has been compared to the hydrogen Maser 40 3818 of the laboratory, during a measurement campaign between MJD 56684 and 56714 (27th January 2014 - 26th February 2014). The fountain operation covers ~ 88 % of the total measurement duration for the period MJD 56684-56714**.** The mean frequency difference at the middle date of the period is given in the following table:

Period (MJD)	Date of the estimation	y(HMaser40 3818 – CsFO2)	u_B	u_A	u_{Link_Maser}
56684-56714	**56699**	**89.5**	**5.0**	**2.9**	**1.0**

Table 1: Results of the comparison in 1 × 10-16.

The relative frequency instability of CsFO2 was : 2.5×10^{-13} $(\tau/s)^{-1/2}$

The uncertainty due to the clock link $\mathbf{u}_{Link\_Lab} = 0.1\times10^{-15}$ is obtained by taking into account the actual measurement time.

The CsFO2 standard uncertainty u_B is estimated as 0.5×10^{-16} (1σ) for the relevant periods.

Figure 1 shows the shot by shot data measurements during the period MJD 56684 to MJD 56714.

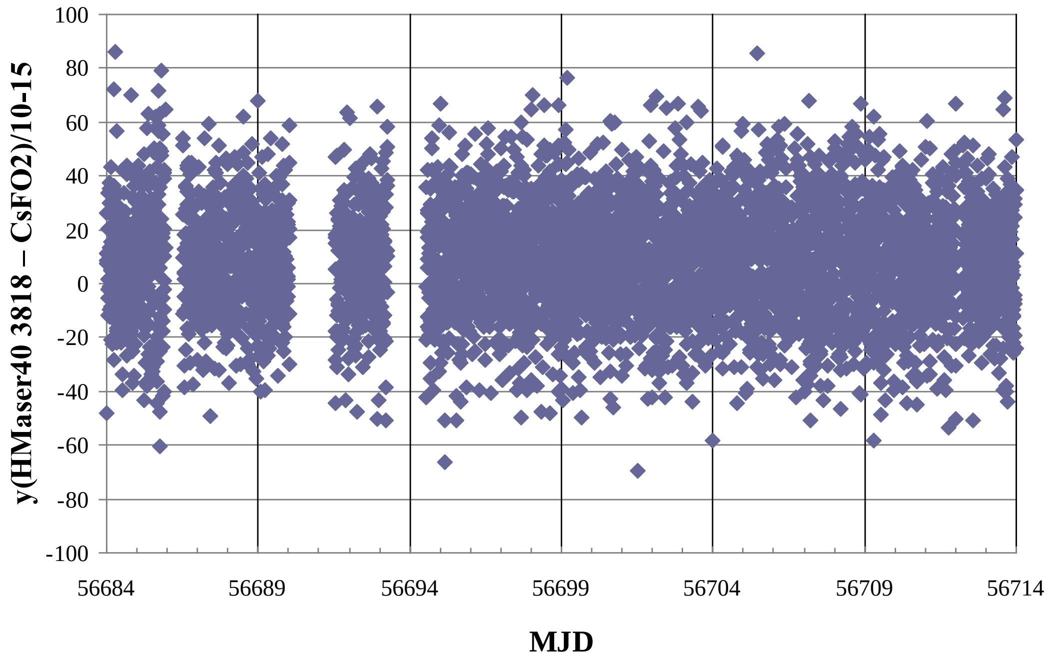

Figure 1: shot by shot data measurements during the period MJD 56684 to MJD 56714

Feature of fountain's measurement procedure

Frequency measurement of H-maser is shared by blocks, each block consists of one hundred shots. Fountain operating mode may differ from block to block or may be the same for all blocks. Fountain work can be programmed with a set of various modes in block.

Collision shift measurement cycle consists of three blocks. The number of atoms is determined by frequency of selection cavity signal.

A detailed description of the measurement procedure together with a complete evaluation of the systematic frequency biases and their uncertainties is given in references [1].

Accuracy

The frequency is corrected from the black body radiation, the cold collisions, phase gradient in microwave cavity, microwave power dependence, microwave lensing and gravity.
The frequency at zero density was obtained from the zero density intercept of a weighted linear least-mean-square fit of frequency versus atom density [2]. In total for low density we obtain a collisional shift uncertainty of $2.5 \cdot 10^{-16}$.
We corrected the coefficients for BBR shift according to the latest data and updated the gravity shift. The following table summarizes the budget of systematic effects and their associated uncertainties. The accuracy is the quadratic sum of all the systematic uncertainties.

Physical Effect	**Correction (10^{-16})**	**Uncertainty (10^{-16})**
Second-order Zeeman effect	1072.4	0.1
Spin-exchange shift (low density)	-1.0	2.5
Black-body radiation	-165.87	0.7
Gravitational shift	244.3	0.8
Resonator pulling	0.014	0.1
Purity of probe signal spectrum	0	0.1
Influence of electronic equipment	0	1
Light shift	0	0.1
Phase gradient in microwave cavity	0	2.7
Microwave leakage	0	0.1
Collisions with residual gas	0	1
Microwave lensing	0	1.5
Unexplored physical effects	0	2.3?
Total	**1149.8**	**5.0**

Table 2: Budget of systematic effects and uncertainties for VNIIFTRI- CsFO2 *fountain for the MJD 56684 – 56714 period*

$$u_B = 5 \times 10^{-16}.$$

Uncertainty due to the dead times

During the evaluation period there were gaps in the data collection (dead time) due to both intentional and unintentional breaks. Most of the unintentional breaks were caused by failures of the laser locking systems (due to rapid change barometric pressure).

Start of date of measurements (MJD)	End of date of measurements (MJD)	Duration of dead Times H:m:s	second	σ_{x_i}
56684	56685,9326	0:00:00		
56686,5148	56690,0394	13:58:22	50302	2.3472E-11
56691,5322	56693,2682	35:49:38	128978	2.5169E-11
56694,5432	56712,0291	30:36:00	110160	2.8814E-11
56712,2226	56714	4:38:38	16718	1.3901E-11

Table 3: Distribution of Dead Times for the MJD 56684 – 56714 period

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

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

Period	$\sigma_{\text{Dead\_Time}}$
56684 - 56714	1.81E-17

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:

$\mathbf{u}_{Link\_Lab} = 1\times10^{-16}$,

$\mathbf{u}_{Link\_Maser} = \sqrt{(\sigma_{Dead\_Time})^2 + (\sigma_{Link\_Lab})^2}$

Period	$\mathbf{u}_{Link\_Lab}$
56684-56714	1.0×10^{-16}

References

[1] Domnin, Yu.; Baryshev, V.; Boyko, A.; Elkin, G.; Novoselov, A.; Kopylov, L.; Kupalov, D., "The MTsR-F2 fountain-type cesium frequency standard", Measurement Techniques, Volume 55, Number 10, January 2013 , pp. 1155-1162(8)

[2] Parker T E, Jefferts S R, Heavner T P, and Donley E A 2005 Operation of the NIST-F1 caesium fountain primary frequency standard with a maser ensemble, including the impact of frequency transfer noise Metrologia 42 423-430