

## FREQUENCY COMPARISON (H\_MASER 40 3845) - (SU-CsFO2) For the period MJD 58539 to MJD 58569.

The primary frequency standard SU-CsFO2 has been compared to the hydrogen Maser 40 3845 of the laboratory, during a measurement campaign between MJD 58539 and 58569 (25<sup>th</sup> February 2019 – 27<sup>th</sup> March 2019). The fountain operation covers ~ 46 % of the total measurement duration for the period MJD 58539-58569. 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 3845 – CsFO2)	$u_B$	$u_A$	$u_{Link\_Maser}$
58539-58569	58554	2105.9	2.4	2.5	1.2

*Table 1: Results of the comparison in  $1 \times 10^{-16}$ .*

For the uncertainty due to the clock link  $u_{Link\_Lab} = 0.1 \times 10^{-15}$  is obtained by taking into account the actual measurement time.

The CsFO2 standard uncertainty  $u_B$  is estimated as  $0.24 \times 10^{-15}$  ( $1\sigma$ ) for the relevant periods.

### 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.

Physical Effect	Shifts ( $10^{-16}$ )	Uncertainty ( $10^{-16}$ )
Second-order Zeeman effect	1070.7	0.10

<b>Black-body radiation</b>	<b>-163.8</b>	<b>1.0</b>
<b>Gravitational shift</b>	<b>244.3</b>	<b>0.5</b>
<b>Resonator pulling</b>	<b>0</b>	<b>0.1</b>
<b>Purity of probe signal spectrum</b>	<b>0</b>	<b>0.1</b>
<b>Light shift</b>	<b>0</b>	<b>0.1</b>
<b>Tilting(DCP)</b>	<b>0</b>	<b>0.3</b>
<b>Microwave leakage</b>	<b>0</b>	<b>0.1</b>
<b>Collisions with residual gas</b>	<b>0</b>	<b>1</b>
<b>Microwave power dependence</b>	<b>0</b>	<b>1.8</b>
<b>Spin exchange shift (mean density)*</b>	<b>0.19*</b>	<b>0.19*</b>
<b>Total( not including spin exchange)</b>	<b>1151.2</b>	<b>2.4</b>

*Table 2: Budget of systematic effects and uncertainties for VNIIFTRI- CsFO2 fountain for the MJD 58539 – 58569 period*

$$u_B = 2.4 \times 10^{-16}.$$

### **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).

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

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

<b>Period</b>	<b><math>\sigma_{Dead\_Time}</math></b>
58539-58569	6.4E-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:

$$u_{Link\_Lab} = 1 \times 10^{-16},$$

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

<b>Period</b>	<b><math>u_{Link\_Maser}</math></b>
58539-58569	1.2E-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] Blinov I.Yu., Boiko A.I, Domnin Yu.S., Kostromin V.P., Kupalova O.V., Kupalov D.S. "Budget of uncertainties in the cesium frequency frame of fountain type" Measurement Techniques 2017. T.60 №1 P. 30-36.