State Scientific Center of the Russian Federation
VNIIFTRI
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FREQUENCY COMPARISON
(H–MASER 40 3845) — (SU–CsFO2)
For the period MJD 59179 to MJD 59214.

The primary frequency standard SU–CsFO2 has been compared to the hydrogen Maser 40 3845 of the laboratory, during a measurement campaign between MJD 59179 and 59214 (26th November 2020 — 31st December 2020). The fountain operation covers $\sim 78\%$ of the total measurement duration for the period MJD 59179 – 59214. The mean frequency difference at the middle date of the period is given in the following table:

Period (MJD)	**Date of the estimation**	y (H–Maser 40 3845 — CsFO2)	u_B	u_A	$u_{\text{Link\_Maser}}$
59179 – 59214	59197	2142.4	2.2	1.9	1.0

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

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

The CsFO2 standard uncertainty u_A is estimated as $0.19 * 10^{-15}$ (1σ) 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
Black-body radiation	-163.8	0.5
Gravitational shift	244.3	0.5
Resonator pulling	0	0.1
Purity of probe signal spectrum	0	0.1
Light shift	0	0.1
Tilting (DCP)	0	0.1

Physical Effect	**Shifts** (10^{-16})	**Uncertainty** (10^{-16})
Collisions with residual gas	0	1
Microwave power dependence	0	1.8
Spin exchange shift (mean density)*	0.19*	0.19*
Total (not including spin exchange)	1151.2	2.2

Table 2: Budget of systematic effects and uncertainties for VNIIFTRI–CsFO2 fountain for the MJD 59179 – 59214 period.

$$\boxed{u_B = 2.2 * 10^{-16}}$$

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 $\frac{\sqrt{\sum_i \sigma^2_{x_i}}}{T} = \sigma_{\text{Dead\_Time}}$.

Period (MJD)	$\sigma_{\text{Dead\_Time}}$
59179 – 59214	$3.1 * 10^{-17}$

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:

$$u_{\text{Link\_Lab}} = 1 * 10^{-16},$$
$$u_{\text{Link\_Maser}} = \sqrt{(\sigma_{\text{Dead\_Time}})^2 + (\sigma_{\text{Link\_Lab}})^2}.$$

Period (MJD)	$u_{\text{Link\_Maser}}$
59179 – 59214	$1.0 * 10^{-16}$

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. 2013. Vol. 55. № 10. PP. 1155–1162.

[2] Blinov I., Boiko A., Domnin Yu., Kostromin V., Kupalova O., Kupalov D. Budget of uncertainties in the cesium frequency frame of fountain type // Measurement Techniques. 2017. Vol. 60. № 1. PP. 30–36.