# FREQUENCY COMPARISON (H_MASER 40 3818) - (SU-CsFO2)
## For the period MJD 56959 to MJD 56989.

The primary frequency standard SU-CsFO2 has been compared to the hydrogen Maser 40 3818 of the laboratory, during a measurement campaign between MJD 56959 and 56989 (29th October 2014 - 28th November 2014). The fountain operation covers ~ 84 % of the total measurement duration for the period MJD 56959-56989.   The mean frequency difference at the middle date of the each period is given in the following table:

| Period (MJD) | Date of the estimation | y(HMaser40 3818 – CsFO2) | $u_B$ | $u_A$ | $u_{Link\_Maser}$ |
|---|---|---|---|---|---|
| 56959-56989 | 56974 | -132.3 | 2.5 (1.7**) | 2.3 | 1.1 |

*Table 1: Results of the comparison in 1 × 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 $0.25(1.7^{**}) \times 10^{-16}$ (1σ) for the relevant
periods.

## Accuracy

The frequency is corrected from the quadratic Zeeman, the Black Body radiation, the cold collisions and cavity pulling, microwave power dependence, and gravity.
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 | 1069 | 0.10 |
| Black-body radiation | -165.5 | 1.0 |
| Gravitational shift | 244.3 | 0.5 |
| Resonator pulling | 0.014 | 0.1 |
| Purity of probe signal spectrum | 0 | 0.1 |
| Light shift | 0 | 0.1 |
| Tilting(DCP) | 0.37 | 0.75 |
| Microwave leakage | 0 | 0.1 |
| Collisions with residual gas | 0 | 1 |
| Microwave power dependence | 0.1 | 1.8** |
| Spin exchange shift (low density)* | 0.4* | 0.3* |
| **Total( not including spin exchange)** | **1148.1** | **2.5** |
| $U_B$ ( not including spin exchange and microwave power dependence ) | | **1.7**\*\* |

*Table 2: Budget of systematic effects and uncertainties for VNIIFTRI- CsFO2 fountain for the MJD 56959 – 56989 period*

$$u_B = 2.5\ (1.7**) \times 10^{-16}.$$

**According to [2,3] the microwave power shift as well as spin exchange shift does not included in the total uncertainty $U_B$.

## 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 | $\sigma_{x_i}$ |
|---|---|---|---|---|
| 56957.37 | 56964.53 | | | |
| 56966.41 | 56974.21 | 45:18:04 | 163084 | 9.85E-11 |
| 56974.54 | 56975.32 | 7:50:49 | 28249 | 4.33E-11 |
| 56975.39 | 56979.23 | 1:31:51 | 5511 | 1.93E-11 |
| 56980.37 | 56988.40 | 27:18:39 | 98319 | 7.66E-11 |

*Table 3: Distribution of Dead Times for the MJD 56959– 56989 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 | $\sigma_{Dead\_Time}$ |
|---|---|
| 56959 - 56989 | 5.2E-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:

$\mathbf{u}_{Link\_Lab} = 1 \times 10^{-16}$,

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

| Period | $\boldsymbol{u}_{Link\_Maser}$ |
|---|---|
| 56959-56929 | 1.1E-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] Domnin, Yu " Fountain formulae" proceedings of Metrology of Time and Space VII International Symposium 2014, September 17-19, Suzdal, Russia, pp.43-45

[3] http://vniiftri.ru/images/files/docs/news/sym7/30%20Домнин%20Ю.С..ppt#299,20,Слайд 20