Evaluation of PTB primary caesium fountain frequency standard CSF2 between MJD 58359 - MJD 58379

PTB's primary caesium fountain frequency standard CSF2 was operated between MJD 58359, 0:00 UTC and MJD 58379, 0:00 UTC. Frequency comparisons were made with respect to PTB hydrogen maser H9, BIPM code 1400509.

The relative frequency instability of the relative frequency differences y(CSF2-H9) was $1.4\times10^{-13}\cdot(\tau/\mathrm{s})^{-1/2}$ during the 20 days, where the statistical uncertainty of the collisional shift evaluation is included. The actual measurement time amounts to 95.1% of the 20×24 hours. This results in a statistical uncertainty $u_A = 0.11\times10^{-15}$, assuming that white frequency noise is the dominant noise source.

For the uncertainty due to the clock link $u_{Lab} = 0.04\times10^{-15}$ is obtained by taking into account the actual measurement time. Finally, the estimated uncertainty for the link to TAI for 20 days is $u_{TAI} = 0.19\times10^{-15}$.

Frequency corrections for the following effects were applied to the raw data:

- Zeeman effect (magnetic field along the atoms' trajectory)
- blackbody effect (thermal radiation along the atoms' trajectory)
- relativistic redshift and relativistic Doppler effect
- cold collisions effect
- distributed cavity phase effect
- microwave lensing effect

The CSF2 standard uncertainty u_B is estimated as 2.0×10^{-16} (1 σ) for the relevant period [1].

<u>Table of results of CSF2 compared to hydrogen maser H9 (1400509)</u>

Interval of evaluation	MJD 58359, 0:00 UTC - MJD 58379, 0:00 UTC
Fractional dead time	4.9%
Resulting frequency difference	y(CSF2 – H9) = -24.72×10^{-15}
Type A uncertainty u_A (1 σ)	0.11×10^{-15}
Type B uncertainty u_B (1 σ)	0.20×10^{-15}
Link to clock u_{Lab} (1 σ)	0.04×10^{-15}
Link to TAI u_{TAI} (1 σ)	0.19×10^{-15} (20 days)
Combined uncertainty (1 σ)	0.30×10^{-15}

Type A (statistical) uncertainty of CSF2

For the microwave synthesis an optically stabilized microwave oscillator is utilized, which is locked to a hydrogen maser in the long-term [2]. For CSF2 operation at high density, in this measurement the resulting CSF2 frequency instability and the hydrogen maser frequency instability yield an overall instability of $\sigma_y = 4.1\times10^{-14}\ (\tau/1s)^{-1/2}$ for relative frequency difference measurements y(CSF2 – Hmaser). The statistical measurement uncertainty u_A includes the statistical uncertainty of the collisional shift evaluation and is given by the CSF2 frequency instability at high and low density operation, the respective measurement durations and the hydrogen maser frequency instability [1].

In total the optically stabilized microwave system was out of operation due to failure or maintenance during 8 minutes (0.03%) of the 20 day TAI measurement interval.

Type B (systematic) uncertainty of CSF2

In the table below we report the type B uncertainty evaluation results valid for the evaluation at hand. Detailed descriptions of the systematic uncertainty contributions of CSF2 have been published elsewhere [1]. Since the frequency detuning technique to suppress microwave leakage effects [1] is not yet in routine operation we still assign the former 1×10^{-16} uncertainty for microwave leakage instead of the projected 0.01×10^{-16} uncertainty [1].

Frequency shifts, corrections and type B uncertainties of CSF2 (parts in 10^{16}):

Frequency shift	Correction	Uncertainty
Quadratic Zeeman shift	-1000.44	0.10
Blackbody radiation shift	164.90	0.63
Relativistic redshift and Doppler effect	-85.45	0.3
Collisional shift	99.7	0.5
Distributed cavity phase shift	-0.28	1.52
Microwave lensing	-0.67	0.20
AC Stark shift (light shift)		0.01
Rabi and Ramsey pulling		0.013
Microwave leakage		1.0
Electronics		0.1
Background gas collisions		0.1
Total type B uncertainty		2.0

References

[1] S. Weyers, V. Gerginov, M. Kazda, J. Rahm, B. Lipphardt, G. Dobrev and K. Gibble, Metrologia https://doi.org/10.1088/1681-7575/aae008, http://arxiv.org/abs/1809.03362

[2] B. Lipphardt, V. Gerginov, S, Weyers, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control **64,** pp. 761–766 (2017), https://ieeexplore.ieee.org/document/7807353