

Evaluation of PTB primary caesium fountain frequency standard CSF1 between MJD 58449 - MJD 58469

PTB's primary caesium fountain frequency standard CSF1 was operated between MJD 58449, 0:00 UTC and MJD 58469, 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 $y(\text{CSF1-H9})$ was $10.2 \times 10^{-14} \cdot (\tau/\text{s})^{-1/2}$ during the 20 days. The actual measurement time amounts to 95.5% of the 20×24 hours. This results in a statistical uncertainty $u_A = 0.08 \times 10^{-15}$, assuming that white frequency noise is the dominant noise source.

For the uncertainty due to the clock link $u_{\text{Lab}} = 0.04 \times 10^{-15}$ is obtained by taking into account the actual measurement time. Finally, the estimated uncertainty for the link to TAI for 20 days is $u_{\text{TAI}} = 0.19 \times 10^{-15}$.

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

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

The CSF1 standard uncertainty u_B is estimated as 2.8×10^{-16} (1σ) for the relevant period [1].

Table of results of CSF1 compared to hydrogen maser H9 (1400509)

Interval of evaluation	MJD 58449, 0:00 UTC – MJD 58469, 0:00 UTC
Fractional dead time	4.5%
Resulting frequency difference	$y(\text{CSF1} - \text{H9}) = -19.25 \times 10^{-15}$
Type A uncertainty u_A (1σ)	0.08×10^{-15}
Type B uncertainty u_B (1σ)	0.28×10^{-15}
Link to clock u_{Lab} (1σ)	0.04×10^{-15}
Link to TAI u_{TAI} (1σ)	0.19×10^{-15} (20 days)
Combined uncertainty (1σ)	0.35×10^{-15}

Type A (statistical) uncertainty of CSF1

For the microwave synthesis an optically stabilized microwave oscillator is utilized, which is locked to a hydrogen maser in the long-term [2]. The frequency instability $10.2 \times 10^{-14} (\tau/s)^{-1/2}$ of the measured relative frequency differences $y(\text{CSF1} - \text{Hmaser})$ is obtained for the combination of low and high density operation and gives the statistical measurement uncertainty u_A [1].

In total the optically stabilized microwave system was out of operation due to failure or maintenance during 8 hours (1.6%) of the 20 day TAI measurement interval.

Type B (systematic) uncertainty of CSF1

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 CSF1 have been published elsewhere [1].

Frequency shifts, corrections and type B uncertainties of CSF1 (parts in 10¹⁶):

Frequency shift	Correction	Uncertainty
Quadratic Zeeman shift	- 1078.02	0.10
Blackbody radiation shift	165.75	0.80
Relativistic redshift and Doppler effect	- 85.6	0.3
Collisional shift	- 5.3	2.4
Distributed cavity phase shift	- 0.04	0.93
Microwave lensing	-0.4	0.2
AC Stark shift (light shift)		0.01
Rabi and Ramsey pulling		0.013
Microwave leakage		0.01
Electronics		0.1
Background gas collisions		0.4
Total type B uncertainty		2.8

References

[1] S. Weyers, V. Gerginov, M. Kazda, J. Rahm, B. Lipphardt, G. Dobrev and K. Gibble, Metrologia **55**, pp. 789–805 (2018), <https://doi.org/10.1088/1681-7575/aae008>

[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>