Evaluation of PTB primary caesium fountain frequency standard CSF1 between MJD 58424 - MJD 58449

PTB’s primary caesium fountain frequency standard CSF1 was operated between MJD 58424, 0:00 UTC and MJD 58449, 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 $10.2 \times 10^{-14} \cdot (\tau/s)^{-1/2}$ during the 25 days. The actual measurement time amounts to 97.1% of the $25 \times 24$ hours. This results in a statistical uncertainty $u_A = 0.07 \times 10^{-15}$, assuming that white frequency noise is the dominant noise source.

For the uncertainty due to the clock link $u_{\text{Lab}} = 0.03 \times 10^{-15}$ is obtained by taking into account the actual measurement time. Finally, the estimated uncertainty for the link to TAI for 25 days is $u_{\text{TAI}} = 0.15 \times 10^{-15}$.

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 $2.9 \times 10^{-16}$ (1 $\sigma$) for the relevant period [1].

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

<table>
<thead>
<tr>
<th>Interval of evaluation</th>
<th>MJD 58424, 0:00 UTC – MJD 58449, 0:00 UTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractional dead time</td>
<td>2.9%</td>
</tr>
<tr>
<td>Resulting frequency difference</td>
<td>$y_{\text{CSF1-H9}} = -21.00 \times 10^{-15}$</td>
</tr>
<tr>
<td>Type A uncertainty $u_A$ (1 $\sigma$)</td>
<td>$0.07 \times 10^{-15}$</td>
</tr>
<tr>
<td>Type B uncertainty $u_B$ (1 $\sigma$)</td>
<td>$0.29 \times 10^{-15}$</td>
</tr>
<tr>
<td>Link to clock $u_{\text{Lab}}$ (1 $\sigma$)</td>
<td>$0.03 \times 10^{-15}$</td>
</tr>
<tr>
<td>Link to TAI $u_{\text{TAI}}$ (1 $\sigma$)</td>
<td>$0.15 \times 10^{-15}$ (25 days)</td>
</tr>
<tr>
<td>Combined uncertainty (1 $\sigma$)</td>
<td>$0.34 \times 10^{-15}$</td>
</tr>
</tbody>
</table>
**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 $1.02 \times 10^{-14} \ (\tau/s)^{1/2}$ 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 3 hours (0.5%) of the 25 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 10^{16}):

<table>
<thead>
<tr>
<th>Frequency shift</th>
<th>Correction</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadratic Zeeman shift</td>
<td>-1078.02</td>
<td>0.10</td>
</tr>
<tr>
<td>Blackbody radiation shift</td>
<td>165.73</td>
<td>0.80</td>
</tr>
<tr>
<td>Relativistic redshift and Doppler effect</td>
<td>-85.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Collisional shift</td>
<td>-5.8</td>
<td>2.6</td>
</tr>
<tr>
<td>Distributed cavity phase shift</td>
<td>-0.04</td>
<td>0.93</td>
</tr>
<tr>
<td>Microwave lensing</td>
<td>-0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>AC Stark shift (light shift)</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Rabi and Ramsey pulling</td>
<td></td>
<td>0.013</td>
</tr>
<tr>
<td>Microwave leakage</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Electronics</td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Background gas collisions</td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>Total type B uncertainty</td>
<td></td>
<td>2.9</td>
</tr>
</tbody>
</table>

### References
