FREQUENCY COMPARISON
(H–MASER 40 3845) – (SU–CsFO2)
For the period MJD 59879 to MJD 59909.

The primary frequency standard SU–CsFO2 has been compared to the hydrogen Maser 40 3845 of the laboratory, during a measurement campaign between MJD 59879 and 59909 (27th October 2022 – 26th November 2022). The fountain operation covers ~ 82.7 % of the total measurement duration for the period MJD 59879 – 59909. The mean frequency difference at the middle date of the period is given in the following table:

<table>
<thead>
<tr>
<th>Period (MJD)</th>
<th>Date of the estimation</th>
<th>y (H–MASER 40 3845 – CsFO2)</th>
<th>$u_B$</th>
<th>$u_A$</th>
<th>$u_{Link,Maser}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>59879 – 59909</td>
<td>59894</td>
<td>1939.8</td>
<td>2.2</td>
<td>2.4</td>
<td>1.6</td>
</tr>
</tbody>
</table>

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

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 $u_A$ is estimated as $0.24 \times 10^{-15}$ (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.

<table>
<thead>
<tr>
<th>Physical Effect</th>
<th>Shifts ($10^{-16}$)</th>
<th>Uncertainty ($10^{-16}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second-order Zeeman effect</td>
<td>1070.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Black-body radiation</td>
<td>-163.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Gravitational shift</td>
<td>244.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Resonator pulling</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Purity of probe signal spectrum</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Light shift</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Tilting (DCP)</td>
<td>0</td>
<td>0.1</td>
</tr>
</tbody>
</table>
### Physical Effect

<table>
<thead>
<tr>
<th>Physical Effect</th>
<th>Shifts $(10^{-16})$</th>
<th>Uncertainty $(10^{-16})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collisions with residual gas</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Microwave power dependence</td>
<td>0</td>
<td>1.8</td>
</tr>
<tr>
<td>Spin exchange shift (mean density)*</td>
<td>0.19*</td>
<td>0.19*</td>
</tr>
<tr>
<td><strong>Total</strong> (not including spin exchange)</td>
<td>1151.2</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 2: Budget of systematic effects and uncertainties for VNIIFTRI-CsFO2 fountain for the MJD 59879 – 59909 period.

\[ u_b = 2.2 \times 10^{-16} \]

### 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 \[ \frac{\sqrt{\sum_i \sigma_i^2}}{T} = \sigma_{\text{Dead Time}} \]

<table>
<thead>
<tr>
<th>Period (MJD)</th>
<th>( \sigma_{\text{Dead Time}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>59879 – 59909</td>
<td>1.3 \times 10^{-16}</td>
</tr>
</tbody>
</table>

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:

\[ u_{\text{Link Lab}} = 1 \times 10^{-16}, \]

\[ u_{\text{Link Maser}} = \sqrt{(\sigma_{\text{Dead Time}})^2 + (\sigma_{\text{Link Lab}})^2} \]

<table>
<thead>
<tr>
<th>Period (MJD)</th>
<th>( u_{\text{Link Maser}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>59879 – 59909</td>
<td>1.6 \times 10^{-16}</td>
</tr>
</tbody>
</table>

### References
