# Frequency Evaluation of the Primary Frequency Standard NPLI-CsF1

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The primary frequency standard NPLI-CsF1 has been compared to the hydrogen Maser (clock code: 1405201), during MJD 57319 -57329. The result of the comparison is given below.

Table 1: Summary of frequency measurement between NPLI-CsF1 and H-maser (1405201)

| **S. No.** | **Evaluation period** | **y(NPLI-CsF1 – HM1405201 [x $10^{-15}$]** | **$u_{total}$ [x $10^{-15}$]** | **Dead Time (%)** |
|---|---|---|---|---|
| 1 | 57319-57329 | 75.02 | 2.97 | 5.94 |

$u_{total}$ is the quadratic sum of $u_A$, $u_B$ and $u_{link/lab}$ as given in the following:

$$u_{total} = \sqrt{(u_A)^2 + (u_B)^2 + \left(u_{link/lab}\right)^2} \qquad (1)$$

$u_A$ is the statistical uncertainty of the frequency measurement, $u_B$ is the uncertainty of systematic effects and $u_{link/lab}$ is the uncertainty between the H-Maser and UTC (NPLI).

The typical relative frequency instability of NPLI-CsF1 is 6.5 x $10^{-13}$ $\tau^{-1/2}$.

## Measurement Procedure:

Before an evaluation, the fountain is run for about 2-4 days for measuring the collision shift. During this run, the atom density is altered between high and low density every 100 shots. The collision shift is estimated at zero density by extrapolating the frequencies at high and low density. The C-field magnitude is also checked before and after each evaluation run. The room temperature, humidity, laser powers are recorded regularly during the run. During the evaluation, the fountain is operated at fixed atom density and the frequency offset between the fountain and H-Maser frequency is recorded every shot to shot. The average fountain frequency offset is obtained by averaging for each day and then averaging over the whole evaluation period. A detailed description of the measurement procedure, evaluation of uncertainties and records of frequency evaluation are given in reference [1, 2].

## Evaluation of Systematic shifts and uncertainties:

The fountain frequency needs to be corrected for systematic effects which shift it from that of the unperturbed atomic transition. There are four systematic shifts which are carefully evaluated along with their uncertainties. These are: 2nd order Zeeman shift, blackbody radiation shift, gravitational red shift and collisional shift. Apart from these four, other effects shift the frequency of the frequency standard by extremely small magnitude and are taken as uncertainty. The budget of systematic uncertainties is summarized in Table 2. Total $u_B$ is the quadratic sum of all the systematic uncertainties.

Table 2: Typical systematic uncertainty budget for NPLI-CsF1

| Effect | Bias $(\times \mathbf{10^{-15}})$ | Uncertainty $(\times\ \mathbf{10^{-15}})$ |
|---|---|---|
| 2nd Order Zeeman Shift | 50.46 | 0.06 |
| Black Body Radiation | -17.27 | 0.23 |
| Gravitational Red Shift | 19.6 | 0.11 |
| Cold Collisional Shift | -12.0 | 2.4 |
| Light shift | 0.0 | 0.2 |
| Background gas collisions | 0.0 | 0.1 |
| Cavity pulling | 0.0 | 0.01 |
| Rabi, Ramsey Pulling | 0.0 | 0.1 |
| Majorana transitions | 0.0 | 0.1 |
| Spectral impurity | 0.0 | 0.2 |
| Microwave leakage | 0.0 | 0.1 |
| DCP | 0.0 | 0.2 |
| **Total($U_B$)** | **39.8** | **2.45** |

## Other Uncertainties:

Statistical uncertainty, $u_A$ is obtained by taking Allan deviation of one day's data. Total $u_A$ is quadratic sum of $u_A$ of individual days divided by number of evaluation days.
$u_{lab/link}$ is uncertainty between the H-Maser and UTC (NPLI). We have not taken dead time uncertainty into account as our Maser has not been modelled yet to calculate this uncertainty.

## Result:

Result of the evaluation is summarized in the following table.
Evaluation Summary

| | |
|---|---|
| Period | 57319-57329 |
| Duration | 10 days |
| y(NPLI-CsF1 – HM1405201) [x $10^{-15}$] | 75.02 |
| Dead time [%] | 5.94 |
| $u_A$ [x $10^{-15}$] | 0.90 |
| $u_B$ [x $10^{-15}$] | 2.82 |
| $U_{link/lab}$ [x $10^{-15}$] | 0.19 |
| $u_{total}$ [x $10^{-15}$] | 2.97 |

## **References**:

[1] A. Acharya et al., "Complete uncertainty evaluation of the cesium fountain primary frequency standard: NPLI-CsF1", ATF Workshop 2015, Beijing, China, October 2015 (2015).

[2] P. Arora et al., IEEE Trans. Instrum. Meas. 62, pp. 2036 (2013).