Frequency Evaluation of the Primary Frequency Standard NPLI-CsF1

CSIR – National Physical Laboratory India (NPLI)

September 2014, corrected November 2014

The primary frequency standard NPLI-CsF1 has been compared to the hydrogen Maser (clock code: 1405201), during seven periods from May 2013 to February 2014. The results of the comparisons are given in Table 1.

Table 1: Summary of frequency measurements 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	56419-56439	11.09	2.66	8.80
2	56514-56529	-22.85	3.05	5.68
3	56589-56599	-131.59	2.81	6.76
4	56604-56614	-74.38	2.78	5.16
5	56644-56654	52.47	2.84	2.14
6	56659-56669	95.89	2.48	2.29
7	56679-56689	145.06	2.54	5.34

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 uncertaintybetween the H-Maser and UTC (NPLI).

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

<u>Measurement Procedure</u>:

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 isquadratic sum of u_A of individual days divided by number of evaluationdays.

$u_{lab/link}$is uncertaintybetween the H-Maser and UTC (NPLI). We have not taken deadtimeuncertainty into account as our Maser has not been modelled yet to calculatethis uncertainty. During all the reported evaluations, it was ensured tokeepthe dead time of less than 7-8 %.

Results:

Results of the seven evaluations are summarized in the following tables.

Evaluation 1

Period	56419-56439
Duration	20 days
y(NPLI-CsF1 – HM1405201) [x 10^{-15}]	11.09
Dead time [%]	8.8
u_A [x 10^{-15}]	0.53
u_B[x 10^{-15}]	2.60
$U_{link/lab}$[x 10^{-15}]	0.13
u_{total}[x 10^{-15}]	2.66

Evaluation 2

Period	56514-56529
Duration	15 days
y(NPLI-CsF1 – HM1405201) [x 10^{-15}]	-22.85
Dead time [%]	5.68
u_A [x 10^{-15}]	0.47
u_B[x 10^{-15}]	3.01
$U_{link/lab}$[x 10^{-15}]	0.15
u_{total}[x 10^{-15}]	3.05

Evaluation 3

Period	56589-56599
Duration	10 days
y(NPLI-CsF1 – HM1405201) [x 10^{-15}]	-131.59
Dead time [%]	6.76
u_A [x 10^{-15}]	0.90
u_B[x 10^{-15}]	2.65
$U_{link/lab}$[x 10^{-15}]	0.20
u_{total}[x 10^{-15}]	2.81

Evaluation 4

Period	56604-56614
Duration	10 days
y(NPLI-CsF1 – HM1405201) [x 10^{-15}]	-74.38
Dead time [%]	5.16
u_A [x 10^{-15}]	0.61
u_B[x 10^{-15}]	2.71
$U_{link/lab}$[x 10^{-15}]	0.19
u_{total}[x 10^{-15}]	2.78

Evaluation 5

Period	56644-56654
Duration	10 days
y(NPLI-CsF1 – HM1405201) [x 10^{-15}]	52.47
Dead time [%]	2.14

u_A [x 10^{-15}]	0.74
u_B[x 10^{-15}]	2.74
$U_{link/lab}$[x 10^{-15}]	0.18
u_{total}[x 10^{-15}]	2.84

Evaluation 6

Period	56659-56669
Duration	10 days
y(NPLI-CsF1 – HM1405201) [x 10^{-15}]	95.89
Dead time [%]	2.29
u_A [x 10^{-15}]	0.75
u_B[x 10^{-15}]	2.36
$U_{link/lab}$[x 10^{-15}]	0.18
u_{total}[x 10^{-15}]	2.48

Evaluation 7

Period	56679-56689
Duration	10 days
y(NPLI-CsF1 – HM1405201) [x 10^{-15}]	145.06
Dead time [%]	5.34
u_A [x 10^{-15}]	0.93
u_B[x 10^{-15}]	2.36
$U_{link/lab}$[x 10^{-15}]	0.19
u_{total}[x 10^{-15}]	2.54

References:

[1] P. Arora et al., submitted to Metrologia (2014).

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