Evaluation of the frequency of the H-maser 1401708 by the primary frequency standard NPL-CsF2

National Physical Laboratory

01 September 2011

The primary frequency standard NPL-CsF2 was used to measure the frequency of the H-maser HM2 identified by the clock code 1401708 during an evaluation campaign in August 2011. The clock 1401708 is a physical realisation of UTC(NPL). The evaluation was performed by measuring mean frequency differences over the reporting periods.

No changes to the physics package of NPL-CsF2 or to the measurement methods have been introduced since the previous reported evaluation. However, a new analysis of type B uncertainties related to leading systematic effects in NPL-CsF2 was performed earlier in 2010 and 2011. Recently, the results of this analysis have been published together with an updated uncertainty budget for the NPL-CsF2 primary frequency standard [1] (see table 1). In the current evaluation, we use the new values for the type B uncertainties.

Type B evaluation	uncertainty / 10^{-16}
Effect	
Second order Zeeman	0.8
Blackbody radiation	1.1
AC Stark (lasers)	0.1
Microwave spectrum	0.1
Gravity	0.5
<u>Cold collisions (Cs-Cs)</u>	<u>0.4</u>[a]
Collisions with background gas	1.0
Rabi, Ramsey pulling	0.1
<u>Cavity phase (distributed)</u>	<u>1.1</u>
Cavity phase (dynamic)	0.1
Cavity pulling	0.2
<u>Microwave leakage</u>	<u>0.6</u>
<u>Microwave lensing</u>	<u>0.3</u>
Second-order Doppler	0.1
Total u_B (1σ)	2.3

Table 1. The new type B uncertainty budget for the NPL-CsF2 primary standard. Underlined are uncertainties reduced since the previous evaluation in 2010 [2].
[a)] An exemplary value of the type B contribution to the uncertainty for a measured residual collisional shift, the frequency difference between high and low densities, below 2.5×10^{-15} [3].

In brief, the type B uncertainties of the following effects were reduced: distributed cavity phase frequency shift, microwave leakage, and microwave lensing [4]. The type B uncertainty of the collisional frequency shift has also been reduced following a new operation protocol described in [3]. The latter technique was implemented in 2010 and already referred to in previous evaluation reports.

In addition, following the accuracy analysis of [1], we have identified frequency biases due to the distributed cavity phase frequency shift and due to the microwave lensing. We now correct the standard frequency of NPL-CsF2 for these biases (see table 2).

Results of the frequency measurements are listed in table 2 below. Frequency biases are given for information only. The given fractional frequency difference *y(CsF2 – HM2)* is a value corrected for those biases. Note that the values for the collisional shift and its uncertainty vary, and so vary the total type B uncertainties u_B for particular campaigns. The value of collisional shift is a time-averaged value for the high and low densities. The total uncertainty u_{total} of the measurement is defined as:

$$(u_{total})^2 = (u_A)^2 + (u_B)^2 + (u_{l/lab})^2$$

Period	(date)	16 Aug 2011 – 31 Aug 2011
Start	MJD	55789
Stop	MJD	55804
Duration	Days	15
duty cycle	%	97.8
Biases: 2nd order Zeeman BBR shift cold collisions gravity cavity phase microwave lensing	$\times 10^{-15}$	 337.02 −16.64 –0.06 1.30 0.15 0.06
y(CsF2 - HM2)	$\times 10^{-15}$	**2.93**
u_A	$\times 10^{-15}$	0.28
u_B	$\times 10^{-15}$	0.23
$u_{l/lab}$	$\times 10^{-15}$	0.01
$\boldsymbol{u_{total}}$	$\times 10^{-15}$	**0.36**

Table 2. Summary of the measurements of the average frequency difference *y(CsF2 – HM2)*.

References:

[1] Li R, Gibble K and Szymaniec K 2011 *Metrologia* **48** 283-289

[2] Szymaniec K, Park S E, Marra G, Chalupczak W 2010 *Metrologia* **47** 363-76

[3] Szymaniec K and Park S E 2011 *IEEE Trans. Instrum. Meas.* **60** 2475-81

[4] Gibble K 2006 *Phys. Rev. Lett.* **97** 073002