Antoine Jallageas, 2019_06_03

Evaluation of the METAS-FOC2 primary frequency standard
Period 58599-58629

The Swiss primary frequency standard METAS-FOC2 was operated between MJD 58599, 0:00 UTC and MJD 58629, 0:00 UTC. The frequency comparison was made with respect to the METAS Hydrogen Maser (BIPM clock code: 1405701).

The standard was measured continuously during 30 days without dead time. The standard seems to reach a flicker floor around 1.00×10^{-15}. This effect is unusual and is under study. In order to be conservative and until we know more about this effect, we have increased the value for u_A, namely $u_A = 1.00 \times 10^{-15}$.

The uncertainty due to the clock link u_{lab} is 0.04×10^{-15}.

A frequency correction of 68.19×10^{-15} was applied to the raw data in order to obtain the relative frequency offset *y(FOC2-HM)*. This correction arises directly from the sum of all the frequency shifts reported in the uncertainty budget (Table 1). This corresponds to corrections applied for the following effects:
- Second-order Zeeman
- Gravitational red shift
- Second-order Doppler
- Blackbody radiation
- Light shifts (from source and from detection parts)
- Ramsey pulling
- End-to-end
- Collisional Cs-Cs

The combined standard uncertainty of the standard is $u_B = 1.38 \times 10^{-15}$.

Results summary:

Evaluation period	u_A	u_B	u_{lab}	y(FOC2-HM)
58599-57629	1.00	1.38	0.04	-96.56

All uncertainties are $k = 1$ uncertainties and all these values are expressed in 10^{-15} unit.

Operation:

METAS-FOC2 was operated continuously without any dead time during the period of measurement. The microwave signal used to interrogate the atoms is provided by a commercial synthesizer, which uses the 5 MHz maser output as external reference. Due to its continuous interrogation scheme, METAS-FOC2 is not limited by the Dick effect and the stability is only dependent on the atomic flux [1].

The relative frequency offset *y(FOC2-HM)* is obtained from the average correction applied to the synthesizer. For this period of measurement, we obtained:

$$y(FOC2 - HM) = -96.56 \times 10^{-15}$$

Type A uncertainty of METAS-FOC2:

As reported in [2], there is no tradeoff between the stability of the standard and the frequency shift due to the atomic density. In METAS-FOC2, the atomic flux is maximized to get the best possible stability. During this period of measurement, the Allan deviation shows a stability $\sigma_y(\tau) = 4.1 \times 10^{-13}\tau^{-1/2}$ for the relative frequency difference *y(FOC2-HM)*. After analysis of the data, the standard seems to reach a flicker floor around 1.00×10^{-15}. To stay conservative, we decided to use the value:

$$u_A = 1.00 \times 10^{-15}$$

Type B uncertainty of METAS-FOC2:

The detailed evaluations of the uncertainty budget of METAS-FOC2 was published in [2] and [3]. Following the recommendation of the working group of the PFS of the CCTF, we have increased the uncertainty of the collisional shift in order to take into account possible long-term drifts of the number of atoms in the atomic beam.

Just after the reported period of measurement, a new evaluation of the second order Zeeman shift was realized. The related uncertainty takes into account the long-term drift of the magnetic field. We consider that the result of this evaluation is valid for the whole reported period.

The collisional shift was also reevaluated using the slope of the effect reported in [2] and the average atomic signal for the current measurement period. It is significantly lower than in [2] due to a reduction of the number of atoms in the atomic beam.
All the other effects are assumed to be the same as in [2], leading to a total uncertainty:

$$u_B = 1.38 \times 10^{-15}$$

In table 1, we report the updated total uncertainty budget valid for this evaluation period.

Uncertainties of the link:

The uncertainty u_{lab} is the uncertainty of the link between the fountain and the maser. It originates from local comparisons. A worst-case estimation of the uncertainty in local phase comparisons is ± 100 ps. For the measurement period reported in this document, this leads to a frequency uncertainty:

$$u_{lab} = 0.04 \times 10^{-15}$$

Tables and Figures:

Figure 1: Allan deviation for the period 58599-57629.The short-term stability at one second is 4.1×10^{-13}.

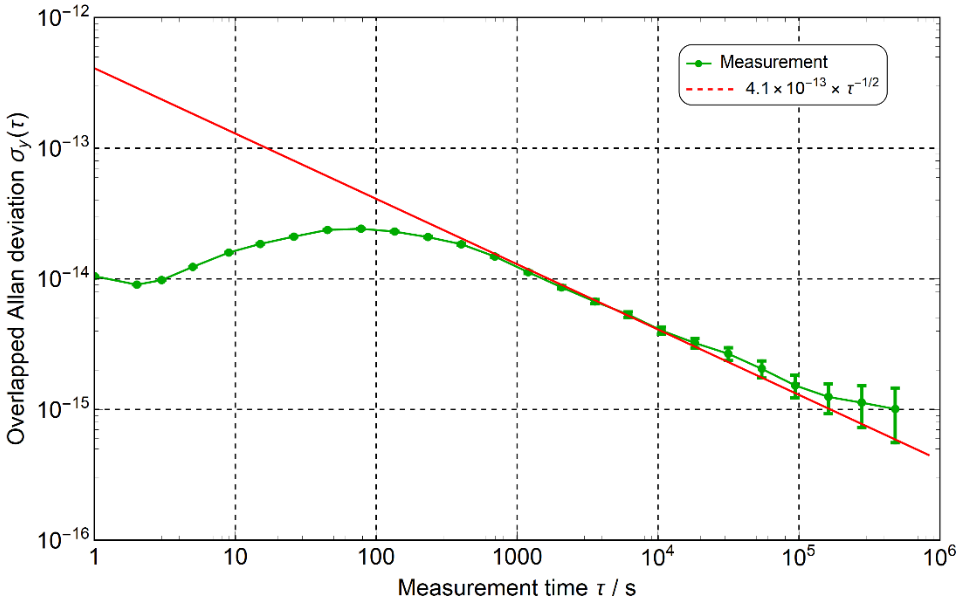

Table 1: Frequency shifts and uncertainty budget of METAS-FOC2 during the period 58599-57629 (in 10^{-15}).

Physical effect	Frequency shift	Uncertainty
Second-order Zeeman	23.53	0.20
Gravitational	59.72	0.02
Second-order Doppler	-0.01	<0.01
Blackbody radiation	-16.67	0.04
Microwave spectrum purity	0.00	0.05
Light shift from source	-0.16	0.04
Cavity pulling	0.00	<0.01
Rabi pulling	0.00	0.02
Ramsey pulling	0.05	0.10
End-to-end	2.17	0.27
Collisional Cs-Cs	-0.33	0.26
Light shift from detection	-0.10	0.41
RF leakage	0.00	0.47
Majorana transitions	0.00	0.50
DCPS	—	1.03
Total	68.19	1.38

References:

[1] A. Joyet, G. Mileti, G. Dudle and P. Thomann, "Theoretical study of the Dick effect in a continuously operated Ramsey resonator," in *IEEE Transactions on Instrumentation and Measurement*, vol. 50, no. 1, pp. 150-156, Feb. 2001.
[2] A. Jallageas et al 2018 Metrologia **55** 366
[3] L. Devenoges et al 2017 Metrologia **54** 23