NTSC
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Frequency comparison between H-maser 1415085 and NTSC-CsF2 for the period MJD 60134 to 60244

The primary frequency standard NTSC-CsF2 has been compared to the local hydrogen Maser 1415085, during four periods MJD 60134-60154, 60154-60184,60184-60214 and 60214-60244 of 2023. The frequency data were averaged over 1-hour interval firstly. Then, an unweighted linear fitting was applied to the mean data points to ascertain the frequency at the midpoint of each evaluation period, as given in Table 1:

Table 1 Results of the frequency comparison in 1×10^{-16}

Period	Date of the estimation	y(H maser 1415085–NTSC-CsF2)	Duty cycle%	u_A	u_B	$u_{link/lab}$
1	MJD 60134-60154	1395.35	99.1	6.3	5.1	1.00
2	MJD 60154-60184	1398.50	99.9	4.6	6.0	1.00
3	MJD 60184-60214	1407.48	95.5	4.5	5.6	1.01
4	MJD 60214-60244	1412.57	91.9	3.1	2.6	1.02

The combined total uncertainty u_{total} is the square root of the three uncertainties as following:

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

Type A uncertainty u_A is the statistical uncertainty about the frequency measurement, u_B is the Type B uncertainty from bias evaluations, $u_{link/lab}$ is the uncertainty due to link between NTSC-CsF2 and the H-maser H1415085, which including the dead time and the phase noise of the link between the fountain and H-maser.

Uncertainties

- u_A Short term stability and type A uncertainty

The uncertainty of the extrapolated zero frequency ν_0 is

$$\sigma_0^2(\tau) = \left(\frac{R}{R-1}\right)^2 \sigma_L^2(\tau_L) + \left(\frac{1}{R-1}\right)^2 \sigma_H^2(\tau_H) + \left(\frac{\upsilon_H - \upsilon_L}{(R-1)^2}\right)^2 \sigma_R^2 \qquad (2)$$

where σ_L and σ_H are the uncertainties of the measured frequencies at high and low densities, respectively. τ_H and τ_L are the averaging time for the high and low density. The σ_R is the uncertainty of the ratio R. The first two terms of right part are related to the statistical frequency uncertainties in equation（2）.

u_A is extrapolated using the Allan variance in the first two terms of the equation（2）for the frequency measurement period.

During the three periods， MJD 60134-60154, 60154-60184 and 60184-60214, NTSC-CsF2 was operated continually in a differential configuration with 500 cycles of HD and 500 cycles of LD, and R is 2.

During the last period, NTSC-CsF2 was operated continually in a differential configuration with 250 cycles of HD and 1000 cycles of LD, and R is 4.

- u_B Type B uncertainties

NTSC-CsF2 was corrected for frequency shifts due to the following effects: second-order Zeeman, black body radiation, cold atom collisions and gravitational redshift, microwave leakage, as stated in reference [1]. The frequency biases due to all other physical effects are negligible. Its performance was also tested and reported in reference [1]. A summary of systematic frequency shifts for four evaluations are listed in Table 2-5 respectively.

Table 2 Uncertainty budget of NTSC-CsF2 for the MJD 60134-60154

Effect	Correction/10^{-16}	Uncertainty/10^{-16}
Second-order Zeeman	–1282.2	0.8
Blackbody radiation	166.1	0.8
Cold atom collisions	29.0	4.4
Gravitational redshift	–524	0.5
Microwave leakage	–4.7	1.5
DCP	0	1.4
Lensing	0	0.6
Background gas collisions	0	0.1
Total	–1615.8	5.1

Table 3 Uncertainty budget of NTSC-CsF2 for the MJD 60154-60184

Effect	Correction/10^{-16}	Uncertainty/10^{-16}
Second-order Zeeman	–1282.2	0.8
Blackbody radiation	166.0	0.8
Cold atom collisions	36.8	5.5
Gravitational redshift	–524	0.5
Microwave leakage	-4.7	1.5
DCP	0	1.4
Lensing	0	0.6
Background gas collisions	0	0.1
Total	–1608.1	6.0

Table 4 Uncertainty budget of NTSC-CsF2 for the MJD 60184-60214

Effect	Correction/10^{-16}	Uncertainty/10^{-16}
Second-order Zeeman	–1282.2	0.8
Blackbody radiation	165.9	0.8
Cold atom collisions	33.7	5.0
Gravitational redshift	–524	0.5
Microwave leakage	-4.7	1.5
DCP	0	1.4
Lensing	0	0.6
Background gas collisions	0	0.1
Total	–1611.1	5.6

Table 5 Uncertainty budget of NTSC-CsF2 for the MJD 60214-60244

Effect	Correction/10^{-16}	Uncertainty/10^{-16}
Second-order Zeeman	–1301.7	0.8
Blackbody radiation	165.6	0.8
Cold atom collisions	17.9	0.9
Gravitational redshift	–524	0.5
Microwave leakage	-4.7	1.5
DCP	0	1.4
Lensing	0	0.6
Background gas collisions	0	0.1
Total	–1646.9	2.6

- ## Uncertainty due to the link in the laboratory $u_{\mathbf{link/lab}}$

The uncertainty induced from the link in the laboratory is obtained by

$$u_{\text{link/lab}} = \sqrt{(u_{\text{dead\_time}})^2 + (u_{\text{internal\_link}})^2} \quad (3)$$

$u_{\text{dead\_time}}$ is the uncertainty due to operational dead time of NTSC-CsF2. During the evaluation period, there were gaps in the data collection (dead time) due to both system maintenance and occasionally unintentional breaks such as laser unlocks, etc.

The dead time for period MJD 60154-60184 remained below 0.1%. The dead time distributions of periods MJD 60134-60154, 60154-60184, 60184-60214 and 60214-60244 are shown in the Figures 1-4 respectively.

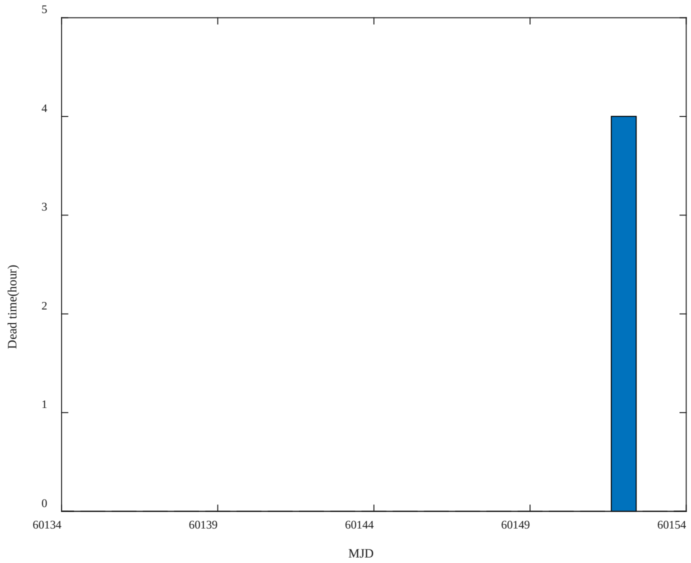

Figure 1 Dead time distributions for the period MJD 60134-60154

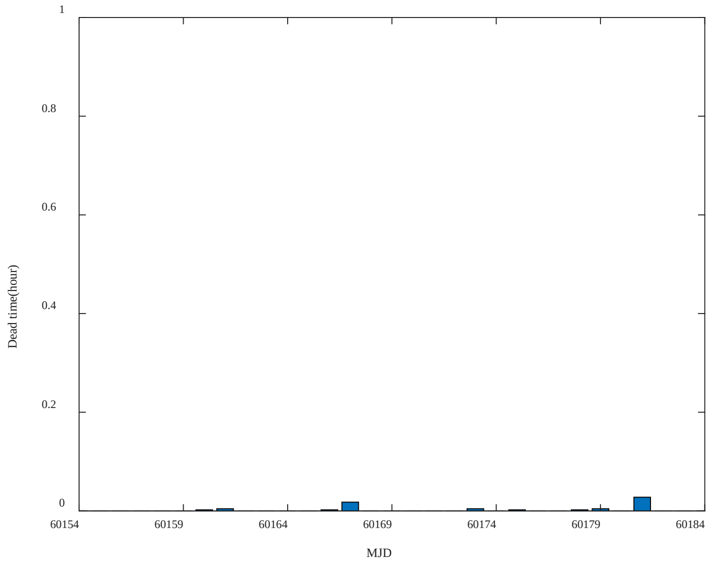

Figure 2 Dead time distributions for the period MJD 60154-60184

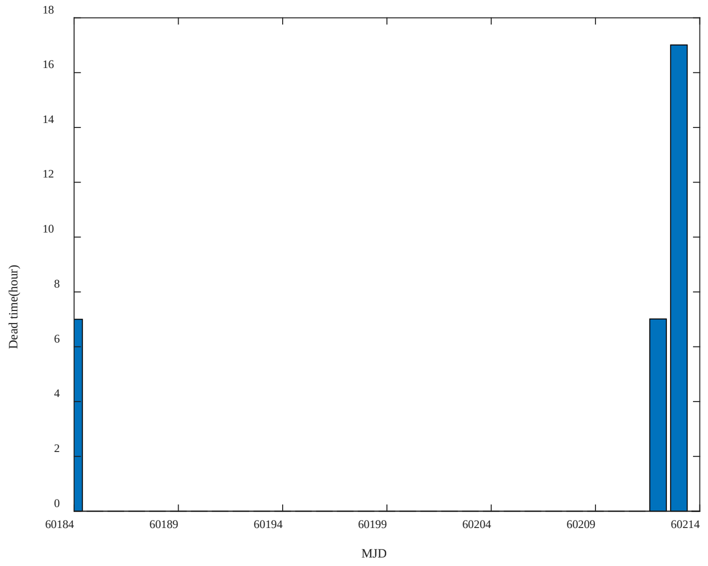

Figure 3　Dead time distributions for the period MJD 60184-60214

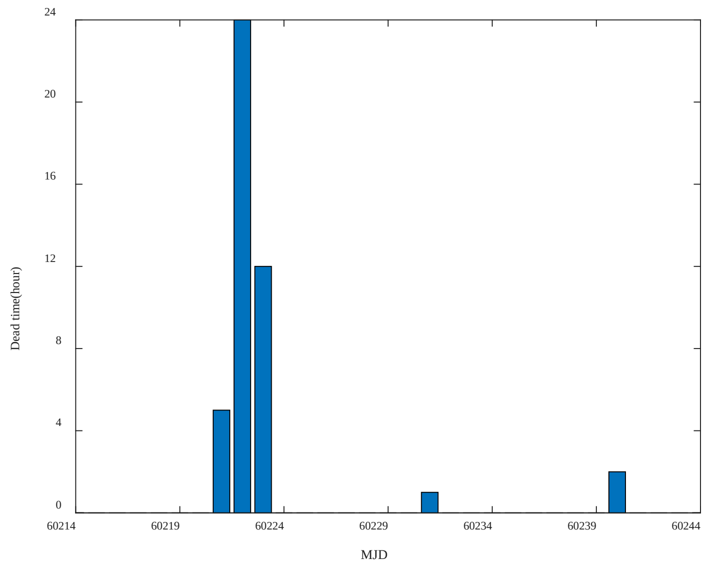

Figure 4　Dead time distributions for the period MJD 60214-60244

The standard deviation of the fluctuations of frequency due to the dead times in measurements is estimated by the ratio.

$$u_{\text{dead\_time}} = \frac{\sqrt{\sum_{i=1}^{i=N} \sigma_{x_i}^2}}{T} \qquad (4)$$

where σ_{xi} are the time deviations (TDEVs) of the H-maser for each dead times.

$u_{\text{internal\_link}}$, encapsulates the phase fluctuation resulting from the cables connecting H-maser 1415085 to the NTSC-CsF2. It is estimated to be 1×10^{-16}.

References

1. Xin-Liang Wang et al, 2023 Metrologia, 60 065012