Long Term Study of the H-Maser Clocks at the Royal Observatory of Belgium

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Abstract— **Two hydrogen masers are in operation in the time lab of the Royal Observatory of Belgium. One is a CH1-75 operational since 1991 and the other one is a CH1-76 operational since the 1999. This second one is used to provide a frequency needed by the active HM CH1-75 for the cavity auto-tuning. The stability of the masers since their putting in operation is studied.**

I. TIME LAB OF THE ROYAL OBSERVATORY OF BELGIUM

One of the missions of the Royal Observatory of Belgium (ROB) is to integrate Belgium into international space and time reference systems through “determination of Time”, and precise positioning. The time scales where the ROB is involved are: UTC(ORB), local realization of UTC, TAI (basis of the legal time) and IGS Time scale IGST (IGS is the International GPS Service), which is provided in quasi-real time.

The time lab of the Royal Observatory of Belgium is presently equipped with 5 clocks: 3 HP5071A Cesium clocks with standard tubes (CES4, CES5 and CES6, see Picture 1) and 2 H-Maser clocks (1 active CH1-75 and one passive CH1-76, respectively MAS1 and MAS2, see Pictures 2 and 3). The UTC realization UTC(ORB) is obtained from the 5 Mhz frequency provided by the active H-Maser clock (CH1-75) of which the cavity auto-tuning is realized using the 5 Mhz frequency of the passive H-Maser (CH1-76). The maximum difference between UTC and UTC(ORB) is kept below 60 nanoseconds (ns).

As contribution to the TAI, the Royal Observatory of Belgium sends presently the data of 4 clocks (3 cesium clocks and the active Hydrogen Maser) to the BIPM. Furthermore, the ROB time laboratory contains GPS receivers which are used for both the time transfer (remote clock comparisons) and geodesy.

The monitoring of the clocks is realized by a comparison of their behavior with respect to UTC(ORB). The clocks are located in temperature stabilized basements, where the temperature is stable at the 0.1°C level.

The time lab has been installed in a new temperature stabilized room in April 2002. Figure 1 gives a diagram of the time lab.

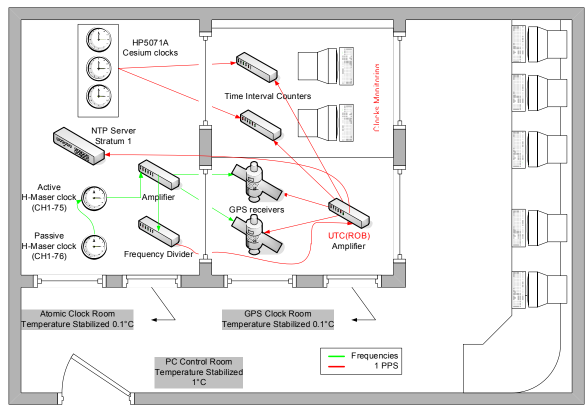

Figure 1. Diagram of the Time Lab.

II. EVENTS AND BREAKOUTS OF MASER CLOCKS SINCE NOVEMBER 2001

In the following tables, we give the special events and breakouts of our maser clocks since November 2001, which corresponds to the switch from CES5 to MAS1 for the realization of UTC(ORB).

Table 1 shows the manual frequency changes applied to MAS1 in order to be kept as close as possible to UTC.

Table 2 shows the periods when MAS2 was not functioning. During that time, MAS1 was working without cavity autotuning.

Table 3 shows the periods when MAS1 was not functioning. During that time, UTC(ORB) was realized by CES5.

Note that all these breakouts, listed in tables 2 and 3, are due to electronic problems in the clocks.

Finally, Table 4 shows special events that have occurred since November 2001 and that could influence the quality of MAS1.

TABLE I. MAS1 FREQUENCY CHANGES

Modified Julian Day	Frequency change (x 10-14 s/s)
52240	-1
52278	-2
52305	-2
52374	+3
52389	-3
52450	-4
52460	-5
52466	+1
52491	-4
52507	-4
52519	-18
52529	+19
52537	+5
52597	-1
52624	-2
52655	-2
52774	-1
52787	-2
52872	+1
52904	-1
53017	-2
53261	-1

TABLE II. MAS2 STOPPED

From	To
01 Dec 2001 (52244)	01 Mar 2002 (52334)
25 May 2002 (52419)	01 Sep 2002 (52518)
07 Nov 2003 (52950)	05 Mar 2004 (53069)

TABLE III. MAS1 STOPPED (ELECTRICAL PROBLEM INDUCING FREQUENCY CHANGE)

From	To
03 Jul 2003 (52823)	01 Aug 2003 (52852)

TABLE IV. SPECIAL EVENTS

From	To	Event
01 Apr 2002 (52365)	01 Sep 2002 (52518)	1 PPS out of order
16 Apr 2002 (52383)	19 Apr 2002 (52383)	New Time Lab
23 May 2002 (52417)	25 Jun 2002 (52450)	Microphase stepper activated
09 Sep 2003 (52891)	10 Sep 2003 (52892)	Air conditioning out of order
20 May 2005 (53510)	now	Decrease in the MAS1 generation power resulting in CAT system off

III. COMPARISONS

A. *UTC-UTC(ORB)*

The following graph (Figure 2) shows the differences between our reference clock (CES5 or MAS1) and UTC since July 1994.

We have intentionally removed data before July 1994, corresponding to the period when our reference clock was a rubidium one. We have used blue dots when the reference clock was CES5 and red dots when it was MAS1. The jump around MJD 51525 corresponds to a reset of UTC(ORB). Note also that due to a failure of MAS1 between MJD 52823 and MJD 52852, CES5 has been used as reference clock during that time.

The black curve is the sample set that we have chosen for studying the frequency stability when our reference clock was CES5. This corresponds to the period between mid-September 1997 and mid-December 1999 when no change was operated on the microphase stepper controlling CES5. The corresponding Modified Allan Deviation is given on Figure 3.

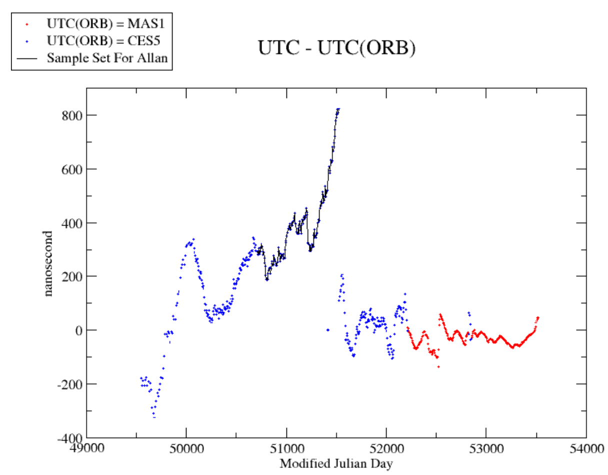

Figure 2. Differences between our reference clock (CES5 or MAS1) and UTC since July 1994.

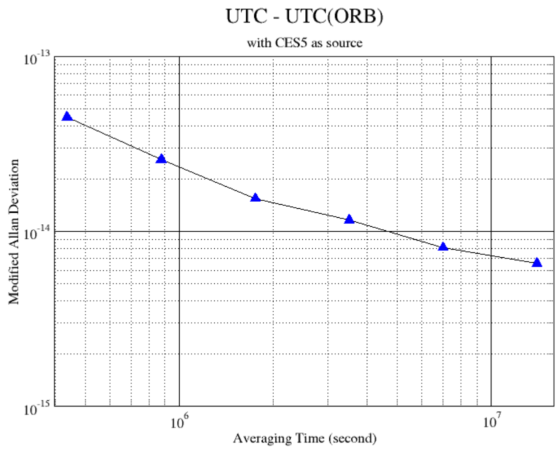

Figure 3. Modified Allan Deviation of Fig. 2

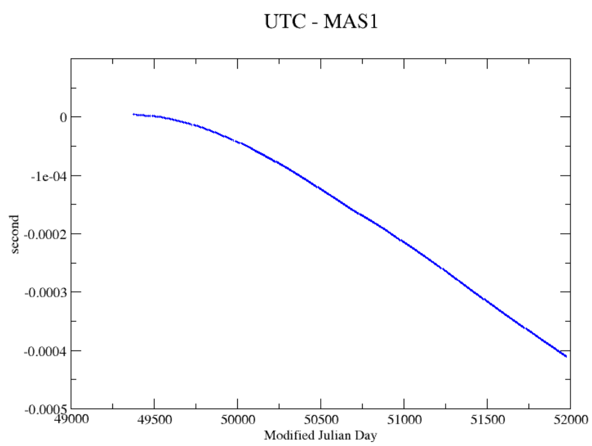

Figure 4. UTC - MAS1 when our reference clock was CES5 (between July 1994 and mid-March 2001).

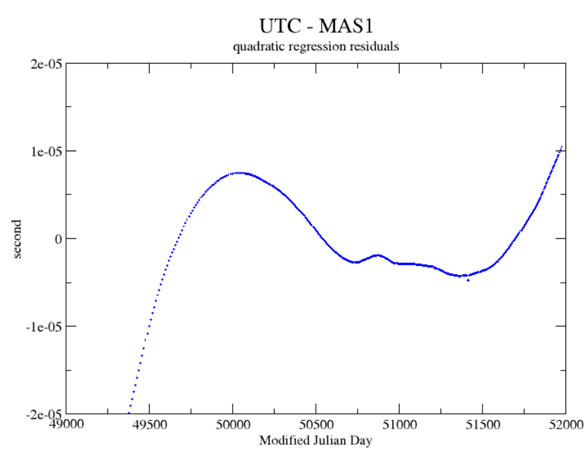

Figure 5. The same graph after removing a quadratic regression

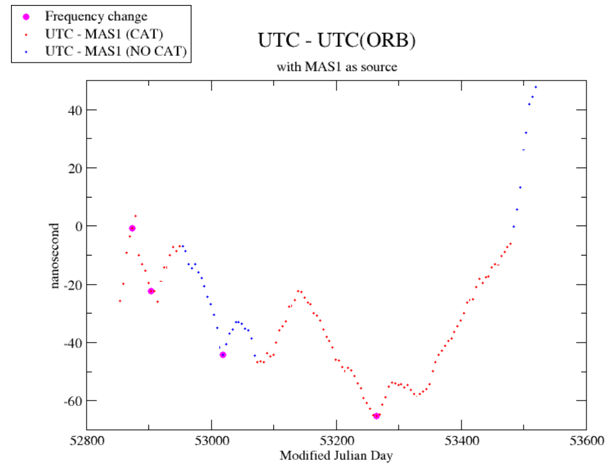

Figure 6. UTC-MAS1 since August 2003, when MAS1 was the reference clock for UTC(ORB).

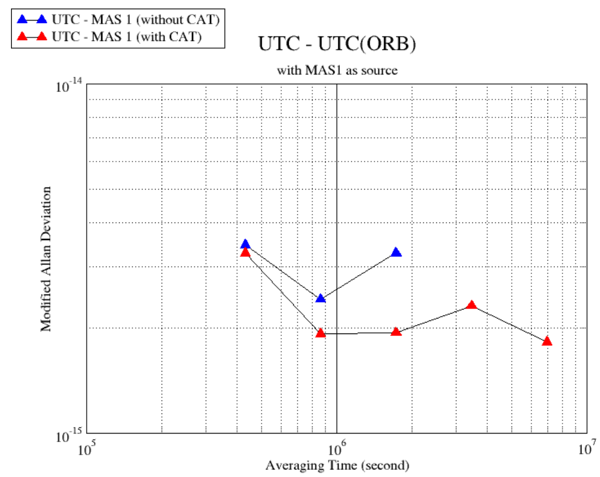

Figure 7. Modified Allan Deviation of Fig. 6

B. *UTC-MAS1*

These graphs have been obtained by differencing the values of UTC - UTC(ORB) given by the BIPM and the values UTC(ORB) - MAS1, available locally at the ROB.

The first graph (Figure 4) shows the values of UTC - MAS1 when our reference clock was CES5 (between July 1994 and mid-March 2001). No clock reset was applied to MAS1 during that time. The same graph after removing a quadratic regression is shown on Figure 5.

The second graph (Figure 6) shows the values of UTC-MAS1 since August 2003, when MAS1 was the reference clock for UTC(ORB). We have chosen this period in order to enlighten the effect of the cavity auto-tuning (CAT) done by our MAS2. The blue dots correspond to periods without CAT while the red dots correspond to periods with CAT. Note that, from MJD 53510, MAS1 gives larger variations due to a decrease in the Maser generation power. The corresponding Modified Allan Deviation is given on Figure 7. Note that, because during that time MAS1 was the reference clock for UTC(ORB), some manual frequency changes have been applied in order to follow UTC. These changes have been removed before computing the Modified Allan Deviation.

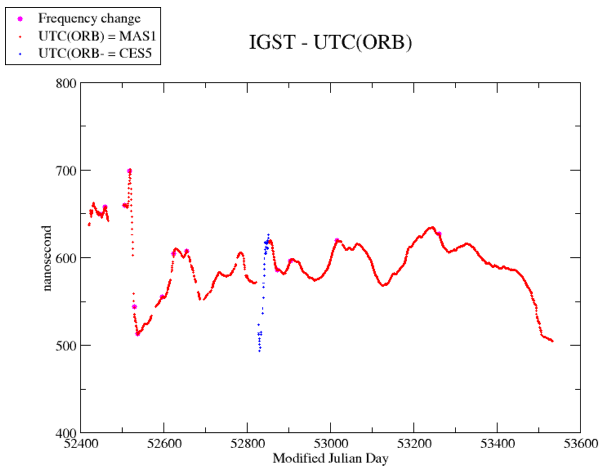

Figure 8. IGST - UTC(ORB) since June 2002.

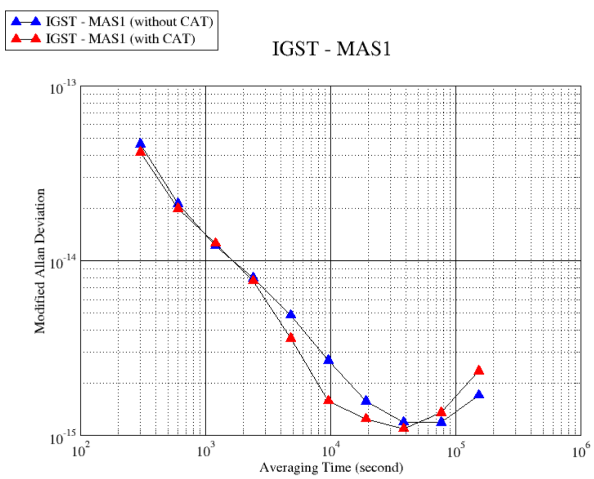

Figure 9. Modified Allan Deviation of Fig. 8

C. *IGST - UTC(ORB)*

Comparisons with UTC, with 1 point every 5 days give information about the long term stability of our maser clocks. For getting information about the short term stability, we make comparisons with the IGST time scale, for which the differences between IGST and UTC(ORB) are given every 30 seconds.

The Figure 8 shows the values IGST - UTC(ORB) since June 2002. During a breakout of MAS1, between MJD 32823 and MJD 52852, CES5 was used as UTC(ORB). This is shown in blue dots on the graph.

For studying the short term stability of MAS1, we have chosen two weeks on the graph: GPS week 1310 and GPS week 1250. the first one corresponds to a period with the CAT activated, while the second one doesn't have it. The corresponding Modified Allan Deviation are given on Figure 9.

Note that we choose the option to correct the time series for the day boundary jumps before computing the Allan deviations.

D. *MAS1 - MAS2*

We have also analyzed the short term stability of MAS2 by means of MAS1. We have compared the two maser clocks with a frequency and phase comparator A7 from QuartzClock during one month, starting from 25 July 2005. The sample step used in the measurements was 1 point every 30 seconds.

The resulting graph after removing a quadratic regression and the Modified Allan Deviation are given on Figure 10 and 11.

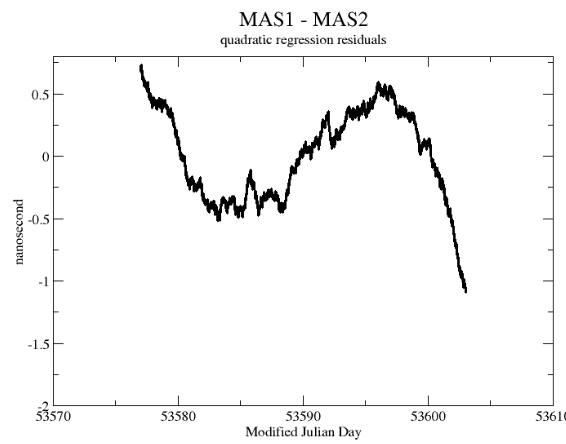

Figure 10. MAS1 – MAS2 after removing a quadratic regression

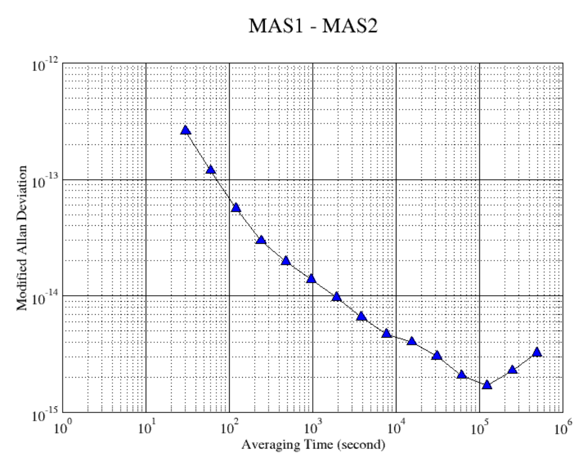

Figure 11. Modified Allan Deviation of Fig. 10

IV. Conclusion

MAS1 is used for the realization of UTC(ORB) since November 2001. During that time, it has been stopped only 1 month, in July 2003. Failures affecting MAS2 have also resulted in running MAS1 without cavity auto-tuning (CAT) at certain epochs (see table 2). Due to a decrease in the MAS1 generating power, it is also operating without CAT since 20 May 2005.

As we can see on Figure 9, the short term stability of MAS1 is not significantly modified when the CAT is running or not. On the contrary, on Figure 7, we see clearly the improvement of the CAT on the long term stability.

Finally, when we compare Figure 3 with Figure 7, we see that UTC(ORB) is more stable when it is realized by MAS1 with CAT than with CES5 with a standard tube (by a factor ~10 at 10 days averaging time and a factor ~3 at 100 days averaging time).