MASCOT time scales

Jens Biele, Hans-Herbert Fischer, DLR MUSC

Document ID: MCS-TN-1053_Time Scales
Version: 1.1
Date: 1/9/2019 10:20 AM File: TN-1053_MASCOT time scales_2019_01_09_iss1.1.docxp

Contents

1 References

RD1 MASCOT MAG Data Analysis Report, MASCOT MAG time conversion procedure. Ref: MASCOT-MAG-DR01-TimeConv-000, Issue: 0 Rev.: 0, Date: 14.12.2018

RD2 emails by Y. Tsuda, Nov 2018

RD3 emails by F. Cordero, Nov 2018

RD4 MASCOT OBC Thermal Analysis, MSC-DSI-OBC-AN-002, iss. 3.0, 2013-03-08

RD5 HY2-MASCOT Interface Control Document, MSC-RYES-ICD-002, iss. 5.3, 2014-12-01

RD6 www.frequencymanagement.com/web_pdfs/brochure_pdfs/FMI_HiTemp Brochure_06252015.pdf
Frequency Management, Huntington Beach, CA 92649, USA (retrieved November 2018)

2 Abbreviations

ΔT	Temperature difference OXO- CpuMain_M15 (assumed to be constant)
e	relative frequency deviation Δf/f of OXO
EoL	End of Life
HOBT	HY2 OnBoard Time
MAGT	MAG internal time
MOBT	MASCOT OnBoard Time
NEA	Non-explosive Actuator
OBC	OnBoard Computer
OME	OnBoard Minerva Equipment (HY2 interface to MASCOT and rovers)
OnA	On Asteroid
OXO	Oscillator (Quartz)
SCET	Spacecraft elapsed time
TC	Telecommand
TM	Telemetry
UTC	Coordinated Universal Time (true)
UTC(SM)	Coordinated Universal Time as output by SpaceMaster in archived telemetry
UTC(HY2)	Coordinated Universal Time as given by JAXA in HY2 in archived telemetry
ϑ(CpuMain_M15)	temperature of M15 sensor near CPU main, °C
ϑ (OXO)	temperature of oscillator beneath CPU main, °C
t_0	Oct. 1, 2018, 18:16:30, OME TC for TimeUpdate
t	time argument for slowly variable quantities: hours from Oct 3, 0:00:00 UTC

Note that all uncertainties values have been converted here into 1sigma Gaussian uncertainties. This implies, e.g., dividing uniform maximum error bars by $\sqrt{3}$ *and adding uncertainties quadratically. Engineers may want to multiply 1sigma-errors with the factor of 3, ESA flight dynamics folks with a factor of 6.*

3 Goal

Several steps of data acquisition and processing must be considered for inferring the actual measuring time of a data point from the time-stamps in telemetry. The timing of the measuring process itself should be best known by the unit providers. Different delays apply when these data were collected by the OBC and the telemetry packets, either housekeeping or science TM, were eventually time-stamped with MOBT. Information on this has been provided by Federico Cordero; for convenience, we include his email in annex B. It contains as well information on the time synchronization of unit internal clocks (if any). It should thus be possible to assign a creation MOBT to each measured value.

MOBT is fine for relative timings among MASCOT units. We focus here on the conversion of MOBT to HOBT, or UTC(HY2): estimate the time-dependent function MOBT-UTC(HY2), which is apparently different from MOBT-UTC(SM) by up to 2..3 seconds. Basically this reduces to an estimation of the MOBT drift as a function of time. This drift has been arbitrarily set equal to the drift of HOBT in UTC(SM).

This allows to compare MOBT directly with UTC(HY2), which is important to co-register images from ONC and MASCAM. For all other applications, the small deviations between UTC(SM) and UTC(HY2) are irrelevant.

4 HOBT and UTC

The HY2 on-board clock was initialized (SCET=0) around launch time (epoch1=2014-12-02 21:20:03 UTC) and resetted on 2017-09-05 04:59:58.709555 UTC (epoch2). HOBT is calculated from SCET(HY2) by adding the applicable epoch. Relevant for on-asteroid operations is epoch2, which corresponds to 1504587598.710 s after 1970-01-01 00:00:00 UTC. Each tick of the SCET (and of the HOBT) accounts for 1/32 s, the resolution of all on-board times available in telemetry received at MUSC.

The correlation UTC with HOBT is provided by JAXA and seems to be known to a few 100 ms [RD2]. Processing at MUSC induces another uncertainty < 10 ms. The HY2 on-board clock runs faster than UTC (i.e. than an ideal clock). On 2018-10-03, the difference HOBT-UTC(HY2) was ≈ 452 s, i.e. 7min 32s (see Annex A, which also contains details of the HY2 time correlation).

The HY2 time correlation is applicable for the timestamps of HY2 ancillary data that were received at MUSC. Lacking further information, real-time processing of MASCOT data applied this correlation as well to the MOBT (Figure 1). But actually MOBT and HOBT were synchronized only once shortly after MASCOT last boot and the clocks of HY2 and MASCOT run independently from each other afterwards. By assuming the same drift of the two onboard clocks, MOBT – UTC(SM) appears to be up to ≈2.5 s off the true MOBT-UTC(HY2). This is close to the accuracy of +/- 1 s initially requested by the science and system teams [RD5]; an attempt is made here to find a better estimation of the MOBT-UTC correlation.

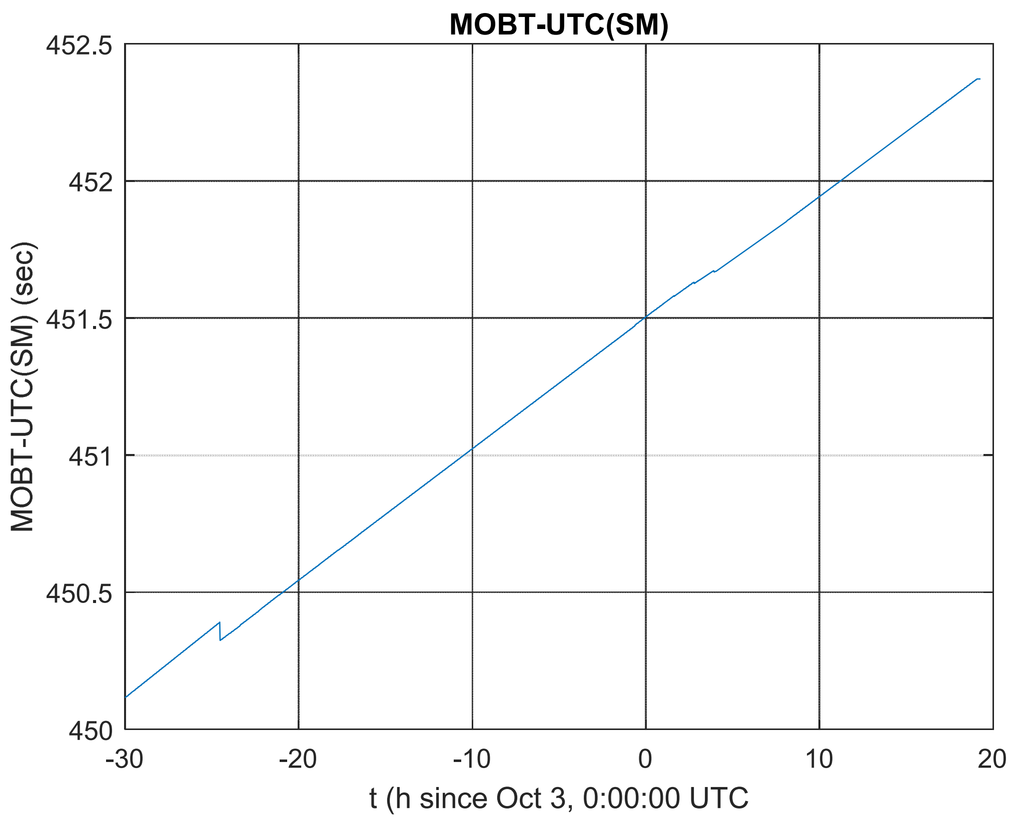

Figure 1 MOBT-UTC(Spacemaster). Note that this curve is not continuous due to several updates of HY2 time correlation information during operations (see table A1 in Annex A).

5 HOBT-MOBT time synchronisation

After MASCOT's final switch-on, the MOBT was set to HOBT with a telecommand from the HY2 time-line. The TC(9,130) "Set Mascot Time" was scheduled for 2018-10-01 18:16:30 UTC and it was kind of acknowledged by MASCOT sending the first MASCOT Time Packet (see below) with timestamp 18:16:31.371 UTC(SM) = UTC(HY2) (18:24:01.500 MOBT).

The execution delay between the release of the TC and its activation on MASCOT side is in the range 83 to 283 ms. "83 ms can be considered as a systematic delay, to account for the transmission of the command packet through the RF link (the TC is 17 bytes long; the PCOM-CCOM TC TX bandwidth is 6 bytes/27.648ms). 200ms is instead variable, to account for the CCOM telecommand processing SW thread cycle (5Hz), completely asynchronous w.r.t. to the TC reception time. OBC processing time of the TC and any CCOM to OBC transmission time via UART RS422 interface can be instead neglected (<1ms)." [RD3]

This yields the difference between MASCOT onboard time and UTC(HY2) at time synchronization (t_0):
MOBT – UTC(HY2) = 449.996 ± 0.058 (1sigma) s.
[MOBT-UTC(SM) (2018-10-01 18:16:30) = 450.129 s; MOBT is set to this HOBT *minus* time execution delay [83, 283] = 133±100 ms].

MASCOT Separation

Separation provides a further reference point for MOBT – UTC(HY2). It is the single event that was observed by both, HY2 and MASCOT, with sufficient accuracy of the respective timestamps.

According to information provided by Y. Tsuda, the on-board separation sequence was triggered at 2018-10-03 01:57:10.08 and the electric igniters were activated between 01:57:20.28 and 01:57:21.28 UTC(HY2); no delay shall be considered until the NEA was powered [RD2]. NEA typically fires 30..40 ms after powering.

A peak in MASCOT-MAG data (taken at 100 ms sampling intervals), likely due to the NEA current, is visible at SCET = 33944691.989 s = 02:04:50.699 ± 31 ms MOBT [RD1; estimated uncertainty modified]. This corresponds to 01:57:19.105 ± 30.4 ms UTC(SM). Thus separation (actually, NEA powering) occurred at 01:57:20.300 ± 22 ms UTC(HY2) and 02:04:50.699 ± 31 ms MOBT, yielding MOBT-UTC(HY2) = 450.399±0.037 s at t=1.9556 h (2018-10-03 01:57:20 UTC). UTC(SM) then deviated from UTC(HY2) by UTC(HY2)-UTC(SM) = 1.195±0.033 s.

In short:

@ t0: MOBT-UTC(HY2) = 449.996±0.058 s
At separation (t=1.9556 h), MOBT-UTC(HY2) was 450.399±0.037 s.

6 MASCOT Time Packets

Every minute during periods with established communications between MASCOT and HY2, MASCOT generated so called Time Packets. When processing these packets, HY2 OME added its current on-board time and sent the extended MASCOT Time Packets to ground. By comparing the HY2 timestamps and the MASCOT packet times it should thus be possible to detect and correct for a potential relative drift of the two on-board clocks. In particular, it was expected that the evaluation of the tuples (HOBT, MOBT) would yield HOBT(MOBT) and, by applying the known UTC(HOBT) relation, eventually leads to UTC(MOBT).

Unfortunately, the HOBT timestamps in the Time Packets have a resolution of 1 s only. The significance of the fractional seconds (the 5 least-significant bits) of HOBT is not evident, as all HOBT timestamps had the same value (0.375 s) in all Time Packets ever received. It is tempting to ignore the fractional part and add 0.5 s to the HOBT timestamps to correct for the truncation to integers, which would result in a net correction (+0.5 – 0.375) s = +0.125 s to the original HOBT timestamps. But we do not know how the time stamps were actually created and each one represents a range 1 s, anyway. The unchanged values of the HOBT timestamps were used for Figure 2.

With the given resolution of HOBT, the difference between MOBT and HOBT was seemingly constant in the period from time synchronization to approximately separation, when MOBT drift appears to be lower than that of the HOBT, resulting in increasing differences of the timestamps (Figure 2). The latency between the samplings of the MOBT and the HOBT is largely responsible for the offset of MOBT – HOBT visible in Figure 2, as this difference should actually be zero shortly after time synchronization (assuming a correct initialization of MOBT). The range of the overall latency is somewhat constrained by the expected delays on MASCOT and HY2 sides: the delay between MOBT sampling and packet transmission to OME is claimed to be τ_{Mlat} < 55 ms. The *requested* accuracy ("latency delay") of the period τ_{Hlat} between the reception of the Time Packet by OME-E COM and the OME timestamp should be better than +/-200 ms [RD5].

Around separation, on-board activities changed rapidly from lazy to very busy (eg. packet rates of 4 packets/s occurred around separation and afterwards only). Significantly increasing latencies of the HY2 processing of MASCOT TM packets due to high packet rates were observed eg. during MASCOT Health Check 6. They rendered the evaluation of the time packets completely useless. An update of the OME software took place later and means for limiting the packet rate have been installed on MASCOT side. It cannot be excluded that latencies of the telemetry processing were systematically changing during on-asteroid operations and contributed to the differences MOBT – HOBT. Actually we found no clear evidence for this effect and apparently different drifts of the HY2 and MASCOT clocks cause indeed the profile visible in Figure 2.

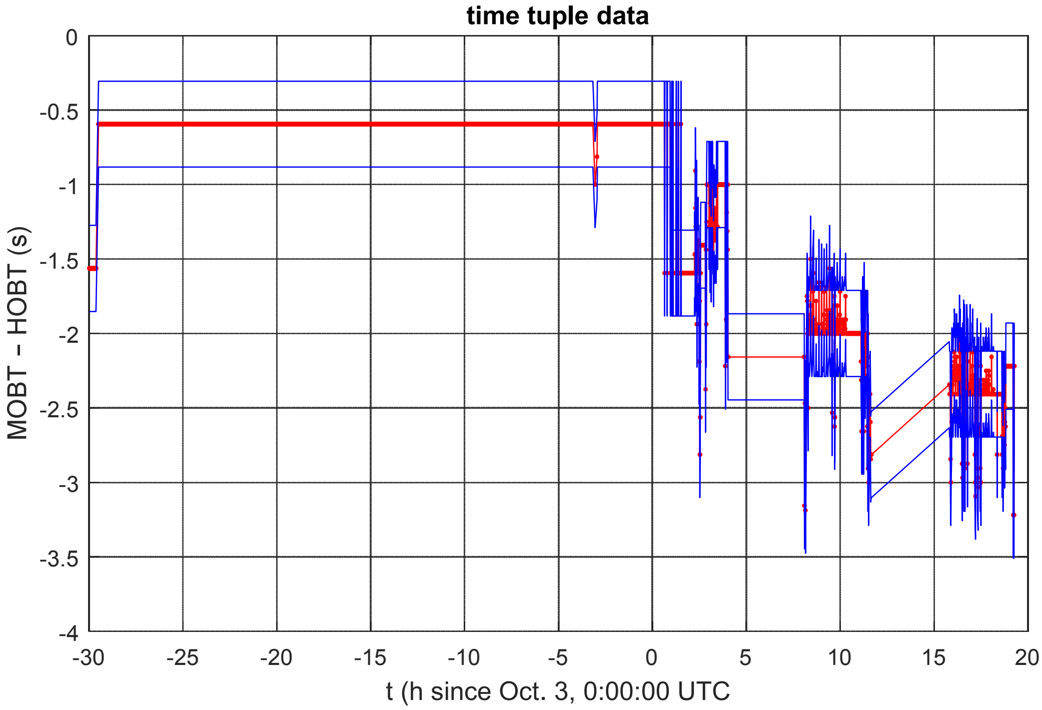

Figure 2 Difference between MOBT and HOBT in the MASCOT Time Packets from time synchronization to MASCOT EoL. Red: data, outliers < -5 s removed. Blue: data ±0.5 s

7 Basic Data on MASCOT Clock Drift

Once the MOBT is synchronized with HOBT, it is maintained by the internal CPU clock oscillator at $f_0 \approx$ 40 MHz, whose short term stability mainly depends on temperature variations. The exact base frequency f_0 at some reference temperature in October 2018 is unknown; it probably changed by aging. The value measured in December 2013 at ambient temperatures (39.99 MHz [RD3]) would be too unprecise for our purposes, anyway.

The oscillator (2770096-40M00 from FMI) has a frequency uncertainty of max 75 ppm over the total operating range (-55..+125 °C) [RD3]. The typical temperature dependence of such oscillators is depicted in Figure 3 and the profile derived from that and applied for the MASCOT components in this report is shown in Figure 4.

Telemetry channel MTsm15_CpuMainTemp provides temperature samples at intervals of up to 16 seconds. Temperature was rather stable between 2018-10-01 18:24:17 MOBT, ie. around HOBT-MOBT synchronization, and 2018-10-02, 20:03:13 MOBT. Larger temperature excursions then started and continued until 2018-10-03 19:11:29 MOBT (Figure 5).

The temperature sensor and the oscillator are mounted somewhat apart on the PCB (see annex C) and their temperatures were thus driven by heat sources (eg. transceivers, CPU) and sinks with different weights. We use MTsm15_CpuMainTemp as a the principal proxy for the oscillator temperature but allow a constant temperature difference of the OXO with respect to MTsm15_CpuMainTemp.

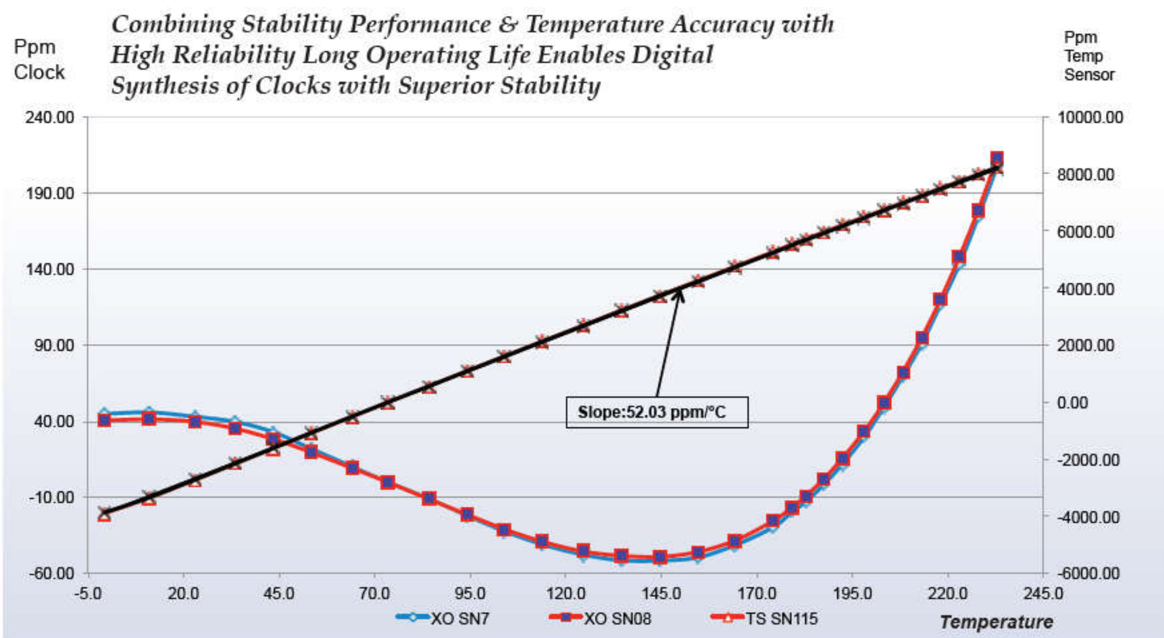

Figure 3 Typical temperature dependence of FMI oscillators (XO SN7, XO SN08) clock frequency used on other hi-rel fields. Reproduced for internal use from RD6. Oscillators are always derived from the same manufacturing process/technology so it should be representative of the MASCOT components [RD3].

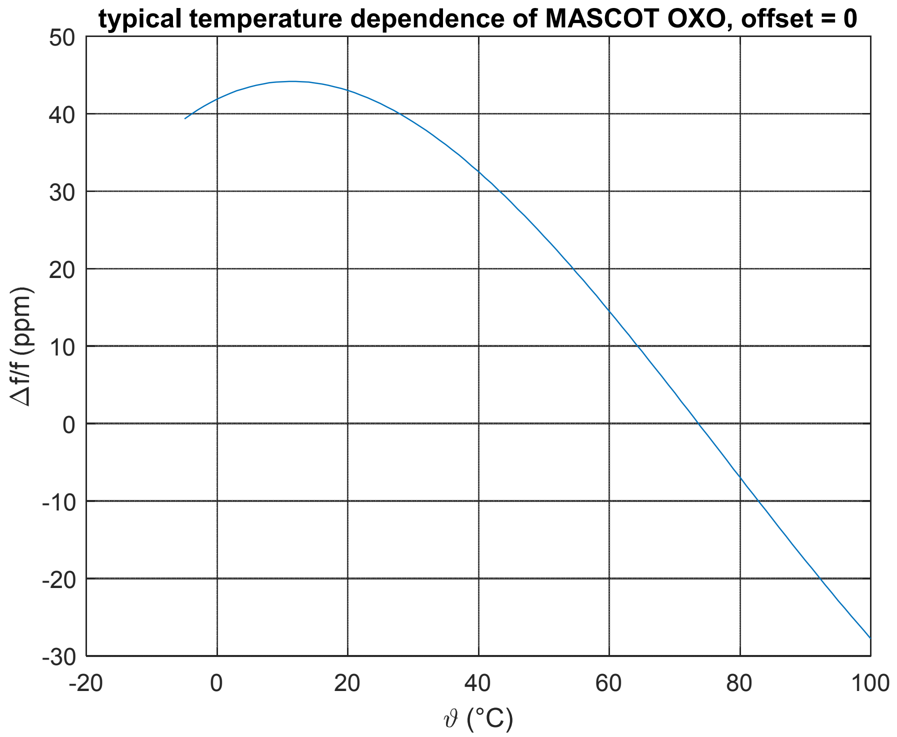

Figure 4 Variation of OXO frequency with temperature. Digitized from Figure 3 (average of SN07 and SN08, fit rms 0.54 to 0.86 ppm < 1pixel). The actual in-flight curve is assumed to have a vertical offset, a result of production tolerances and aging.

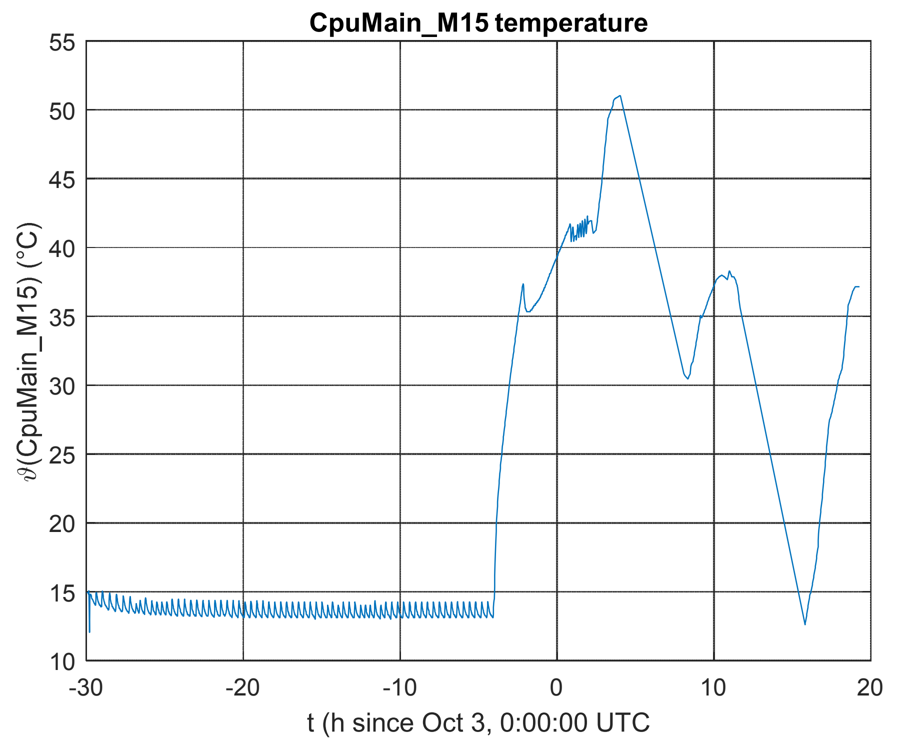

Figure 5 Temperature of sensor MTsm15_CpuMainTemp from time synchronization to MASCOT End of mission.

8 Rationale

As the MOBT-HOBT time tuple data are obviously truncated at integer seconds, they unfortunately only give a very rough estimate of the MASCOT OXO drift, their weight is very low but their number (2439 points) is high. We thus use mainly the two instants where a direct comparison between HOBT and MOBT could be made (t_0 and the separation, rather NEA powering instant seen by MASMAG) to constrain the frequency offset of the MASCOT oscillator with its temperature as the other main input. After separation, we integrate the temperature-dependent oscillator drift MOBT-UTC(HY2) as a function of time t by

$$MOBT - UTC\left(HY2\right) = \int_{t_0}^{t} \left[e_0 \left\{ \vartheta(t') + \Delta \mathrm{T} \right\} + offset \right] dt' + c$$

Here, e_0 is the temperature drift of the oscillator.

The integration constant c must be the known value of MOBT-UTC(HY2) at t_0 (449.996±0.058 s) within its uncertainties. An optimized value of c and the temperature difference ΔT can be determined by simultaneously fitting all of the MOBT-HOBT time tuple data together with the two precisely known synchronization data in a weighted least-squared fit. We note that ΔT is seen more a fit constant to the time tuples than a really physically meaningful temperature excursion of the OXO with respect to MTsm15_CpuMainTemp; in the uncertainty estimation, we include as one uncertainty contribution the difference of the result to the case where we fix the OXO temperature as 1.8K lower than MTsm15_CpuMainTemp as suggested by the steady state OBC Thermal Analysis [RD4].

9 Result

$$MOBT - UTC\left(HY2\right) = \int_{t_0}^{t} e_0\left\{\vartheta_{CpuMain\_M15}(t') + 20.42K\right\} dt' + 449.896\,s$$

$$e_0(\vartheta) = (8.4975 \cdot 10^{-5}\vartheta^3 - 0.01959\vartheta^2 + 0.4128\vartheta + 13.141) \cdot 10^{-6}$$

offset: -28.68±1.24 ppm

c= 449.8955 s

ΔT=20.53±1.75 K

ϑ is the temperature

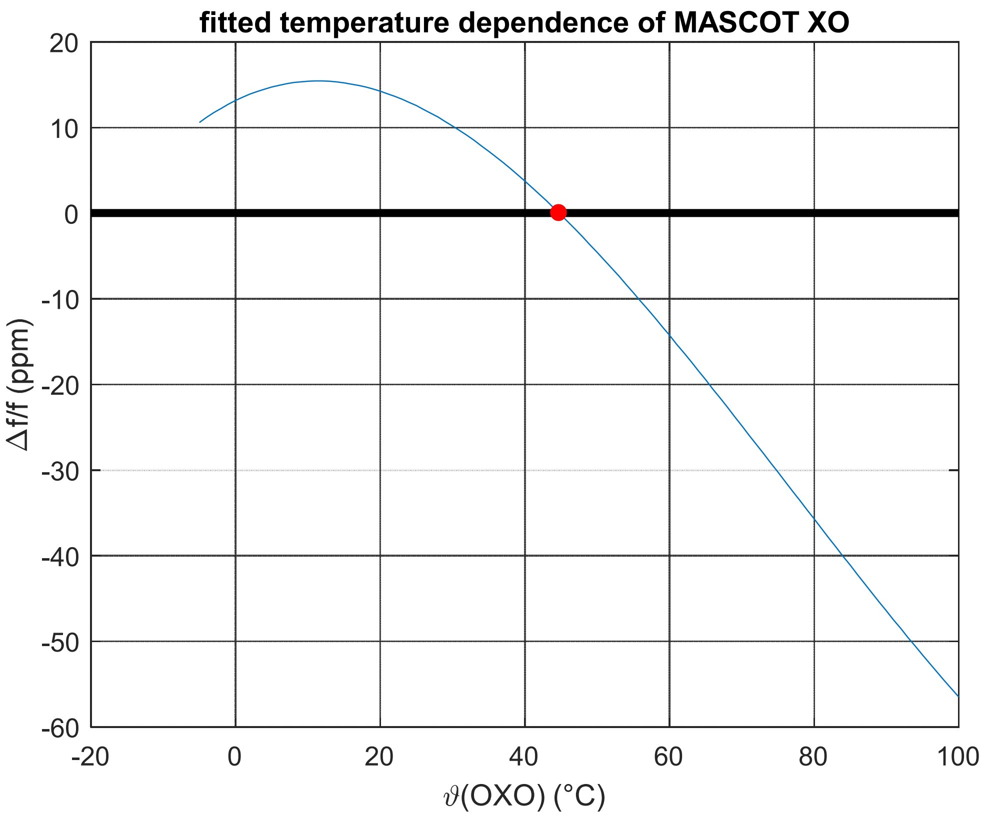

Figure 6 Result for free ΔT: fitted temperature dependence of OXO (that is, nominal curve + fitted offset). Zero at 44.75°C

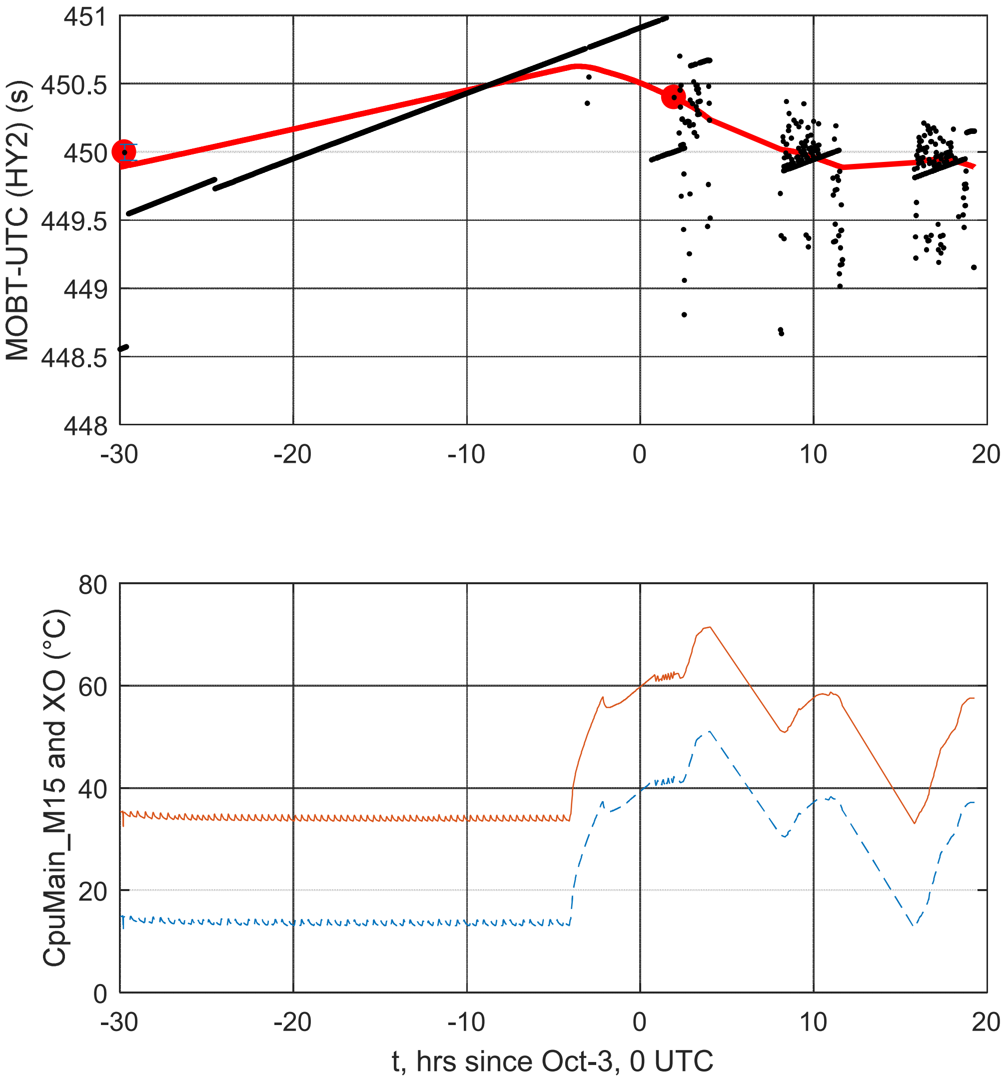

Figure 7 Result for free ΔT: red line in upper panel shows best estimate of MOBT-UTC(HY2). Black dots are time tuples with an uncertainty of about ±0.5s or more. Big red dots indicate the 2 precise synchronizations at t_0 and separation. Lower panel shows the measured CpuMain_M15 temperature (blue, broken line) and the estimated OXO temperature in our simplified model with free ΔT (red line).

Result as a table, interpolated at every hour UTC of Oct 3, 2018:

t(h)	MOBT-UTC(HY2) (s)	MOBT-UTC(SM) (s)	UTC(SM) -UTC(HY2) (s)
0	450.51	451.5	-0.999
1	450.45	451.55	-1.102
2	450.39	451.6	-1.204
3	450.33	451.64	-1.306
4	450.24	451.67	-1.431
5	450.15	451.71	-1.551
6	450.09	451.75	-1.659
7	450.05	451.8	-1.751
8	450.02	451.85	-1.829
9	450	451.9	-1.9
10	449.96	451.94	-1.984
11	449.91	451.99	-2.077
12	449.87	452.04	-2.164
13	449.86	452.09	-2.224
14	449.87	452.13	-2.261
15	449.89	452.18	-2.285
16	449.92	452.23	-2.303
17	449.94	452.27	-2.332
18	449.93	452.32	-2.39
19	449.9	452.37	-2.47

10 Uncertainty estimation

Generally, the uncertainty (always corresponding to 1sigma!) is very low (70..100 ms) near separation and then increases to ~0.2 s near end of mission. We calculated the MOBT-UTC(HY2) fit with various alterations (see below - everything else was set to nominal), and compared with the nominal curve; the absolute differences of both, divided by sqrt(3), give the 1 sigma model uncertainties of each contribution. The rms sum of all contributions is plotted as the bold red curve, which is the best guess on the total 1sigma uncertainty of MOBT-UTC(HY2).

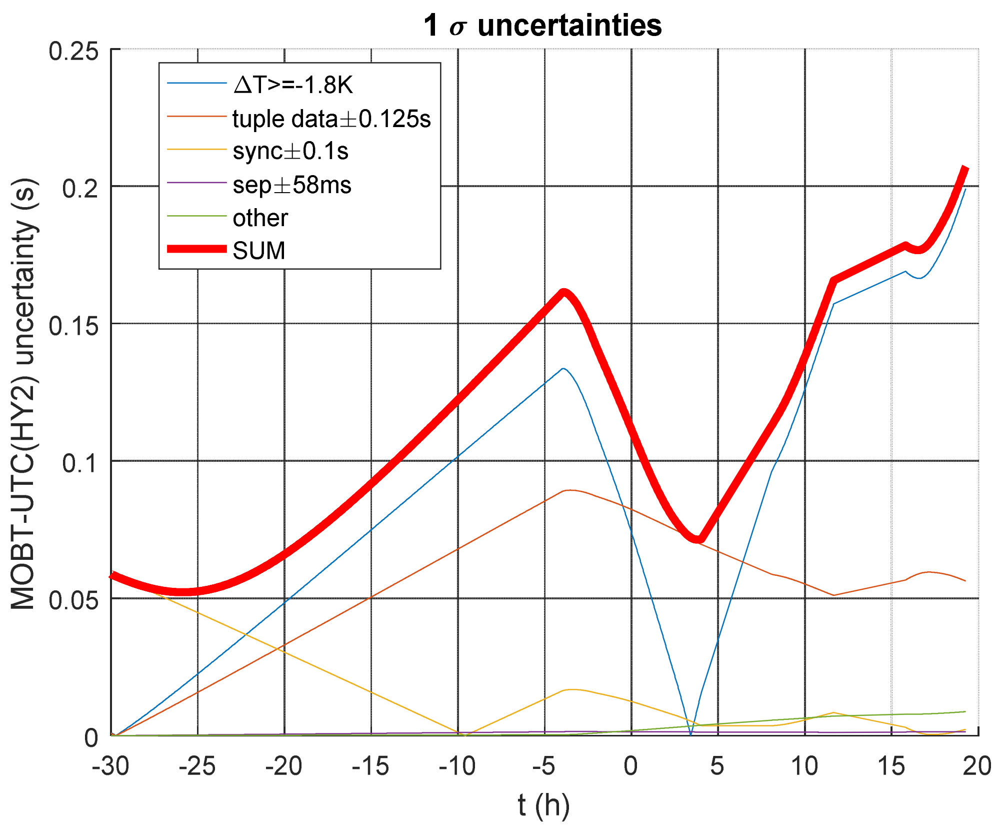

Figure 8 Uncertainty of MOBT-UTC(HY2). The bold red curve is the quadratic sum of all curves; basically this uncertainty is very low (70..100 ms) near separation and then increases to ~0.2 near end of mission.

Considered uncertainty contributions:

- Use of OXO SN07 and SN08 temperature dependencies of clock frequency rather than the averaged characteristics: totally negligible, not shown in figure 8
- ΔT=-1.8K or ΔT as free parameter: largest contribution to overall uncertainty, up to 0.2s rms, but near zero at separation. The nominal MOBT-UTC(HY2) is the one with free ΔT
- Adding ±0.125s to all of the time tuple data (possible rounding effects or processing time bias): second-largest contribution, up to 80 ms rms.
- Range of data at sync (t_0) and separation, i.e. data were set to their error bar extremes (first makes up to 0.1s difference near t_0, the latter is negligible)
- Other: nominally, we de-weighted time tuple data if they deviated more than their ±0.5s error bar from the nominal curve to dampen the influence of outliers. This contribution results if this procedure is switched off.

Result of total uncertainty as a table:

t(h)	1 σ Uncertainty of MOBT-UTC(HY2) (s)
0	0.111
1	0.096
2	0.083
3	0.074
4	0.071
5	0.077
6	0.087
7	0.100
8	0.112
9	0.123
10	0.138
11	0.155
12	0.171
13	0.180
14	0.183
15	0.182
16	0.178
17	0.178
18	0.188
19	0.203

Note that in the end you might want to consider, additionally, the time discretization uncertainty of 1/32/sqrt(3)=18 ms and the up to 10 ms SCET(MUSC) uncertainty.

11 Annex A: Conversion of HOBT to UTC

Information that can be used for the conversion of HY2 on-board time to UTC is provided by JAXA in a file called “time_cal_sa48”. The file contains pairs (number of on-board clock ticks, corresponding UTC) and, for extrapolation purposes, how much any additional clock tick would be worth in terms of UTC time, i.e. the instantaneous slope in µs/tick (called rate in table A1). Information in the file was usually updated several times in each pass.

In the period of final MASCOT operations, the difference between HOBT and UTC can be described by

HOBT[s] – UTC[s] = (1.33098279 ± 0.00368676) 10^{-5} * UTC[s] – (20025.99 ± 56), see fig. A1.

The residuals of the linear regression line are obviously not randomly distributed (fig. A2), but they rarely exceed one LSB of the telemetry time-stamps (the mean of residuals has a standard deviation of 16 ms) and use of the unbeatably steady and simple linear fit is thus possible. For accuracy better than the clock resolution, interpolation of the tabulated values should be applied (that would resemble the way SpaceMaster applied the time correlation; not being able to look into the future, it actually took the most recent UTC(HY2) value corresponding to a given HOBT or MOBT and extrapolated with the most recent rate).

EtiBase	SCET [s]	HOBT [s]	UTC	UTC [s]	HOBT-UTC [s]	Rate [usec/tick]
1.08081973837109E+09	33775616.82410	1538363215.5341	*2018-10-01 02:59:26.166*	1538362766.1670	449.3671	*31249.54918*
1.08095087437109E+09	33779714.82410	1538367313.5341	*2018-10-01 04:07:44.108*	1538366864.1080	449.4261	*31249.55443*
1.08121295437109E+09	33787904.82410	1538375503.5341	*2018-10-01 06:24:13.993*	1538375053.9940	449.5401	*31249.56196*
1.08317904605859E+09	33849345.18933	1538436943.8993	*2018-10-01 23:28:13.565*	1538436493.5650	450.3343	*31249.59652*
1.08331011805859E+09	33853441.18933	1538441039.8993	*2018-10-02 00:36:29.510*	1538440589.5110	450.3883	*31249.58242*
1.08344116412109E+09	33857536.37878	1538445135.0888	*2018-10-02 01:44:44.643*	1538444684.6440	450.4448	*31249.57196*
1.08357223612109E+09	33861632.37878	1538449231.0888	*2018-10-02 02:53:00.588*	1538448780.5890	450.4998	*31249.57854*
1.08370330812109E+09	33865728.37878	1538453327.0888	*2018-10-02 04:01:16.533*	1538452876.5340	450.5548	*31249.58256*
1.08383438012109E+09	33869824.37878	1538457423.0888	*2018-10-02 05:09:32.478*	1538456972.4790	450.6098	*31249.57917*
1.08396545212109E+09	33873920.37878	1538461519.0888	*2018-10-02 06:17:48.424*	1538461068.4240	450.6648	*31249.58458*
1.08409652412109E+09	33878016.37878	1538465615.0888	*2018-10-02 07:26:04.369*	1538465164.3700	450.7188	*31249.58443*
1.08593154205859E+09	33935360.68933	1538522959.3993	*2018-10-02 23:21:47.915*	1538522507.9160	451.4833	*31249.58332*
1.08606261405859E+09	33939456.68933	1538527055.3993	*2018-10-03 00:30:03.861*	1538526603.8610	451.5383	*31249.58473*
1.08619368605859E+09	33943552.68933	1538531151.3993	*2018-10-03 01:38:19.809*	1538530699.8100	451.5893	*31249.60672*
1.08632481212109E+09	33947650.37878	1538535249.0888	*2018-10-03 02:46:37.452*	1538534797.4520	451.6368	*31249.64025*
1.08645582702734E+09	33951744.59460	1538539343.3046	*2018-10-03 03:54:51.627*	1538538891.6270	451.6776	*31249.69111*
1.08658689902734E+09	33955840.59460	1538543439.3046	*2018-10-03 05:03:07.581*	1538542987.5820	451.7226	*31249.65048*
1.08671796302734E+09	33959936.34460	1538547535.0546	*2018-10-03 06:11:23.281*	1538547083.2820	451.7726	*31249.61765*
1.08684903005859E+09	33964032.18933	1538551630.8993	*2018-10-03 07:19:39.072*	1538551179.0730	451.8263	*31249.58971*
1.08868407005859E+09	34021377.18933	1538608975.8993	*2018-10-03 23:15:23.273*	1538608523.2730	452.6263	*31249.56449*
1.08881511005859E+09	34025472.18933	1538613070.8993	*2018-10-04 00:23:38.215*	1538612618.2150	452.6843	*31249.55679*
1.08894619502734E+09	34029568.59460	1538617167.3046	*2018-10-04 01:31:54.562*	1538616714.5630	452.7416	*31249.56074*
1.08907726702734E+09	34033664.59460	1538621263.3046	*2018-10-04 02:40:10.504*	1538620810.5040	452.8006	*31249.55351*
1.08920833902734E+09	34037760.59460	1538625359.3046	*2018-10-04 03:48:26.446*	1538624906.4460	452.8586	*31249.55766*
1.08933941102734E+09	34041856.59460	1538629455.3046	*2018-10-04 04:56:42.389*	1538629002.3890	452.9156	*31249.56183*
1.08947047502734E+09	34045952.34460	1538633551.0546	*2018-10-04 06:04:58.081*	1538633098.0810	452.9736	*31249.55941*
1.08960155502734E+09	34050048.59460	1538637647.3046	*2018-10-04 07:13:14.273*	1538637194.2730	453.0316	*31249.55887*

Table A1 HY2 Onboard Time Parameters in the period of on-asteroid operations. JAXA's "Extended Time Indicator" (ETIBase),UTC and rate were read from file "time_cal_sa48" (ref. Okada, Naoki and Yukio Yamamoto, "Development of Spacecraft Time Calibration System for Science Spacecrafts"). Other values were calculated using the equations in the text.

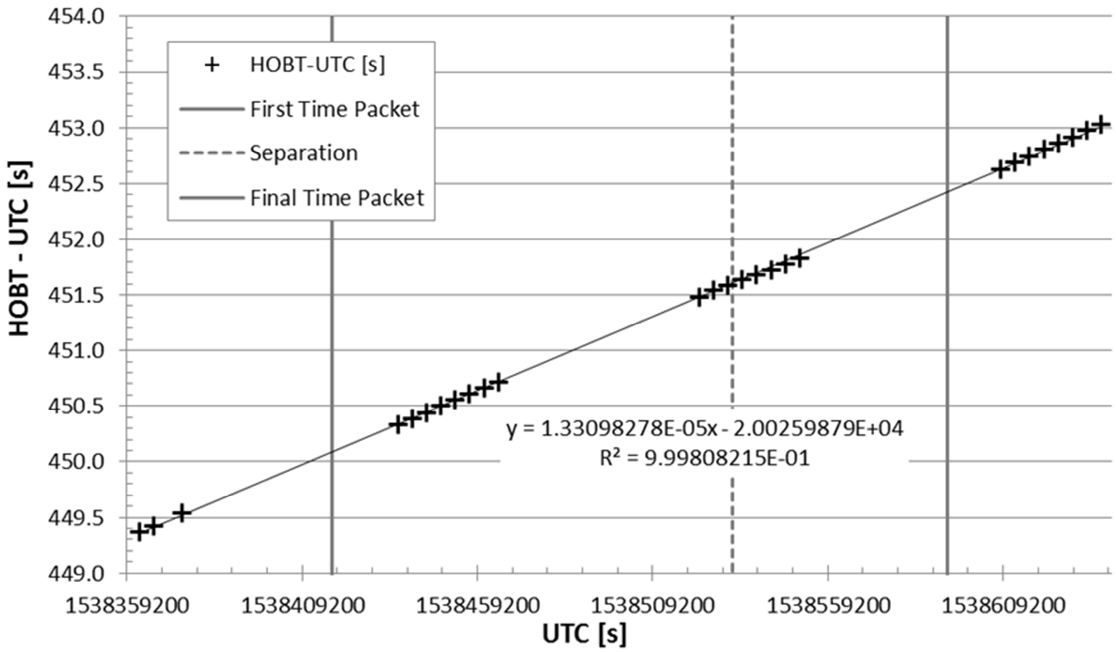

Fig. A1 Differences between HOBT and UTC inferred from "time_cal_sa48" in the period 2018-10-01 02:00 to 2018-10-04 08:00 UTC. The period of MASCOT operations after final switch-on is approximately indicated with the solid horizontal lines. The first MASCOT time packet was probably generated shortly after HOBT->MOBT time synchronization.

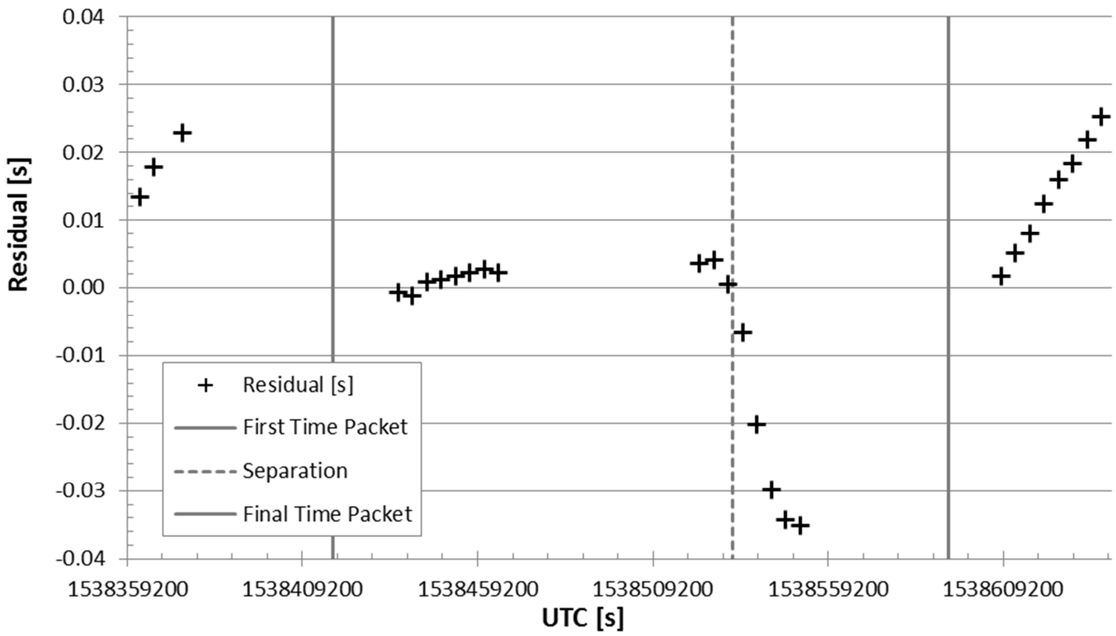

Fig. A2 Residuals of the linear regression in the period 2018-10-01 02:00 to 2018-10-04 08:00 UTC.

12 ANNEX B: OBC Data Processing Delays and Internal Unit Clocks

E-Mail by Federico Cordero (2018-11-07)

1) There is a negligible dependency [of the OBC timing when processing units data] on the CPU load, that may show itself as jittering of the periodicity of the packetization. This is certainly in the order of much less than a millisecond. The normal CPU usage is in fact very low < 10%, most of the time sleeping in a low power status. Only when compression of CAM/MMEGA images is active, the CPU is fully used at 100% for several seconds by the compression SW thread, but even in this condition there is no real effect on the rest of the SW. In fact, all other SW threads, in charge of the I/O with the HW, run MAM, execute TC Sequences, etc etc and ultimately producing all other telemetry packets (packetization), are executed at a higher priority, meaning that the RTOS pre-empts the compression thread (i.e. stops it to resume it later) and let the pending thread(s) to run when due. The jitter is caused by the thread context switch - which takes just a few microseconds - plus some possible mutex protected criticial section to complete - which would still take anyway much less than a millisecond (by design critical sections are very short).

If you have examples where the CPU load may have influenced the generation of any telemetry packet, other than CAM/MMEGA image science packets, please let me know. Every CAM/MMEGA image science product (made of several packets) is supported by an auxiliary report packet with the actual MOBT of the image (and other meta data). All other instrument/equipment/system packets have instead the packet time closely related to the acquisition time of their cargo data. Some have even additional time parameters as part of the cargo data, on top of the packet time. This is explained in the following point.

2) The packetization process defines the packet time stamp. There are essentially two types of packetization processes that embeds HW parameters, those driven directly by the equipment SW managers (MagMgr, MaraMgr, CamMgr, PcduMgr, MobilityMgr etc) and those driven by the centralised HK reporting service.

In either cases the time is set at the exact instant the packet is dispatched to the central TM Packet Router for storage into a Packet Store or forwarding to CCOM for immediate downlink.

The acquisition of the packet cargo data, if coming from an HW unit, occurs at a earlier time, of course and is separate from the packetisation.

For those packets produced by the equipment managers, each manager takes care both of the acquisition process from the HW unit and the packetisation process in a synchronous way: Any manager runs periodically at a given frequency and normally (there are exceptions!) at cycle N the processing (packetization) of the data acquired from the HW at cycle N-1 is performed.

For those packets produced by the centralised HK reporting service, the packetization process is asynchronous w.r.t. the acquisition of HW parameters, still performed by the equipment managers.

Having in mind this general mechanisms and assuming that the actual sampling from HW sensors occurs on the equipment when requested by the OBC, the following delays can be expected between the sampling time and the packet time (I list here only packets with HW data):

Packets produced directly by the managers:

GM000014 MagMgr Science Data 200ms (this packet contains an additional MOBT time stamp, related to the acquisition of the science data, directly filled by the unit, which maintains an independent MOBT counter, synchronised with the OBC MOBT at unit power on - see SURD-0176)

AM000014 MaraMgr Science Data 200ms (this packet contains an additional MOBT time stamp, related to the acquisition of the science data, directly filled by the unit, which maintains an independent MOBT counter, synchronised with the OBC MOBT at unit power on - see SURD-0196)

OM000012 MicrOmegaMgr Housekeeping SID 0x00 < 10 ms (the packetization is in this case interrupt driven, immediately when data arrives from the Spacewire interface)

CM000012 CamMgr Housekeeping SID 0x01 200ms

GM000009 MagMgr Housekeeping Basic SID 0x00 200ms

GM000010 MagMgr Housekeeping Conf SID 0x01 200ms

AM000009 MaraMgr Housekeeping Basic SID 0x00 200ms

AM000010 MaraMgr Housekeeping Conf SID 0x01 200ms

AM000015 MaraMgr Housekeeping CalTarget SID 0x02 200ms

AM000016 MaraMgr Housekeeping HeadTarget SID 0x03 200ms

MM000009 MobilityMgr Housekeeping SID 0x01 200ms

MM000018 MobilityMgr Housekeeping SID 0x0A 200ms

MM000019 MobilityMgr Housekeeping SID 0x0B 200ms

MM000020 MobilityMgr Housekeeping SID 0x0C 200ms

MM000021 MobilityMgr Housekeeping SID 0x0D 200ms

NM000002 GncMgr OPS PEC AttEst MotionStatus Processing Report
(parameters are derived from averages of OPS/PEC samples acquired at 10Hz during the previous OPS measurement cycle, ~12.4s)

Packets produced by the centralised HK reporting service:

RM000005 ComMgr Diag Data <1s

DM000028 IomMgr Main Diag Data <1s

DM000029 IomMgr Red Diag Data <1s

PM000005 PcduMgr Diag Data <400ms

DM000121 IomMgr Analogue Acquisitions Diag Data <10s

NM000005 GncMgr Diag Data (parameters are derived from averages of OPS/PEC samples acquired at 10Hz during the previous OPS measurement cycle, ~12.4s, if OPS measurement is on, otherwise 10s for PEC related parameters)

SM000048 FlightSw System Status 1 HK - with B field <8s for MAG B field, <1s for CCOM HW parameters, <400ms for PCDU HW parameters, <10s for analogue parameters acquired by the OBC IOM (AVM, TSM channels), <1s for any other OBC HW parameters

13 ANNEX C: Thermal setup

The oscillator XCO is mounted on the bottom side of the CPU PCB, just beneath the CPU. See component X1 on the bottom page of the assembly drawings below.

The CpuMain_M15 sensor is on the U5 component on the first page of the drawing (a LVDS transceiver used for the Spacewire interfaces, this was identified (by simulation!) as one of the hottest spots on the CPU board (see RD4, OBC Thermal Analysis) by a few Kelvin. According to that simulation (steady state – only conduction, no radiation), the CPU and XCO are about 1.8 K cooler than the U5 component. Results of steady state simulations are actually not very useful when considering the thermal conditions after MASCOT separation. The free ΔT fit results, based on the time tuple data, in a ~20K hotter OXO than CpuMain_M15 sensor. This is maybe unlikely; therefore we take the difference of ΔT=0 and free ΔT as one of the chief components of the uncertainty of the final result.

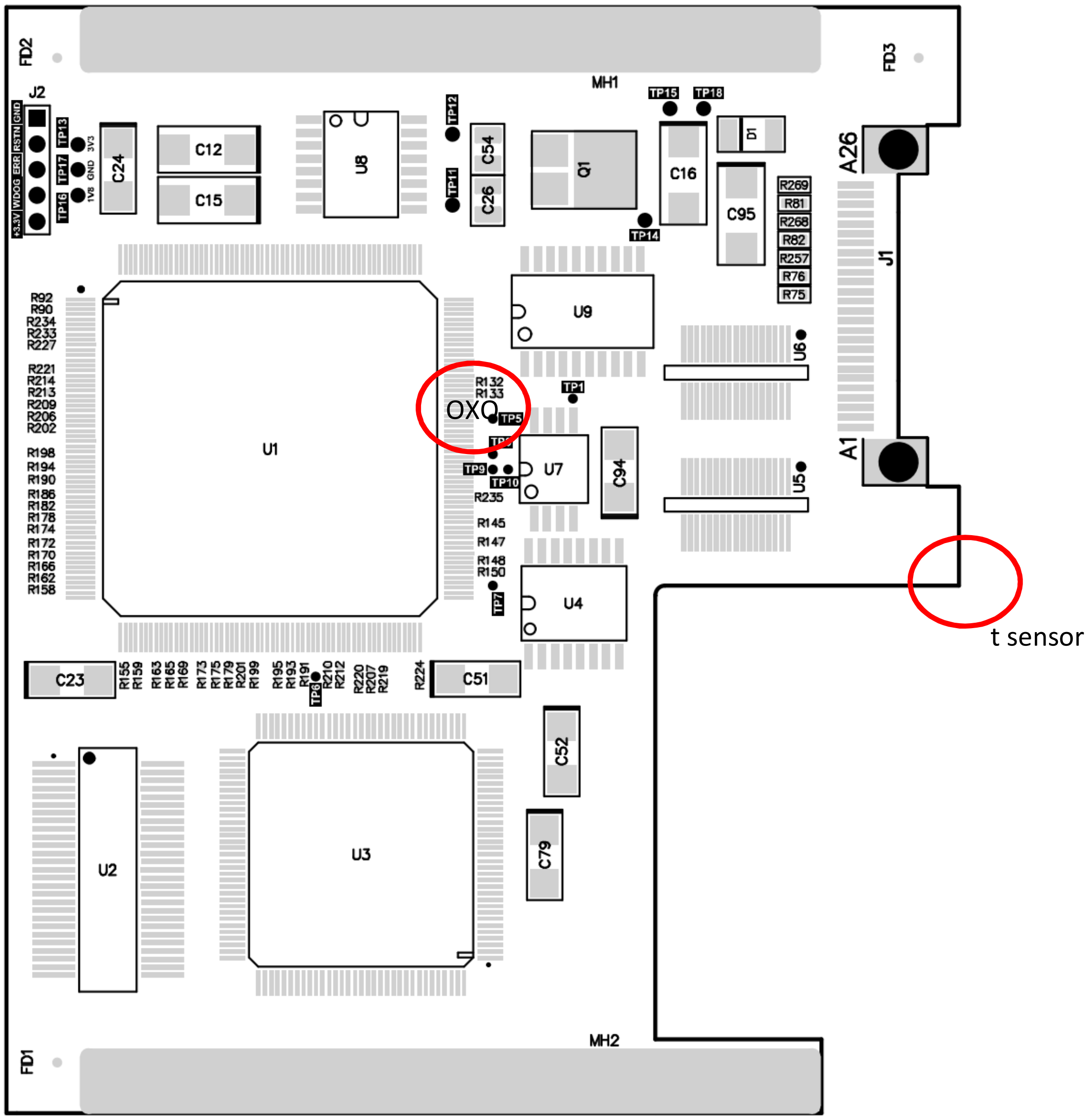

Figure C1 MASCOT OBC Main PCB: MSC-DSI-OBC-DR-202_1.0_CPU_FM_PCB_Assembly_Drawings_20130809, top side

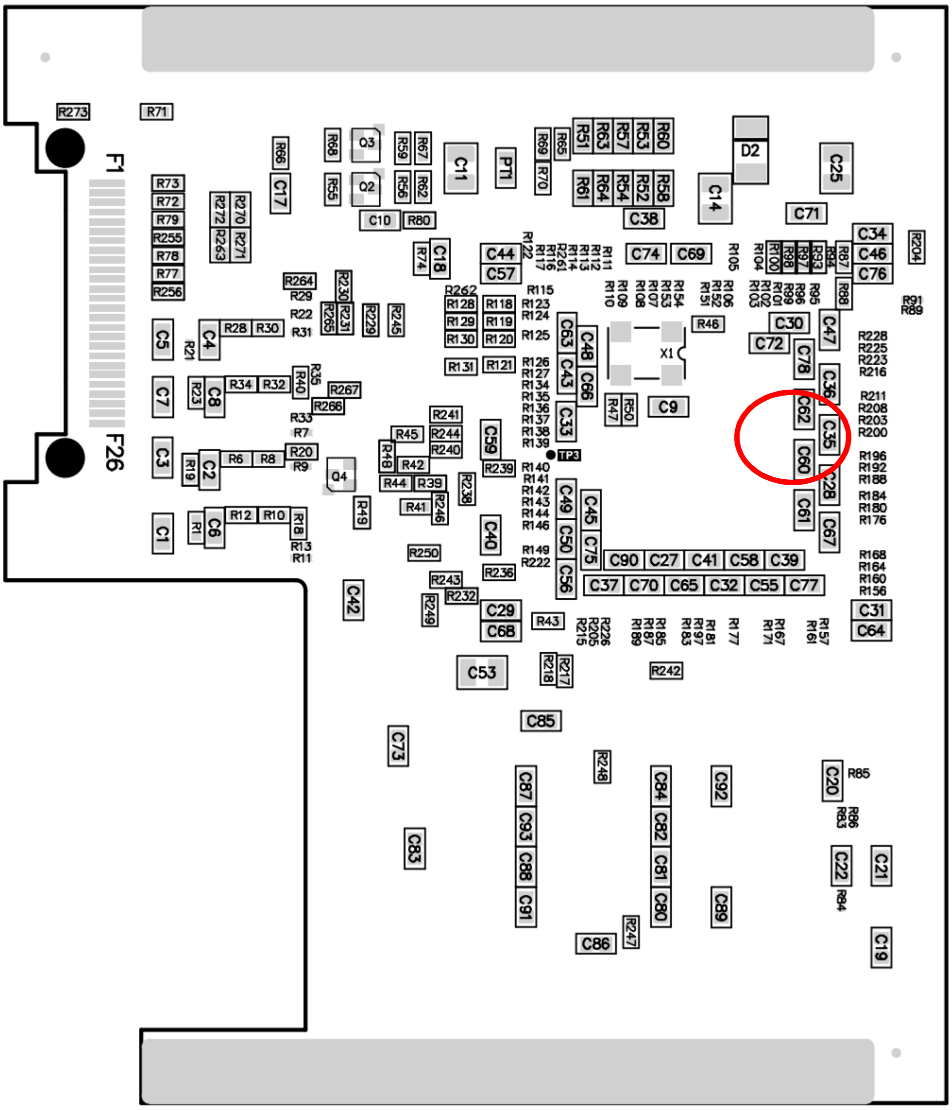

Figure C2 MASCOT OBC Main PCB: MSC-DSI-OBC-DR-202_1.0_CPU_FM_PCB_Assembly_Drawings_20130809, bottom side

Figure C3 Photo of the CPU (main) board, top side (B. Cozzoni, pers. comm.)

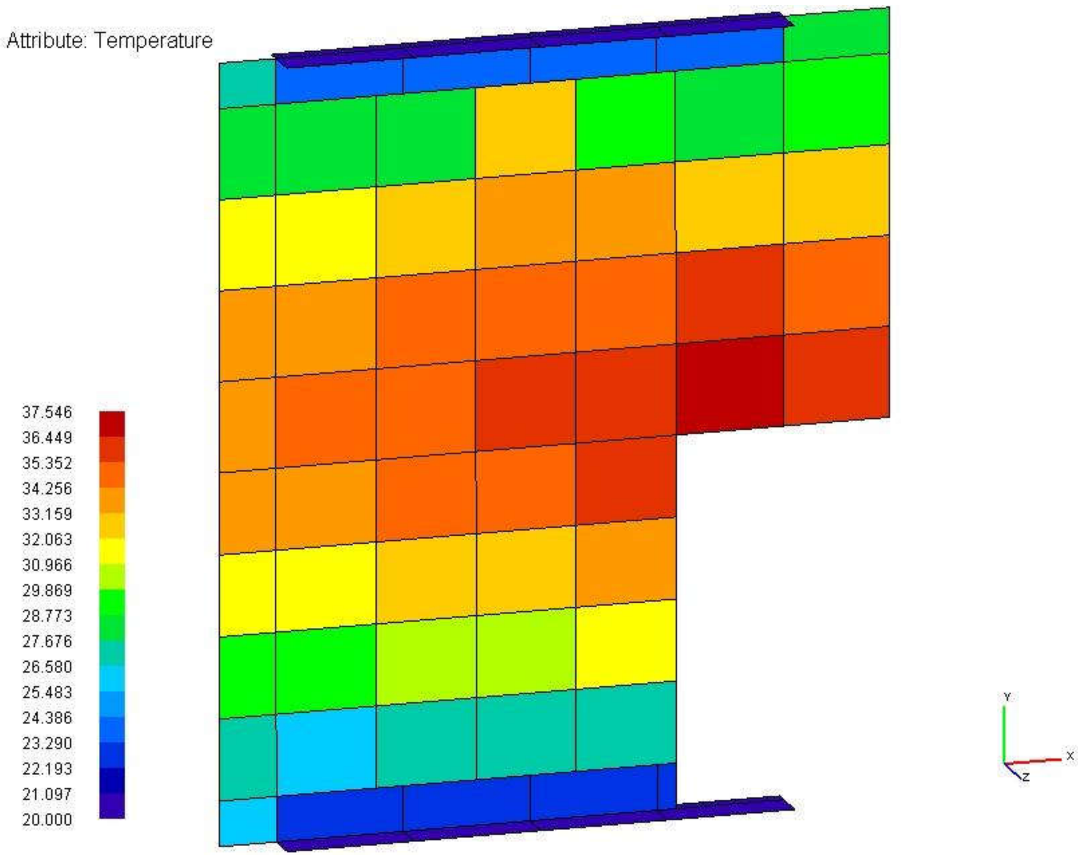

Figure C4 [RD4] Temperature over CPU Board Operational Case (20°C)

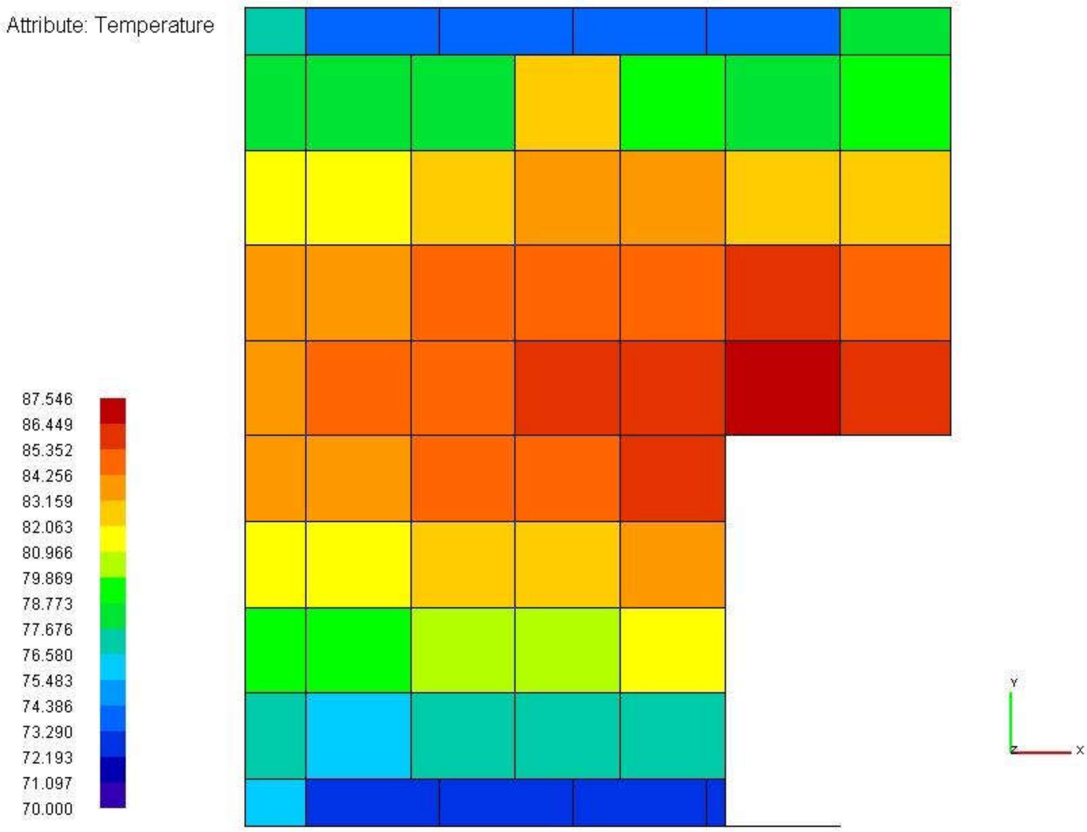

Figure C5 [RD4] Temperature over CPU Board, Operation (Flight) Case (70°C)

Designator	Part Number	PCB Temp@20°C [°C]	PCB Temp@70°C [°C]	PCB Temp@-50°C [°C]	Max. Allowed Junction Temp. [°C]	Max. Applied Junction Temp. [°C]	Margin [°C]
Q1	JANSR2N7480U3	29.2	79.2	-40.8	110	79.4	30.6
Q2	2N2907AUB	29.2	79.2	-40.8	110	87.3	22.7
Q3	SOC2222AUB12SW	29.2	79.2	-40.8	110	86.2	23.8
U1	GR712-PQ240	35.7	85.7	-34.3	110	92.2	17.8
U2	3DMR2M16VS2427	29.8	79.8	-40.2	125*	79*	46.0
U3	UT8R4M39	30.7	80.7	-39.3	110	80.7	19.3
U4	M54AC139	36.1	86.1	-33.9	110	95.8	14.2
U5	3DLV3304VS1374	37.5	87.5	-32.5	125*	87.5*	37.5
U6	3DLV3304VS1374	36.1	86.1	-33.9	125*	86.1*	38.9
U7	ISL706ARHVF	35.3	85.3	-34.7	110	85.4	24.6
U8	RHFL4913KPA	32.4	82.4	-37.6	110	103.8	6.2
U9	M54AC244	33.6	83.6	-36.4	110	90.3	19.7
U10	M54AC139	31.5	81.5	-38.5	110	91.2	18.8
X1	Oscillator 40MHz	35.7	85.7	-34.3	125*	86*	39.0

Table C1 [RD4] Temperature of CPU Board Components