Title: **S2 On Board Time Synchronization**

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Change Record

Issue	Date	Sheet	Description of Change
1	16.06.2008	all	first issue
2	18.09.2008	all	• Update after internal review • Added time synchronisation failure cases
3	27.07.2009	all	Note: This issue of the document contains no change bars against previous issue 3 because of major changes to document structure and contents. Update of document according to the disposition of the following S2 System PDR RIDS: • SEAO-79 • SEAO-134 • SEAO-327 In particular, update of document including: • Description of individual units using LOBT and synchronised to COBT; • Definition of COBT Synchronisation Modes and corresponding mode transitions; • Refinement of COBT “Time/Sync Quality” byte contents for individual Synchronisation Modes; • Description of IMU time tag provision; • Definition of COBT and LOBT failure cases and detection mechanisms; • Description of the RTC feature provided by the OBC to the CSW; • Section discussing relevant system requirements and how they are implemented; • On-board time correlation by Ground.

Issue	Date	Sheet	Description of Change
4	17.08.2010	all	Update of document according to the disposition of the following S2 CSW V2 SRR RIDs: • RID-78 • RID-79 • RID-80 • RID-125 Update of document including: • Definition of LOBT "Time/Sync Quality" byte for LCT/OCP • Identification of Time Synchronisation requirements on the CSW (Section 3) • Tracing of SRS requirements related to time management and synchronisation • Update of the Time Synchronisation mode transitions • Document is now maintained within a DOORS module, therefore there are no changebars included against the previous issue of this document
5	18.10.2010	all	Update of document for CSW V3: • Refinement of Section 5.1
6	07.07.2011	all	Update of document for CSW V3 PDR: • Refinement of of table in Section 5.1 • Reworded requirement OBTM-650 in section 3.3.2 • Added requirement OBTM-1149 in section 3.3.2 • Added figure with CSW specification tree in section 1.5

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1 INTRODUCTION

1.1 Scope of the Document

This document defines the detailed of On-Board Time Management and Synchronisation concept to be implemented within the Sentinel-2 satellite, including the interface to the LOBT users.

In addition it provides requirements for the CSW supplier on OBC and unit time management.

The following technical aspects are addressed:

- Definition of relevant time formats and time synchronisation quality/status information;
- Definition of COBT Synchronisation Modes;
- Initialisation of COBT by ground command;
- Synchronisation of COBT to GPST when the GPSR is switched-on;
- Internal Synchronisation of COBT within the three OBC OBTs when the GPSR is unavailable;
- Synchronisation of units LOBT to COBT using either a PPS signal or MIL-Bus Major Frame as synchronisation mechanism;
- Synchronisation error handling of COBT, including the three OBC OBTs;
- Synchronisation error handling of LOBT.

Note: The Level-1B Processor is outside the scope of the ASD Sentinel-2 contract and therefore not addressed within this technical note.

Note: Earlier issues 1 and 2 of this document were made applicable to local time users. Since the relevant requirements are included in the relevant equipment specifications, recent issues (Issue 3 and later) are no longer applicable to on-board unit suppliers but only to the CSW supplier.

1.2 References

1.2.1 Applicable Documents

[AD1]	System Requirements Document	S2-RS-ESA-SY-0001
[AD2]	MIL-Bus Protocol Specification	GS2.RS.ASD.SY.00005
[AD3]	CCSDS Un-segmented Time Code Standard	CCSDS-301.0-B-3

1.2.2 Reference Documents

[RD1]	Abbreviation List	GS2.LI.ASD.SY.0001
[RD2]	Packet Utilisation Standard	GS2.STD.ASD.SY.00001
[RD3]	OBC User Manual	GS2.TN.RSE.OBC.00015
[RD4]	GPRS Software User Manual	S1-MA-AAE-SC-00001
[RD5]	MSI S2 Source Packet Dating Budget	GS2.TN.ASF.MSI.00059
[RD6]	VCU Technical Budgets Report	GS2.RP.JOP.MSI.22016

[RD1]	Abbreviation List	GS2.LI.ASD.SY.0001
[RD7]	MSI On-Board Time, Synchronisation and Datation	GS2.TN.JOP.MSI.22002
[RD8]	Satellite Design Description	GS2.RP.ASD.SY.00024
[RD9]	Astrix 200 Space Inertial Measurement Unit Technical Description	FOG.NT.281.T.ASTR
[RD10]	GPSR Command and Housekeeping Data Interface Specification	S1-IF-AAE-SC-0001

1.3 Definitions

1.3.1 General Terms

Clock Synchronisation. To synchronise means to set two clocks to have one and the same clock reading within a defined error bound (i.e. $t_{clk1} = t_{clk2} + \varepsilon$) at a given instant;

Clock Correlation. To correlate means to establish a relationship between two clocks such that it is possible to determine the value of one clock from the value of the other clock (i.e. to determine $f(t_{clk2})$ where $t_{clk1} = f(t_{clk2})$).

Direct Synchronisation overwrites the existing OBT value with a new value. This method corrects the OBT skew instantaneously but results in jumps in the OBT reading either forward or backward.

MIL-Bus Time-Broadcast Message. The CSW running on the OBC distributes the COBT using the MIL-Bus Time-Broadcast Message. This message is represented by a MIL-Bus broadcast receive command to SA29R and it is sent at least 200 milliseconds before start of the next major frame.

Spacecraft Elapsed Time (SCET) starts at power-on of the satellite and simply counts the seconds since power-on.

Smooth Synchronisation adjust the OBT module clock frequency by setting the NCO thus compensating for initial and ageing effects on clock drift. This method avoids jumps in the OBT reading.

1.3.2 Time References

CCSDS Unsegmented Time Code (CUC). The time from a defined epoch in seconds coded on 4 octets and sub-seconds coded on 3 octets.

$$\text{Time} = C_0 * 256^3 + C_1 * 256^2 + C_2 * 256 + C_3 + F_0 * 256^{-1} + F_1 * 256^{-2} + F2 * 256^{-3}.$$

Central On Board Time (COBT) is the time maintained by the On-Board Computer (OBC) and is the time reference for all spacecraft on-board activities including time-tagged command scheduling and telemetry packet time stamping (both instrument data and house keeping telemetry).

Coordinated Universal Time (UTC) is maintained by the Bureau International des Poids et Mesures (BIPM) and follows TAI exactly except for an integral number of leap seconds which are introduced to comply with the international agreement that UTC is kept within 0.9 seconds of UT1. Leap seconds are inserted on the advice of the International Earth Rotation Service (IERS) nominally up to twice yearly, during the last minute of the day of June 30 and December 31. In exceptional cases it is also possible to introduce them during the last minute of the day of March 31 and September 30 (although so far this has never been done). On the day when an adjustment is made the last minute of the day will have either 59 or 61 seconds. UTC is the modern successor of Greenwich Mean Time, GMT, which was used when the unit of time was the mean solar day. For most practical purposes, UTC is equivalent to mean solar time at the prime meridian (0° longitude) such that on average the Sun is overhead within 0.9 seconds of 12:00:00 UTC on the meridian of Greenwich.

The relationship between UT1, UTC, TAI and GPS is illustrated in Figure 1.3-1.

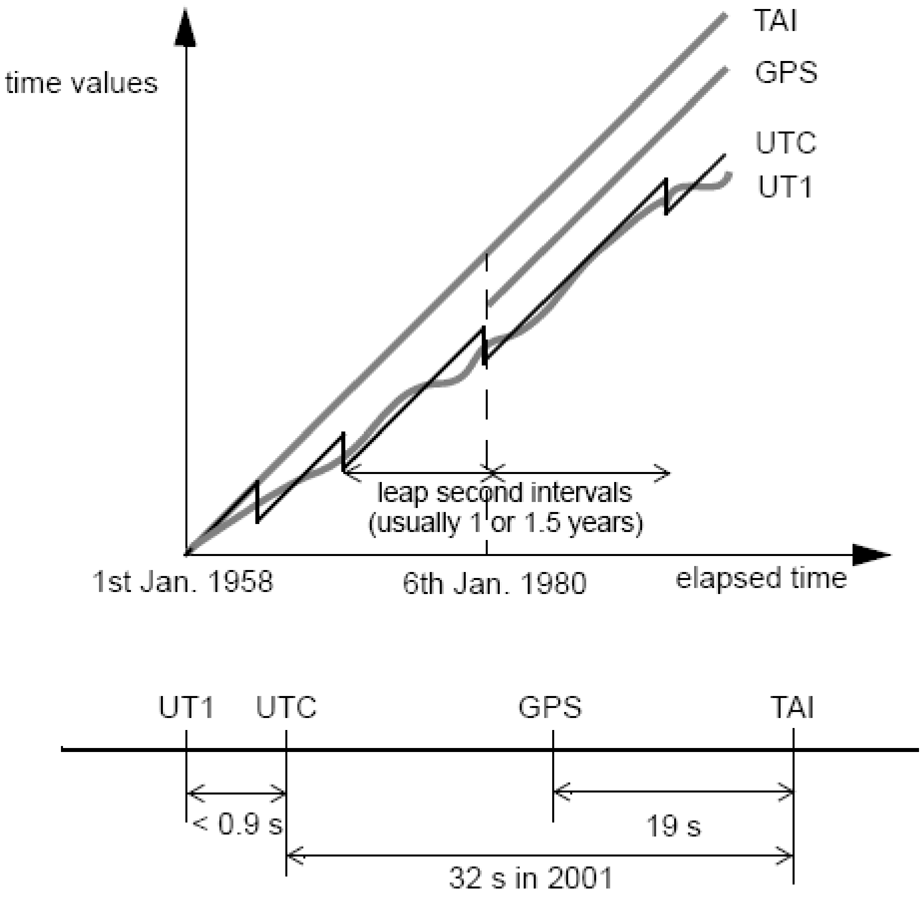


Figure 1.3-1: UT1, UTC, TAI and GPS relationship

Extended GPS Time Format (EGPSTF). This is similar to GPSTF but with the Week Number extended to 32 bits allowing incorporation of the GPS Epoch which is incremented by wrap around of the GPSTF Week Number. The Time Of Week unit is seconds rather than 1.5 seconds. The GPS satellites do not support EGPSTF so the Epoch must be set within the GPS Receiver by the ground.

GPS Time (GPST) is referenced to a UTC zero time-point defined as midnight on the night of January 5 1980 / morning of January 6 1980. GPST increments with TAI. GPST lags TAI by 19 seconds with an error of less than 1 microsecond.

GPS Time Format (GPSTF). The GPS System provides time information in the form of a Week Number, WN, (in the range 0 to 1023 and coded on 10 bits) and Time Of Week, TOW, (in the range 0 to 403199 periods of 1.5 seconds and coded on 19 bits). Consequently the GPST provided by the GPS System wraps around every 1024 weeks (about once per 20 years). The last wrap around of GPST was on 22nd August 1999 and the next wrap around of GPST will be on 7th April 2019. Each period of 1024 weeks is known as a GPS Epoch.

International Atomic Time (TAI) is calculated by the Bureau International des Poids et Mesures (BIPM) from the readings of more than 200 atomic clocks located in metrology institutes and observatories in over 30 countries around the world. TAI is made available every month in the BIPM Circular T. It is estimated that TAI does not lose or gain with respect to an imaginary perfect clock by more than about one tenth of a microsecond (10-7 seconds) per year. Its fundamental unit is exactly one Systeme International (SI) second at mean sea level where the SI second is defined as the duration of 9,192,631,770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium 133. TAI is a constant and continuous time scale with a zero reference time of zero hours on 1st January 1958.

Local On Board Time (LOBT) is the time maintained by the individual on-board units, for example GPSR, MMFU, STR, and VCU.

Master TTRM OBT. The OBC provides two hot powered on-board timers in the TTRM module. The CSW selects one of the two TTRM timers to be the master (Master TTRM OBT) while the other timer serves as a slave (Slave TTRM OBT).

PM OBT. Each of the two cold-redundant OBC Processor Modules (PM) provides a on-board timer (PM OBT). The PM OBT of the active PM represents the COBT.

Slave TTRM OBT. The OBC provides two hot powered on-board timers in the TTRM module. The CSW selects one of the two TTRM timers to be the master (Master TTRM OBT) while the other timer serves as a slave (Slave TTRM OBT).

1.4 Abbreviations

General abbreviations are defined in [RD1].

Specific abbreviations used in this document are given below.

CUC	CCSDS Unsegmented Time Code
COBT	Central On-Board Time
FOG	Fiber Optic Gyroscope
LOBT	Local On-Board Time
MIL-Bus	MIL-STD-1553 Digital Internal Time Division Command/Response Multiplex Data Bus
NCO	Numerical Controlled Oscillator
OBC	On-Board Computer
OBT	On-Board Timer
TM	Telemetry
PPS	Pulse per Second
PVT	Position Velocity Time
SIA	Sagnac Interferometer Assembly
SCET	Spacecraft Elapsed Time

1.5 Applicability

This technical note is applicable to the Sentinel-2 system-level and the Central Software (CSW).

This technical note also describes LOBT management of the following Sentinel-2 on-board units:

•Global Positioning System Receiver (GPSR);

•Star Tracker Electronics (STRA-E);

•Mass Memory & Formatting Unit (MMFU);

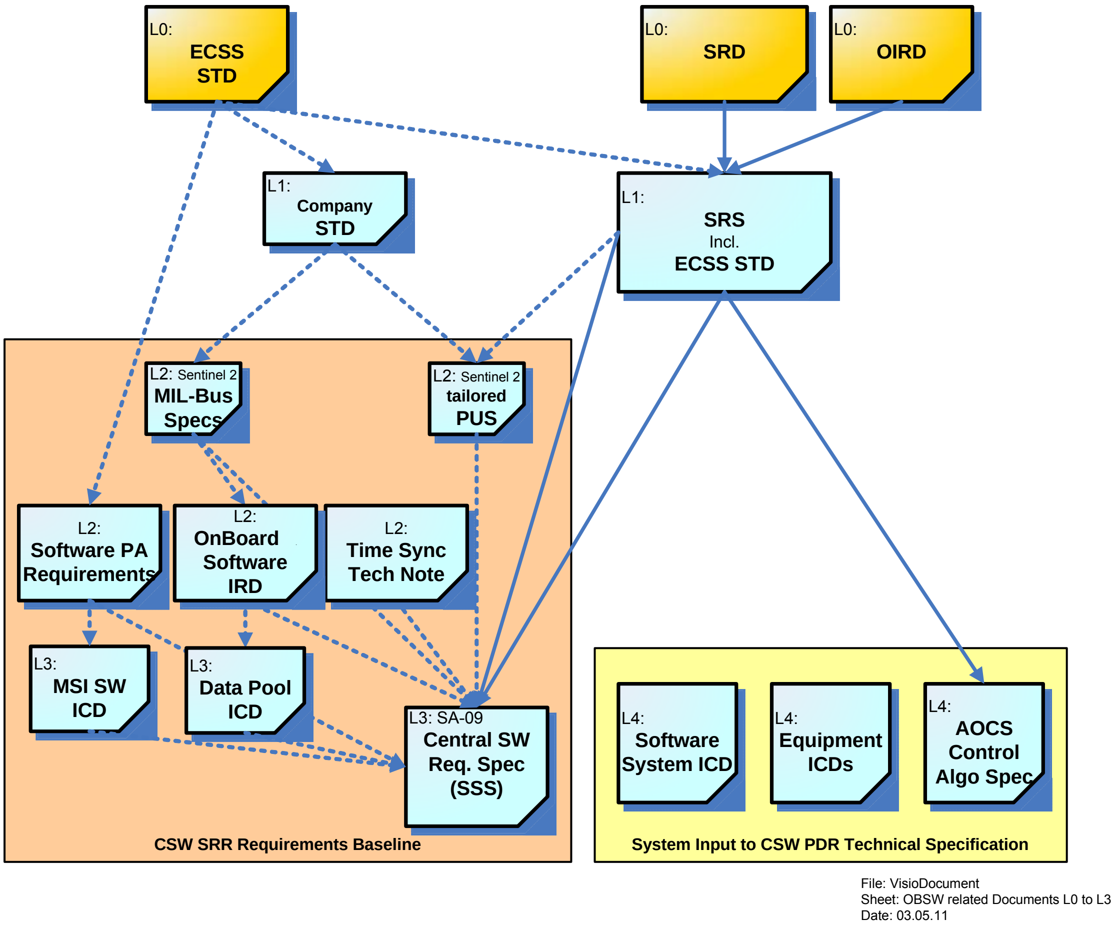
•Multi-Spectral Imager (MSI);

•Laser Communication Termical (LCT).

Note: LOBT management requirements for on-board units are defined in the relevant equipment specifications.

Requirements related to on-board time management and synchronisation for units are defined in the individual equipment specifications.

The following figure shows the CSW specification tree, including this document.



2 ON-BOARD TIME MANAGEMENT

This section provides an overview of the Sentinel-2 on-board time management concept and of CSW and the various on-board units involved.

In the following, the specific On-Board Time synchronisation design considerations are provided.

MSI related trades are provided in the technical note GS2.TN.JOP.MSI.22002.

2.1 System Overview

The Satellite on-board time system consists of the following main entities:

- An absolute time provider, the GPS Receiver (GPSR), issuing a 1 Hz synchronisation signal (GPSR Sync Pulse) identifying the GPS time (GPST) system at second roll-over and a GPS time message as part of the Time Correlation Packet;

- A Central On-Board Time (COBT), maintained by the Central Software (CSW) running on the on-board computer (OBC). The CSW distributes the COBT across the satellite by sending on-board time synchronisation messages via the MIL-Bus and PPS signals (OBC PPS) to local units;

- A number of satellite on-board units, which represent datation users, each comprising a Local On-board Time (LOBT) function for standalone operation. The unit synchronises its LOBT with COBT in order to ensure consistent and full performance operation.

There are two classes of datation users defined depending on the accuracy of the synchronised operation:

- Class A datation users will be synchronised by dedicated HW line, the PPS signal;

- Class B datation users will be synchronised by communication protocol embedded synchronisation reference, which is the start of the major frame of the MIL-Bus Protocol.

The COBT is distributed as part of the on-board time synchronisation message, which is provided before the next synchronisation reference signal and contains the time of the next synchronisation reference. Depending on the datation user the reference signal can be represented by either of the following sources:

- Class A datation user: the PPS signal from the OBC;

- Class B datation user: the major frame start of the MIL-Bus Protocol.

In addition to the COBT maintained by the OBC, the following satellite units maintain a LOBT and are synchronised to the COBT:

- Global Positioning System Receiver (GPSR);

- Star Tracker Electronics (STRA-E);

- Mass Memory & Formatting Unit (MMFU);

- Multi-Spectral Imager (MSI);

- Laser Communication Termical (LCT);

The purpose of each individual unit is described in the following section.

The following on-board units, shown in dark gray in the Figure below, do not maintain a LOBT according to the format defined in this technical note:

- The Remote Interface Unit (RIU) does not provide a datation of the generated TM packets. Therefore, the CSW has to provide a timestamp for the data in the TM packet received from the RIU based on the COBT value when the TM acquisition packet has been send to the RIU;

•The Inertial Measurement Unit (IMU) generates a datation information, called “Time Tag”, along with each angle value measured at reception of a 10PPS (10 Hz pulse from the OBC) and includes this time tag in the IMU Inertial Telemetry. Note: the 10PPS is synchronised to the PPS inside the OBC.

During nominal operation, the COBT is synchronised to GPST and the LOBT of each unit is synchronised to COBT.

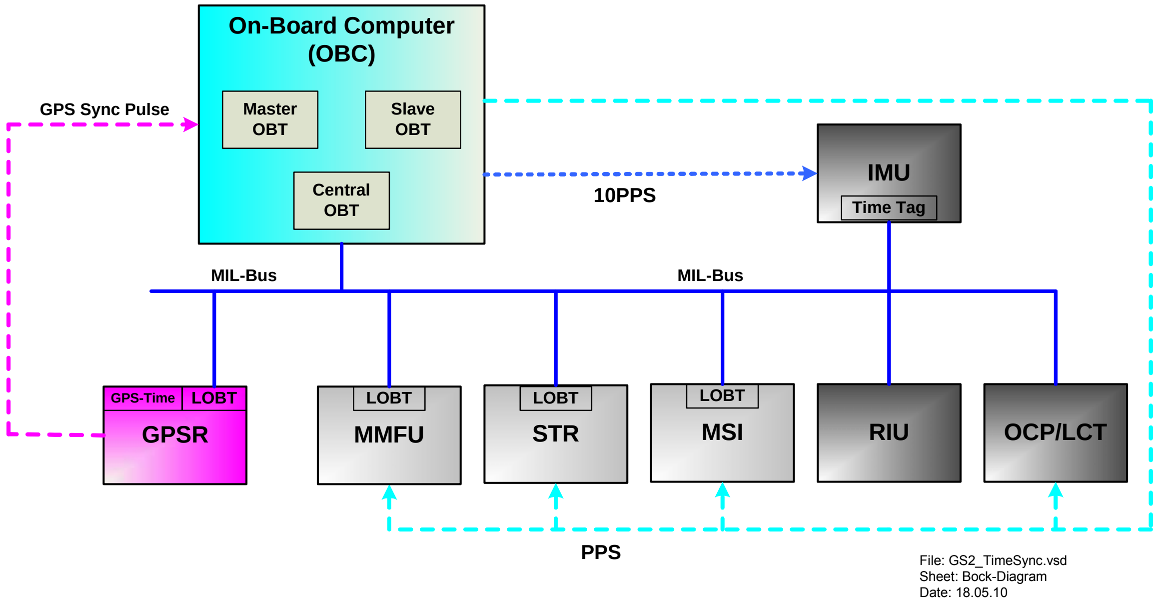


Figure 2.1-1: Overview of nominal time synchronisation of the COBT and unit LOBT with GPST using the periodic GPSR Sync Pulse

2.2 Unit Descriptions

2.2.1 On-Board Computer (OBC)

The OBC implements the timing and synchronisation function by providing three on-board timers (OBT) running in parallel:

•Two hot-redundant on-board timers in the TTRM module;

•A single cold powered on-board timer in the active processor module.

The PM OBT can be kept in sync with the Master TTRM OBT or used standalone.

Since the PM OBT can be accessed much faster by the CSW than the two hot redundant TTRM OBTs, it is used in all software operations that need to sample the COBT.

The OBTs provide the following main functions:

•Maintaining an on-board time counter;

•Supporting synchronisation to an incoming pulse received from the GPSR;

•Direct or smooth synchronisation modes;

•Synchronisation signals outputs;

•Sampling of internal events like software requests and TM frame start.

The OBC OBT functions are based on hardware time counters using the CCSDS Unsegmented Time Code (CUC) format.

In order to be able to use a non-power-of-2 input clock, the OBC uses Numeral Controlled Oscillators (NCO) for generating the clock to the individual OBT counters. The CSW can adjust the NCO value to handle different ratios between the power-of-2 OBT clock and the source clock. The source oscillator of the OBC has a 20 MHz clock and the nominal NCO value is set to 0.8388608 to give a 2^{24} Hz output. The NCO register is 28 bits wide, thus giving a resolution of:

$$\frac{20\,MHz}{2^{28}} = 74{,}505\,mHz$$

In case an external synchronisation pulse is not available, one of the two TTRM timers is chosen to be the master (Master TTRM OBT) while the other timer serves as a slave (Slave TTRM OBT). By default, the TTRM providing the Master TTRM OBT is selected according to the active TM Encoder selection status in the TTRM. The CSW synchronises the Slave TTRM OBT to the Master TTRM OBT by adjusting the NCO of the slave clock. Similarly, the on-board timer of the active processor module (PM OBT) is synchronised with the Master TTRM OBT. This PM OBT represents the COBT, which the CSW distributes to all units maintaining a LOBT.

The OBC generates the OBC PPS when the sub-seconds of the COBT wrap-around and reach 0.

In case an external synchronisation pulse is available from the GPSR, these pulses are used as synchronisation reference and all OBC OBTs are adjusted accordingly.

The OBC distributes the COBT every second to all other units via MIL-Bus broadcast receive command to SA29R, as defined in the MIL-Bus Protocol Specification [AD2].

The OBC also provides the OBC PPS and the Major Frame sync to the related units. These signals are used for the synchronisation of the units, depending on the datation user class assignment.

An overview of OBC PPS signal routing is shown in OBTM-1002.

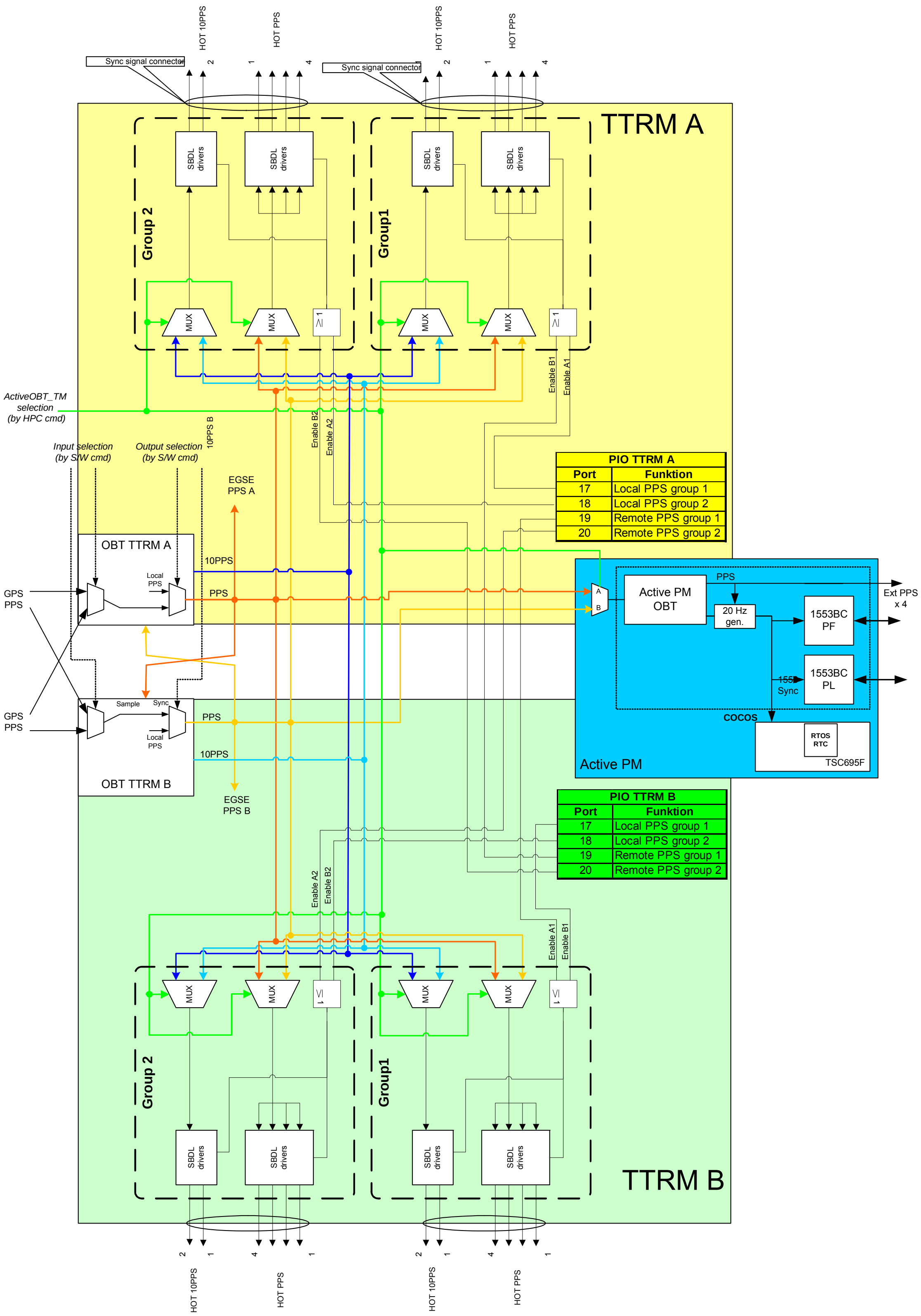


Figure 2.2-1: OBC PPS Routing Overview

2.2.2 Global Positioning System Receiver (GPSR)

The Global Positioning System (GPS) is a space-based radio-navigation system managed and operated by the United States Government.

The GPSR receiver is a dual-frequency (L1, L2) GPS navigation receiver for real-time navigation and Precise Orbit Determination. It acquires and tracks carrier phases and C/A - and P(Y)-code of up to 8 satellites simultaneously and provides an accurate time reference related to GPS time (GPST) and a Pulse Per Second (GPSR Sync Pulse) signal generated at a rate of 1 Hz is used to synchronise the COBT to GPST. On board are two GPSR running in cold redundancy.

The GPSR maintains three time bases:

- The GPS Time (GPST) is the GPS System Time derived from the GPS signals processed; this seconds/sub-seconds counter starts at the reference date 06.01.1980, 0:00:00h;
- The Local on-board time (LOBT) using a CUC-based time format. The LOBT is not derived from the GPST but received via MIL-Bus from the OBC. The LOBT is provided in the Data Field Header of every PUS packet used for telemetry;
- The Instrument Measurement Time (IMT), which is used for internal purposes.

2.2.3 Inertial Measurement Unit (IMU)

The acquisition inertial data measurements (angular increment register frozen) from the IMU is synchronised with an external synchronisation signal (called 10PPS), which is distributed by the OBC at a rate of 10 Hz to each of the IMU channel electronics (GEUs).

Inertial data measurement acquisition (angular increment register frozen) is synchronised with the external synchronisation signal with the following accuracy (see [RD9]):

- Synchronisation between channels (considering that synchronisation signal occurs simultaneously on all channels) is better than 11 microseconds;
- The delay between synchronisation signal reception and axis measurement is less than 30 microseconds.

The IMU generates a datation information, called “Time Tag”, along with each angle value. This datation is based on the FOG loop oscillator, whose frequency is precisely matched with the SIA's own frequency.

The IMU Time Tag TM field is included in the IMU Inertial Telemetry and is 2 x 16 = 32 bits wide, thus providing a resolution of about 72 nanoseconds. The stability of the IMU Time Tag counter is better than 25 ppm.

2.2.4 Star Tracker Electronics (STRA-E)

The ASTRO-APS system is a autonomous star tracker that autonomously provides high accurate 3-axis attitude information with regard to the J2000 inertial reference frame and 3-axis angular rate measurements of the satellite body system.

The star tracker time tags the measured quaternion with an accuracy of < 1 millisecond. The output TM data is time tagged using the STR LOBT with 4 byte coarse and 3 byte fine time. The internal time data structure omitts the last significant byte.

Time synchronization by the OBC is performed by sending a new time value to the STR (via MIL-Bus Time-Broadcast to SA29R). The new provided COBT will become valid, i.e. will become the new LOBT, upon reception of the next external synchronization pulse (1pps pulse).

If no COBT has yet been received by the STR since the last boot or if the 1pps synchronization fails, the time stamp in the DFH of all TM packets delivered by the STR will denote the time elapsed in the STR since last boot and the TimeSync/Quality field of the DFH will be set to indicate ‘SCET’.

STR measuremet data are tagged with a time tag giving the time elapsed relatively in milliseconds, starting from the last received PPS to the centre of the integration time window from which the star centroids and quaternion data respectively were derived.

2.2.5 Mass Memory & Formatting Unit (MMFU)

The Mass Memory Formatting Unit (MMFU) comprises the following main functions:

•Acquire, store and protect the mission data generated by the payload instrument as well as satellite housekeeping data provided by the Onboard Computer (OBC); and

•Retrieve, encode, format and transmit stored instrument and satellite Housekeeping data to the Payload Data Transmission (PDT) subsystem via dedicated communication links for subsequent downlink to earth.

2.2.6 Multi-Spectral Imager (MSI)

The Sentinel 2 Multi Spectral Instrument (MSI) is a push-broom instrument based on a Three Mirror Anastigmat (TMA) optical design to provide a wide field of view of 20.6° and a swath width of more than 290 km.

The MSI provides four interfaces, two at each VCU in order to provide redundancy, to receive time synchronisation pulses from the Spacecraft. The time synchronisation is realised by means of PPS signals.

2.3 Time Format Definition

2.3.1 On-Board Time Format

The On-Board time format for all units (LOBT) and the OBC (COBT) are according to *CCSDS Unsegmented Time Code (CUC)*, see [AD 3].

Note: This time format enables the COBT to count continuously; i.e. there will be no jumps due to leap seconds.

The CUC time format for timers with high sub-second resolution is as defined in the table below.

Note: It is used for the COBT in the OBC and for the LOBT of MMFU and MSI.

Format for COBT and LOBT	Resolution	Range (hex)	LSB
Seconds	32 bit	0 to FF.FF.FF.FF	1 second
Sub-Seconds	24 bit	0 to FF.FF.FF	app. 0,0596 µs

Table 2.3-1: Time Format of the COBT and LOBT

The CUC time format for timers with lower sub-second resolution is shown in the table below.

Format for units with short LOBT	Resolution	Range (hex)	LSB
Seconds	32 bit	0 to FF.FF.FF.FF	1 second
Sub-Seconds	16 bit	0 to FF.FF	app. 15,26 µs

Table 2.3-2: Time Format of the short COBT and LOBT

Note: The coarse seconds part wraps around about every 136 years. The CUC P-Code is 0010_1110 bin.

The short COBT and LOBT CUC format representation provides a sufficient resolution for the datation of HK telemetry and MTL time tagging, since a 2 byte sub-seconds field supports a resolution of 15.26 microseconds.

This resolution is sufficient to fulfil the time resolution requirement stated in CDH-FUN-200.

The following table summarises the time format (LOBT or otherwise) of each relevant satellite unit:

Unit	Format	Synchronisation Mechanism
GPSR	32-bit seconds, 16-bit sub-seconds	MIL-Bus Major Frame
IMU	32-bit local counter with 72 nanoseconds resolution (no LOBT)	OBC 10PPS
STR (PUS protocol)	56-bit unsigned integer CUC format, b_0-b_{31} = seconds part b_{32}-b_{55} = subseconds part	OBC PPS
STR (internal application data stuctures)	48-bit unsigned integer CUC format, b_0-b_{31} = seconds part b_{32}-b_{47} = subseconds part	OBC PPS
MMFU	32-bit seconds, 24-bit sub-seconds	OBC PPS
MSI	32-bit seconds, 24-bit sub-seconds	OBC PPS
OCP/LCT	32-bit seconds, 16-bit sub-seconds	OBC PPS

Table 2.3-3: Summary of Time Format and Synchronisation per On-Board Unit

2.3.2 On-Board Time Epoch Definition

The on-board time is derived from the GPSR and therefore the zero time-point reference of the COBT is the same as of the GPST, i.e. midnight on the *night of January 5 1980 / morning of January 6 1980*.

2.3.3 On-board Time/Sync Quality Byte

The sync-status of each unit will be reported together with each TM packet time-stamp inside the Data Field Header in the “Time/Sync Quality” byte. The format and contents is defined by the following table.

Bit	Description	**Value** COBT	**Value** LOBT	**COBT** Bit Transition Condition
0	Not used; spare	N/A	N/A	N/A

Bit	Description	**Value** COBT	**Value** LOBT	**COBT** Bit Transition Condition
1	Not used; spare	N/A	N/A	N/A
2	Not used; spare	N/A	N/A	N/A
3	Time Type	0 = SCET after boot 1 = OBT	0 = SCET 1 = OBT	0 to 1: Ground issues TC(9,128) "Set Central OBT" or Master TTRM OBT greater than or equal to Initial COBT
4	Sync Source	0 = Internal 1 = External	0 = Internal 1 = External	0: GPS synchronisation lost 1: GPS synchronisation established or commanded by TC(9,133)
5	Sync Method	1 = 1Hz Pulse	0 = Major frame 1 = 1Hz Pulse	Set to 1 for COBT always
6	Sync Status	0 = NoSync 1 = Synchronised	0 = NoSync 1 = Synchronised	0: No GPS synchronisation 1: GPS synchronisation established
7	Sync Ena/Dis	0 = Disabled 1 = Enabled	0 = Disabled 1 = Enabled	0: TC(9,134) received 1: TC(9,133) received

Table 2.3-4: Format of the COBT and LOBT "Time/Sync Quality" byte

The following table defines the contents of the COBT "Time/Sync Quality" byte for the individual COBT Synchronisation Modes.

Time Type	Sync Source	Sync Method	Sync Status	Sync Ena/Dis	**Mode Description** (COBT)	COBT Sync Mode
Bit 3	Bit 4	Bit 5	Bit 6	Bit 7		
0 (SCET)	0 (Internal)	1 (1Hz Pulse)	0 (No Sync)	0 (Disabled)	Satellite power-on or Master TTRM OBT less than threshold	INTERNAL_SYNC

Time Type	Sync Source	Sync Method	Sync Status	Sync Ena/Dis	**Mode Description** (COBT)	COBT Sync Mode
1 (OBT)	0 (Internal)		0 (No Sync)	0 (Disabled)	TC(9,128) received from ground or Master TTRM OBT greater than thresholdor TC(9,134) received from ground	
1 (OBT)	0 (Internal)		0 (No Sync)	1 (Enabled)	TC(9,133) received from ground No Sync Pulses from GPSR	WAIT_FOR_GPS
1 (OBT)	1 (External)		0 (No Sync)	1 (Enabled)	Sync Pulses received from GPSR but GPSR Quality index below threshold	SYNC_IN
1 (OBT)	1 (External)		1 synchronised with GPSR	1 (Enabled)	COBT synchronised with GPST (GPSR Quality index above threshold)	GPS_SYNC

Table 2.3-5: Contents of the COBT "Time/Sync Quality" byte for individual COBT Synchronisation Modes

Note: The COBT Synchronisation Modes used in the table above are explained in more detail in OBTM-639.

2.4 On-Board Time Correlation to UTC by Ground

2.4.1 Overview

The on-board time correlation concept is based on the time management service defined in the Packet Utilisation Standard [RD2]. The standard Time Report subservice TM(9,2) provides the capability for the generation of Time Reports, such that the satellite time correlation procedures in the Ground segment can be performed. This service has access to Spacecraft Elapsed Time (SCET) after satellite power-on or to the

COBT based on GPST after external synchronisation (either by ground or GPSR).

In order to support the correlation between the COBT and the UTC reference on ground the Telemetry Encoder provides a time strobe synchronised to the first bit of nth VC0 CADU, which is used for sampling the COBT for later insertion into the next Standard Spacecraft Time Source Packet.

TC(9,1) is used to modify the Time Report packet generation frequency. The TC updates

the parameter that determines the generation rate used to sample and downlink the satellite time. Its value shall be in the range [0..8]. The corresponding generation rate is equal to once every 2^{Rate} telemetry transfer frames. This parameter is programmed in the telemetry encoder function of the TFG. At initialisation, the Time Report packet generation is enabled, and the generation frequency is set to 2^5.

2.4.2 Calculation of Time Period between two TM(9,2) Packets

The s-band downlink budget for VC0 is 12 Kbps = 1500 bytes/sec the length of a VC0 transfer frame is 1115 bytes, thus appr. 1.35 VC0 frames are generated in one second in average. Assuming the *generation rate* has been set to 32, a TM(9,2) would be generated with a period of **23.7secs**.

3 CENTRAL ON-BOARD TIME SYNCHRONISATION REQUIREMENTS

This section provides requirements on the CSW regarding On-Board Time Synchronisation.

3.1 Overview

The following COBT Synchronisation Modes exist and are described briefly:

•**INTERNAL_SYNC:** This is the default Mode entered upon PM boot. In this Mode the COBT is not synchronised with GPST and therefore free running. The Master TTRM OBT provides the time reference for the PM OBT (and thus the COBT) and the Slave TTRM OBT for redundancy purposes. The CSW synchronises every second the COBT and also the Slave TTRM OBT to the Master TTRM OBT using the smooth synchronisation algorithm;

•**WAIT_FOR_GPS:** This mode is entered upon reception of a ground request to initiate synchronisation of the COBT with GPST. The CSW monitors the availability of the Sync Pulses from the GPSR. In addition, the CSW monitors the quality index provided by the GPSR against a defined threshold in order to determine as to whether a successful synchronisation of the GPSR with GPST has been established. The CSW synchronises every second the COBT and also the Slave TTRM OBT to the Master TTRM OBT using the smooth synchronisation algorithm;

•**SYNC_IN:** Once both GPSR Sync Pulses are detected and the GPSR quality index is above the defined threshold, the CSW synchronises every second all three OBC OBTs (thus including the COBT) to GPST using the smooth synchronisation algorithm. Once the time difference between COBT and GPST is below 1 microsecond the GPS_SYNC mode will be entered;

•**GPS_SYNC:** The COBT is synchronised to GPST. The CSW continues to perform the smooth synchronisation algorithm for the three OBC OBTs every second. The GPSR quality index must remain above the defined threshold, otherwise synchronisation is considered lost and WAIT_FOR_GPS mode is entered.

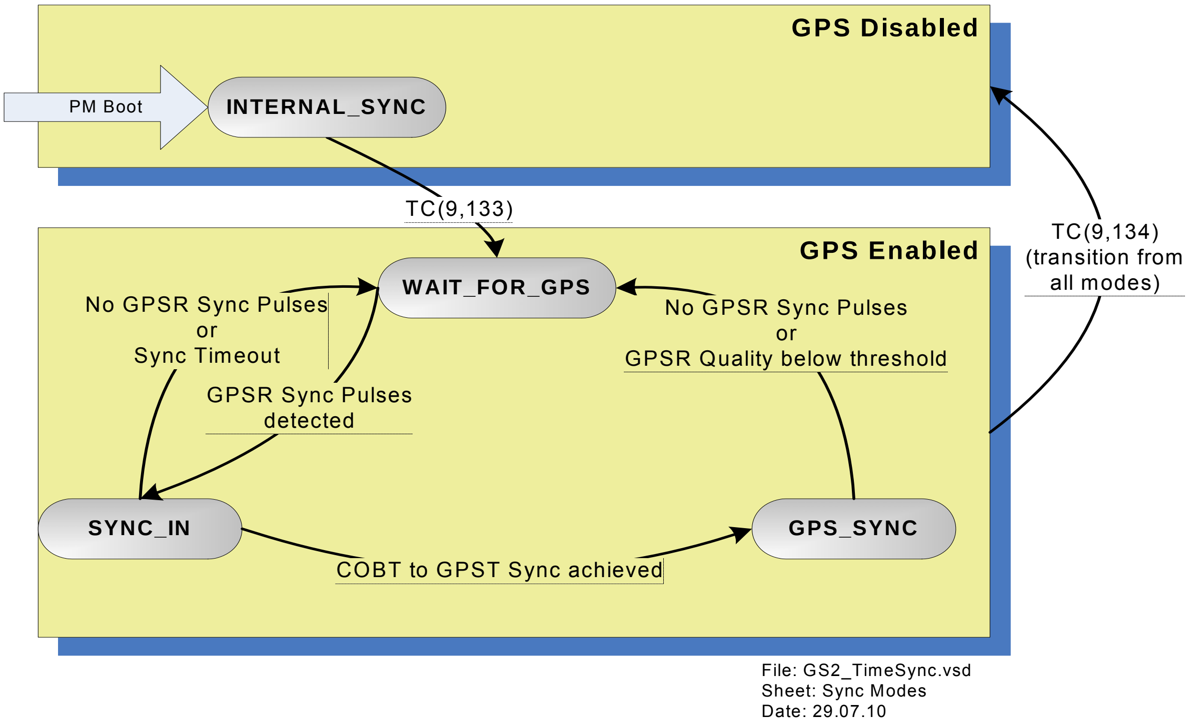


Figure 3.1-1: COBT Synchronisation Modes and Transitions

3.2 COBT Time Format and Epoch

OBTM-1143/SRS-1174,SRS-1208/T

The CSW shall maintain a COBT that will be used to time stamp all time tagged events, mission data, and housekeeping data.

OBTM-1133/SRS-1179,SRS-11780/R

The CSW shall implement a COBT format using 56 bits (32 bits coarse time and 24 bit fine time) according to CCSDS Unsegmented Time Code (CUC), *see [AD 3]:*

•*Coarse Time: full seconds coded on 4 octets C_0 to C_3;*

•*Fine Time: sub-seconds coded on 3 octets F_1 to F_3.*

Time from Epoch:

$= C0 * 256^3 + C1 * 256^2 + C2 * 256 + C3 + F0 * 256^{-1} + F1 * 256^{-2} + F2 * 256^{-3}$

Note: See also OBTM-441.

OBTM-1134/SRS-1174/R

The CSW shall use the PM OBT using PmObt_GetPmObt HDSW service as the only source for sampling the COBT.

Note: That means that the Master TTRM OBT and Slave TTRM OBT are used as reference clocks for time synchronisation and initial time source only.

OBTM-1140/SRS-1209/R

The CSW shall use as COBT epoch the initial GPS epoch, i.e. midnight on the night of January 5, 1980 to January 6, 1980.

3.3 COBT Synchronisation without GPSR

3.3.1 General

OBTM-658/SRS-1181/T,A

The CSW shall be designed such that time jumps larger than 1 millisecond per second in the COBT cannot occur unless commanded by Ground.

OBTM-1058//T

The CSW shall use the smooth synchronisation algorithm provided in the OBC HDSW in order to synchronise the PM OBT and Slave TTRM OBT to the Master TTRM OBT.

3.3.2 COBT Initialisation

OBTM-991//T

After PM boot, the CSW shall enter the synchonisation mode INTERNAL_SYNC.

OBTM-1149//T

The CSW shall enable the generation of the following PPS signals to external units (LOBT users):

•Master TTRM PPS (local group 1 and 2);

•Master TTRM 10PPS;

•PM PPS.

OBTM-650//T,R

The CSW shall perform the following steps upon PM (re-)boot in order to synchronise the used PM OBT and Slave TTRM OBT to the Master TTRM OBT:

•Enable and route the PPS signal of the TTRM OBT selected as active TM Encoder (i.e. Master TTRM OBT) to the used PM;

•Read the Master TTRM OBT;

•Set the Slave TTRM OBT to the Master TTRM OBT value;

•Set the used PM OBT (and thus the COBT) to the Master TTRM OBT value;

•Start cyclic internal synchronisation of the PM OBT and Slave TTRM OBT to the Master TTRM OBT.

OBTM-656//R

The CSW shall execute the initial PM and Slave TTRM OBT synchronisation to the Master TTRM OBT as quickly as possible in order to minimise the time offsets between the three OBC OBTs.

Note: This initialisation can result in a jump of the coarse time of the PM OBT. Jumps in the fine time of the PM OBT, however, may cause cyclic task overruns or watch dog triggers due to non-deterministic pulse timing.

OBTM-659/SRS-1215/T

The CSW shall set the "Time/Sync Quality" byte in accordance with OBTM-570 (INTERNAL_SYNC Mode).

OBTM-666//T

The CSW supplier shall use default NCO values according to System Software ICD [AD4] for the Master TTRM OBT, Slave TTRM OBT, and PM OBT, respectively.

OBTM-667//T

During initialisation the CSW shall read the default NCO value for the active PM stored in the SGM RAM and set the NCO value for the active PM OBT accordingly.

OBTM-1048//T

At initialisation the CSW shall enable the time report generation with a default rate_value = 5 (2^5= 32).

3.3.3 Internal Synchronisation of OBC OBTs

OBTM-661/SRS-1176/T

The CSW shall perform internal time synchronisation of the three OBC timers (Master TTRM OBT, Slave TTRM OBT, and PM OBT) in case no external synchronisation of the COBT to the GPST is available, for example, due to GPSR unavailability.

OBTM-662//T,R

The CSW shall configure the OBC OBTs as follows for internal time synchronisation:

- *The Master TTRM OBT is free-running using either the default (see below) or last-modified NCO value and provides an OBC internal synchronisation signal to the other two OBTs;*
- *The Slave TTRM OBT is synchronised to the Master TTRM OBT;*
- *The active PM OBT is synchronised to the Master TTRM OBT.*

OBTM-665//T

The CSW shall synchronise both the PM OBT and Slave TTRM OBT to the Master TTRM OBT using a smooth synchronisation algorithm as described in the OBC User Manual [RD3].

OBTM-1032//T,A

The CSW shall be able to operate at full performance with cycle time deviations of up to +/- 10 milliseconds per second.

OBTM-993//T,R

The default maximum value of the cycle deviation (i.e. correction step) between two subsequent Sync Pulses shall be +/- 1 millisecond per second.

OBTM-986//T

The CSW shall store the last used NCO values in the SGM upon user request.

OBTM-1145/SRS-1177/T

After the CSW receives a TC(9,134) “Disable Synchronisation of GPS to OBC time” from Ground, the CSW shall enter the Synchronisation Mode INTERNAL_SYNC.

3.3.4 Synchronisation by Ground Command

At satellite power-on, the OBC is switched-on automatically while the GPSR remains switched-off. The counter values of all three OBTs inside the OBC start counting from zero, i.e. in this case the COBT is represented as Spacecraft Elapsed Time (SCET).

OBTM-671//T

In order to be able to distinguish between SCET and COBT after PM re-boot, the CSW shall compare the Master TTRM OBT value against a predefined threshold.

OBTM-987//T,R

The CSW Supplier shall use the threshold defined in the System Software ICD [AD4].

Note: The threshold is defined such that it is less than any time value possible during Satellite AIT and Operations.

OBTM-988//T

If the Master TTRM OBT value is below the threshold, the CSW shall interpret the Master TTRM OBT as SCET, or COBT otherwise, and shall set the corresponding bit in the Time/Quality Byte accordingly.

Nominally, the Ground segment performs the first on-board time initialisation by using PUS Service TC(9,128) "Set Central OBT" (see [RD2]). The TC(9,128) parameter contains:

•an *absolute time* value (set new OBT action in TC) in order to set the coarse time in CUC-Format (i.e. seconds) that will be valid at the time of the next OBC PPS;

•a *relative time* value (add/subtract delta time from OBT action in TC) in order to set both the coarse and fine time in CUC-Format that will be used to adjust the current COBT at the time of the next OBC PPS.

OBTM-673//T

In case of an absolute time *value, the CSW shall update the COBT using direct synchronisation, i.e. the COBT is overwritten with the new time value (seconds elapsed since Epoch).*

OBTM-674//T

In case of a relative time *value, the CSW shall synchronise both the coarse and fine time of the COBT with the provided relative time correction using a smooth synchronisation algorithm:*

•***add delta time****: adjust Master TTRM OBT NCO to* accelerate *clock;*

•***subtract delta time****: adjust Master TTRM OBT NCO to* decelerate *clock.*

OBTM-996//T

The CSW shall accept a TC(9,128) only while in synchronisation mode INTERNAL_SYNC.

The contents of the COBT "Time/Sync Quality" byte is defined in OBTM-570 (INTERNAL_SYNC Mode).

The Ground segment is expected to ensure that the COBT is set to a time value close (i.e. a few seconds) to the current GPST time before synchronisation is enabled. This is to avoid excessive duration until the coarse time is finally synchronised.

OBTM-1067//T

The CSW shall calculate the offset between the current COBT and the absolute time value sent by Ground.

OBTM-1066//T

The CSW shall send an event TM packet and remain in INTERNAL_SYNC mode in case the given threshold values for relative time correction are exceeded.

3.4 COBT Synchronisation with GPSR

3.4.1 COBT Synchronisation with GPST

OBTM-680/SRS-1177/T

After the CSW receives a TC(9,133) "Enable Synchronisation of GPS to OBC time" from Ground, the CSW shall enter the Synchronisation Mode WAIT_FOR_GPS.

OBTM-992//T

In addition, the CSW shall set the "Time/Sync Quality" byte in accordance with OBTM-570 (WAIT_FOR_GPS).

OBTM-1060//T

The CSW shall determine the time offset between the COBT and the occurence of the GPSR Sync Pulse by reading the PM OBT at the receiption of the GPSR Sync Pulse.

Note: Obviously, there will be a systematic measurement error caused by the latency of the involved HDSW services calls.

OBTM-1062//A

The CSW supplier shall estimate the measurement error and report it in the CSW Budget Report.

OBTM-1144/SRS-1175/T

The CSW shall synchronise the COBT to GPST with an accuracy better than 1 microsecond using a smooth synchronisation algorithm as described in the OBC User Manual [RD3].

OBTM-681//T

The CSW shall route the GPSR Sync Pulse to both the Master TTRM OBT and Slave TTRM OBT once the Master TTRM OBT PPS and the GPSR Sync Pulse are synchronised within 1 microsecond.

OBTM-682//T

The CSW shall check the consistency of a configurable number of GPSR Sync Pulses (Default 4) and the GPSR Quality Index, before it starts adjusting the NCO of the OBC OBTs using the smooth synchronisation algorithm.

OBTM-683//T,R

The CSW shall adjust the NCO not later than 250 ms after the GPSR Sync Pulse is received.

Note: The CSW uses a smooth synchronisation algorithm in order to slowly synchronise the phase of the OBC PPS with the phase of the GPSR Sync Pulse thus avoiding jumps in the time. During the synchronisation, the maximum cycle deviation between two subsequent Sync Pulses is +/- 1 millisecond per second. The maximum difference between the OBC PPS and the GPSR Sync Pulse can be up to +/- 0.5 seconds in case the COBT is not synchronised to GPST. During the smooth synchronisation process, frequency and phase of the OBC PPS are brought in-line with the GPSR Sync Pulse, until they are fully synchronised.

Assuming a max. allowed cycle time deviation of +/- 1 millisecond, this will lead up to 0.5 seconds / 1 millisecond per second = 500 seconds = 8 minutes and 20 seconds until both pulses and also the COBT fine time are synchronised.

OBTM-685//T

In addition to the smooth synchronisation of the COBT fine time (sub-seconds) with GPST, the CSW shall apply the same algorithm to the synchronisation of the coarse time.

OBTM-687//T

The CSW shall make the time difference between the COBT and GPSR Sync Pulse available as datapool parameter.

OBTM-1064//T

The CSW shall record the duration of the smooth synchronisation process while in mode SYNC_IN.

Note: The duration of the smooth synchronisation process as well as the time difference between COBT and GPST will be observed by on-board FDIR.

The GPSR generates every second a dedicated GPSR Time Correlation Packet, which contains the GPST valid at the occurence of the next GPSR Sync Pulse. This GPSR TM packet is distributed via MIL-Bus to the OBC.

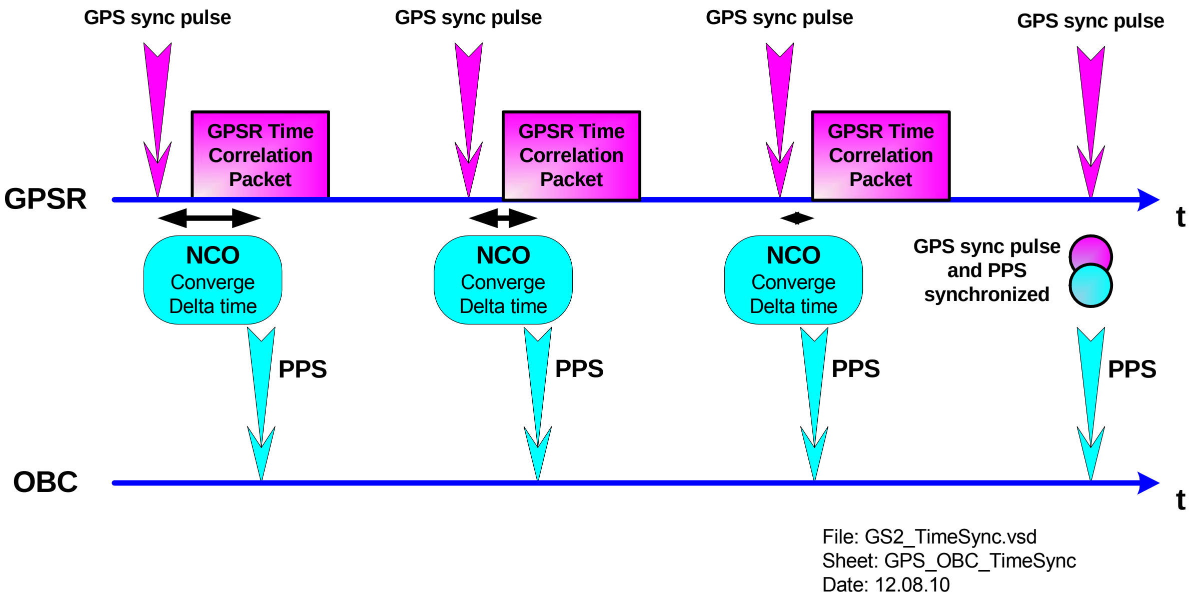


Figure 3.4-1: Synchronisation of OBC PPS with GPSR Sync Pulse using smooth synchronisation algorithm

OBTM-691//T

The CSW shall extract the GPST from the GPSR Time Correlation Packet and calculate the time offset from COBT.

OBTM-1147//T

The CSW shall make the time difference between the COBT and GPST available as datapool parameter.

OBTM-692//T

The OBC PPS will be phase-locked to the GPSR Sync Pulse, as long as the GPSR Sync Pulse synchronisation is considered valid. In this case, the CSW shall enter the COBT Synchronisation Mode GPS_SYNC if GPSR Sync has been enabled by Ground by means of a TC(9,133).

OBTM-994//T

In addition, the CSW shall set the "Time/Sync Quality" byte in accordance with OBTM-570 (GPS_SYNC Mode).

OBTM-693//T

The CSW shall continously check the validity of the synchronisation using the criteria defined in the Section 3.4.2.

OBTM-694//T

The CSW shall reject any TC(9,128) while COBT Synchronisation with GPST is enabled, i.e. being either in WAIT_FOR_GPS, SYNC_IN, or GPS_SYNC synchronisation mode. The CSW shall accept TC(9,128) only in Synchronisation Mode INTERNAL_SYNC.

3.4.2 GPSR Unavailability or GPST Synchronisation Lost

OBTM-696//T

The CSW shall treat the COBT external synchronisation to GPST as being lost by detecting:

- *Whether neither TTRM OBT receives a Sync Pulse from the GPSR (loss of pulse);*

•Whether at least 4 GPSR Sync Pulses are outside the expected time window of 4 ms;

•Whether the GPSR quality index has gone below a configurable quality threshold.

OBTM-701//T

Upon loss of GPST synchronisation, the CSW shall perform the following actions:

•Enter COBT Synchronisation Mode WAIT_FOR_GPS in case GPSR quality index has gone below the given quality threshold;

•Enter COBT Synchronisation Mode WAIT_FOR_GPS in case at least 4 GPSR Sync Pulses are outside the expected time window of 4 ms or there are no GPSR Sync Pulses at all;

•Change the PPS input of both the Master TTRM OBT and Slabe TTRM OBT from GPSR Sync Pulse to the Local PPS provided by the TTRM;

•Continue to synchronise the COBT with the Master TTRM OBT but let the COBT be free running with respect to GPST.

Note: Without GPST synchronisation the maximum clock drift of the COBT is 100 microseconds per second (see [RD3]).

3.5 Real Time Clock (RTC) Provision to the CSW

The OBC PM OBT provides a 20 Hz RTC pulse that is used as an interrupt to the CPU of the active PM. It should be noted that this RTC is different from the RTEMS RTC, which is generated internally in the CPU. This allows the operating system to start before the OBT function has been initialised.

OBTM-637//T,R

The CSW shall synchronise cyclic tasks to the 20 Hz RTC pulse received from the PM OBT.

OBTM-638//T

The CSW shall detect a missing RTC pulse. In case of a missing RTC pulse, the CSW shall raise an event.

Note: The system-level FDIR reaction to this event will be to reconfigure the Slave TTRM OBT as new Master TTRM OBT. If the RTC pulse is still missing after TTRM OBT reconfiguration, a reconfiguration of the PM will be required.

3.6 Time Reporting

OBTM-1142/SRS-11321/T

The CSW shall provide the synchronisation status between the MSI LOBT and COBT, obtained through MSI TM, in the System Data Pool.

OBTM-1146//T

The CSW shall sample the COBT at the TTRM time strobe event and insert the sampled COBT into the next Standard Spacecraft Time Source Packet.

OBTM-1049//T

The CSW shall provide the COBT of the last time strobe as nominal HK.

4 UNIT LOBT SYNCHRONISATION WITH COBT

This section gives an overview of on-board unit time synchronisation. It does not define any requirements applicable to on-board unit suppliers.

4.1 Overview

External time synchronisation is achieved between the following on-board time entities:

•Synchronisation of the COBT to the GPST;

•Synchronisation of each individual LOBT to the COBT.

During nominal operations, the GPSR is in Navigation mode and the time synchronisation of Unit LOBTs to COBT is performed in a two-step-approach:

•The CSW synchronises the COBT to GPST using a smooth synchronisation algorithm;

•The OBC distributes a synchronisation signal (either OBC PPS or MIL-Bus Major Frame) to all units maintaining a LOBT and sends the COBT + 1 second via MIL-Bus Time-Broadcast Message.

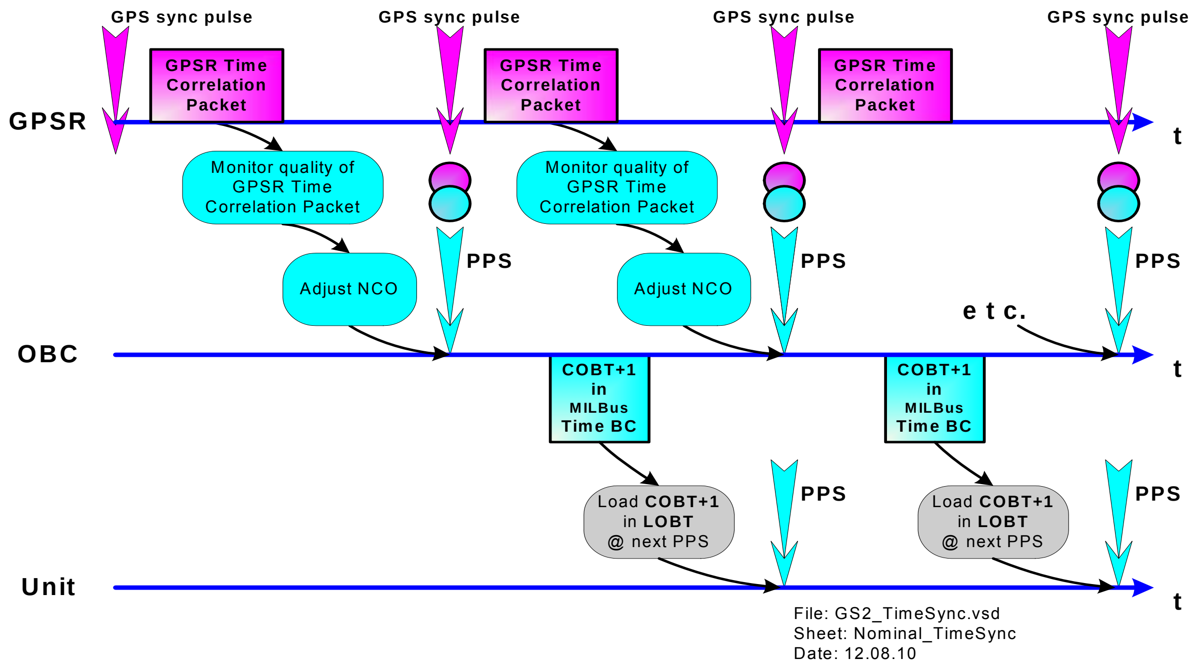


Figure 4.1-1: Time Synchronisation of the COBT and Unit LOBT with GPST using the periodic GPSR Sync Pulse

4.2 GPSR LOBT Synchronisation with COBT

After power-on, the GPSR receives the MIL-Bus Time-Broadcast Message from the OBC. The GPSR reads this Time-Broadcast Message during boot and synchronises its LOBT with this time information at the next MIL-Bus Major-Frame (since there is no PPS reception implemented).

Now the GPSR time-stamps all its TM with the synchronised LOBT. This leads to the ”Time/Sync Quality” byte for the GPSR TM packets as detailed in OBTM-719.

Bit	Description	Value

Bit	Description	Value
0	Not Used	
1	Not Used	
2	Not Used	
3	Time Type	1 = OBT
4	Sync Source	1 = External
5	Sync Method	0 = MIL-Bus Major Frame (always)
6	Sync Status	1 = synchronised with COBT (always, if no error)
7	Sync Ena/Dis	1 = Enabled (always)

Table 4.2-1: GPSR LOBT "Time/Sync Quality" byte after synchronisation with COBT (0x1B)

After about 20 minutes, the GPSR gets in Navigation mode and calculates the GPS Time and the related GPS quality index. Furthermore, the GPSR generates a Sync Pulse every full second and distributes it to the OBC.

4.3 LCT LOBT Synchronisation with COBT

Bit	Description	Value
0	Not Used	
1	Not Used	
2	Not Used	
3	Time Type	0 = SCET
4	Sync Source	1 = External
5	Sync Method	1 = 1Hz Pulse
6	Sync Status	0 = No Sync
7	Sync Ena/Dis	1 = Enabled (always, if no error)

Table 4.3-1: LCT LOBT "Time/Sync Quality" byte contents *before* synchronisation with COBT (0x0D)

Note: The LCT LOBT "Time/Sync Quality" byte contents *after* synchronisation with COBT corresponds to the bit vector defined in OBTM-1071.

4.4 Unit LOBT Synchronisation with COBT

The OBC generates the OBC PPS each full second and distributes it to all units. The CSW reads the COBT valid at the most recent OBC PPS, adds 1 second and distributes this COBT+1 second via MIL-Bus Time-Broadcast Message to all units. At the leading edge of the OBC PPS, each unit receives the MIL-Bus Time-Broadcast Message and synchronises its local timer LOBT with this time information at the next OBC PPS.

Note: The MSI-VCU ignores the MIL-Bus Time-Broadcast Message. Therefore the OBC generates a dedicated MIL-Bus TC with the same time stamp.

At unit power ON, the LOBT of the unit will be first synchronised to COBT, before time-stamping all TM packets. Nominally the unit continues reading and synchronising the LOBT each second.

Bit	Description	Value
0	Not Used	
1	Not Used	
2	Not Used	
3	Time Type	1 = OBT
4	Sync Source	1 = External
5	Sync Method	1 = 1Hz Pulse
6	Sync Status	1 = synchronised with COBT (always)
7	Sync Ena/Dis	1 = Enabled (always, if no error)

Table 4.4-1: Unit LOBT “Time/Sync Quality” byte contents after synchronisation with COBT (0x1F)

5 TIME SYNCHRONISATION ERROR HANDLING

5.1 COBT Synchronisation Error Cases

This section defines FDIR measures related to COBT management and synchronisation and is applicable to CSW Version 3. As far as CSW Versions 1 and 2 are concerned, the contents of this sections shall be regarded as for information only.

The following table identifies failure cases relevant to the COBT and its synchronisation with GPST.

Failure Case	Observability	Measure	Surveillance / Monitor
Master TTRM OBT Excessive Drift	Master TTRM OBT cannot be synchronised to external reference clock (GPSR) within predefined time-period	Reconfigure Slave TTRM OBT as new Master TTRM OBT. Exclude defective OBT from OBC internal synchronisation and declare corresponding TTRM unhealthy	
Slave TTRM OBT Excessive Drift	Slave TTRM OBT cannot be synchronised to Master TTRM OBT within predefined time-period	Exclude defective OBT from OBC internal synchronisation	
PM OBT Excessive Drift	PM OBT cannot be synchronised to Master TTRM OBT within predefined time-period	Reconfigure PM	
GPSR Sync Pulse missing/timeout	The first indication of this failure case is that the PM OBT no longer receives a PPS from the Master TTRM OBT (timeout to be handled by the CSW). If both the Master TTRM OBT and Slave TTRM OBT receive the GPSR Sync Pulse, the PM OBT is in error or the Master TTRM OBT output is in error.	The CSW shall perform the following two-level approach: (1) Reconfigure Slave TTRM OBT as new Master TTRM OBT; (2) If still no PPS is received, the PM OBT must be in error.	

Failure Case	Observability	Measure	Surveillance / Monitor
	Both Master and Slave TTRM OBTs do not receive the GPSR Sync Pulse	GPSR Sync Pulse is lost, e.g. due to GPSR outage. Continue using the PM OBT and Master TTRM OBT in free-running mode using the most recently (i.e. before loss of GPSR synchronisation) NCO settings. CSW shall initiate GPSR reconfiguration via Monitor.	
	Slave TTRM OBT receives the GPSR Sync Pulse but not the Master TTRM OBT. In this case the Master TTRM OBT is in error	Reconfigure Slave TTRM OBT as new Master TTRM OBT. Exclude defective OBT from OBC internal synchronisation and declare corresponding TTRM unhealthy	
GPSR Sync Pulse incorrect timing	GPSR Sync Pulse not received within a 4 milliseconds time window	CSW shall switch to a free running mode 'WAIT_FOR_GPS' using the PM OBT and Master TTRM OBT in free-running mode using the most recently (i.e. before loss of GPSR synchronisation) NCO settings. CSW shall switch over to GPSR-B	
GPSR TM missing or corrupted	TM not received within a 4 milliseconds time window and/or GPST corrupted	CSW shall switch to a free running mode 'WAIT_FOR_GPS' using the PM OBT and Master TTRM OBT in free-running mode using the default NCO settings. CSW shall switch over to GPSR-B	

Failure Case	Observability	Measure	Surveillance / Monitor
No internal PPS Sync (PpsOut from TTR)	Lack of expected SyncPps1 interrupt in the PM OBT Pending Interrupt Register	CSW shall reconfigure Slave TTRM OBT as new Master TTRM OBT	
No internal PPS Sync to/from Slave TTRM OBT	Lack of expected Sample2 interrupt in the TTR OBT Pending Interrupt Register in Slave TTRM		

Table 5.1-1: Overview of COBT Synchronisation Error Cases

5.2 LOBT Loss of COBT Synchronisation

Time synchronisation with COBT of units maintaining a LOBT needs the following two inputs:

•a time stamp (distributed via MIL-Bus);

•a synchronisation signal (OBC PPS or start of MIL-Bus Major Frame).

In case one of these inputs is missing, the unit shall autonomously switch to its local clock (LOBT) and continue incrementing the time locally.

Also, in case of missing or corrupted time broadcast message the unit will autonomously switch to a local clock and continue incrementing the time locally.

The various synchronisation error cases are summarised in OBTM-871.

Function	Failure Case	Detection	Measure
MIL-Bus Time Broadcast	Time stamp missing		The unit shall continue using the LOBT without synchronisation to the COBT
MIL-Bus Time Broadcast	Time stamp transmission error		The unit shall continue using the LOBT without synchronisation to the COBT
MIL-Bus Major Frame	Major Frame missing	After Minor Frame #19, Major Frame #0 is not received MIL-Bus Major Frame not received within 200 milliseconds before its expected arrival	The unit shall continue using the LOBT without synchronisation to the COBT

Function	Failure Case	Detection	Measure
OBC PPS	PPS missing	PPS is not received within 4 milliseconds *after* the expected time of the next PPS	The unit shall continue using the LOBT without synchronisation to the COBT. The unit shall generate a “Missing PPS” event
OBC PPS	PPS spurious	PPS is received before 4 milliseconds *before* the expected time of the next PPS	The unit shall continue using the LOBT without synchronisation to the COBT. The unit shall generate a “Spurious PPS” event In case multiple spurious signals are received within one second, the unit shall generate only one event message.

Table 5.2-1: Overview of LOBT Synchronisation Error Cases

On-Board Units will set the LOBT ”Time/Sync Quality” byte as defined in OBTM-904.

Bit	Description	Value
0	Not Used	
1	Not Used	
2	Not Used	
3	Time Type	1 = OBT
4	Sync Source	0 = Internal
5	Sync Method	1 = 1Hz Pulse
6	Sync Status	0 = NoSync
7	Sync Ena/Dis	1 = Enabled (always, if no error)

Table 5.2-2: Unit LOBT “Time/Sync Quality” byte contents after loss of synchronisation with COBT due to missing PPS signal or missing or corrupted time broadcast message (0x15)

Note: Synchronised operation of any datation user needs to be compatible with a variation of the synchronisation reference signal period of 4 milliseconds of the expected arrival of the synchronisation reference.

6 TIMING AND DATATION ACCURACY REQUIREMENTS

This section provides a discussion of non-functional (mostly quantitative) requirements related to time synchronisation and datation and how they are addressed by the Sentinel-2 system design.

Requirement CDH-FUN-025 of the ESA System Requirements Document [AD1] states:

The Satellite on-board master time shall be synchronised to GNSS time with accuracy better than 1 microsecond.

This requirement is met as long as the COBT, comprised of the three OBC on-board timers, is kept synchronised within 0.5 microseconds to the Sync Pulse provided by the GPSR using smooth synchronisation. The accuracy of the GPSR Sync Pulse versus GNSS time is 0.5 microseconds.

The smooth synchronisation algorithm compensates for oscillator drifts by adjusting the clock rate each time the synchronisation pulse appears. The algorithm uses a Numerically Controlled Oscillator (NCO) that can either speed-up or slow-down the OBT counters advancement with a resolution of 74.5 mHz. The maximum drift of the OBC oscillators, including temperature and ageing, is less than 100 ppm.

In case the Sync Pulse from the GPSR is lost while the COBT has already been synchronised to GPST, the last NCO value (i.e. the most recent clock drift correction) remains in use. This eliminates all initial and ageing effects on clock drift accumulated until GPST synchronisation was lost. The OBC oscillators are now free running and subject to clock drift due to temperature and voltage variation. As far as the on-board time accuracy is concerned in this case, the remaining clock drift due to temperature variation etc. needs to be assessed and provided by the OBC supplier and the expected availability figure for the GPSR taken into account.

Requirement CDH-FUN-060 of the ESA System Requirements Document [AD1] states:

The satellite on-board master time shall not wraparound for 15 years in orbit.

The On-Board Time format for all units is in accordance with the CCSDS Unsegmented Time Code (CUC). The above requirement is met since the CUC time format uses a 4 octets coarse time field for seconds and thus has a wrap-around time of about 136 years ($2^{32} - 2^{-24}$ seconds) since zero time point (Epoch).

Requirement CDH-FUN-075 of the ESA System Requirements Document [AD1] states:

The mission data shall be time-stamped with a knowledge accuracy of 1 microsecond w.r.t. the Satellite On-Board Master Time.

The above requirement will be met by MSI with the following rationale:

- The MSI CUC time information is amended by a time correction figure provided in the CCSDS source packets in order to meet the 50 microseconds datation accuracy requirement stated in the Satellite Requirements Specification;

- A datation accuracy of 1 microsecond will be achieved by providing the scene start time value in the MSI on-board time scale and in addition a time correction value, represented by the difference between the counted time ticks for the current scene and the default number of time ticks between two successive PPS signals;

- Use a correction clock frequency of 1.198375 MHz.

Requirement CDH-FUN-080 of the ESA System Requirements Document [AD1] states:

The correlation from Satellite On-Board Master Time (OBT) to ground UTC will be performed in the TT&C ground station, by correlation of the leading edge of the first bit of the sync word of the S-band telemetry frame to UTC. The inaccuracy of this leading edge as transmitted with respect to the Satellite clock shall be considered as contribution to the Satellite datation budget.

In order to support the correlation between the Spacecraft Elapsed Time and the UTC reference on ground the Telemetry encoder provides a time strobe synchronised to the first bit of nth VC0 CADU, which is used for sampling the OBT for later insertion into the next Standard Spacecraft Time Source Packet.

The table below provides the clock delays in microseconds between the latching of the OBC OBT and the falling edge of the first bit of the Attached Synchronisation Marker (ASM). The clock delay is calculated for combinations of convolutional encoding switched on and off, and for TM symbol rates of 128 kbit/s and 2.048 Mbit/s. The two different downlink data rates can be selected by command. The applied encoding schemes are as follows:

Convolutional Enconding	128kbit/s	2.048 Mbit/s
OFF	42,02	(1,73)
ON	(81,08)	4,17

Note: the values in parentheses do not represent nominal configuration (see [RD08], TFG configuration) and are included for completeness only.

The propagation delay, which is independent from the TM symbol rate, has to be added to the above figures. The propagation delay will be determined during OBC unit test by the OBC supplier.

Requirement CDH-FUN-200 of the ESA System Requirements Document [AD1] states

CDHS shall have the capability to timetag housekeeping data and event reports with (a) a time accuracy better than 4 milliseconds, and (b) a time resolution better than 4 milliseconds.

Each HK TM packet contains a time stamp with a 4 octets coarse time field (seconds) and a 2 octets fine time field (sub-seconds). The fine time field supports a resolution of 15.26 microseconds.

Requirement/Section Cross Reference

Sentinel 2

Distribution Sheet

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