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ROSETTA

Time Handling

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28 Feb 2006	1	1		Correction of the meaning of the fractional seconds in the SPACECRAFT_CLOCK_START/STOP_COUNT (section 4.2). Simplification of Distribution List.	

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1. Introduction

1.1 Purpose

The purpose of this document is to give a clear and comprehensive overview of the time handling in the Rosetta project. This information is distributed over a number of documents where it is given in different contexts, which makes it cumbersome to find and understand for the experiment teams and the science operations team. Thus the present document collects and explains the important topics pertaining to time handling.

1.2 Contents

Chapter 2 describes how the On-Board Time (OBT) is maintained on the spacecraft and how it is correlated to Coordinated Universal Time (UTC). The time information contained in the experiment data packet headers and attached DDS headers is explained.

Chapter 3 gives an overview of the orbit and attitude access software delivered by the DDS. Emphasis is placed on the used time scales and time formats.

Chapter 4 explains how OBT and UTC are specified in PDS labels.

1.3 Applicable Documents

AD1 Rosetta / Mars Express Mission Control System (RMCS/MEMCS) Data Delivery Interface Control Document (DDID), RO-ESC-IF-5003 / MEX-ESC-IF-5003, Iss. B6, 23 Oct 2003.

AD2 Appendix H to AD1, FD Products, Iss. 2, 22 Aug 2003.

AD3 ESA Packet Telemetry Standard, ESA-PSS-04-106, Iss. 1, Jan 1988.

AD4 CCSDS Recommendation for Time Code Formats, CCSDS 301.0-B-3, Blue Book, Iss. 3, Jan 2002.

AD5 Rosetta Experiment Interface Document Part A (EID A), RO-EST-RS-3001, Iss. 2.1, 1 Oct 2000.

AD6 Planetary Data System Standards Reference, JPL D-7669, Part 2, Version 3.6, 1 Aug 2003.

1.4 Reference Documents

RD1 Time Standards Overview, SOP-RSSD-TN-014, Iss. 2.1, 8 Jul 2003.

1.5 Acronyms

AD	Applicable Document
APID	Application Process ID
CCSDS	Consultative Committee for Space Data Systems
CUC	CCSDS Unsegmented time Code
DDS	Data Distribution System
DMS	Data Management System
HFC	High Frequency Clock
MJD	Modified Julian Day or Date
MJT	Modified Julian Time
OBT	On-Board Time
PDS	Planetary Data System

RD	Reference Document
SCET	Spacecraft Elapsed Time
SFDU	Standard Formatted Data Unit
SSMM	Solid State Mass Memory
TAI	International Atomic Time
tbc	to be confirmed
tbd	to be defined
TC	telecommand
TCP	Time Correlation Packet
TDB	Barycentric Dynamical Time
TDT	Terrestrial Dynamical Time
TM	telemetry
UTC	Coordinated Universal Time
VC	Virtual Channel

2. Time Correlation

This chapter starts with a description of the spacecraft clock which maintains the On-Board Time (OBT). The time correlation procedure between OBT and Coordinated Universal Time (UTC) is carried out during the downlink process of the transfer frames to the mission control system on ground.

The experiments on board the spacecraft generate telemetry source packets with an OBT time-stamp in the header. By employing the time correlation, this OBT time-stamp is converted to UTC and included in the additional DDS packet header when the data packets are distributed via the DDS.

The time correlation information is delivered via the DDS as Time Correlation Packets (TCP).

2.1 Spacecraft Clock

The OBT is based on the spacecraft High Frequency Clock (HFC) running at 131.072 kHz = 2^{17} s^{-1}.

All instrument clocks are time synchronised with the spacecraft HFC using timer synchronisation pulses and telecommand time packets. The timer synchronisation pulse is distributed continuously with a repetition rate of 8 seconds to all experiments in parallel. The TC time packets contain the OBT of the next time synchronisation pulse. The rising (first) edge of the next timer synchronisation pulse is used to set the instrument internal clock to the OBT transmitted within the TC time packet. The experiments are furnished with a TC time packet at power-on and at agreed regular intervals (of the order of hours).

The field in the TC time packet containing the OBT is characterised as follows:

Field Name	Field Size	Field Type
SCET	6 octets	CUC time

The SCET (Spacecraft Elapsed Time) field contains the transmitted OBT coded in CUC time format (AD4): 4 octets of unit seconds followed by 2 octets of fractional seconds. **The OBT is set to zero at 00:00:00 UTC on 1 Jan 2003.**

Note that the term SCET is used with different meanings in the applicable documents. It will be avoided as much as possible in this document in order to avoid ambiguity.

2.2 Telemetry Downlink and Time Correlation Procedure

This section describes the end-to-end processing employed during the telemetry downlink procedure in order to correlate OBT with UTC. Figure 1 is an illustration.

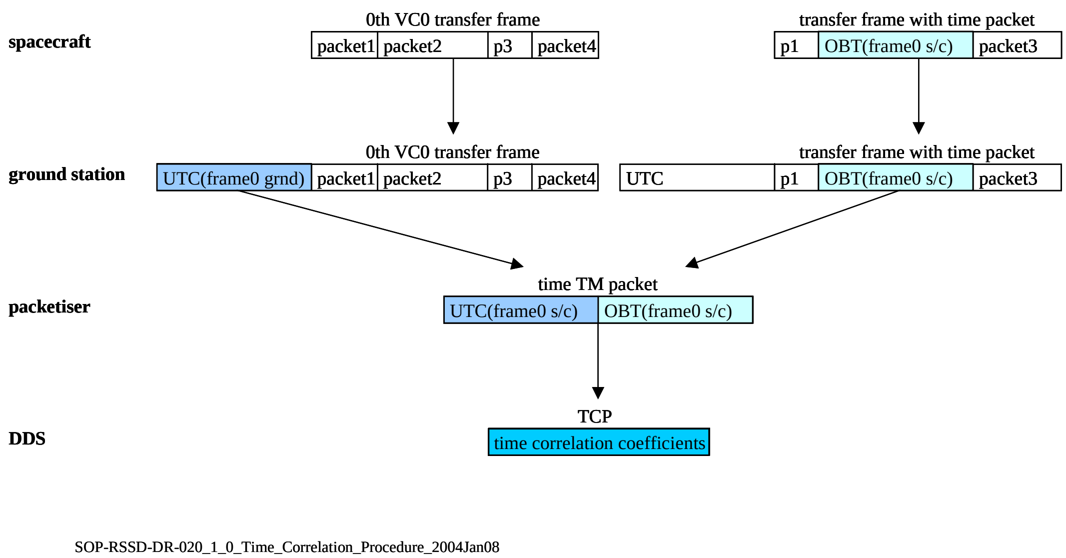


Figure 1: Time correlation procedure.

On board the spacecraft all telemetry data, i.e. experiment science and housekeeping data as well as spacecraft housekeeping data, are packetised in source packets. For downlinking, these source packets are collected into transfer frames. Transfer frames are distinguished by Virtual Channel (VC). VC0 transfer frames are generated from real-time data, i.e. source packets coming directly from the Data Management System (DMS). VC1 transfer frames contain play-back data, i.e. source packets that were stored in the Solid State Mass Memory (SSMM) and then dumped. The transfer frames are downlinked with a constant rate (switchable to take into account different mission phases and ground stations). If a VC0 transfer frame is complete, it is transmitted when the next frame is due. Otherwise the spacecraft checks whether a full VC1 frame is available. If yes, the VC1 frame is downlinked. If neither a VC0 frame nor a VC1 frame is complete, an empty transfer frame named VC7 is transmitted.

The time correlation procedure is performed using the VC0 transfer frames at regular frame intervals, these are by default the VC0 transfer frames with a VC frame count '0'. (Strictly speaking, the frequency of the reference frame can be varied, but this is not important here.) The contents of the spacecraft clock are sampled when the zeroth VC0 transfer frame leaves the frame generator (more exactly, at occurrence of the leading edge of the first bit of the attached synchronisation marker). This time sample is then placed into the standard spacecraft time source packet in CUC time format (see section 2.1) and telemetered to ground within a later frame. The time packet thus contains the OBT when the zeroth VC0 transfer frame was generated on the spacecraft, called OBT(frame0 s/c) in Figure 1.

On reception at the ground station, all telemetry frames are time-tagged with the current UTC (obtained from the station clock which is synchronised with UTC) and routed to the packetiser of the control system at ESOC (i.e. the application responsible for extracting the source packets from the received transfer frames). Figure 1 shows that the ground station header containing the UTC when the zeroth VC0 transfer frame was received on ground, called Earth Reception Time (ERT) or UTC(frame0 grnd), is added to the frame.

The packetiser extracts the ERT and computes the UTC when the zeroth VC0 transfer frame was generated on the spacecraft, called UTC(frame0 s/c) in Figure 1. This is done by applying the following corrections:

- Delay between the downlinked transfer frame arriving at the antenna and it actually reaching the equipment where the ERT is time-stamped on the frame.
- Propagation delay or One Way Light Time, i.e. the time taken for the signal to travel from the spacecraft to the ground station antenna.
- Delay in processing the telemetry frame on the spacecraft.

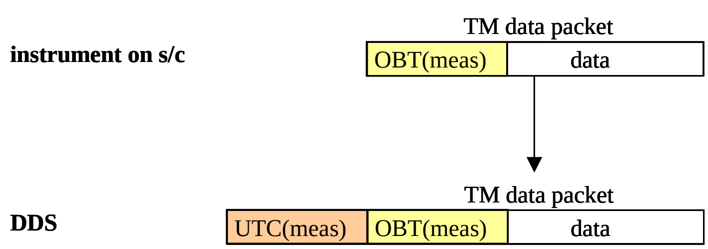
The packetiser also extracts the standard spacecraft time source packet from the later transfer frame and reads the OBT when the zeroth VC0 transfer frame was generated on the spacecraft, OBT(frame0 s/c).

The packetiser then generates a time telemetry packet which contains both UTC(frame0 s/c) and OBT(frame0 s/c), i.e. the same event measured on the two time scales.

The time telemetry packets from a specified time range are used to calculate the time correlation coefficients by a least squares fit. The time correlation coefficients allow to convert OBT to UTC for the time range they are valid.

2.3 Telemetry Source Packet on the Spacecraft

The experiments provide their telemetry data formatted in source packets to the spacecraft computer. The telemetry source packets are illustrated in Figure 2.



SOP-RSSD-DR-021_1_0_Experiment_Telemetry_Source_Packet_2004Jan09

Figure 2: Experiment telemetry source packet.

The structure of the TM source packet is:

Packet Header 48 bits			Packet Data Field variable	
Packet ID 16 bits	Packet Sequence Control 16 bits	Packet Length 16 bits	Data Field Header 80 bits	Source Data variable

The data field header contains the OBT when the acquisition of the data within the packet was initiated:

SCET Time	PUS-Version	Checksum Flag	Spare	Packet Type	Packet Subtype	Pad
48 bits	3 bits	1 bit	4 bits	8 bits	8 bits	8 bits

The SCET time field contains the OBT when the data were measured by the instrument on board the spacecraft, in CUC time format (see section 2.1). This is called OBT(meas) in Figure 2.

The header of the telemetry source packet contains the data acquisition start time in OBT time scale and seconds since 00:00:00 UTC on 1 Jan 2003 (i.e. OBT = 0) time format.

2.4 Telemetry Packets on the DDS

Finally, the telemetry source packet generated by the instrument on board the spacecraft is distributed via the DDS. Its contents is unprocessed, although a small DDS packet header is attached to its beginning (see Figure 2). The format of this DDS packet header is shown below:

Octet	Field	Type	Description
0-7	SCET	Sun MJT	UTC(meas) derived from OBT(meas) by time correlation
8-11	Packet Length	32 bit integer	number of octets within the data packet excluding the DDS header
12-13	Ground Station ID	16 bit integer	
14-15	Virtual Channel ID	16 bit integer	0 = VC0, 1 = VC1
16	SLE Service	8 bit integer	identifies SLE service channel and data type
17	Time Quality	8 bit integer	0 = good, 1 = inaccurate, 2 = bad (see section 18.1.2.1.4 of AD1)

The time correlation coefficients are employed to calculate the SCET field of the DDS packet header from the data acquisition start time in OBT in the header of the contained telemetry source packet. **The DDS packet header thus contains the UTC when the data where measured by the instrument on board the spacecraft,** called UTC(meas) in Figure 2.

OBT(meas) in the header of the experiment telemetry source packet and UTC(meas) in the DDS packet header both refer to the same event, i.e. the start of the measurement, but on different time scales.

The time format used to code the UTC(meas) in the DDS packet header is the Sun Modified Julian Time (MJT), as standard on Sun Solaris UNIX platforms. It corresponds to the number of seconds since 00:00:00 UTC on 1 Jan 1970 with leap seconds taken into account, i.e. every day has 60 * 60 * 24 = 86400 seconds.

The Sun MJT is formatted in the following way:

Field	Octets 0-3	Octets 4-7
Type	32 bit integer	32 bit integer
Meaning	seconds since epoch (00:00:00 UTC on 1 Jan 1970)	addition microseconds from seconds in first field

Note that within in the underlying software of the mission control system leap seconds are not taken into account. The leap seconds are inserted manually into the Flight Dynamics products (e.g. time correlation coefficients).

For data delivery, the experiment packets with DDS headers are packed into Standard Formatted Data Units (SFDU) which can handle a variety of data packet sizes and a varying number of data packets. The SFDUs also provide descriptions of the data they contain.

2.5 Time Correlation Packets (TCP)

The Time Correlation Packets (TCP) contain the time correlation coefficients. They belong to the telemetry packets generated within the mission control system. They are distributed via the DDS with APID 1966, type 190 and subtype 40.

The TCPs are stored without a source packet header and consist of:

SCOS-2000 TM Packet Header	Packet Data Field

The time correlation packet data field has the following structure:

Gradient	Offset	Standard Deviation	Generation Time
64 bits	64 bits	64 bits	48 bits
240 bits			

Gradient, offset and standard deviation are IEEE 8-byte double precision real numbers (most significant byte first order). The generation time is given in UTC time scale as number of seconds since 00:00:00 UTC on 1 Jan 1970 (tbc) with leap seconds taken into account. It is coded in CUC time format (AD4), i.e. 4 octets of unit seconds followed by 2 octets of fractional seconds.

It should be noted that **for the TCP the DDS header contains the time at which the contained time correlation became valid**. A TCP is expected to be valid for a few days (tbd).

Using the TCP, OBT is converted to UTC with the following formula: **UTC = gradient * OBT + offset**. The OBT input is in seconds since 00:00:00 UTC on 1 Jan 2003 (i.e. OBT = 0) time format. The UTC output is in Sun MJT time format (seconds since 00:00:00 UTC on 1 Jan 1970 with leap seconds taken into account).

3. Orbit and Attitude Data

The DDS distributes spacecraft orbit (including velocity) and attitude data as well as orbit (including velocity) data for the target comet and the fly-by asteroid(s) as auxiliary data, see appendix A of AD1 and section 2.8 of AD2. No DDS packet header is added to auxiliary data files. Where multiple files are returned, they are wrapped into a UNIX tar file. For delivery the auxiliary data are packed into SFDUs if requested.

In addition, the DDS delivers software to access the orbit and attitude data files. A detailed description of this software can be found in chapter 3 of AD2.

3.1 Orbit Files

Spacecraft, comet and asteroid orbit data are stored in a binary direct access file. The orbit file contains orbital information at discrete, non-equidistant times. There are two types of orbit files, L-type and H-type. For the L-type file the orbital information consists of the epoch and the state vector. So one logical record of orbital information contains the epoch, 3 position and 3 velocity components. In the H-type file the orbital information is augmented by the state time derivative at the epoch.

All epochs refer to the TDB time scale in MJD2000 time format.

Barycentric Dynamical Time (TDB) is the independent argument for orbital motions referenced to the centre of mass of the solar system, the origin of this reference frame. It is as close as possible to an inertial reference frame in the gravitational theory, thus it fulfils the equation of motion of the celestial bodies with only diminutive corrections. The accuracy is much better than the errors of orbit determination.

Modified Julian Day or Date (MJD) is a continuous count of days and fractions. **MJD2000 starts at 00:00:00** (TDB when used as format to code TDB scale) **on 1 Jan 2000.**

Read access to the orbit data is established by a number of FORTRAN subroutines which require as input the identifier of the orbit file and an arbitrary epoch, and deliver as output the state together with information on the central body and the reference frame the state refers to. The state is computed from the stored discrete orbital information by interpolation. The type of interpolation depends on the file type (L or H) and user supplied input.

The access software reads the data only from binary direct access files. To allow the transfer of data between machines which are not binary compatible, orbit data are made available in ASCII format together with a FORTRAN utility for conversion into the required binary format on the target platform.

3.2 Attitude Files

The storage of spacecraft attitude data follows the same lines as for the orbit data. Instead of discrete states, discrete quaternions are stored. Attitudes for arbitrary epochs are derived by interpolation. FORTRAN access subroutines are provided which allow to retrieve attitude and angular rates from the attitude file.

3.3 Orbit Data Access Software

In order to access an orbit state at a certain epoch, the following steps are necessary:

1. 3 top-level FORTRAN subroutines (rofcl.f, rofop.f and rofrr.f) and a series of low-level subroutines have to be transferred from the DDS. The low-level subroutines are only called by the top-level subroutines and thus remain invisible to the user. The user needs to write an application program that calls the 3 top-level routines. The subroutines have to be compiled on the target platform and linked together with the application program.
2. The orbit file covering the period which contains the desired epoch is collected from the DDS and converted into binary format using the FORTRAN program as2bin.f.
3. The application program opens the orbit file by a call to the subroutine rofop.f.
4. By a call to rofrr.f the orbit state is found.
5. After retrieval of all required states, the orbit file is closed by a call to rofcl.f.

The input to the subroutine rofrr.f is the time to retrieve the orbit state in TDB time scale and MJD2000 time format.

The output of the subroutine rofrr.f is

- State vector. 3 position components in km and 3 velocity components in km/s. (One might expect that additionally the time derivative of the state vector is returned if a H-type orbit file is used. However, this is not true, as the output state vector is always of dimension 6. The file type of the orbit file only affects the way how the low-level subroutines compute the state vector from the data stored in the file.)
- Reference frame for returned state vector is always mean earth equator frame of equinox J2000.0 (= **12:00:00** TDB on 1 Jan 2000).
- Reference body for returned state, i.e. sun, earth, mars or comet.

3.4 Attitude Data Access Software

In order to access a spacecraft attitude at a certain epoch, the same 5 steps as for the orbit state are necessary (see section 3.3 above), but the FORTRAN subroutines rafcl.f, rafop.f and rafrr.f have to be used instead of rofcl.f, rofop.f and rofrr.f.

The input to the subroutine rafrr.f is the time to retrieve the spacecraft attitude in TDB time scale and MJD2000 time format.

The output of the subroutine rafrr.f is

- 4 attitude quaternions specifying the rotation from the reference frame to the spacecraft mechanical frame. It should be noted that the quaternions do **not** follow a specific rule concerning the sign of the elements (quaternions q and -q, i.e. with all entries multiplied by -1, represent the same attitude). It may therefore happen that, after retrieval of a quaternion q1 at time t1, a quaternion q2 at time t2 close to t1 is returned by the subroutine that is 'closer' (w.r.t. the elements of the vector and scalar part) to -q1 than to q1.
- 3 components of angular rate of the spacecraft mechanical frame w.r.t. the reference frame expressed in the spacecraft frame in unit 1/s.
- Reference frame for returned attitude is always mean earth equator frame of equinox J2000.0 (= **12:00:00** on 1 Jan 2000 TDB).

3.5 Time Format and Time Scale Conversion Software

3.5.1 Time Format Conversion

The following FORTRAN subroutines are a available:

- JD2000 converts a calendar date (year, month, day, hours, minutes, seconds) between 1 Jan 1950 and 31 Dec 2099 to MJD2000.
- DJ2000 converts MJD2000 to calendar date.

3.5.2 Time Scale Conversion

The following FORTRAN functions convert between the time scales Coordinated Universal Time (UTC), International Atomic Time (TAI), Terrestrial Dynamical Time (TDT) and Barycentric Dynamical Time (TDB). **The time format used for all inputs and outputs is MJD2000.**

- TDBUTC converts TDB to UTC an vice versa. The function calls the functions TDBTDT and TDTUTC (which calls TAIUTC).
- TDBTDT converts TDB to TDT and vice versa.
- TDTUTC converts TDT to UTC and vice versa. The function calls the function TAIUTC.
- TAIUTC converts TAI to UTC and vice versa.

It should be noted that the function TAIUTC contains a list of leap seconds from 1 Jan 1972 in a DATA statement. As soon as a new leap second is announced, the DATA statement in the function will be updated and a new version will be available via the DDS. TAIUTC and the functions calling it (i.e. TDTUTC and TDBUTC) are valid from 1 Jan 1972.

3.5.3 Conversion between Sun MJT and Calendar Date within UTC

The conversion between the time formats Sun MJT and calendar date/time only makes sense when using the time scale UTC. The method described in this section is a two-step procedure that makes use of MJD2000 as an intermediate format.

1. Conversion between Sun MJT and MJD2000:
   Sun MJT corresponds to the number of (floating-point) seconds since 00:00:00 UTC on 1 Jan 1970 with leap seconds taken into account. MJD2000 is the number of (floating-point) days since 00:00:00 UTC on 1 Jan 2000 with leap seconds taken into account. Seconds are converted into days by division by 60*60*24 = 86400. In order to compute the offset days between 1970 and 2000, one needs to take into account the 7 leap years 1972, 1976, 1980, …, 1996. Thus there are 30*365+7 = 10957 days from 1970 to 2000. This leads to the following formula to convert between Sun MJT and MJD2000: MJD2000 = Sun MJT / 86400 - 10957.
2. Conversion between MJD2000 and calendar date/time:
   This task is performed by the FORTRAN subroutines DJ2000 and JD2000 distributed via the DDS (see section 3.5.1).

4. Time in PDS Labels

The PDS uses both UTC and OBT. Adoption of UTC as a standard facilitates comparison of data from a particular spacecraft or ground-based facility with data from other sources. Including the OBT of an observation or event allows the comparison of measurements on the same spacecraft with high accuracy, before additional errors are introduced by the OBT-to-UTC conversion.

4.1 Conventional Date/Time

UTC is the PDS time standard and must be formatted in one of the two recognised date/time formats:

YYYY-MM-DDThh:mm:ss.fff (preferred format)
YYYY-DDDThh:mm:ss.fff

Each format represents a concatenation of the conventional date and time expressions with the two parts separated by the letter T:

YYYY	year (0000-9999)
MM	month (01-12)
DD	day of month (01-31)
DDD	day of year (001-366)
T	date/time separator
hh	hour (00-23)
mm	minute (00-59)
ss	second (00-59)
fff	fractions of second (000-999)

Note that no "Z" is appended to the expression. This is not clearly stated in AD6.

The date/time formats may be truncated on the right to match the precision of the date/time values in any of the following forms:

2004
2004-02
2004-02-26
2004-02-26T07
2004-02-26T07:24
2004-02-26T07:24:09
2004-02-26T07:24:09.3

The PDS keywords START_TIME and STOP_TIME providing the date and time of the beginning and end of an observation or event use the above UTC format. **In PDS labels the precision is restricted to 3 digits after the decimal point.**

The same format can be used to express UTC date/time values in tables and spreadsheets, but here the precision is not restricted. The keyword DATA_TYPE = TIME indicates this date/time format within the column of the table and the field of the spreadsheet.

4.2 Spacecraft Clock Count

The PDS keywords SPACECRAFT_CLOCK_START_COUNT and SPACECRAFT_CLOCK_STOP_COUNT refer to OBT.

The header of the experiment telemetry source packets contains the data acquisition start time in OBT as 32 bit of unit seconds followed by 16 bit of fractional seconds (see section 2.3). OBT = 0 is at 2003-01-01-T00:00:00 UTC. The time resolution is $2^{-16} = 1.53 \times 10^{-5}$ seconds.

The OBT is represented in the following format:

SPACECRAFT_CLOCK_START/STOP_COUNT =
"<reset number>/<unit seconds>.<fractional seconds>"

The unit seconds and the fractional seconds are separated by the full stop character. **Note that this is not a decimal point.** The fractional seconds are expressed as multiples of $2^{-16} = 1.53 \times 10^{-5}$ seconds and count from 0 to $2^{16} - 1 = 65535$. E.g. in `SPACECRAFT_CLOCK_START_COUNT = "1/21983325.392"` the 392 fractional seconds correspond to $392 \times 2^{-16} = 0.00598$ decimal seconds.

The spacecraft clock could be reset during the mission (although this is not planned). This would imply a change of the zero point. The zero point of the OBT will be indicated by pre-pending the reset number (integer starting at 1) and a slash to the unit seconds, i.e. "1/" means OBT = 0 at 2003-01-01T00:00:00 UTC.

Examples:

```
SPACECRAFT_CLOCK_START_COUNT = "1/21983325.39258"
SPACECRAFT_CLOCK_START_COUNT = "1/21983325.392"
SPACECRAFT_CLOCK_STOP_COUNT  = "1/21983342"
```