E u r o p e a n S p a c e A g e n c y

Research and Scientific Support Department

Planetary Missions Division

SMART-1 Time Correlation.
From Time Correlation Packets to SCLK

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1 Introduction

1.1 Purpose

The Time Correlation process is of vital importance in the analysis of scientific data of the planetary missions. STOC and the SMART-1 Project Scientist have decided to support the scientific community with the implementation of the SPICE data sets for SMART-1. The SPICE Toolkit is a F77, C and IDL library maintained by the Navigation and Ancillary Information Facility (NAIF) at JPL/NASA. The NAIF team aims to offer a common information system that allows scientists and engineers to access navigation and other ancillary spacecraft data from many spacecraft from several space science disciplines. The primary SPICE data sets are often called "kernels" or "kernel files". The name SPICE comes from the information type the toolkit offer: Spacecraft, Planets, Instrument, C-Matrix (Instrument and/or Spacecraft Attitude), Events.

SPICE kernels are generated by STOC using the available tools that have been implemented for Mars Express. These tools are used to produce spacecraft ephemeris kernels (SPK), attitude information kernels (CK) and spacecraft clock kernels (SCLK).

This document describes the format of the different types of data involved in the generation of the spacecraft clock kernels from the available time correlation information that the FCT provides to the community. The time correlation processes used in the SMART-1, Mars Express and Rosetta missions are described. Finally, the process to generate the SLCK files from the available data using the Mars Express conversion software is analyzed.

1.2 Intended Readership

- SMART-1 STOC Team
- SMART-1 FCT Team
- …

1.3 Naming Conventions

TBW

1.4 References

1.4.1 Applicable Documents

[AD-1] SMART-1 Mission Control System. Time Correlator Technical Note.
TERMA-SPD-63-MCS-S1MCS-TN-2200-TCO, Issue1.0

[AD-2] Recommendation for Space Data System Standards: Time Code Formats.
CCSDS 301.0-B-2, Blue Book, Issue 2.

[AD-3] Rosetta / Mars Express Mission Control System. Data Delivery Interface Document.
RO-ESC-IF-5003 / MEX-ESC-IF-5003, Issue B6

[AD-4] Auxiliary Data Conversion Process and Distribution.
MEX-EST-PL-10210, Issue 1.7

1.5 Acronyms

CCSDS	Consultative Committee for Space Data Systems
CDS	CCSDS Day Segmented Time Code
CK	C-Matrix (Spacecraft and/or Instrument attitude) Kernel
CUC	CCSDS Unsegmented Time Code
DDS	Data Disposition System
ERT	Earth Reception Time
FCT	Flight Control Team
MCS	Mission Control System
OBT	Onboard Time
SCET	Spacecraft Elapsed Time
SCLK	Spacecraft Clock Kernel
SPK	Spacecraft and Planetary Ephemeris Kernel
STOC	Science and Technology Operations Center

2 Data Formats.

2.1 Introduction

A detailed description of the data involved in the generation process of the SMART-1 Spacecraft Clock Kernel (SCLK) file if given in this chapter. The information source for the process is the SMART-1 DDS time correlation packets (APID 81, type 16, subtype 81). These packets are generated continuously in the MCS and ingested in the DDS. There is a packet every 30 seconds, if the generation process is working nominally.

In other missions, such as Rosetta and Mars Express, the MCS generates every few weeks a time correlation coefficient packet that is to generate the SCLK file. This packet is not available for SMART-1 and therefore, the same software used for Rosetta and MEX cannot be used for SMART-1 without any modification.

Since the RSSD department aims for a mission-independent SPICE conversion tool for all ESA planetary missions, it is required a conversion of formats between SMART-1 time correlation packets and time correlation coefficients packets.

Since both packets are wrapped up with the DDS header, its format is also described in this chapter.

2.2 SMART-1 DDS Time Correlation Packets (81, 16, 81)

These packets are sampled every 30 seconds (nominally). In the case of lost of synchronization, the MCS does not produce time packets until the synchronization is restored. The resynchronization can last minutes, hours or days. During these period no time correlation packets are available on the DDS and the correlation performed before the lost of synchronization remains valid until a new packet is ingested in the DDS.

The format of the SMART-1 DDS Time Correlation Packets is given in the following table, obtained from [AD-1]:

Field Name	Remarks	Size	Data Type
ERT1	ERT of the last VC-0 frame to which the OBT refers.	8 bytes	Modified CDS format
OBT	OBT generated from the satellite and contained in the last STSP	8 bytes	CCSDS CUC format
Sum of Delays	Correction to apply to the ERT considering the 3 delays.	8 bytes	IEEE Double format
VALIDITY	Status of the Time Correlation. Possible values are VALID (1) or INVALID (0)	4 bytes	32-bit Integer
Valid OBT	Correspond to the OBT0. It is the same value of SCET if the couple is valid	8 bytes	CCSDS CUC format
Valid ERT	Correspond to the UTC0. It is the same value of the corrected ERT1 if the couple is valid	8 bytes	Modified CDS format
SLOPE	Indicate the multiplying factor to be used form conversion from OBT to UTC	8 bytes	IEEE Double format

BIAS	Indicate the adjustment factor to convert OBT in UTC	8 bytes	IEEE Double format
ACCURACY	Status of the time correlation. Values are: ACCURATE (1) or INACCURATE (0)	4 bytes	32-bit Integer
Validity of the last received couple	Flag to indicate if the couple (SCET, ERT1) is valid.	4 bytes	32-bit Integer

Table 1: SMART-1 DDS Time Correlation Packet Format

The Modified CDS format is the CCSDS CDS time format without the preamble field. Each field represents the state of a binary counter. This code is UTC-based, therefore the leapseconds correction must be made before creating each packet. Further information about this format can be found in [AD-2]. This format is described in the following table:

Field Name	Remark	Size	Data Type
DAY	Continuous counter of days from 1st January 1958.	2 bytes	16-bit Integer
milliseconds	Milliseconds of the day	4 bytes	32-bit Integer
microseconds	Microseconds of millisecond	2 bytes	16-bit Integer

Table 2: Modified CDS Time Format

The CCSDS CUC time format is described in the following table. For further description of this time format, please refer to [AD-2].

Name	Length		Description
S_FIELD	1 byte	Bits 0-3	Not used, set to 000
		Bits 4-7	Value corresponding to the sample rate of the spacecraft clock
P_FIELD	1 byte		Set to 00101110. This value means the time format is composed by 4 coarse time bytes and 2 fine time bytes.
T_FIELD	6 bytes	Bits 0-31	Spacecraft elapsed time as an un-segmented binary count of seconds.
		Bits 32-47	Spacecraft elapsed time as an un-segmented binary power of sub-seconds [1].

Table 3: CCSDS CUC Time Format

2.3 Mars Express / Rosetta Time Correlation Coefficients Packets

Time Correlation Coefficients Packets are generated within the Mars Express / Rosetta MCS. These packets contain the information necessary to enable the UTC time of a packet to be obtained form its OBT.

The actual generation of the Time Correlation Coefficients packet is instigated manually by the Flight Control Team who have the ability to specify a time range from which the Time Telemetry

[1] Fine time is the number of sub-seconds. To obtain the real fraction of a second that is contained in this field, divide the number contained in this field by 65536 (2 bytes). This gives a resolution of 15 microseconds.

Packets should be used to obtain a correlation[2]. Once the applicable Time Telemetry Packets from the specified time range have been extracted from the archive a least squares fit is calculated to obtain the coefficients necessary to convert the OBT in the source packets to UTC. A time correlation remains valid until the next time correlation packet is generated. Further information about the Time Correlation Coefficients packets can be found in [AD-3]

The format of the Time Correlation Coefficients packets is given in the following table:

Field Name	Remarks	Size	Data Type
Gradient	'Gradient' value of Coefficients pair	8 bytes	IEEE Double format
Offset	'Offset' value of Coefficients pair	8 bytes	IEEE Double format
Std	Standard Deviation value associated with the Coefficients pair	8 bytes	IEEE Double format
Gen Time	Generation Time of the Coefficients	6 bytes	Modified CUC format

Table 4: Mars Express / Rosetta Time Correlation Coefficients Packet Format

The Modified CUC format is the CCSDS CUC time format without the sample field (S_FIELD) and the preamble field (P_FIELD). Please refer to Table 3: CCSDS CUC Time Format for a detailed description of the CCSDS CUC format.

2.4 DDS Header Record Format

SMART-1 DDS Time Correlation Packets and Mars Express / Rosetta Time Correlation Coefficient Packets are wrapped up with the DDS Header. This record is attached to the beginning of each packet. For a detailed description of the DDS header please refer to [AD-3]. The format is described in the following table:

Field Name	Remarks	Size	Data Type
SCET	Time correlated OBT; DDS time.	8 bytes	DDS time format
Packet Length	Number of bytes within the data packet (excluding the DDS packet header)	4 bytes	32-bit integer
Ground Station ID	Ground station ID	2 bytes	16-bit integer
Virtual Channel ID	0=VC0; 1=VC1	2 bytes	16-bit integer
SLE Service	Identifies the SLE service channel and the type of data	1 byte	8-bit integer
Time Quality	0=Good; 1=Inaccurate; 2=Bad	1 byte	8-bit integer

Table 5: DDS Header Record Format

The DDS time format is described in the following table:

Field Name	Remarks	Size	Data Type
Seconds	Seconds since epoch 00:00:00 1st Jan 1970	4 bytes	32-bit Integer
Microseconds	Addition microseconds from seconds in first field	4 bytes	32-bit Integer

[2] In the case of SMART-1, the time range is nominally 2.5 minutes (about 150 seconds) since the Flight Control Team uses the last 5 Time Correlation Packets (also called Time Telemetry Packets) to perform the correlation.

Table 6: DDS Time Format

3 SMART-1 MCS Time Correlation

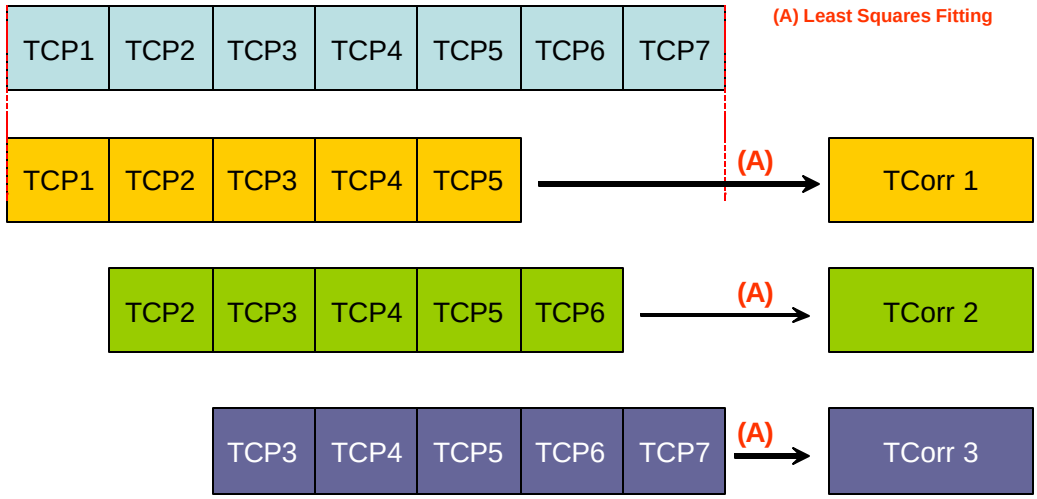
SMART-1 DDS Time Correlation packets are used to perform the time correlation on the SMART-1 mission. The process to obtain these packets is described in [AD-1]. The Time Correlation packets contain information about the correlation process and the validity of the couple ERT-OBT (more precisely, UTC-OBT). The MCS obtains the Onboard Time from the UTC and/or the UTC from the Onboard Time by using the last 5 valid Time Correlation packets.

Before performing the translation of times, a least square fit algorithm is used to obtain the values of gradient and offset to be used in the conversion. The following formula is used to obtain then the OBT and/or UTC from the UTC and/or OBT:

$$UTC - UTC_0 = m \times (OBT - OBT_0) + c$$

Where UTC_0 and OBT_0 are the last received good couple OBT and UTC values.

The SMART-1 MCS allows the user to re-initialize the time correlation, and in this case the Time Correlator process resets the structure and starts to collect a certain number of valid OBT/UTC pairs. As soon the minimum number of good couples has been received and stored, the least square fit to the couple is performed and the new coefficients are mad available. The number of good couples used to perform the least square fit is five. This fitting is done in the following way:



Valid SMART-1 DDS Time Correlation Packets for a given period of time.

Correlation to be used during a given period of time

4 Mars Express / Rosetta MCS Time Correlation

Mars Express and Rosetta Time Correlation Coefficients packets are used to perform the time correlation for these missions. The process to obtain these packets is described in [AD-3]. These packets are generated from "Time Telemetry Packets" which contains both the spacecraft time and the UTC at which it was generated. These packets are meant to be the same as the SMART-1 DDS Time Correlation Packets, although the format is different [TBC].

The actual generation of the Time Correlation Coefficients packets is instigated manually by the Flight Control Team who has the ability to specify a time range from which the Time Telemetry Packets should be used to obtain a correlation. This time range is typically one hour and this process is performed on average every two weeks. Once the applicable Time Telemetry Packets from the specified time range have been extracted from the archive a least squares fit is calculated to obtain the coefficients necessary to convert the OBT in the source packets to UTC. Once the appropriate coefficients have been calculated the FCT can the either reject the obtained correlation, or accept it. If the obtained correlation is accepted a validity start time is specified which is the time from which that correlation is valid, i.e. it is used to derive the UTC timestamps from the OBT time contained in the source packets. A time correlation remains valid until the next time correlation packet is generated. The Time Correlation Coefficients Packet is accepted only if the difference between the timestamp of the time packet and the correlated time of its contents is within a pre-defined threshold.

5 Conversion from SMART-1 Time Correlation Packets to Time Correlation Coefficients Packets

5.1 Objectives

The conversion from Mars Express / Rosetta Time Correlation Coefficients Packets to SPICE SCLK format has been already implemented for these missions. This process has been tested and the in-flight experience demonstrates that results obtained using the SCLK generated from these packets are accurate enough for the objectives of these missions.

The aim of the SPICE working group is to generate mission-independent software to reduce costs and increase the reliability of the conversion tools. Therefore, to be able to generate the SCLK file for SMART-1 with the already existing tools, a previous conversion is required.

This previous conversion is also recommended to reduce the amount of data to be used in the generation of the SCLK. Each Time Correlation Coefficient Packet corresponds to a line in the SCLK file. The use of the SMART-1 Time Correlation Packets instead of the Time Correlation Coefficient Packets would conduce to an enormous file with the consequent difficulties for its handling by the SPICE system.

5.2 Algorithm

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5.3 Error estimation

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6 Conversion from Time Correlation Coefficients Packets to SCLK

TBW. For further details, please refer to [AD-4]