Earth Observation
Mission CFI Software

MISSION SPECIFIC CUSTOMIZATIONS

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1 SCOPE

All features and conventions defined and used in the Earth Observation Mission CFI Software are described in the document "Earth Observation Mission CFI Software Conventions" [MCD].

This document covers all CFI SW mission specific customizations that are not described in [MCD], i.e. those features and conventions that are defined and used within specific missions.

2 ACRONYMS AND NOMENCLATURE

2.1 Acronyms

ADM/Aeolus	Atmospheric Dynamics Mission
ANX	Ascending Node Crossing
AOCS	Attitude and Orbit Control Sub-system
CFI	Customer Furnished Item
DRS	Data Relay Satellite
DORIS	Doppler Orbitography and Radio positioning Integrated by Satellite
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESTEC	European Space Technology and Research Centre
EO	Earth Observation
EOCFI	Earth Observation CFI Software
GOCE	Gravity Field and Steady-state Ocean Circulation Mission
GPS	Global Positioning System
METOP	Meteorological Operational Polar Satellite
OBT	On-Board Time
SBT	Satellite Binary Time
SIRAL	Synthetic-Aperture Interferometric Radar Altimeter
SMOS	Soil Moisture and Ocean Salinity Mission
TAI	International Atomic Time
TM	Telemetry
UTC	Coordinated Universal Time

3 APPLICABLE AND REFERENCE DOCUMENTS

3.1 Applicable Documents

3.2 Reference Documents

ADM_AGL	AOCS Guidance Laws. AE.RP.ASU.PL.044
CRYO_ATT	CryoSat Star Tracker Data Usage for Attitude Determination. CS-TN-ESA-GS-0300. Issue 1.5.
S1_ATT	Sentinel-1: Roll Steering Law. EXPCFI-NOTE-042. Issue 1.2. 10/02/2010
CRYO_SRD	CryoSat System Requirements Document. CS-RS-ESA-SY-0006. Issue 6.
DRSENV_ICD	ICD between the DRS and the Envisat-1 System. CD/1945/mad. D/TEL/R. K. Falbe-Hansen. Issue 5. April 1996.
KLINKRAD	Semi-Analytical Theory for Precise Single Orbit Predictions of ERS-1. ER-RP-ESA-SY-004. H.K. Klinkrad (ESA/ESTEC/WMM). Issue 1.0. 28/06/87.
MCD	Earth Observation Mission CFI Software Conventions Document. EO-MA-DMS-GS-0001. Issue 1.0. 27/10/2009.
S2_ATT	Sentinel-2: AOCS Coordinate Systems Document. GS2.TN.ASD.SY.00035. Issue 2 30/09/2010

4 TIME REFERENCES AND MODELS

4.1 Earth Observation CFI Software Time Formats

Table 1 describes the time formats used within specific missions:

Table 1: Earth Observation time formats

Mission Name	Time format	Description	Usage
Cryosat	Transport CryoSat General TM	Three 32-bits integer numbers for days, milliseconds and microseconds	Time values exchange between computers
Cryosat	Transport CryoSat SIRAL TM	Four 32-bits integer numbers for days, milliseconds, microseconds and an extra counter of 80 MHz ticks	
SMOS	Transport SMOS Transport format	Three 32-bits integer numbers for week number, seconds of the week and fraction of seconds	
Envisat	ASCII Envisat	Text string: “dd-mmm-yyyy hh:mm:ss“	Readable output, such as file headers, log messages, ...
Envisat	ASCII Envisat with reference	Text string: “RRR=dd-mmm-yyyy hh:mm:ss“	
Envisat	ASCII Envisat with microseconds	Text string: “dd-mmm-yyyy hh:mm:ss.uuuuuu“	
Envisat	ASCII Envisat with reference and microseconds	Text string: “RRR=dd-mmm-yyyy hh:mm:ss.uuuuuu“	

4.2 Earth Observation CFI Software On-board times

4.2.1 Envisat On-board clock ticks

Table 2: On-board clock ticks

Time reference and format	Description	Usage
Satellite Binary Time (SBT)	32-bits integer number: · Count of 256 Hz clock ticks	Processing of satellite binary
On Board Time (OBT)	32-bits integer numbers:	Processing of instrument on-

	· obtm = most significant bits · obtl = least significant bits	board time

The Satellite Binary Time (SBT) is a 32 bits counter, incremented by 1 at a frequency of about 256Hz (defined as the step-length PER_0). It varies from **00000000** (Hexadecimal) to **FFFFFFFF** (Hexadecimal), the next value being again **00000000** (Hexadecimal) and so on. This reset of the counter after **FFFFFFFF** (Hexadecimal) is called the **wrap-around**.

The On Board Time (OBT) is a generic term to represent any of the instrument counters, used to date their source packets. Most instruments use a 32 bits counter synchronized with the SBT. Some instruments use a 40 or 43 bits counter, where the 32 most significant bits are synchronized with the SBT (i.e. they use a more precise clock).

Figure 1 shows the relationship between SBT and OBT.

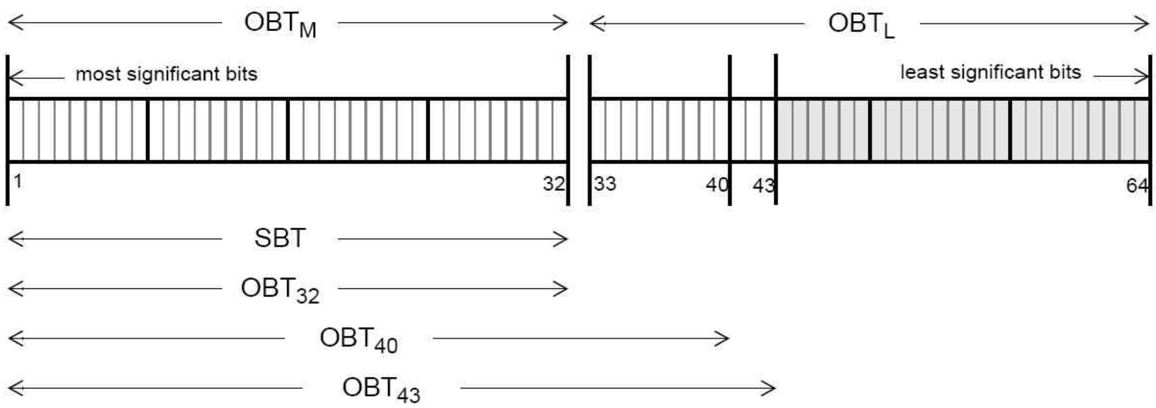

Figure 1: SBT and OBT relationship

4.2.2 TAI time

If DORIS is used to perform the orbit determination, the satellite will work with TAI time reference using dedicated transport formats (Telemetry formats).[1]

4.2.3 CryoSat SIRAL extra counter

The main payload of CryoSat is the Synthetic-Aperture Interferometric Radar Altimeter (SIRAL). The way the SIRAL instrument performs the on-board datation of each TM packet is the following:

Every time SIRAL receives the 1 Hz PPS signal (Pulse-Per-Second) from the central computer, it reads and sets in its memory the first 3 time parameters (days / milliseconds / microseconds). These won't change until the next PPS tick.

1 Not applicable to ENVISAT

At the same time, it resets the fourth time parameter (extra counter) to 0, and starts counting ticks of the internal 80MHz clock in it. Each tick of the 80 MHz clock is 12.5 nanoseconds. The extra counter actually has a lower resolution, it actually counts a multiple (165) of the 80 MHz. This results in a counter resolution of 165 * 12.5 nanoseconds = 2.0625 microseconds.

From then on, at each TM packet production (which is about every 46 ms), SIRAL dates using the "frozen" first 3 parameters, plus the counter of 2 microsec ticks in the fourth parameter.

The actual date of the packet can be calculated by adding up all four parameters (with the appropriate scaling for each, of course), as for any other format.

At the next PPS, the same sequence starts.

It has to be remarked that these TM transport formats use vectors of long integers in the CFI (according to CFI standard). This, however, does not match the TM packet time contents, in which byte efficiency is important. For example, days are on 16-bits, milli-seconds on 32-bits, micro-seconds on 16-bits, and the extra counter on 16-bits.

This does not allow users to simply copy the sequence of bytes into memory and point the time vector to it, they will have to read each time component and set it into a long integer (and vice-versa for users producing test data).

4.2.4 SMOS On-board time

SMOS will manage two time sources:

- OBET: This value is derived by a HW counter 48 bits wide which is increased at a frequency of 65536 KHz, starting in 0 after power-on.
- UTC provided by Proteus each second.

The following tables shows the format for the OBET and the UTC-Proteus times:

Table 3: SMOS OBET time

P-Field				T-Field	
Extension Flag	Time Code identification	Details Bits for the information on the code		Coarse Time	Fine Time Note
1 bit	3 bits	4 bits		32 bits	24 bits
0	110	01	10	(Seconds from epoch)	(2-24 seconds)
1 byte				4 bytes	3 bytes

Table 4: UTC Proteus time format

Week Number	Unused	H3	Second of Week	Fraction of Seconds
12 bits	3 bits	1 bit	32 bits	16 bits
	000		(Seconds from	(2-16 seconds)

			epoch)	
2 bytes			4 bytes	2 bytes

Where “Week Number” is weeks elapsed since January 6-12, 1980. This week is numbered (0). LSB=1 Week.

H3 represents the time source from which the payload is synchronised to the platform.

4.2.5 Aeolus On-board Time

The OBT format for Aeolus is given in CCSDS Unsegmented time code (CUC), that is defined as: the time from a defined epoch in seconds coded on 4 octets and sub-seconds coded on 2 octets.

According to this the time is:

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

OBT is set to GPS Time such that the UTC zero time-point reference of OBT is the same as that of GPS, i.e. midnight on the night of January 5 1980 / morning of January 6 1980. At this UTC zero time-point reference there had been19 leap seconds applied.

Therefore, the conversion from OBT (in CUC) to UTC is:

$$UTC = (\text{CUCseconds} + \text{CUCsub-seconds} * 256\text{-}2) - GPST + UTC_0$$

Where:

CUCseconds is the 4 most significant octets of OBT (C_0 to C_3)

CUCsub-seconds is the 2 least significant octets of OBT (F_0 to F_1)

GPST is the number of leap seconds between UTC and GPS Time (see section 3.2);

UTC_0: UTC time at 06-01-1980 00:00:00.000000

4.2.6 GOCE On-board Time

The OBT for GOCE is provided by telemetry as two parameters, the coarse OBT in 32 bits and the fine OBT in 16 bits. The OBT time is therefore OBT = (Coarse OBT) + (Fine OBT)/2^{16}.

The conversion form a given OBT to UTC is given by:

$$UTC0 = (\text{Coarse } UTC0) + (\text{Fine } UTC0)/2^{16}$$

$$OBT0 = (\text{Coarse } OBT0) + (\text{Fine } OBT0)/2^{16}$$

$$UTC = \text{Gradient}*(OBT-OBT0) + \text{Offset} + UTC0$$

The result is the number of seconds from 1st of Januay 2000 at 00:00:00.000000, without counting the leap seconds (i.e. to convert into a calendar date and time, one has to assume that all days have 86400 seconds).

5 ORBIT CONSISTENCY CHECKS

The EO CFI software will check that the orbit supplied as input complies with a set of tolerances on the main osculating Kepler elements.

Two categories of tolerance requirements will be checked:

- Tight requirements
- Loose requirements

If the tight tolerance requirements are not satisfied, but the loose ones are, then a warning will be returned by the CFI software. If even the loose tolerance requirements are not satisfied, then an error will be returned.

These consistency checks are mission specific.

Table 5 and Table 6 list, for each supported mission, the loose and tight requirements:

Table 5: Loose tolerance requirements

Mission Name	Semi-major axis (m)		Eccentricity		Inclination (deg)	
	A min	A max	E min	E max	I min	Imax
ADM-Aeolus	6680000	6860000	0	0.1	95.7	98.3
CryoSat	1000000	10000000	0	0.5	60.0	120.0
EarthCARE	6720000	6830000	0	0.5	96.62	97.43
Envisat	7000000	7300000	0	0.1	98.0	99.0
ERS 1/2	7000000	7300000	0	0.1	98.0	99.0
GOCE	1000000	10000000	0	0.5	60.0	120.0
METOP 1	7000000	7300000	0	0.1	97	100
Sentinel 1	7000000	7140000	0	0.5	97.7	98.7
Sentinel 2	7120000	7210000	0	0.5	98.16	98.98
Sentinel 3	7100000	7250000	0	0.5	98.22	99.04
SEOSAT	7000000	7090000	0	0.5	97.68	98.49
SMOS	7040000	7220000	0	0.1	97.1	99.7
Swarm A/B	6500000	6975000	0	0.5	85.0	89.0
Swarm C	6500000	6975000	0	0.5	85.0	89.0

Table 6: Tight tolerance requirements

Mission Name	Semi-major axis (m)		Eccentricity		Inclination (deg)	
	A min	A max	E min	E max	I min	Imax
ADM-Aeolus	6730000	6810000	0	0.007	96.7	97.3
CryoSat	1000000	10000000	0	0.5	60	120
EarthCARE	6750000	6790000	0	0.007	96.72	97.33
Envisat	7118050	7194056	0	0.007	98.4475	98.6226
ERS 1/2	7118050	7194056	0	0.507	98.4475	98.6226
GOCE	6500000	6700000	0	0.5	96	97
METOP 1	7154298	7230343	0	0.007	98.5613	98.8165
Sentinel 1	7035000	7105000	0	0.007	97.8	98.6
Sentinel 2	7140000	7190000	0	0.007	98.26	98.88
Sentinel 3	7130000	7210000	0	0.007	98.32	98.94
SEOSAT	7016000	7076000	0	0.007	97.78	98.39
SMOS	7090000	7170000	0	0.007	98.1	98.7
Swarm A/B	6500000	6925000	0	0.007	85.85	88.15
Swarm C	6550000	6925000	0	0.007	85.85	88.15

6 PROPAGATION MODES

6.1 Envisat Operational mode

The effect of the latitude and longitude dependent geoid anomalies up to degree and order 36 (GEM-10B), as well as the effect of a medium air drag (MSIS'77) and luni-solar perturbations, have been modeled in the form of second order correction terms to the satellite position and velocity components (radial, along track, and across track).

These correction terms are function of the longitude of the true ascending node in the Earth fixed reference frame, and of the true latitude of the propagated state vector using the longitude independent mode, expressed in the True of Date reference frame.

This mode is based on the equations derived in KLINKRAD reference.

7 ATTITUDE MODES

The Attitude modes supported in the EO CFI SW are described in [MCD].

The following are mission specific attitude modes that are implemented and supported in the EO CFI:

Table 7: Attitude modes

Mission Name	Attitude Law	Reference documentation
Envisat	Envisat attitude law	TBD
Cryosat	Cryosat attitude law	CRYO_ATT
ADM-Aeolus	ADM-Aeolus attitude law	ADM_AGL
Sentinel 1	Sentinel 1 attitude law	S1_ATT
Sentinel 2	Sentinel 2 attitude law	S2_ATT

7.1 Sentinel-1 attitude law

The Sentinel-1 attitude is defined by the Roll Steering Law described in the document S1_ATT.

The law for the roll steering is:

$$\theta_{offNadir} = \theta_{ref} - \alpha_{roll}(H - H_{ref})$$

where the parameters are:

Table 8: Definition of Sentinel-1 roll steering law

Parameter	Description	Value	Units
$\Theta_{offNadir}$	Antenna bore sight off nadir angle as function of altitude		
Θ_{ref}	Antenna bore sight off nadir angle at reference altitude	29.450	deg
α_{roll}	Roll steering sensitivity versus altitude	0.05660	deg/km
H	Actual satellite altitude		
H_{ref}	Reference altitude	711.700	km

The actual altitude of the satellite is approximated by the following function:

$$H(t) = h_0 + \sum_{n=1}^{N} h_n \cdot \sin(n \cdot \omega_{orb} \cdot (t - t_{ANX}) + \phi_n)$$

where

Table 9: Sentinel-1 numerical values describing altitude versus time by a series of four terms

Parameter	Description	Value	Units
t_{ANX}	Time of ascending node crossing		
ω_{orb}	Orbital frequency	$\omega_{orb} = 2\pi / T_{orb}$	
h_0		707722.812*a)	m
h_1		9217.8955*a)	m
h_2		8939.14477*a)	m
h_3		22.488588*a)	m
h_4		18.1305543*a)	m
φ_1		3.14417817*a)	rad
φ_2		-1.56575883*a)	rad
φ_3		-3.13313437*a)	rad
φ_4		4.69127422*a)	rad
T_{orb}	12 days / 175 orbits	5924.57*a)	sec

*a) These values may have to be recalculated, depending on actual orbit data

8 DRS-ARTEMIS ORBIT

The EOCFI allows for Envisat the visibility computation of the DRS-Artemis Satellite:

8.1 DRS-Artemis Orbit Definition

The initial DRS space segment comprises the Artemis Satellite located in the GEO orbit over Europe (16.4^{o} E). Artemis was launched the 12th of July 2001 reaching its operational orbit in xxxxx and is planned to be moved to 59^{o} E when the first DRSS is launched (DRSENV_ICD reference).

The orbit of the DRS is known on ground to an accuracy corresponding to the following errors ± 20.0 Km along track, ± 15.0 Km across track and ± 15.0 Km radial. These accuracies are achieved for a 24 hour prediction and are achieved when UT is the time reference (DRSENV_ICD reference)

Due to launch failure the North-South station keeping is not operationally implemented. The inclination drift has not been modeled in the EO CFI Software. However it has been modelled in the Envisat CFI Software.

The CFI software will check the compliance of the DRS orbit supplied on input with a set of requirements on the main osculating Kepler elements:

Table 10: DRS orbit tolerance requirements

Osculating Kepler element	Tight tolerance	Loose tolerance
Semi-major axis	42000 / 43000 Km	30000 / 50000 Km
Eccentricity	0.0 / 0.1	0.0 / 0.9
Inclination	- 0.1 / + 0.1 deg	- 1.0 / + 1.0 deg

If the tight tolerance requirements are not satisfied, but the loose ones are, then a warning will be returned by the CFI software.

If even the loose requirements are not satisfied, then an error will be returned.

8.2 DRS-Artemis Orbit Propagation Model

The 24-hour prediction of DRS will be available in equinoctial elements at a given epoch valid for certain validity period, and assuming that the user will propagate this state vector, within the validity period using the following algorithm:

$a = a_{initial}$

$e_x=(e_x)_{initial}$

$e_y=(e_y)_{initial}$

$i_x=(i_x)_{initial}$

$i_y=(i_y)_{initial}$

$\lambda=\lambda_{initial} + (t - t_{initial})\ d\lambda_{initial}\ dt$

$d\lambda_{initial}\ dt = (\mu/a^3)^{1/2}$

$\mu = 3{,}9860044\ 10^5\ km^3/s^2$

where $a_{initial}$, $(e_x)_{initial}$, $(e_y)_{initial}$, $(i_x)_{initial}$, $(i_y)_{initial}$ and $\lambda_{initial}$ are the equinoctial elements at $t_{initial}$.