IF-03

Satellite – Ground Segment

Interface Control Document

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CONTENTS

FIGURES

TABLES

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1. INTRODUCTION

This document describes the interfaces between the S-band and X-band ground stations and the satellite for the Sentinel 5p mission.

2. DOCUMENTATION AND NOMENCLATURE

2.1 Applicable Documents

AD[1] – Sentinel 5p System Requirements Document
S5P-RS-ESA-SY-0002

AD[2] – *Sentinel 5p Operation Interface Requirement Document*
S5P-RS-ESA-SY-0006

AD[3] - *Space engineering. Radio frequency and modulation*
ECSS-E-50-05A

AD[5] - *Space data links – Telecommand protocols, synchronization and channel coding*
ECSS-E-50-04C

AD[6] - *Space data links – Telemetry synchronization and channel coding*
ECSS-E-50-01C

AD[7] - *Space data links – Telemetry transfer frame protocol*
ECSS-E-50-03C

AD[8] - *Advanced Orbiting Systems Space Data Links Protocols*
CCSDS 732.0-B-1

2.2 Reference Documents

[RD-1] – *Directory of Acronyms and Abbreviations*
S5P.LI.ASU.SY.00001

[RD-2] – *AS250 - Generic TM/TC Interface Control Document*
DIV.ICD.00001.T.ASTR Iss 02 Rev 00, 08/02/2012

[RD-3] – *AS250 - Space Segment User Manual Volume 0200 - Data Handling System*
DIV.UM.00008.T.A8TR Iss 7 Rev 0, 06/04/2012

[RD-4] – *CDHS TM/TC Interface Control Document*
ASG7.ICD.12873.ASTR, Iss 1, rev 0, 11/03/2009

[RD-5] –*Sentinel 5p System Budgets*
S5P.RP.ASU.SY.00001

[RD-6] – *Spacecraft – Payload Software ICD*
S5P.ICD.ASU.SC.00004

[RD-7] – *Not Used*

[RD-8] – Not Used

2.3 Acronyms

See [**RD-1**].

3. SENTINEL 5P SYSTEM OVERVIEW

3.1 Introduction

The Sentinel 5p mission includes an Earth observation satellite for providing atmospheric spectral images, a Flight Operations Segment for operating the spacecraft, a set of receiving stations to ensure image data is obtained on every orbit and a dedicated PDGS to process the images to Level 1b. The objective is to provide daily global coverage of the atmosphere with a high resolution spectrograph covering UV, VIS, NIR and SWIR spectrums that enables measurements of particular atmospheric constituents to be taken.

The Sentinel 5p mission will provide atmospheric data for the scientific community that will be down linked regularly and rapidly to ensure a minimum time between the acquisition and the delivery of the processed Level 1b products to the end users.

3.2 System Components

The system is an observation mission based on a sun-synchronous orbit (SSO) satellite, comprising a platform hosting the TROPOMI payload and linked to a ground segment, where the final image data product is distributed to GMES users.

This system is composed of following segments:

- Ground segment.
- Launcher segment.
- Space segment

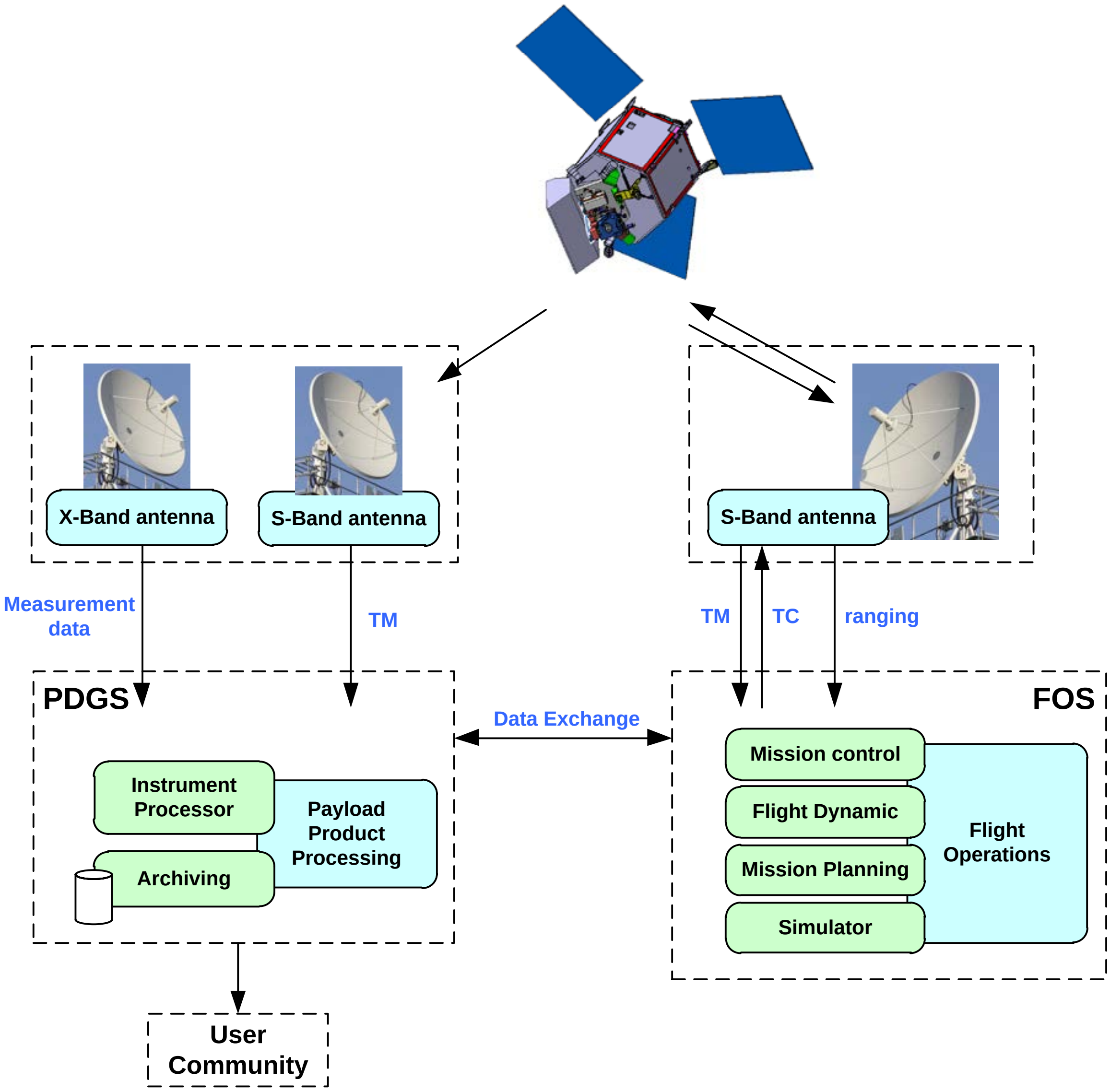

Figure 3-1 Sentinel 5p Space to Ground interface simplified schematic

3.2.1 Ground Segment

The Sentinel 5p Ground Segment comprises two major systems: the Flight Operations Segment (FOS) and the Payload Data Ground Segment (PDGS).

The Flight Operations Segment is in charge of monitoring and controlling the satellite and payload during the commissioning and routine phases. The FOS components are the Mission Control System (MCS), the Flight Dynamics System (FDS), the Satellite and Payload Simulator (SSIM), the TT&C Ground Station(s) that provide the link with the satellite, and the communication networks.

The Payload Data Ground Segment receives science data through X-band downlink at a rate of 310Mbps that allows for example the downlink of 1 orbit worth of TROPOMI data (139 Gbits/orbit) in less than 550s. The PDGS makes the Level 1B and Level2 products available for external distribution to the end users.

3.2.2 Launcher Segment

Mission of this segment consists to offer the launch service for injecting the satellite in its appropriate sun-synchronous orbit. The segment includes the launcher vehicle, which has external interfaces to the satellite.

The current design of S/C is compatible with the baseline VEGA launch vehicle. The geometry and mechanical interfaces of the spacecraft as well as its mass properties comply with the VEGA requirements on accommodation and performance capability.

The design of the S/C also allows compatibility with the backup launcher Rockot.

3.2.3 Space Segment

The space segment of the Sentinel 5p System comprises a low Earth orbit satellite capable of acquiring spectral measurement of the atmosphere images of the Earth's atmosphere using the TROPOMI instrument payload. The TROPOspheric Monitoring Instrument (TROPOMI) is an ultra-violet, visible, near-infrared and short-wave infrared imaging spectrometer, which is designed to provide atmospheric chemistry measurements with high temporal and spatial resolution. The instrument is split into two modules, the Ultraviolet-Visible-Near Infrared (UVN) module and the Short-Wave Infrared (SWIR) module, together with an Instrument Control Unit (ICU), which controls the instrument and provides the electrical interface to the platform. In addition, a dedicated instrument cooling system is required which will consist of a passive radiant cooler.

3.3 Principle Data flows

The principle data flows (Telecommand, Telemetry and Measurement Data) are illustrated in Figure 3-2

It is important to note that the Measurement Data down linked at X-Band includes not only the Observation data from the instrument (image data from each of the detector halves, so 8 APIDs), but also the full set of Image Ancillary data (TROPOMI housekeeping telemetry including the four ISM and four DEM parameter tables, on dedicated APID) along with the Satellite Ancillary data (Position-Velocity-Time, Attitude Quaternion and temperature data on dedicated APID) generated by the platform and passed to the Instrument Control Unit (ICU). The Image Ancillary data is also passed to the platform OBC for downlink at S-Band, but without the four ISM and four DEM parameter tables being included.

The details on these flows are provided in Chapters 1. and 7.

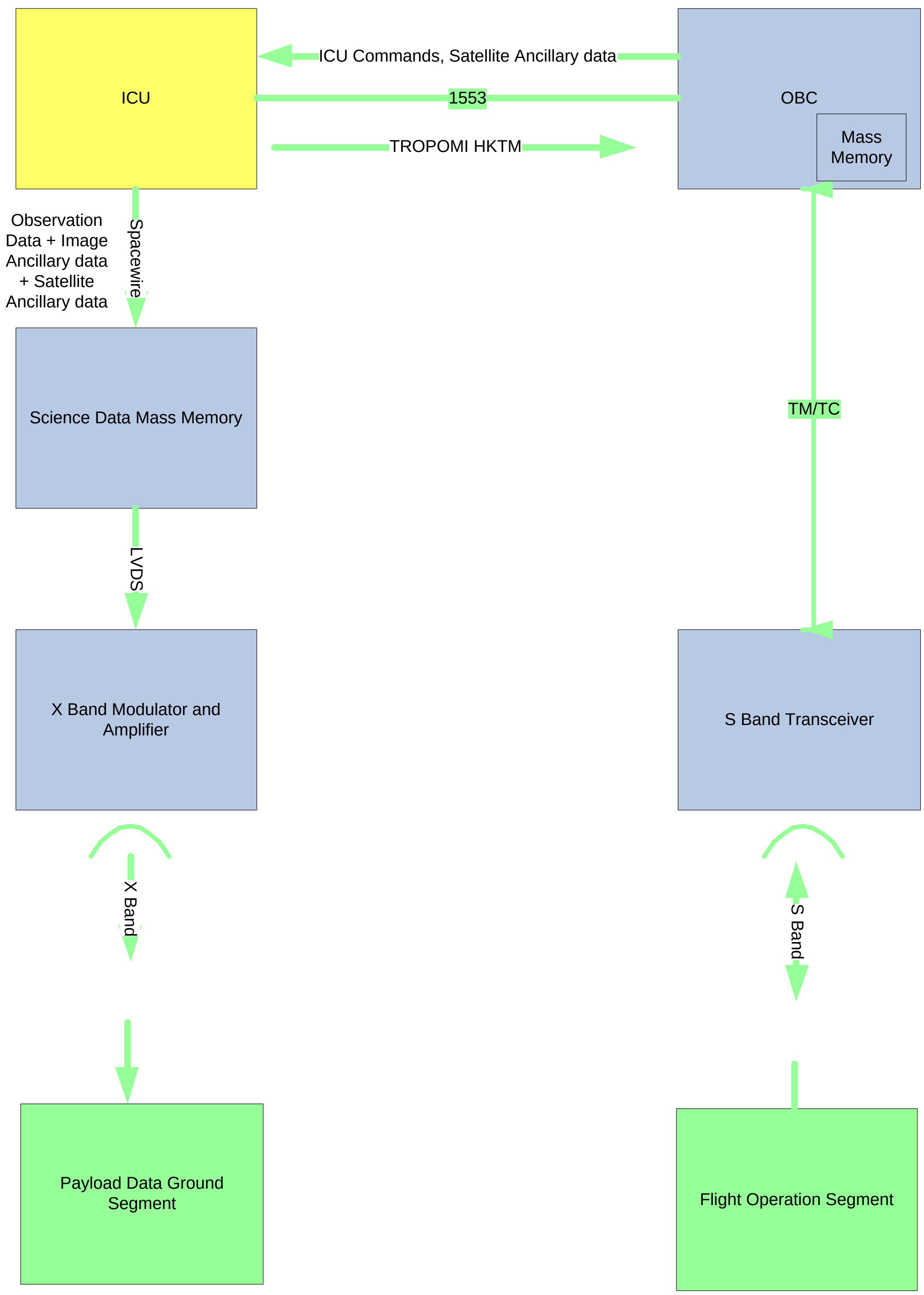

Figure 3-2 Principle Data Flows

4. SATELLITE AND ORBIT DEFINITION

4.1 Baseline Orbit

The S5p Reference orbit is

	Mean	Osculating
Epoch	18/12/2014 00:00:00	
Semi-Major Axis	7205.931 km	7214.887 km
Eccentricity	0.001145	0.0012383
Inclination	98.667 deg	98.661 deg
Right Ascension of the Ascending Node	290.083 deg	290.083 deg
Argument of Perigee	88.463 deg	67.521 deg
True Anomaly	271.505 deg	292.448 deg

Table 4-1 – Reference Orbit

This orbit is consistent with flying in a trailing orbit to a NASA spacecraft with a 1:30 LTAN which would allow cloud data obtained from the NASA mission to be used in the generation of higher level S5p products.

The launch vehicle will inject the Sentinel 5p satellite into an inclined Sun-synchronous polar orbit with a local ascending node time of 13:35. This orbit will provide the required solar illumination of the atmosphere and global coverage. Acquisition of the nominal orbit includes the standard correction of launcher errors but also the need to possibly catch up with another spacecraft (up to 180 degrees in true anomaly away from Sentinel 5p).

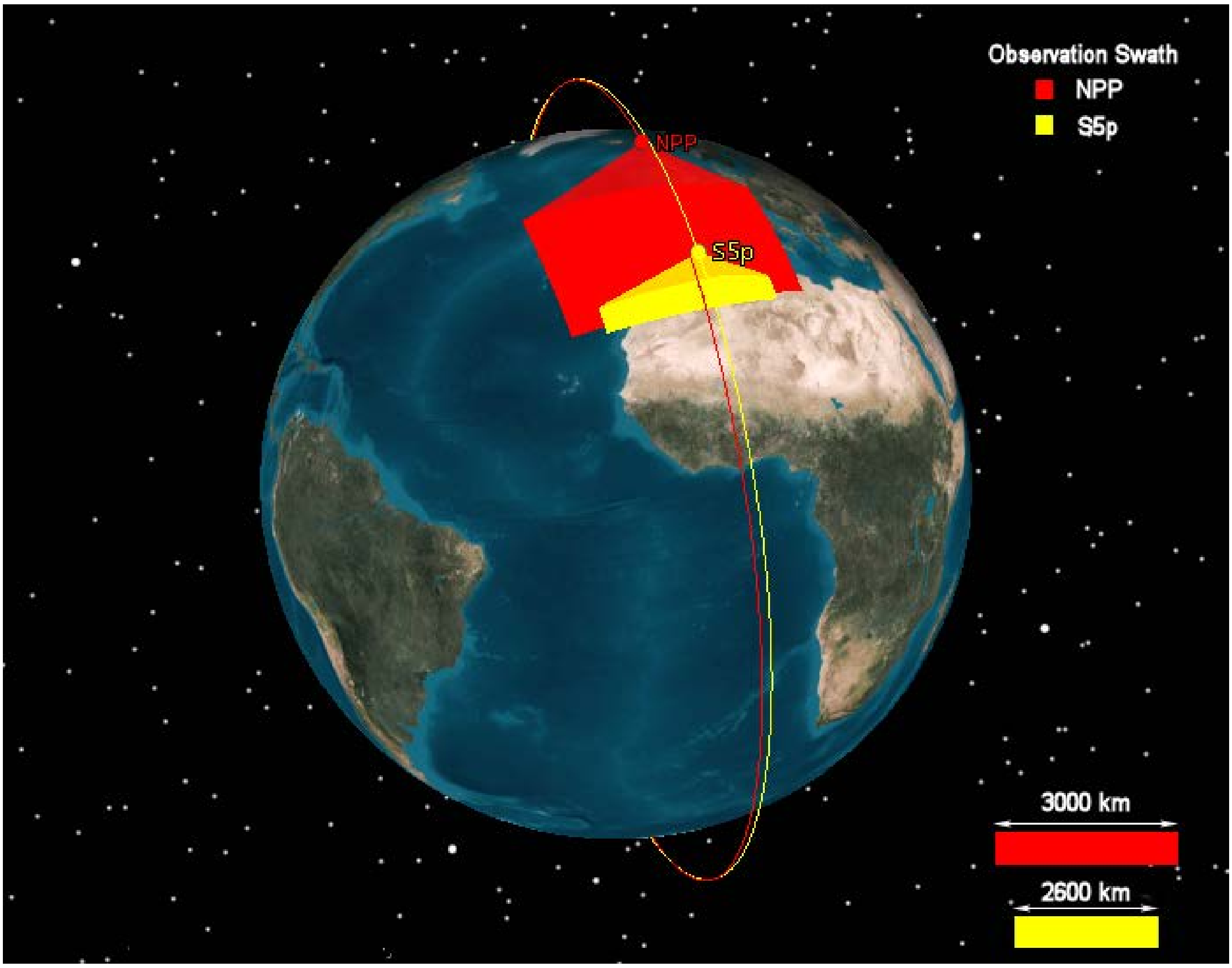

Figure 4-1 - Sentinel 5p swath overlaid on possible cooperating NPP/JPSS mission

5. REFERENCE PROFILE ASSUMPTIONS

TROPOMI is making global measurement of the atmosphere and so the sunlit period of the orbit between Solar Zenith Angle +/- 92 degrees is always used for collecting measurements. During the eclipse then some or all of the time can be spent on dark current calibrations i.e. simply taking measurements even though the Earth is not illuminated by the sun. In addition there are other calibration possibilities making use of an internal white light source (WLS) or observing the solar spectrum (via the solar calibration port and diffuser which has to occur close to SZA = 90degrees)

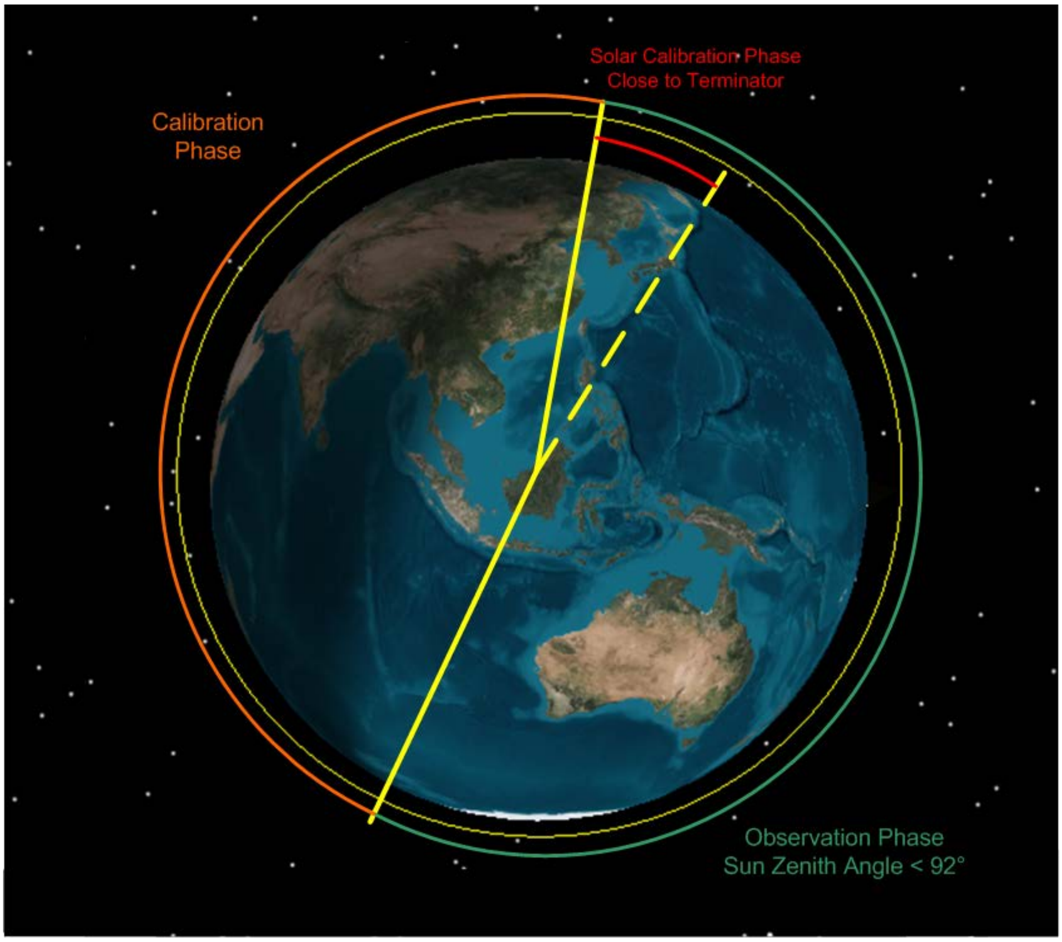

Figure 5-1 Possible TROPOMI Observations

Each orbit will be planned on ground and uplinked as one of the following types:

- Nominal Measurement
- Daily Calibration
- Weekly calibration

Differences between the types are the types and durations of measurements made including the use of solar/WLS light sources. These configurations are controlled by the ICU timeline and have limited impact on the platform (some power increase while mechanisms/WLS are activated and the periods when science data are generated).

The provisional pattern of orbit types (O=Observation, D/W/M=Daily/Weekly/Monthly Calibration) and how they line up with “days” is shown in Figure 5-2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	D1	W1			D2	W2				D3	W3			D4	
2	D1	W4			D2	W5				D3	W6			D4	
3	D1	W7			D2	W8				D3	W9			D4	M1
4	D1	W10			D2	W11				D3	W12			D4	
5	D1	W13			D2	W14				D3	W15			D4	W16
6	D1	F1			D2					D3	F2			D4	
7	D1	W1			D2	W2				D3	W3			D4	
8	D1	W4			D2	W5				D3	W6			D4	
9	D1	W7			D2	W8				D3	W9			D4	M2
10	D1	W10			D2	W11				D3	W12			D4	
11	D1	W13			D2	W14				D3	W15			D4	W16
12	D1	F3			D2					D3	F4			D4	
13	D1	W1			D2	W2				D3	W3			D4	
14	D1	W4			D2	W5				D3	W6			D4	
15	D1	W7			D2	W8				D3	W9			D4	M3
16	D1	W10			D2	W11				D3	W12			D4	
17	D1	W13			D2	W14				D3	W15			D4	W16
18	D1	F1			D2					D3	F2			D4	
19	D1	W1			D2	W2				D3	W3			D4	
20	D1	W4			D2	W5				D3	W6			D4	
21	D1	W7			D2	W8				D3	W9			D4	M4
22	D1	W10			D2	W11				D3	W12			D4	
23	D1	W13			D2	W14				D3	W15			D4	W16
24	D1	F3			D2					D3	F4			D4	

orbit ID	interval	periodicity	name
O	1	360	orbit
D	15	24	daily
W	90	4	weekly
F	180	2	fortnight
M	360	1	monthly

Figure 5-2 TROPOMI Operations

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TROPOMI contains 1 telescope feeding 4 detectors covering SWIR, UV, VIS and NIR. Each detector is programmed for a particular image size (an image consists of spatial separation along one axis and spectral separation along the other) The readout of the detectors can be adjusted in-orbit.

The TROPOMI ICU generates ~139Gbits of packetized data per orbit (image data plus ancillary data) that is fed to the PDHU and stored. During each Ground Station pass, the PDHU applies Reed Solomon encoding and assembles the data into CADU frames, which leads to an expected data flow over the X-band link to the ground per orbit of ~164Gbits.

6. X-BAND ASSEMBLY TO GROUND SEGMENT INTERFACE

6.1 Data Modulation

The main characteristics of the transmitted signal are as follows:

- Frequency range : 8.025 to 8.4 GHz < ±20 ppm
- Bit rate : 310 Mbps.
- Modulation scheme: DQPSK
- Reed Solomon 255/223 with interleaving depth 5.

6.2 Transmission Frequencies

The available carrier frequency range of the X band assembly is 8.025 – 8.4GHz. The frequency finally chosen is **8.150GHz**.

6.3 Link Budgets

The following description provides details of the X-Band payload data downlink. Link budgets for the S5p mission can be found in [**RD-5**].

6.4 Ground Station Front End Characteristics

The assumptions made for the ground segment X band stations, from a RF point of view, as provided by the Agency are summarized in the following tables:

X Band TERMINAL	Inuvik - INU	Inuvik - IVK	Inuvik - 3rd
Longitude	133.539 W	133.539 W	133.539 W
Latitude	68.318 N	68.318 N	68.318 N
Altitude [m]			
Ant Diameter [m]	13	13	13
G/S RX Ant. gain dBi	59.22	59.22	59.22
G/S RX Ant. Axial ratio dB	<1	<1	<1
G/S RX Ant. Pointing losses dB	0.4	0.4	0.4
Earth Station G/T dB/°K at 5 deg el	36.5	36.5	36.5
TM Demod Tech Losses dB	(Cortex XXL HDR)	(Cortex XXL HDR)	(Cortex XXL HDR)

Table 6-1 - X-Band Ground Station Characteristics: Inuvik

X Band TERMINAL	Svalbard SG1	Svalbard SG2	Svalbard SG3	Svalbard SG4	Svalbard SG24	Svalbard SG25
Longitude	15 deg 24’ 28.03” E	15 deg 24’ 28.03” E	15 deg 24’ 28.03” E	15 deg 24’ 28.03” E	15 deg 24’ 28.03” E	15 deg 24’ 28.03” E
Latitude	78 deg 13’ 47.18” N	78 deg 13’ 47.18” N	78 deg 13’ 47.18” N	78 deg 13’ 47.18” N	78 deg 13’ 47.18” N	78 deg 13’ 47.18” N
Altitude [m]	501.2934	501.2934	501.2934	501.2934	501.2934	501.2934
Ant Diameter [m]	11.28	11	13	13	11.3	13
G/S RX Ant. gain dBi						
G/S RX Ant. Axial ratio dB	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
G/S RX Ant. Pointing losses dB	0.4	0.4	0.4	0.4	0.4	0.4
Earth Station G/T dB/°K at 5 deg el	35.4	35	35.5	36	35.5	35.5
TM Demod Tech Losses dB	(MEOS Capture HRDFEP)	(MEOS Capture HRDFEP)	(MEOS Capture HRDFEP)	(MEOS Capture HRDFEP)	(MEOS Capture HRDFEP)	(MEOS Capture HRDFEP)

Table 6-2 – X-band Ground Station Characteristics: Svalbard

6.4.1.1 Spacecraft Parameters

The spacecraft X-Band data downlink performance is specified in the Sentinel 5p X Band Transmitter Requirements Specifications (S5P.SP.ASU.SC.00037)

XDA Power

Parameter	Unit	Sub-Param	Specified Value	Spot 6	Spot 7	KRS
Output Power (modulated)	dBm	Chan A	>46.0 and <48.2	47,45	47,48	46,95
		Chan B	>46.0 and <48.2	47,45	47,48	46,92

These are measured results from the last 3 deliveries. Note, this does not include the waveguide losses between the XDA assembly and the antenna interface. Allow 1 dB in Waveguide losses.

For S5p: 46.92 dBm used as Nominal, 46.0 dBm as adverse and 47.48 as favourable case

6.4.1.2 X-band Subsystem

The general layout of the **Sentinel 5p** X-Band data downlink system is schematically depicted in Figure 6-1.

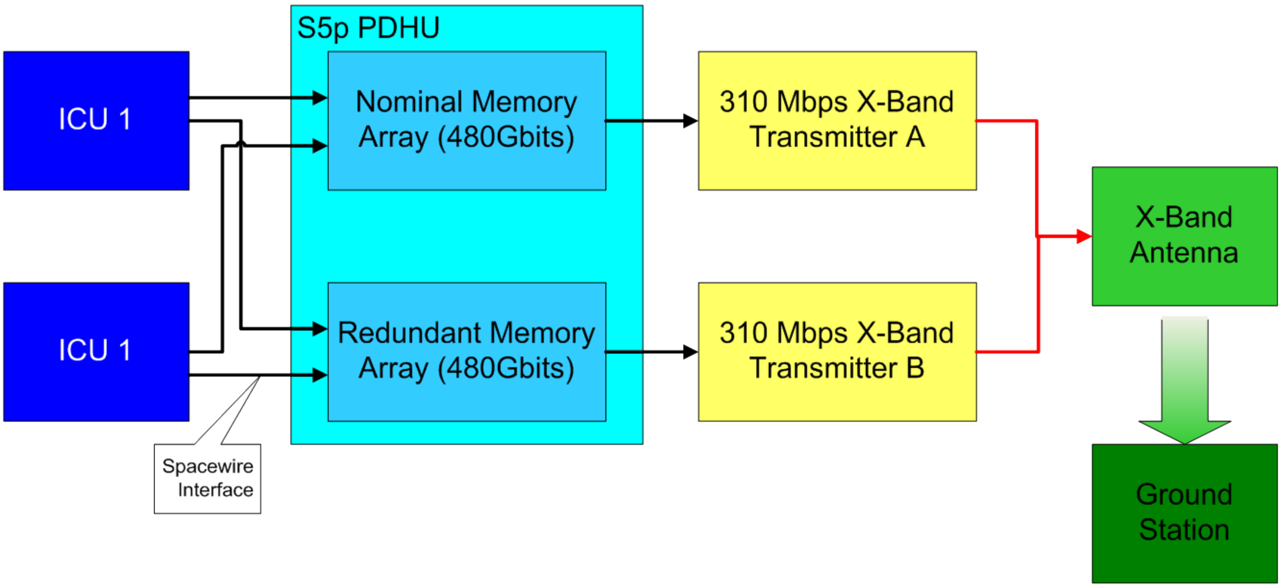
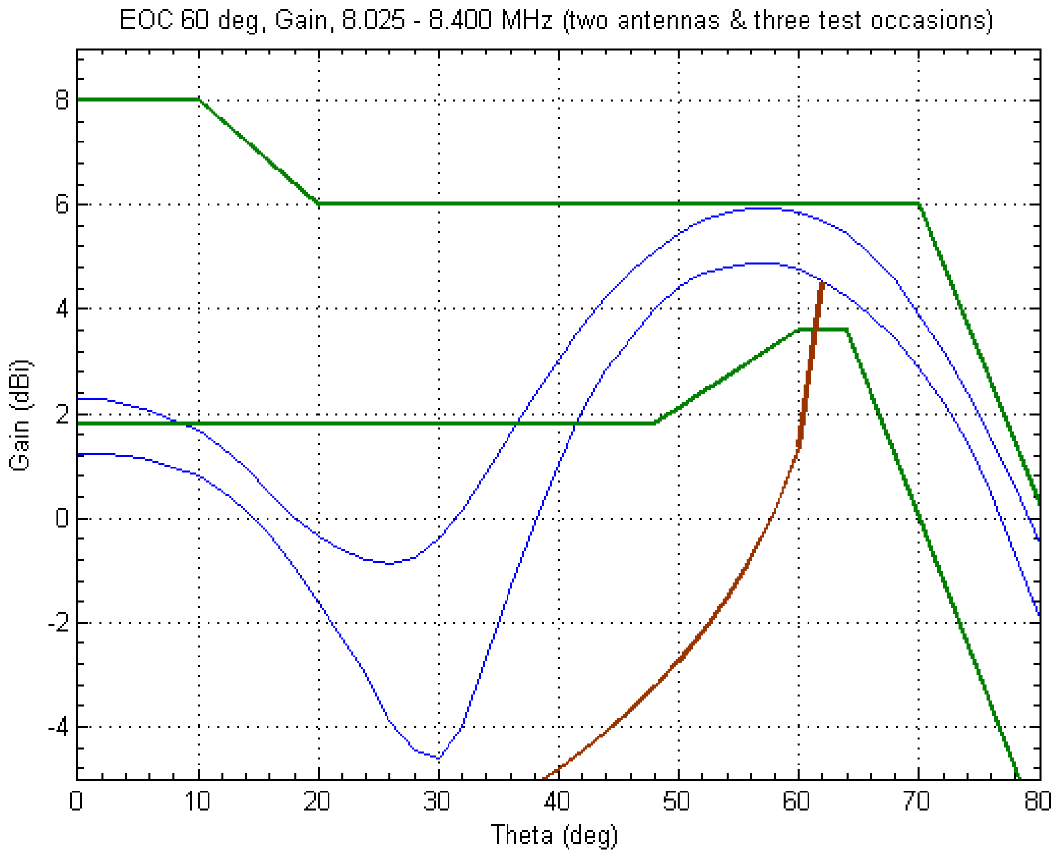


Figure 6-1 - X-band downlink configuration

The S5p X Band antenna radiation pattern provided by the subcontractor is shown in the following figures:



The 2 blue curves in the above antenna gain plot are the minimum and maximum gain that the antenna provides considering a full 360° sweep around the antenna boresight in azimuth at different elevations (Theta). For the link budget the minimum of the 2 gain curves should be taken

Figure 6-2 S5p X-Band antenna pattern

According to the link budgets presented in [RD-5] the maximum operational value of Theta will be 61.8°, which corresponds to the look-angle geometry when the Ground Station elevation angle is 5°.

6.5 Telemetry Downlink

The applicable Standards for Telemetry link are described in **[AD- 6]** and **[AD- 8]**, which fix some parameters and leave a number of configuration parameters to be chosen for the mission.
X-Band Telemetry downlink is used for payload data transmission using QPSK modulation.

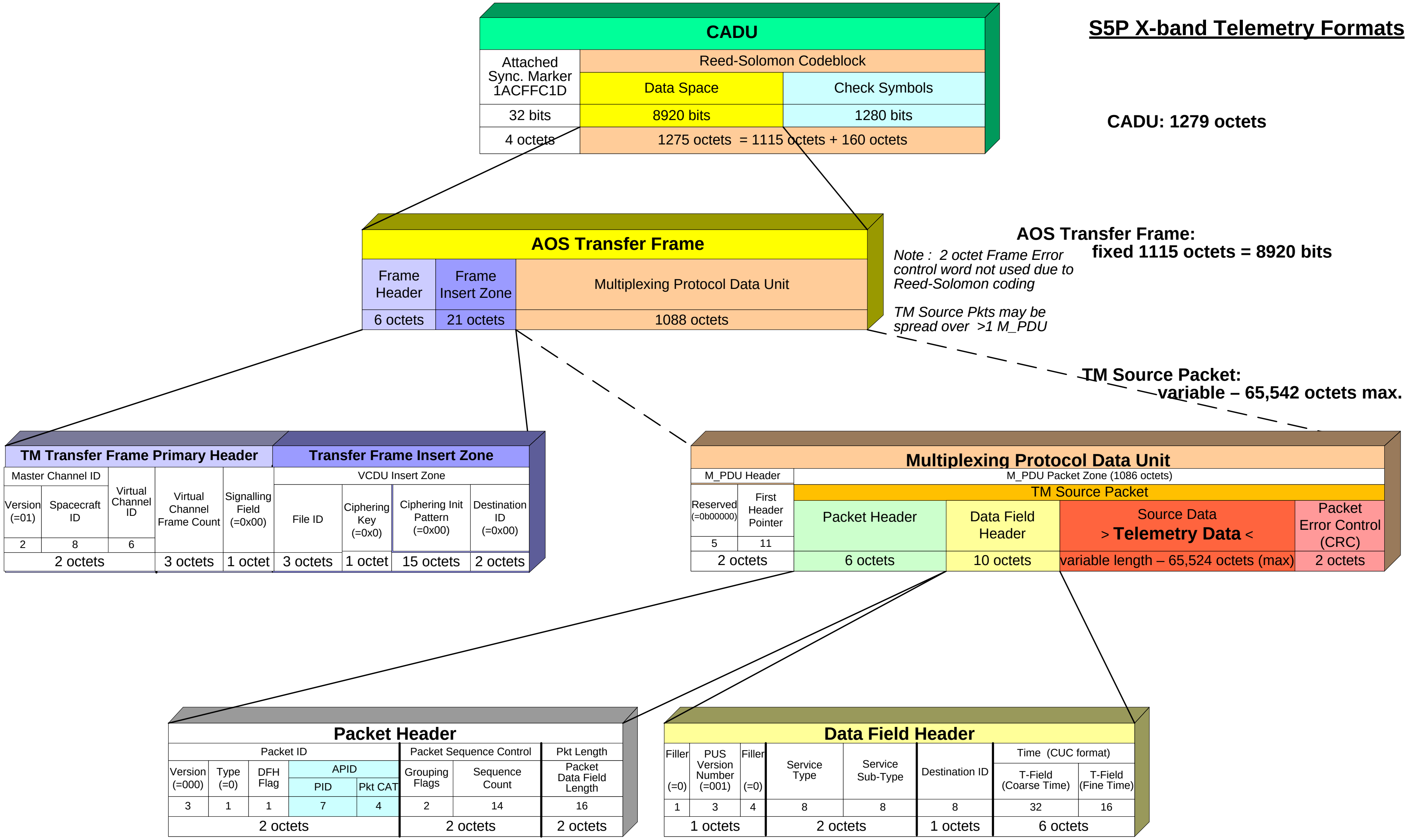


Figure 6-3 X-band TM Formats – Structure & Contents

6.5.1 Physical Channel Coding Options

6.5.1.1 Channel Coding Scheme

The channel coding scheme is Reed-Solomon coding **255/223 with E=8, J=8 and I=5**

6.5.1.2 Frame length

The length of a TM Transfer Frame is fixed for S5p X-band to 1115 Octets

6.5.1.3 Pseudo-randomization

In accordance with **[AD- 3]**, in order to ensure recovery of the symbol clock by the ground demodulators, the transition density has to be ensured by implementing Pseudo-randomization option.

6.5.1.4 ASM of embedded data stream

[AD- 6] Subclause 8.6 defines a different ASM pattern that can be used for an embedded data stream.

Data type ASM in hexadecimal notation for non-turbo-coded data, as is the case of Sentinel 5p is 1ACFFC1D.

6.5.1.5 Length of Virtual Fill

No virtual fill will be used.

6.5.1.6 Channel Access Data Unit (CADU) format

Figure 6-4 shows CADU format used.

<table>
<tr><th colspan="3">CADU</th></tr>
<tr><td rowspan="2">Attached Sync. Marker 1ACFFC1D</td><td colspan="2">Reed-Solomon Codeblock</td></tr>
<tr><td>Data Space</td><td>Check Symbols</td></tr>
<tr><td>32 bits</td><td>8920 bits</td><td>1280 bits</td></tr>
<tr><td>4 octets</td><td colspan="2">1275 octets = 1115 octets + 160 octets</td></tr>
</table>

Figure 6-4 - X-Band link CADU format

6.5.2 Telemetry Transfer Frames

[AD- 8] defines Telemetry transfer Frame. Figure 6-5 shows Telemetry Transfer Frame format used in **Sentinel 5p** mission for the payload data link. Figure 6-6 shows the format of its Primary Header and Figure 6-7 shows the format of its Secondary Header.

<table>
<tr><th colspan="3">TM Transfer Frame</th></tr>
<tr><td>Frame Header</td><td>Frame Sec Header</td><td>Frame Data Field</td></tr>
<tr><td>6 octets</td><td>23 octets</td><td>1086 octets</td></tr>
</table>

Figure 6-5 – X-Band Telemetry Transfer Frame format

Note: The 2 octet Frame Trailer is not used at the end of the Frame Data Field as Reed Solomon coding will be applied to the Transfer Frame at CADU level.

TM Transfer Frame Primary Header				
Master Channel ID				
Version (=01)	Spacecraft ID	Virtual Channel ID	Virtual Channel Frame Count	Signalling Field (=0x00)
2	8	6		
2 octets			3 octets	1 octet

Figure 6-6 X-Band Telemetry Transfer Frame Primary Header format

TM Transfer Frame Secondary Header					
VCDU Insert Zone				M_PDU Header	
File ID	Ciphering Key (=0x0)	Ciphering Init Pattern (=0x00)	Destination ID (=0x00)	Reserved (=0b00000)	First Header Pointer
				5	11
3 octets	1 octet	15 octets	2 octets	2 octets	

Figure 6-7 X-Band Telemetry Transfer Frame Secondary Header format

6.5.2.1 Length of the TM Transfer Frame

The length of the TM Transfer Frame is defined by the selected Reed-Solomon encoding parameters to 1115 octets.

6.5.2.2 Transfer Frame Version Number

For the TM Transfer Frames specified in AD-7 it is set to ‘01’, indicating a version-2 transfer frame. The value is constant for all frames of the physical channel.

6.5.2.3 Spacecraft ID (SCID)

The 8-bit SCID is set to a unique value assigned by the international inter-agency regulatory authorities.

The Sentinel 5p X-band Telemetry has been assigned the SCID 0x**DB**

6.5.2.4 Multiplexing Parameters

Only two Virtual Channel IDs will be used for the Sentinel 5p X-Band telemetry:

- VCID = 0x2A is reserved for Measurement data (all Image and ancillary TM)
- VCID = 0x3F is reserved for Idle frames

The term ‘Idle Frame’ means a Transfer Frame containing (only) Idle Data in its Transfer Frame Data Field.

6.5.2.5 Virtual Channel Frame Count

This 3-byte field contains a sequential binary count (modulo-16777216) of each Transfer Frame transmitted within a specific Virtual Channel. A resetting of the Virtual Channel Frame Count before reaching 16777216 will not take place unless it is unavoidable. Any case where this is unavoidable will be documented in the Spacecraft user manual. For Idle Frames, the Virtual Channel Frame Count is set to zero.

6.5.2.6 File ID

The first 3 bytes of the TM Transfer Frame Secondary Header can be used to allocate an identifier to each X-Band downlink data set. The “Start readout” command to the PDHU includes a variable field that the ground can use to set the File ID to be inserted into each TM Transfer Frame until that readout sequence terminates.

6.5.2.7 First Header Pointer

The First Header Pointer contains information on the position of the first Telemetry Source Packet within the Transfer Frame Data Field; i.e. the binary representation of the location of the first byte of the first Packet Primary Header. The locations of any subsequent headers within the same Transfer Frame Data Field will be determined by calculating these locations using the Packet Data Length Field.

If no Packet Primary Header starts in the Transfer Frame Data Field, the First Header Pointer shall be set to «11111111111» BIN.

For Idle Frames (VC63) the First Header Pointer shall be set to «11111111110» BIN.

6.5.3 Telemetry Packets

See **[RD-3]** document for Telemetry Packet detailed description. A preliminary definition is presented in Figure 6-8 and subsequent figures. The Telemetry data from the TROPOMI instrument is transmitted in uncompressed form only.

TM Source Packet			
Packet Header	Packet Data Field		
	Data Field Header	Source Data > **Telemetry Data** <	Packet Error Control (CRC)
6 octets	10 octets	variable length – 65,536 octets (max)	2 octets

Figure 6-8 - Payload TM Source Packet format

Packet Header

Figure 6-9 shows the structure of the Packet Header whilst Table 6-3 shows the range of values each element can take.

Packet Header							
Packet ID					Packet Sequence Control		Pkt Length
Version (=000)	Type (=0)	DFH Flag	APID		Grouping Flags	Sequence Count	Packet Data Field Length
			PID	Pkt CAT			
3	1	1	7	4	2	14	16
2 octets					2 octets		2 octets

Figure 6-9 - . Payload TM Source Packet Primary Header format

<table>
<tr><th>Parameter</th><th>Description</th><th>Range or value</th></tr>
<tr><td>Version Number</td><td>CCSDS Version Number</td><td>Must be set to 0 for all TM source packets</td></tr>
<tr><td>Type</td><td>Packet type (0 = telemetry, 1 = telecommand)</td><td>Must be set to 0 for all TM source packets</td></tr>
<tr><td>Packet Secondary Header Flag</td><td>Indicates the presence of a secondary (data field) header (when set to 1)</td><td>Must be set to 1 for all TM source packets except for Idle Packets</td></tr>
<tr><td>PID</td><td>Process ID (part of the APID)</td><td>Set to 0x14 for all Payload TM packets</td></tr>
<tr><td>Pkt CAT</td><td>Packet category (also known as PCAT; part of the APID)</td><td>PCAT allocations for X-Band Payload TM:
<table>
<tr><th>PCAT</th><th>Meaning</th></tr>
<tr><td>0</td><td>Not Used</td></tr>
<tr><td>1</td><td>Observation Data(Band 1)</td></tr>
<tr><td>2</td><td>Observation Data(Band 2)</td></tr>
<tr><td>3</td><td>Observation Data(Band 3)</td></tr>
<tr><td>4</td><td>Observation Data(Band 4)</td></tr>
<tr><td>5</td><td>Observation Data(Band 5)</td></tr>
<tr><td>6</td><td>Observation Data(Band 6)</td></tr>
<tr><td>7</td><td>Observation Data(Band 7)</td></tr>
<tr><td>8</td><td>Observation Data(Band 8)</td></tr>
<tr><td>9</td><td>Image Ancillary Data</td></tr>
<tr><td>10</td><td>Not Used</td></tr>
<tr><td>12</td><td>Not Used</td></tr>
<tr><td>13</td><td>Not Used</td></tr>
<tr><td>14</td><td>Satellite Ancillary Data</td></tr>
<tr><td>15</td><td>IDLE</td></tr>
</table></td></tr>
<tr><td>Grouping (Segmentation) Flag</td><td>Indicates the grouping (segmentation) of TM source packets</td><td>- 01 bin first packet of a group of packets
- 00 bin continuation packet
- 10 bin last packet of a group of packets
- 11 bin Standalone</td></tr>
<tr><td>Source Sequence Count</td><td>Wrap around counter used to count each TM packet from a certain APID</td><td>Must be set to 0 for first packet, increments up to 2^{14}-1, wrap around to 0</td></tr>
<tr><td>Packet Length</td><td>Number of bytes contained in the packet data field minus 1</td><td>The max. number contained in the packet data field is :

10 bytes (data field header) + (source data) + 2 optional bytes (packet error control) minus 1</td></tr>
</table>

Table 6-3 – Payload TM Source Packet components

All Measurement Data down linked at X-Band is collected from the Payload ICU and stored by the Payload Data Handling Unit (PDHU) in a single circular buffer in the -order it was received

The Measurement Data includes not only the Observation data from the instrument (eight streams of image data from each of the detector halves), but also the full set of Image Ancillary data (TROPOMI housekeeping telemetry including the four ISM and four DEM parameter tables) along with the Satellite Ancillary data (Position-Velocity-Time, Attitude Quaternion and temperature data) generated by the platform and passed to the Instrument Control Unit (ICU) at 1Hz. Packet interleaving in the Measurement Data stream is a consequence of the ICU behaviour.

The Data Field Header

Figure 6-10 shows the structure of the Data Field Header whilst Table 6-4 list the contents of each element of the header.

Data Field Header							
Filler (=0)	PUS Version Number (=001)	Filler (=0)	Service Type	Service Sub-Type	Destination ID	Time (CUC format)	
						T-Field (Coarse Time)	T-Field (Fine Time)
1	3	4	8	8	8	32	16
1 octets			2 octets		1 octets	6 octets	

Figure 6-10 - Payload TM Source Packet Data Field Header format

PARAMETER	DESCRIPTION	RANGE OR VALUE
Spare 1	Not used	Must be set to 0 for all TM source packets
TM Source Packet PUS Version Number		Must be 1
Spare 2	Filler to complete the byte	Must be set to 0 for all TM source packets
Service Type	Indicates the service to which the packet relates	
Service Subtype	Indicates the service subtype to which the packet relates	
Destination ID	Indicates the destination of the packet	
Time	Onboard time (OBT)	Contains 6 octets indicating time down to a fine level.

Table 6-4 - Payload TM Source Packet Data Field Header contents

7. S-BAND ASSEMBLY TO GROUND SEGMENT INTERFACE

7.1 Data Modulation

UPLINK

The main characteristics of the uplink signal are:

- Bit rate (useful): 8bps - 64 kbps.
- Modulation scheme: SP-L/PM (Split Level / Phase Modulation).
- Coding: No.
- Ranging: Yes.

DOWNLINK

For the downlink, two modes of operation have been considered; one for a data rate of 59.259kbps, and another one for a data rate of 571.429kbps. The main performances of the first mode are:

- Bit rate: 59.259 Kbps.
- Modulation scheme: PCM(NRZ-L)/PSK/PM.
- Coding: Reed Solomon (255, 223) with interleaving depth 5.
- Ranging: Yes.

The main characteristics of the second mode are:

- Bit rate (useful): 571.429kbps.
- Modulation scheme: OQPSK.
- Coding: Reed Solomon (255, 223) with interleaving depth 5 and Convolutional (1/2, 7).
- Ranging: No.

In both modes the S-Band Tx Power is 1 W

Losses to antenna are 6 dB

7.2 S-band TM Security

S-band TM is sent in clear mode.

7.3 Transmission Frequencies

Frequencies for the S-band link are allocated as follows:

Uplink frequency carrier: 2080.163 MHz

Downlink frequency carrier: 2259.000 MHz

7.4 Link Budgets

The Sentinel 5p Link Budgets for the S-Band TT&C up/down link can be found in [**RD-5**].

The formulas used for the TC/TM margins are based on Astrium Astrolink tool, already used in various programmes (Gaia, Aeolus, …) and take into consideration the relevant ECSS standard.

The different spacecraft TT&C configurations, i.e. downlink bit rate mode, are considered in this description.

The orbital characteristics considered in the link calculations are those Specified in the Sentinel 5p SRD AD[1].

7.4.1 Link Budget Parameters

7.4.1.1 Atmospheric, Rain and Ionosphere Losses

The values considered for the Atmospheric, Rain and Ionosphere Losses have been obtained using ESA RAPIDS tool (http://saruman.estec.esa.nl/rapids), considering 99.9% probability.

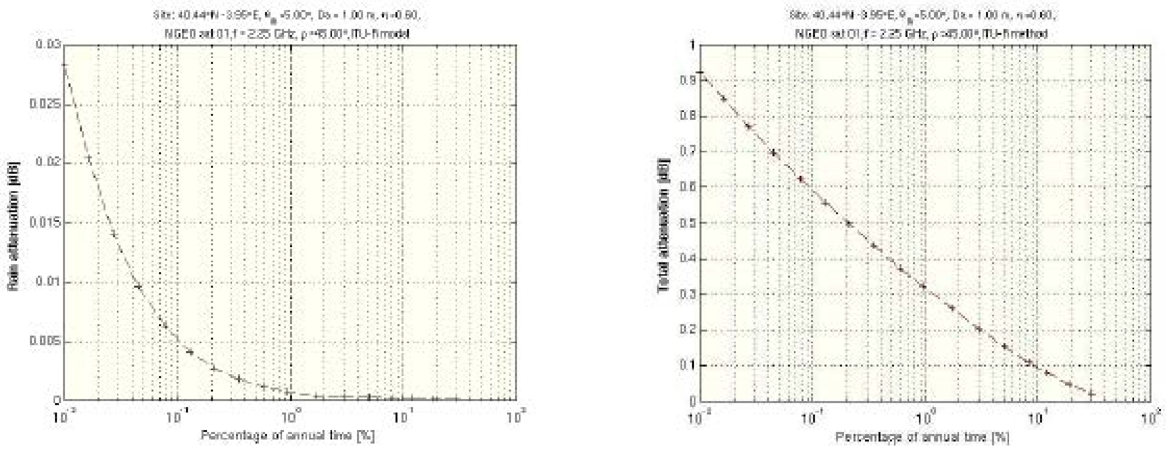


Figure 7-1 - S-Band Atmospheric, Rain and Ionosphere Losses (RAPIDS)

7.4.1.2 Spacecraft Parameters

The spacecraft S-Band downlink performance is specified in the S Band Communications Baseline Requirements Specifications ABL.AST.RS.10004

7.4.1.3 S-band TTC Subsystem

The general layout of the Sentinel 5p S-Band TT&C subsystem is schematically depicted in Figure 7-2.

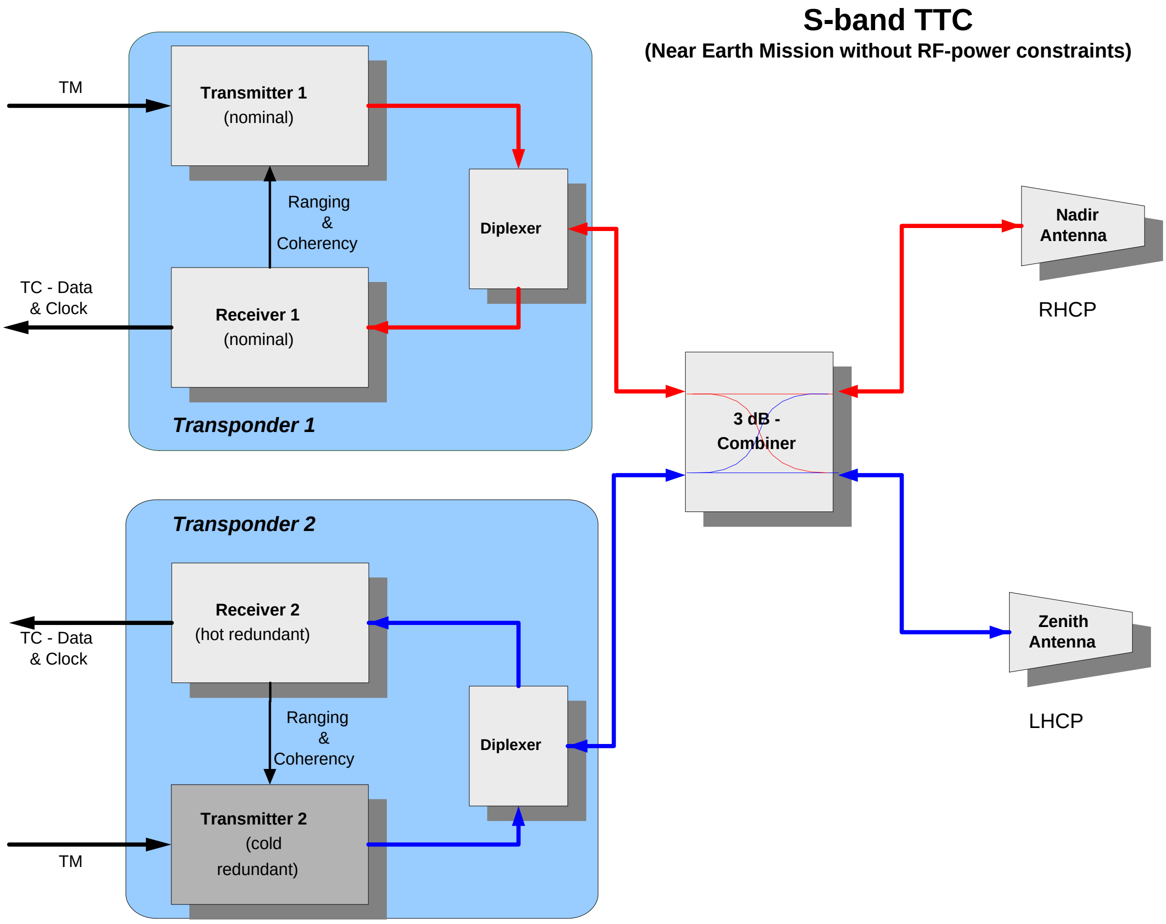


Figure 7-2 – Dual redundant S-band TM/TC Configuration

Both receivers operate in hot redundancy, and each transmitter works in cold redundancy with one being designated the nominal transmitter for normal mission operation. Receive and transmit paths are separated by the diplexers. Within the transponder, the ranging signal can be forwarded from the receiver to the transmitter in either coherent or non-coherent mode. The downlink bit rate and the corresponding modulation type is selectable by command.

The **receiver** acquires and tracks the uplink carrier at received power levels as low as -128 dBm typically. The receiver demodulates the uplink carrier signal to extract the 64 kbps telecommand data as an NRZ-L waveform. This telecommand data and a bit clock are provided to the decoder within the OBC, for further processing, along with an indication of data quality. The receiver also extracts the base-band ranging modulation tones from the uplink carrier and provides this ranging signal to the associated transmitter. This is possible for the low 59.259 kbps downlink data rate.

The **transmitter** accepts the external coded telemetry signal from the OBC and the internal ranging signal from its own receiver. The telemetry input signal will be modulated onto the downlink carrier. Two modes are foreseen for transmission:

- 59.259 kbps PCM(NRZ-L)/PSK/PM (includes RS encoding), this mode will also support ranging
- 571.429 kbps OQPSK (Includes RS encoding)

For the higher data rate, no ranging is possible and OQPSK is used in order to minimise the occupied band according to the RF and Modulation Standard, ECSS-E-ST-50-05C.

The 3dB coupler provides cross-coupling between the two transponders and the antennas. The antennas are constructed from shaped helices and each provides full hemispherical coverage. Each antenna also acts simultaneously as both transmit and receive antenna. Opposite circular polarisations are used in order to distinguish between the reception paths via zenith or nadir antenna. GTD analysis gives a minimum gain of -5 dBi for TM and -7dBi for TC for the full 4π coverage.

When the spacecraft attitude is changing rapidly with respect to the ground station (spacecraft tumbling prior to first attitude acquisition or after a dynamic anomaly) it may not be possible for the ground station to react quickly enough to configure the uplink polarisation to match the changing down link polarisation. In such a situation it should be born in mind what the converged Safe Mode dynamic state will be (rotating at twice the orbit rate in eclipse and –Z sun pointing out of eclipse) and that a command received through the opposite polarisation antenna will still be processed if it is the strongest signal received.

The application of the ranging modulation to the downlink carrier is selectable by telecommand. The transponder can be operated in coherent or non-coherent mode, selectable by telecommand and, once selected, is dependent on the lock status of the receiver. In coherent mode, the downlink (transmit) frequency will be derived from the uplink (receive) frequency, according to the turnaround frequency ratio of 240/221. In non-coherent mode, the transmit frequency is derived from an internal high-stability reference oscillator.

The Sentinel 5p S-band antenna has the pattern shown in the following figure :

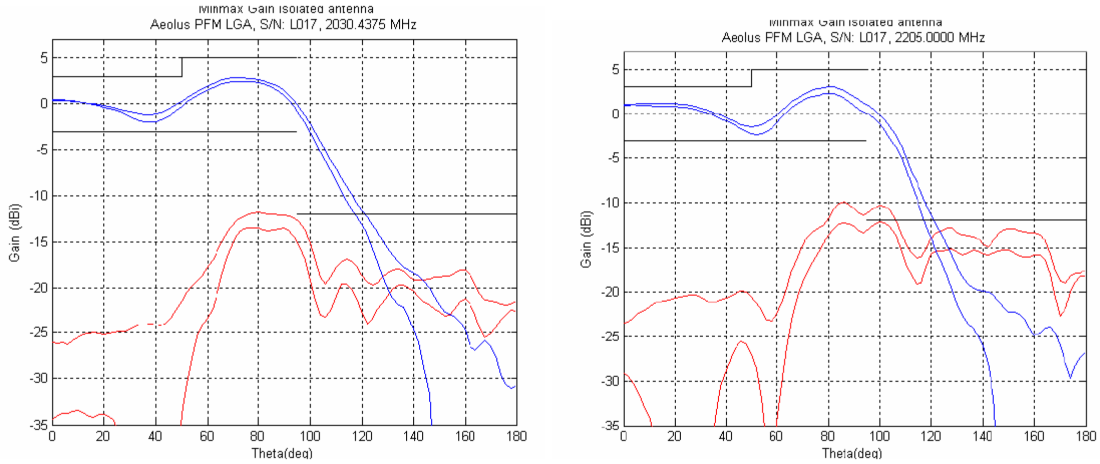


Figure 7-3 - Typical S-Band antenna pattern

7.4.2 S-band Link Budgets

The S-band link budgets can be found in [**RD-5**]. .

7.5 Ground Station Front End Characteristics

The main performance characteristics of the Sentinel 5p mission supporting ground stations as defined by the Agency are shown in the following tables : -

S Band Tx/Rx TERMINAL	Kiruna-1	Kiruna-2	Svalbard-3	Troll
Longitude	20 deg 57’ 51.57” E	20 deg 58’ 00.77” E	15 deg 24’ 28.03” E	2 deg 32’ 2” E
Latitude	67 deg 51’ 25.66” N	67 deg 51’ 30.34” N	78 deg 13’ 47.18” N	72 deg 0’ 7” S
Altitude [m]	402.1724	400.6815	501.2934	1250
Ant Diameter [m]	15	13	13	7.3
G/S Tx Ant. Gain dB	48.5	46.3		
G/S Tx EIRP dBW (capped to 63 dBm by ITU)	101 dBm	99 dBm	98 dBm	53 dBm
G/S Pointing losses dB	0.05	0.05		
G/S Axial Ratio dB	0.5	1		
G/S RX Ant. gain dBi	49.3	47.1		
G/S RX Ant. Axial ratio dB	0.5	1		
G/S RX Ant. Pointing losses dB	0.03	0.03		
Earth Station G/T dB/°K at 5deg el	27.7	22.5	23	19
TM Demod Tech Losses dB	Cortex XL	Cortex XL		

Table 7-1 - FOS S-band Ground Station Characteristics

PDGS S Band Rx Only	Inuvik - INU	Inuvik - IVK	Inuvik - 3rd	Svalbard SG1	Svalbard SG2	Svalbard SG3	Svalbard SG4	Svalbard SG24	Svalbard SG25
G/S RX Ant. gain dBi	47.19	47.19	47.19						
G/S RX Ant. Axial ratio dB	<1	<1	<1	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
G/S RX Ant. Pointing losses dB	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Earth Station G/T dB/°K	23.5	23.5	23.5	23	22.6	23	23	22.5	22.5
TM Demod Tech Losses dB	(Coretx CRT)	(Coretx CRT)	(Coretx CRT)	(Coretx CRT)	(Coretx CRT)	(Coretx CRT)	(Coretx CRT)	(Coretx CRT)	(Coretx CRT)

Table 7-2 -PDGS S-band Receive Ground Station Characteristics

7.6 Command Management

The applicable Standard for Telecommand link is **[AD- 5]**, which fixes some parameters and leaves a number of configuration parameters to be chosen for each mission.

7.6.1 Physical Channel Coding Options

The Security sub-layer which is implemented at coding sub-layer requires Physical layer operation Procedure PLOP-2 in order to ensure there is idle sequence between consecutive CLTUs.

Minimum duration of Idle sequence (CMM-4) will be larger than the minimum defined in **[AD- 5]** and is TBD.

7.6.1.1 Fixed Parameters

The following configuration parameters of the physical channel have values fixed by the requirements of **[AD- 5].**

- A CLTU Start Sequence with one-bit error is accepted.
- The codeblocks of a CLTU are decoded in the error-correcting mode.
- Pseudo-randomization is used.
- A CLTU does not carry multiple TC Transfer Frames.
- The Frame Error Control Field is present in all TC Transfer Frames.

7.6.1.2 Length of Acquisition Sequence

The minimum length of the acquisition sequence is 128 bits. The length can be increased (TBC) to suit different hardware characteristics or channel bit error rates.

7.6.1.3 Physical Layer Operation Procedure

[AD- 5] defines two physical layer operation procedures. PLOP-2 is selected and an idle sequence between CLTUs is always used.

Minimum duration of idle sequence between telecommands is lower than 2 ms (TBC), depending of the processing delay introduced by the security sub layer.

Codeblock N	
TC Data	Error Control 7 parity bits 1 filler bit
7 octets	1 octet

Figure 7-4 - BCH codeblock format

7.6.2 Telecommand Transfer Frames

The Telecommand Transfer Frame format is shown in Figure 7-5, with a maximum TC Frame Data Field length of 249 octets.

TC Transfer Frame		
Frame Header	TC Frame Data Field = 1 TC Segment	TC Frame Error Control Field
5 octets	Variable length 249 octets max (TBC)	2 octets

Figure 7-5 - Telecommand Transfer Frame Format

TC Frame Primary Header							
Version (=00)	Bypass Flag	Control Cmd Flag	Spare (=00)	Spacecraft ID	Virtual Channel ID	Frame Length	Frame Sequence Number
2	1	1	2	10	6	10	8
2 octets					2 octets		1 octet

Figure 7-6 - Telecommand Frame Header format

See **[RD-3], [RD-4] and [RD-5]** for details on definition and contents of the fields of the Telecommand Frame Primary Header.

7.6.2.1 Transfer Frame Version Number

For the TC Transfer Frames specified in AD-5 Version Number is set to '00', indicating a version 1 TC Transfer Frame. The value is constant for all frames of the physical channel.

7.6.2.2 Maximum Length of a TC Transfer Frame

The maximum length of a TC Transfer Frame is fixed for Sentinel 5p to 256 octets.

7.6.2.3 Spacecraft ID (SCID)

The 10-bit SCID is set to a unique value assigned by the international inter-agency regulatory authorities.

The Sentinel 5p S-band Telecommand and Telemetry links have been assigned the SCID 0x**2D1**

7.6.2.4 Virtual Channels

Virtual Channel allocation is as follows:

- VC ID =0x10 - Telecommand Decoder A
- VC ID =0x21 - Telecommand Decoder B

Telecommand Transfer Frames received on-board are simultaneously routed to both TC Decoders (A and B) though are processed only by the decoder referred to by the VCID.

7.6.2.5 Use of the Expedited Service

There is a mission configuration parameter that defines the operational circumstances under which the expedited service of the Transfer Sublayer is used. In the case of Sentinel 5p these circumstances remain TBD.

Within COP-1 implementation, the packet telecommand services AD (Sequence Controlled Service) and BD (Expedited Service) are supported in parallel.

7.6.3 Telecommand Segments

Telecommand Segmentation is defined in Figure 7-7

TC Segment		
Segment Header		Segment Data Field
Sequence Flags	MAP ID	TC Packet or aggregation of TC Packets (5 pkts max) or TC Segment
2	6	
1 octet		variable length – 248 octets (max)

Figure 7-7 - Telecommand Segment format (no Authentication)

The Telecommand segmentation layer supports the following, as outlined in **[AD- 5]**:

- Telecommand Segmentation (any single TC longer than the segment data field is transmitted in multiple segments)

- Telecommand Aggregation (blocking of multiple TC in one TC segment)
- MAP multiplexing

7.6.3.1 MAP Multiplexing

MAP ID's is be used to route the telecommands from the decoder depending on the type of handling required for the command e.g. OBC software or Command Pulse Distribution Unit (CPDU).

MAP ID's shall not be used to address the currently active DMS processor.

- MAP-ID = "CPDU" = 0 is used for CPDU commands.
- MAP-ID = "Normal" = 1 is used for normal commanding other than CPDU command
- MAP-ID = "MAP 63" = 111111 is used for Authentication Control Commands for the uplink (not relevant to S5p).

Note: An Authentication Unit (AU) is implemented in the standard AS250 OBC to allow TC data to be received in clear form but with key seeded encrypted authentication signatures. This authentication facility will be permanently disabled for S5p by means of a hardware strap in the OBC such that S5p TC interface will only ever operate in "clear" state.

7.6.3.2 Telecommand Packet Aggregation

In order to maximise the throughput of commands on the uplink, packet aggregation may be used by Ground. Aggregation is a CCSDS concept where several complete packets can be put into a single segment. Each segment will always start with the beginning of a packet and the length of the first packet will define the start position of the next packet.

Packet aggregation is not mandatory and the DMS will manage all packets within the Segment Data Field, whether aggregated or not.

Important note: aggregation of CPDU commands is not permitted. Therefore only one CPDU command (DTC) is allowed in the Data Field of a CPDU Segment.

7.6.3.3 Telecommand Packet Segmentation

Sentinel 5p is compatible with segmentation to allow receiving TC packets with a size bigger than 248 octets. In order to transmit a TC packet of the maximum size (1024 octets), the ground will use 5 segments.

If the ground cannot handle segmentation, then it will be limited to sending TC packets of 248 octets maximum.

Important note: CPDU commands (DTC) cannot be segmented (Packet sequence flags shall be '11') so it shall be carried inside a single telecommand segment.

7.6.4 Telecommand Packets

See [**RD-2], [RD-3] and [RD-4]** for a detailed description of Telecommand Packet formatting.

7.7 Telemetry Downlink

The applicable Standards for Telemetry link are **[AD- 6]** and **[AD- 7]**, which fix some parameters and leaves a number of configuration parameters to be chosen for each mission.

The Telemetry downlink has two different modes of operation:

- Low bit rate mode, 59.259 Kbps which is compatible with simultaneous coherent ranging
- High bit rate mode, 571.429 Kbps, which is for use when no simultaneous ranging is taking place

The overall scheme and formatting of the S-band downlink is shown in Figure 6-1

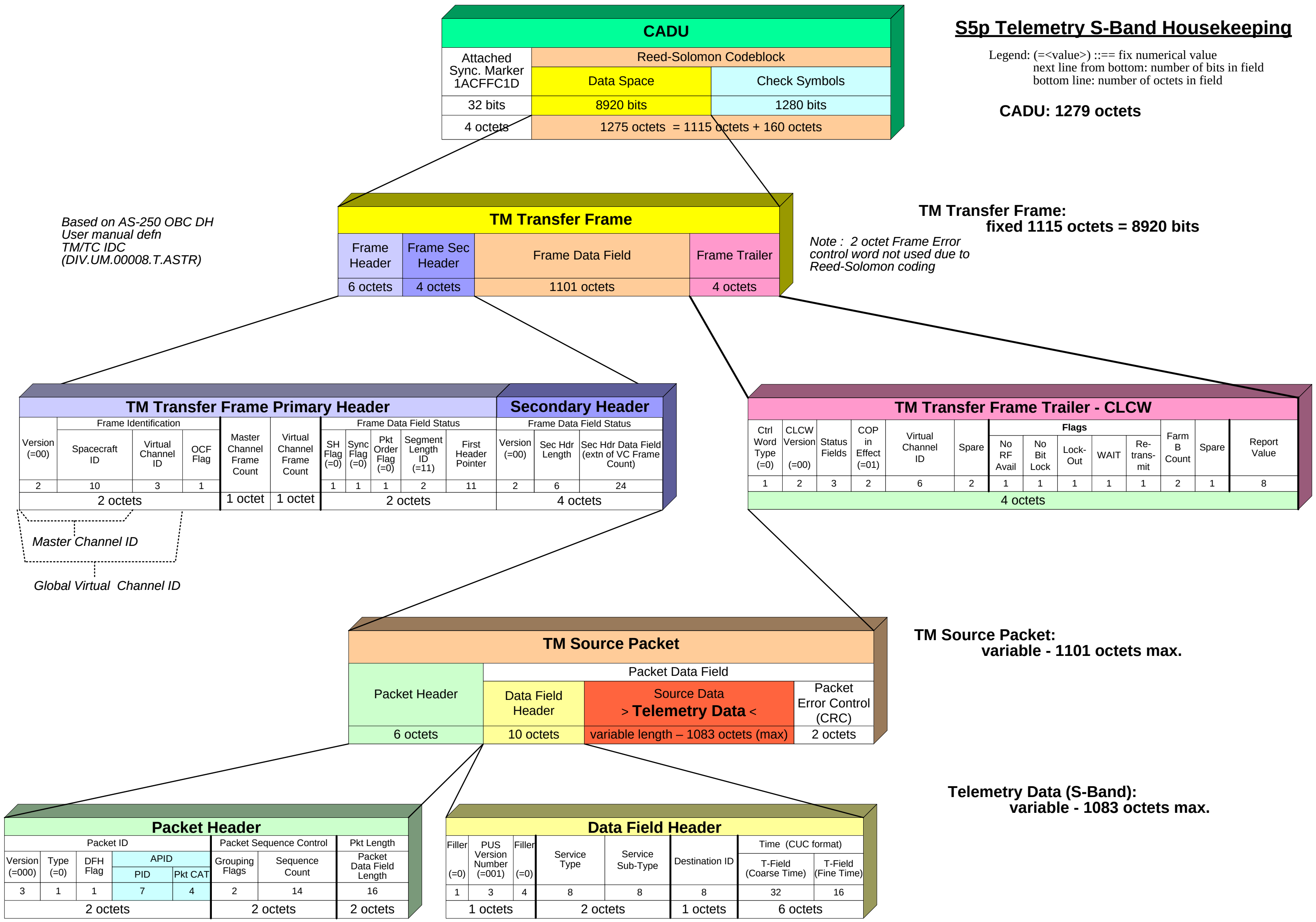


Figure 7-8 - S-band TM formats

7.7.1 Physical Channel Coding Options

7.7.1.1 Channel Coding Scheme

The channel coding scheme is different for each (low or high bit rate) TM operation mode

- Low bit rate mode: Reed-Solomon coding with 255/223 with interleaving depth 5 with E=16, J=8, I=5
- High bit rate mode: Concatenated coding with Convolutional coding r=1/2 and Reed-Solomon coding with 255/223 with interleaving depth 5 E=16, J=8, I=5

7.7.1.2 Frame Length

The length of a TM Transfer Frame is fixed for Sentinel 5p to 1115 octets

7.7.1.3 Pseudo-randomization

In accordance with **[AD- 3]** and in order to ensure recovery of the symbol clock by the ground demodulators, the Pseudo-randomization option is implemented to ensure the appropriate transition density.

7.7.1.4 ASM of embedded data stream

[AD- 6] Subclause 8.6 defines a different ASM pattern that can be used for an embedded data stream. Data type ASM in hexadecimal notation for non-turbo-coded data, as is the case of Sentinel 5p is 1ACFFC1D.

7.7.1.5 Length of Virtual Fill

No virtual fill will be used.

7.7.1.6 Channel Access Data Unit (CADU) format

Figure 7-9 shows CADU format used either for Low Rate and High Rate modes.

CADU		
Attached Sync. Marker 1ACFFC1D	Reed-Solomon Codeblock	
	Data Space	Check Symbols
32 bits	8920 bits	1280 bits
4 octets	1275 octets = 1115 octets + 160 octets	

Figure 7-9 - S Band link CADU format

7.7.2 Telemetry Transfer Frames

AD-4 define Telemetry Transfer Frame version 1. Figure 7-10 shows Telemetry Transfer Frame format used in Sentinel 5p mission. Figure 7-11 shows the format of its Primary Header.

TM Transfer Frame		
Frame Header	Frame Data Field	Frame Trailer
6 octets	1105 octets	4 octets

Figure 7-10 - Telemetry Transfer Frame format

TM Transfer Frame Primary Header										
	Frame Identification					Frame Data Field Status				
Version (=00)	Spacecraft ID	Virtual Channel ID	OCF Flag	Master Channel Frame Count	Virtual Channel Frame Count	SH Flag (=0)	Sync Flag (=0)	Pkt Order Flag (=0)	Segment Length ID (=11)	First Header Pointer
2	10	3	1			1	1	1	2	11
2 octets				1 octet	1 octet	2 octets				

Figure 7-11 - Telemetry Transfer Frame Primary Header format

7.7.2.1 Length of TM Transfer Frame

The length of the TM Transfer Frame is defined by the selected Reed-Solomon encoding parameters to 1115 octets.

7.7.2.2 TM Transfer Frame Version Number

For the TM Transfer Frames specified in **[AD- 7]** it is set to '00', indicating a version-1 transfer frame. The value is constant for all frames of the physical channel. The value applies to all master channels and all virtual channels of the physical channel.

7.7.2.3 Spacecraft ID (SCID)

The 11 bits SCID will be set to a unique value assigned by the international inter-agency regulatory authorities.

7.7.2.4 Handling of Frames containing detected errors

The handling of TM Transfer Frames containing detected errors is mission dependent and is specified for each mission or mission phase.

Faulty frames can be delivered or discarded (TBD by Ground Segment)

7.7.2.5 Multiplexing Parameters

A single master channel is mapped onto the physical channel.

The VC allocation for Sentinel 5p S-band TM is assigned according to the following scheme :

- VC 0 for HK Real Time
  (All packets – e.g. Services 1, 2, 3, 5, 6, 9, 11, 12, 14, 15, 17, 18, 19 & private, including Dwell)
- VC 1 for Play Back TM

(Data packets – e.g. Success reports (1,1), (1,7), (5,1), TM (3,25), TM (5,1), Service 6, 9, 11, 12, 14, 15, 17, 18, 19, & private, excluding Dwell and error reports. All telemetry & event reports originating from the ICU and the CSW Payload Manager application)

- VC 2 for Diagnostic TM
  (TM (3,26), Dwell, private service diagnostic reports)
- VC 3 and 4 are reserved for spare
  VC 5 for Events / log
  (TM (1,2), (1,8), (5,2), (5,3), (5,4) and private service error reports)
- VC6 is not used in AS250
- VC7 is used to automatically generate idle frames when there is no packet to downlink.

The term «Idle Frame» means a Transfer Frame containing (only) Idle Data in its Transfer Frame Data Field. Such a frame can still carry non-idle information outside the Transfer Frame Data Field and then be used for «active» purposes (e.g. extraction of the CLCW in the OCF for the Telecommand protocol; reference Time for time calibration procedures, etc.).

Other Virtual Channels may contain Idle Packets if no data are available when they have to be transmitted.

For further details of the multiplexing of virtual channels onto the master channel including algorithms, priorities and other related parameters, refer to **[RD-3]**.

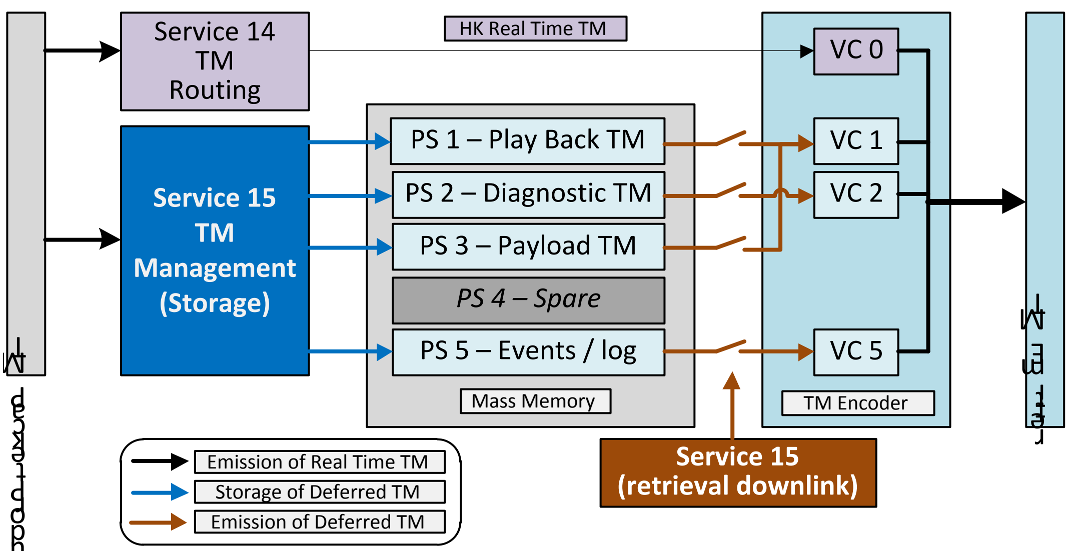


Figure 7-12 Packet Stores and Virtual Channels

7.7.2.6 TM Transfer Frame Secondary Header Flag

A Transfer Frame Secondary Header will be inserted in all frames so the flag will always be set to '1'. See Section 7.7.2.12 for details of the header.

7.7.2.7 Master Channel Frame Count

The Master Channel Frame Count field will contain a sequential binary count (modulo 256) of each Transfer Frame transmitted within the ASTROSAT-250 specific Master Channel. A resetting of the MASTER CHANNEL FRAME COUNT before reaching 255 will not take place unless it is unavoidable. Any case when it is unavoidable will be documented in the Spacecraft user manual.

7.7.2.8 Virtual Channel Frame Count

The Virtual Channel Frame Count field will contain a sequential binary count (modulo 256) of each Transfer Frame transmitted through a specific Virtual Channel of a Master Channel. A resetting of the Virtual Channel Frame Count before reaching 255 will not take place unless it is unavoidable. Any case when it is unavoidable will be documented in the Spacecraft user manual.

7.7.2.9 Data Field Synchronization Flag

The Data Field Synchronisation Flag will be set to zero; i.e. byte-synchronised and forward ordered Telemetry Source Packet or Idle Data (only for VC6) will be inserted in the Transfer Frame Data Field.

7.7.2.10 Packet Order Flag

The Packet Order Flag shall be set to zero. The Packet sequence count order shall be forward.

7.7.2.11 First Header Pointer

As the Synchronisation Flag is set to zero, the First Header Pointer shall contain information on the position of the first Telemetry Source Packet within the Transfer Frame Data Field; i.e. the binary representation of the location of the first byte of the first Packet Primary Header. The locations of any subsequent headers within the same Transfer Frame Data Field will be determined by calculating these locations using the Packet Data Length Field.

If no Packet Primary Header starts in the Transfer Frame Data Field, the First Header Pointer shall be set to «11111111111» BIN.

For Idle Frames (VC6) the First Header Pointer shall be set to «11111111110» BIN.

7.7.2.12 TM Transfer Frame Secondary header

This shall contain a header and an expansion of the virtual channel frame counter. Figure 7-13 shows its format.

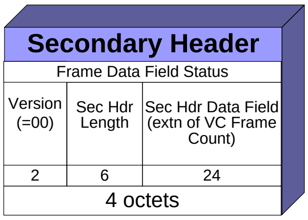


Figure 7-13 - Telemetry Transfer Frame Secondary Header format

The secondary header ID will be 8 bits in length and shall indicate the version number and the header length, this shall be set to 00000011 BIN.

The secondary header data shall be a 3 Byte field containing an additional 24 bits of the virtual channel frame count as defined in [AD-03]

7.7.2.13 Transfer Frame Data Field

The Transfer Frame Data Field will contain TM Source Packets: See section 7.7.3

7.7.2.14 Operational Control Field

A Command Link Control Word (CLCW) shall be inserted in the Operational Control Field (OCF) for all frames of the master channel.

- CLCWs with a VC ID belonging to the nominal Command Decoder are transmitted in the Transfer Frames with an even Master Channel Frame Count
- CLCWs with a VC ID belonging to the redundant Command Decoder are transmitted in the Transfer Frames with an odd Master Channel Frame Count.

Figure 7-14 shows the format for the Operational Control field.

Transfer Frame Trailer													
CLCW													
Ctrl Word Type (=0)	CLCW Version (=00)	Status Fields	COP in Effect (=01)	Virtual Channel ID	Spare	Flags					Farm B Count	Spare	Report Value
						No RF Avail	No Bit Lock	Lock-Out	WAIT	Re-trans-mit			
1	2	3	2	6	2	1	1	1	1	1	2	1	8
4 octets													

Figure 7-14 - Command Link Control Word format

7.7.2.15 Frame Error control Field

Since the physical link uses Reed-Solomon encoding, the presence of the Frame Error Control Field is not used.

7.7.3 Telemetry Packets

See **[RD-3]** document for S-Band Telemetry Packet detailed description. A summary definition is presented in Figure 6-8 and subsequent figures.

TM Source Packet			
Packet Header	Packet Data Field		
	Data Field Header	Source Data > **Telemetry Data** <	Packet Error Control (CRC)
6 octets	10 octets	variable length – 1083 octets (max)	2 octets

Figure 7-15 – S-Band TM Source Packet format

Packet Header

Figure 6-9 shows the structure of the Packet Header whilst Table 6-3 shows the range of values each element can take.

<table>
<tr><th colspan="9">Packet Header</th></tr>
<tr><td colspan="5">Packet ID</td><td colspan="2">Packet Sequence Control</td><td>Pkt Length</td></tr>
<tr><td rowspan="2">Version (=000)</td><td rowspan="2">Type (=0)</td><td rowspan="2">DFH Flag</td><td colspan="2">APID</td><td rowspan="2">Grouping Flags</td><td rowspan="2">Sequence Count</td><td rowspan="2">Packet Data Field Length</td></tr>
<tr><td>PID</td><td>Pkt CAT</td></tr>
<tr><td>3</td><td>1</td><td>1</td><td>7</td><td>4</td><td>2</td><td>14</td><td>16</td></tr>
<tr><td colspan="5">2 octets</td><td colspan="2">2 octets</td><td>2 octets</td></tr>
</table>

Figure 7-16 – S-Band TM Source Packet Primary Header format

<table>
<tr><th>Parameter</th><th>Description</th><th>Range or value</th></tr>
<tr><td>Version Number</td><td>CCSDS Version Number</td><td>Must be set to 0 for all TM source packets</td></tr>
<tr><td>Type</td><td>Packet type (0 = telemetry, 1 = telecommand)</td><td>Must be set to 0 for all TM source packets</td></tr>
<tr><td>Data Field Header Flag</td><td>Indicates the presence of a secondary (data field) header (when set to 1)</td><td>Must be set to 1 for all TM source packets except for Time and Idle Packets where it must be set to 0.</td></tr>
<tr><td>PID</td><td>Process ID (part of the APID)</td><td>Must be set to a registered PID value</td></tr>
<tr><td>Pkt CAT</td><td>Packet category (also known as PCAT)</td><td>PCAT allocations for Platform TM:
<table>
<tr><th>PCAT</th><th>Meaning</th></tr>
<tr><td>0</td><td>TIME</td></tr>
<tr><td>1</td><td>ACKNOWLEDGE</td></tr>
<tr><td>2</td><td>HK_RT[1]</td></tr>
<tr><td>3</td><td>TABLE</td></tr>
<tr><td>4</td><td>HK_PB</td></tr>
<tr><td>5</td><td>Not Used (spare)</td></tr>
<tr><td>6</td><td>Not Used (spare)</td></tr>
<tr><td>7</td><td>EVENT</td></tr>
<tr><td>8</td><td>DIAGNOSTIC</td></tr>
<tr><td>9</td><td>DUMP</td></tr>
<tr><td>10</td><td>Payload (not HK)</td></tr>
<tr><td>12</td><td>TELECOMMAND</td></tr>
<tr><td>13</td><td>Payload (HK)</td></tr>
<tr><td>14</td><td>Reserved for OCC/EGSE</td></tr>
<tr><td>15</td><td>IDLE</td></tr>
</table>
As defined in [RD-6], only two PCAT values (10 and 13) will be used for Payload TM (Payload TM frames are created by the ICU)[2]:</td></tr>
<tr><td>Grouping (Segmentation) Flag</td><td>Indicates the grouping (segmentation) of TM source packets</td><td>- 01 bin first packet of a group of packets
- 00 bin continuation packet
- 10 bin last packet of a group of packets
- 11 bin Standalone</td></tr>
</table>

[1] Two categories are used in service 3 over the S-Band link to distinguish packets sent to the Real Time VC (HK_RT) from the ones stored on-board and downlinked in the Playback VC (HK_PB), which allows sequence counters gaps in the real-time telemetry flow when a packet is stored on-board to be avoided.

[2] It should be noted that this arrangement is not compliant with OIRD requirement TM-24 since both Playback and Real-time payload housekeeping TM routed through the OBC and the S-Band downlink will use a common Source Sequence Count.

Parameter	*Description*	*Range or value*
Source Sequence Count	Wrap around counter used to count each TM packet from a certain APID	Must be set to 0 for first packet, increments up to 2^{14}-1, wrap around to 0
Packet Length	Number of bytes contained in the packet data field minus 1	The max. number contained in the packet data field is : 10 bytes (data field header) + (source data) + 2 optional bytes (packet error control) minus 1

Table 7-3 – S-Band TM Source Packet components

The Data Field Header

Figure 6-10 shows the structure of the Data Field Header whilst Table 6-4 list the contents of each element of the header.

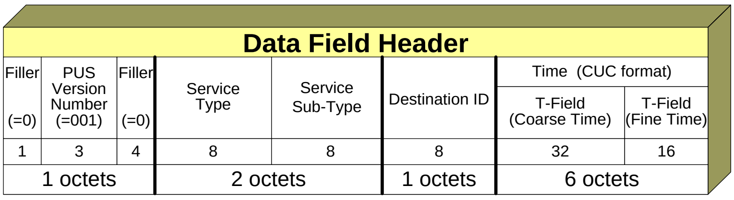


Figure 7-17 – S-Band TM Source Packet Data Field Header format

PARAMETER	***DESCRIPTION***	***RANGE OR VALUE***
Spare 1	Not used	Must be set to 0 for all TM source packets
TM Source Packet PUS Version Number		Must be 1
Spare 2	Filler to complete the byte	Must be set to 0 for all TM source packets
Service Type	Indicates the service to which the packet relates	
Service Subtype	Indicates the service subtype to which the packet relates	
Destination ID	Indicates the destination of the packet	
Time	Onboard time (OBT)	Contains 6 octets indicating time down to a fine level.

Table 7-4 – S-Band TM Source Packet Data Field Header contents

Packet Error Control

The 2-byte Packet Error Control checksum word is not used for Idle packets. All other S-Band TM packet types (including Time packets) do include the Packet Error Control word.

7.7.4 Range/Range Rate measurement Function

Ranging will be used during LEOP and in general whenever low bit rate is selected during the mission. During routine operations, orbit determination will instead be done based on the GPS data.

The range / range rate function is a tailoring for Sentinel 5p of the standard **ECSS-E-50-02A**. The S-Band receiver is able to extract the base-band ranging modulation tone from the uplink carrier and provide this ranging signal to the associated transmitter.

Range rate on ground can be measured by tracking the instantaneous frequency of the downlink carrier.

The S-Band transponder works in **coherent or non-coherent mode selectable by telecommand**.

The transmitter accepts the external coded telemetry signal from the DCU-S and the internal ranging signal form its own receiver. The telemetry input signal and the ranging tone will be modulated onto the downlink carrier. Within the transponder, the ranging signal can be forwarded from the receiver to the transmitter in either coherent (fixed receive / transmit frequency ratio determined by the incoming receive carrier frequency) or non-coherent mode.

Range and range rate measurements are only possible if the **telemetry low data rate** (59.259 kbps) mode is used. In effect, the nominal lower data rate mode ensures simultaneous TC, TM and Ranging.

For cases where the link budget constraints are not met for simultaneous ranging and telecommand, ranging and telecommand can be performed in time sharing (TBC).

The satellite parameters that have been identified to apply for the development of the range and range rate function of the ground segment are shown in **Table 8-8**.

Parameter	Value	Remark
Ranging tone frequency	1447 KHz – 1500 KHz	
Ranging code length	TBD	
Coherent mode turn-around ratio	221/240	
Ranging tone modulation index	0.6 (uplink), 0.5 (downlink)	
Ranging group delay stability	+/- 30 nsec	
Local oscillator's long term stability	+/- 50 KHz	
Local oscillator's phase noise	< 3º rms from 10 Hz to 1 MHz	

Table 7-5 - Provisional satellite ranging parameters that may affect the devpt. of the Ground Segment

8. SATELLITE ANCILLARY DATA

The OBC will deliver a Satellite Ancillary Data packet to the ICU at 1Hz. This packet is then transferred by the ICU to the PDHU as part of the overall Measurement Data output (see Table 6-3 for the PCAT value that identifies this packet amongst all the packet types that make up the Measurement Data).

The content of the Satellite Ancillary Data packet is given in the table below in terms of the telemetry parameter identifiers as defined in the spacecraft TM/TC database and SSUM documentation. Note that where relevant the content of “global” (i.e. composite) parameters is provided immediately below the global parameter entry – thus the 16-byte global parameter ASTG5179 comprises two 8-byte parameters identified as ASTD030 and ASTD031.

Table 8-1 - Satellite Ancillary Data Definition

name	description	length (Bytes)	Coding	Physical type	Calibration	SW Name	Comment
ASTG5179	**NAV Universal Time in MJD**	**16**	-	-	**Globals with details**	**HKA_NAV_MJD_UT1**	Current Universal Time (from OBT) in Modified Julian Date Format [day, fraction of day]
ASTD6030	NAV UT Day	8	DOUI3E	REAL	Id in day	ASTG5179	
ASTD6031	NAV UT Fraction of Day	8	DOUI3E	REAL	Id in day	ASTG5179	
AST05534	**NAV Delta time**	**4**	SINI3E	REAL	Id inseconds [s]	**HKA_NAV_DELTA_TIME**	Time (in seconds) between the current OBT and the OBT of the last valid GPS data
AST05723	**NAV Successive valid measures**	**4**	UINT	INTEGER	-	**HKA_NAV_NB_GPS_VALID_MEAS**	Number of successive valid GPS measurements
AST05662	**NAV GPS PV date in OBT scale**	**8**	DOUI3E	REAL	Id inseconds [s]	**HKA_NAV_GPS_PVT_DATE**	Current GPS PV date in OBT scale
AST05664	**NAV GPS PVT val after check**	**4**	UINT	STRING	False_True	**HKA_NAV_IS_GPS_PVT_CHECK_VALID**	Current GPS PVT validity after check and filter
ASTG5180	**NAV GPS pos in ECEF or J2000**	**24**	-	-	**Globals with details**	**HKA_NAV_GPS_POS**	Current "raw" GPS position in ECEF frame (ECEF is selected by internal GPS configuration)
ASTD6032	NAV GPS position x	8	DOUI3E	REAL	Id inmetre [m]	ASTG5180	
ASTD6033	NAV GPS position y	8	DOUI3E	REAL	Id inmetre [m]	ASTG5180	
ASTD6034	NAV GPS position z	8	DOUI3E	REAL	Id inmetre [m]	ASTG5180	
ASTG5181	**NAV GPS vel in ECEF or J2000**	**24**	-	-	**Globals with details**	**HKA_NAV_GPS_VEL**	Current "raw" GPS velocity in ECEF frame (ECEF is selected by internal GPS configuration)
ASTD6035	NAV GPS velocity x	8	DOUI3E	REAL	Id inmetre per sec [m/s]	ASTG5181	
ASTD6036	NAV GPS velocity y	8	DOUI3E	REAL	Id inmetre per sec [m/s]	ASTG5181	
ASTD6037	NAV GPS velocity z	8	DOUI3E	REAL	Id inmetre per sec [m/s]	ASTG5181	
ASTG5B70	**GPS SV_inPVT**	**4**	-	-	**Dual with details**	ASTG5B00	
ASTD5B70	GPS SV32inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B71	GPS SV31inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	

name	description	length (Bytes)	Coding	Physical type	Calibration	SW Name	Comment
ASTD5B72	GPS SV30inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B73	GPS SV29inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B74	GPS SV28inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B75	GPS SV27inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B76	GPS SV26inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B77	GPS SV25inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B78	GPS SV24inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B79	GPS SV23inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7A	GPS SV22inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7B	GPS SV21inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7C	GPS SV20inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7D	GPS SV19inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7E	GPS SV18inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7F	GPS SV17inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7G	GPS SV16inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7H	GPS SV15inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7I	GPS SV14inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7J	GPS SV13inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7K	GPS SV12inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7L	GPS SV11inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7M	GPS SV10inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7N	GPS SV9inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7P	GPS SV8inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7Q	GPS SV7inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7R	GPS SV6inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7S	GPS SV5inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7T	GPS SV4inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7U	GPS SV3inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	

name	description	length (Bytes)	Coding	Physical type	Calibration	SW Name	Comment
ASTD5B7V	GPS SV2inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTD5B7W	GPS SV1inPVT	1 BIT	UINT	STRING	- False_True	ASTG5B70	
ASTG5B80	**GPS ValidFlag**	**4**	-	-	**Dual with details**	ASTG5B00	
ASTD5B80	GPS UTCLeapSec	8 BIT	SINT	INTEGER	- Id inseconds [s]	ASTG5B80	
ASTD5B81	GPS Reserved	15 BIT	UINT	INTEGER	- Identity	ASTG5B80	
ASTD5B82	GPS HotStartMod	1 BIT	UINT	STRING	- Inactive_Active	ASTG5B80	
ASTD5B83	GPS AttitudeMod	1 BIT	UINT	STRING	- GPS attitude mode	ASTG5B80	
ASTD5B84	GPS ExtClockMod	2 BIT	UINT	STRING	- GPS attitude mode	ASTG5B80	
ASTD5B85	GPS TimeRefMod	1 BIT	UINT	STRING	- GPS time ref mode	ASTG5B80	
ASTD5B86	GPS PlanningMod	1 BIT	UINT	STRING	- GPS appointment mode	ASTG5B80	
ASTD5B87	GPS ECIOutput	1 BIT	UINT	STRING	- GPS PV output	ASTG5B80	
ASTD5B88	GPS DynaSolMod	1 BIT	UINT	STRING	- GPS Solution mode	ASTG5B80	
ASTD5B89	GPS PVTSolution	1 BIT	UINT	STRING	- Invalid_valid	ASTG5B80	
ASTG5159	**OOP Prop position ECEF x**	**24**	-	-	**Globals with details**	**HKA_OOP_PVTE_POS**	The last valid GPS position measurement propagated forward to the current OBT
ASTD5971	OOP Prop position ECEF x	8	DOUI3E	REAL	Id inmetre [m]	ASTG5159	
ASTD5972	OOP Prop position ECEF y	8	DOUI3E	REAL	Id inmetre [m]	ASTG5159	
ASTD5973	OOP Prop position ECEF z	8	DOUI3E	REAL	Id inmetre [m]	ASTG5159	
ASTG5160	**OOP Prop velocity ECEF**	**24**	-	-	**Globals with details**	**HKA_OOP_PVTE_VEL**	The last valid GPS velocity measurement propagated forward to the current OBT
ASTD5974	OOP Prop velocity ECEF x	8	DOUI3E	REAL	Id inmetre per sec [m/s]	ASTG5160	
ASTD5975	OOP Prop velocity ECEF y	8	DOUI3E	REAL	Id inmetre per sec [m/s]	ASTG5160	
ASTD5976	OOP Prop velocity ECEF z	8	DOUI3E	REAL	Id inmetre per sec [m/s]	ASTG5160	
AST05643	**OOP PVT ECEF validity**	**1**	UINT	STRING	DMS Invalid_Valid	**HKA_OOP_PVTE_IS_VALID**	Validity of the propagated PV estimate
ASTG5184	**NAV Norm Sun Direction J2000**	**24**	-	-	**Globals with details**	**HKA_NAV_SUN_DIR_J2000**	Normalized Sun direction vector in J2000 frame
ASTD6044	NAV Sun direction position x	8	DOUI3E	REAL	-	ASTG5184	
ASTD6045	NAV Sun direction position y	8	DOUI3E	REAL	-	ASTG5184	
ASTD6046	NAV Sun direction position z	8	DOUI3E	REAL	-	ASTG5184	
AST05540	**AOCS Current AOCS mode**	**4**	UINT	STRING	Aocs_Mode	**HKA_AOCSMGR_AOCS_MODE**	Current AOCS operating mode
AST05602	**AOCS nmState**	**4**	UINT	STRING	NM_SubMode	**HKA_NM_STATE**	Current submode when AOCS is in Normal Mode

name	description	length (Bytes)	Coding	Physical type	Calibration	SW Name	Comment
AST05543	**AOCS current OBT**	**6**	UINT	STRING	ABSTIME_17 (pre-defined)	**HKA_AOCSMGR_CURRENT_OBT**	OBT of the current AOCS cycle. (Updated at each AOCS cycle)
AST05621	**IAE state**	**4**	UINT	STRING	IAE state	**HKA_IAE_IAE_IAESTATE**	Activation state of the Attitude Estimation function
AST05623	**IAE DSE computed innov valid**	**4**	UINT	STRING	False_True	**HKA_IAE_DSE_DELTATHETASTRVALID**	DSE validity of the computed innovations for the merged quaternion
AST05624	**IAE DSE nb rejected innov**	**4**	UINT	INTEGER	-	**HKA_IAE_DSE_NBREJECTEDINNOV**	DSE number of consecutive rejected innovations
ASTD5931	**IAE DSE Estim quat x**	**4**	SINI3E	REAL	-	-	Estimated quaternion from inertial reference frame J2000 to the satellite frame,
ASTD5932	**IAE DSE Estim quat y**	**4**	SINI3E	REAL	-	-	
ASTD5933	**IAE DSE Estim quat z**	**4**	SINI3E	REAL	-	-	
ASTD5934	**IAE DSE Estim quat s**	**4**	SINI3E	REAL	-	-	
ASTD5935	**IAE DSE Estim ang rate x**	**4**	SINI3E	REAL	Id inrad per sec [rad/s]	-	Estimated angular rate of the satellite frame wrt the inertial reference frame J2000 expressed in the satellite frame
ASTD5936	**IAE DSE Estim ang rate y**	**4**	SINI3E	REAL	Id inrad per sec [rad/s]	-	
ASTD5937	**IAE DSE Estim ang rate z**	**4**	SINI3E	REAL	Id inrad per sec [rad/s]		
ASTG5026	**STROH online conf.**	**16**	-	-	Globals with details	**HKA_STR_ONLINESTROHCONF**	Online STR-OH configuration
ASTD5089	STROH1 online conf.	4	UINT	STRING	Used_NotUsed	ASTG5026	
ASTD5090	STROH2 online conf.	4	UINT	STRING	Used_NotUsed	ASTG5026	
ASTD5091	STROH3 online conf.	4	UINT	STRING	Used_NotUsed	ASTG5026	
ASTD5092	STROH4 online conf.	4	UINT	STRING	Used_NotUsed	ASTG5026	
CRTDT011	**RIUA TH_ST_PZ1**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		Current temperature measurements from the +Z face of the spacecraft
CRTDT037	**RIUA TH_ST_PZ2**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT045	**RIUA TH_ST_PZ3**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT052	**RIUA TH_ST_PZ4**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT063	**RIUA TH_ST_PZ5**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		

name	description	length (Bytes)	Coding	Physical type	Calibration	SW Name	Comment
CRTDT078	**RIUA TH_ST_PZ6**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT099	**RIUA TH_ST_PZ7**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT105	**RIUA TH_ST_PZ8**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT115	**RIUA TH_ST_PZ9**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT130	**RIUA TH_ST_PZ10**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT145	**RIUA TH_ST_PZ11**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT151	**RIUA TH_ST_PZ12**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT170	**RIUA TH_ST_PZ13**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT182	**RIUA TH_ST_PZ14**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		
CRTDT197	**RIUA TH_ST_PZ15**	**2**	UINT	REAL	RIU TH TYPE ANF (15k) Thermistor Betatherm 15K		

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DOCUMENT CHANGE DETAILS

ISSUE	CHANGE AUTHORITY	CLASS	RELEVANT INFORMATION/INSTRUCTIONS
1	-	-	Initial Issue
2			Updated for Spacecraft PDR: SRR actions for RIDs Miss&Sys-7 and 9 addressed; X-band transmitter descriptions updated to reflect the selected equipment; ground segment description text suppressed; updates to payload data interface descriptions.
3			Updated to address Spacecraft PDR comments (RIDs FB-01, JP-02, DM-23), Ground Segment Requirements Review comments (RIDs PDGS_AND_FOS_PANEL-17, -26, -27, -52, -53, -97, -99, -100, -101, -116, -117, -152; X-band formatting clarified; SCID and PCAT values defined; Satellite Ancillary Data defined.

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