Title: **Satellite to Ground Segment Interface Control Document**

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Change Record

Issue	Date	Sheet	Description of Change
1	01.08.2008	all	Initial issue for System PDR
2	16.02.2009		Updates resulting from System PDR: SEAO-147: Various comments SEAO-161: Various comments SEAO-162: BAT description SEAO-347: Uplink in phase SEAO-353: S-band interface diagram SEAO-367: Insertion of CLCW SEAO-369: Clear TC segments SEAO-372: TC throughput Update of X-Band Mission Data TM Layout / MSI source packet layout (System Ancillary Data, PPS LSB) Update of S-band transponder data Update of X-band transmitter data
3	04.05.2009	32, 34	Update of X-Band Mission Data TM Layout Update of X-Band Satellite Housekeeping Data TM Layout
4	10.11.2009	Section 2.2 Section 3.2.2 Section 3.3.3 Figure 4.2-1 Figure 4.3-1	Update of satellite overview S-band uplink acquisition sequence All S-band telemetry provided via X-band S-Band Uplink – Data Format and Content S-Band Downlink – Data Format and Content
5	25.06.2010		Update for Ground Segment PDR
6	01.10.2010	Figure 3.1 1 29 30	Inter-satellite link included Satellite Housekeeping and Ancillary Data Packet Stores 8PSK TCM 2.5b/Hz

		34, Section 4.5 46 Fig. 5.1-2 & -3 Table 5.2-1 Fig. 5.2-2,-3&-4	MMFU Packet Store description Downlink Frequency, channel 1 frequency Update of figures with measured values Downlink frequency, channel 1 corrected Update of figures with simulated or measured values
7	11.02.2011	 Table 5.1-1 Tables 5.1-2 and 5.2-1 sections 3.2.3 and 3.3.2	Updates resulting from System CDR: RID SEO-ASP-24; AI S2_CDR_ASP_31: Dynamic range of S-Band receiver added RID SEO-ASP-22; AI S2_CDR_32: S- and X-Band Parameter corrected RID SEO-ASP-102; AI S2_CDR_29: Description of frame randomizer polynomial added
8	09.05.2011	Section 3.3.2 Figure 4.5 2	Randomization of idle data in X-band downlink included Update of MMFU Packet Store Routing (PCATs)

Table of Contents

1. INTRODUCTION

1.1 Scope of the Document

This document describes the Sentinel 2 Satellite to Ground Segment Interfaces concerning

- Command and control
- Mission data including ancillary data.

This description comprises

- Data format and content
- RF description.

Security related aspects are given in [AD 14], System Security Concept and Implementation (restricted access).

1.2 References

1.2.1 Applicable Documents

Requirements Documents

[AD 01]	Sentinel-2 System Requirements Document	S2-RS-ESA-SY-0001
[AD 02]	Sentinel-2 Operations and Interface Requirements Document	S2-RS-ESA-SY-0006
[AD 03]	Satellite Requirements Specification	GS2.RS.ASD.SY.00007

Packet Utilisation Standard and related documents, budgets, security

[AD 10]	Sentinel-2 Packet Utilisation Standard	GS2.STD.ASD.SY.00001
[AD 11]	Sentinel-2 Satellite Ancillary Data ICD	GS2.ICD.ASD.SY.00012
[AD 12]	Sentinel-2 System Data Pool ICD	GS2.ICD.ASD.SY.00018
[AD 13]	Sentinel 2 Engineering Budgets	GS2.RP.ASD.SY.00013
[AD 14]	System Security Concept and Implementation	GS2.RP.ASD.SY.00014

1.2.2 Reference Documents

General

[RD 01]	Abbreviation List	GS2.LI.ASD.SY.00001

ECSS Standards

[RD 11]	Communications Principles and Requirements	ECSS-E-50 Part 1A
[RD 12]	Telemetry Synchronization and Channel Coding	ECSS-E-50-01 Draft 0.11
[RD 13]	Ranging and Doppler tracking (24 November 2005)	ECSS-E-50-02A
[RD 14]	Telemetry Transfer Frame Protocol	ECSS-E-50-03 Draft 1.8.1
[RD 15]	Telecommand Protocols, Synchronisation and Channel Coding	ECSS-E-50-04A Draft 1.13
[RD 16]	Radio frequency and modulation (24 January 2003)	ECSS-E-50-05A
[RD 17]	Ground System and Operations. Principles and Requirements	ECSS-E-70 Part 1A
[RD 18]	Ground systems and operations - Telemetry and telecommand packet utilization (30 January 2003)	ECSS-E-70-41A

CCSDS Standards

[RD 21]	Space Packet Protocol	CCSDS-133-0-B-1
[RD 22]	Encapsulation Service	CCSDS 133.1-B-1
[RD 23]	CCSDS TM Synchronisation and Channel Coding. Blue Book	CCSDS-131.0-B-1
[RD 24]	Space Link Identifiers	CCSDS 135.0-B-2
[RD 25]	CCSDS Un-segmented Time Code Standard	CCSDS-301.0-B-3
[RD 26]	Advanced Orbiting Systems Space Data Links Protocols	CCSDS 732.0-B-1
[RD 27]	Space Link Identifiers	CCSDS 135.0-B-2

MSI

[RD 40]	MSI Mission Data ICD	GS2.ICD.ASF.MSI.00008
[RD 41]	MSI TM/TC Data ICD	GS2.ICD.ASF.MSI.00011

OCP/LCT

[RD 45]	LCT ICD	SEN2-TESAT-LCT-ICD-0010

Equipments

[AD 51]	OBC Software ICD	GS2.ICD.RSE.OBC.00001
[AD 52]	OBC Hardware Software ICD	GS2.ICD.RSE.OBC.00003
[AD 53]	RIU Command and Telemetry Handbook	GS2.ICD.PAT.RIU.46087
[AD 54]	PCDU ICD	GS2.ICD.CRS.PCDU.00005
[AD 55]	MMFU ICD	GS2.IF.ASG.MMFU.00001
[AD 56]	SBS Interface Data Sheet	GS2-IF-TSE-SBS-00001
[AD 57]	XBS Modulator Interface Data Sheet	1119831/904
[AD 58]	XBS TWTA Interface Data Sheet	S123-ETCA-IS-0015
[AD 59]	GPS Command and Housekeeping Interface Specification	S1.IF.AAE.SC.00001
[AD 60]	GPS Measurement Data Interface Specification	S1.IF.AAE.SC.00002
[AD 61]	STR PUS ICD	GS2.ICD.JOP.STR.02402
[AD 62]	IMU ICD	FOG.0.ICD.177.T.ASTR
[AD 63]	RWU MIL-STD-1553B ICD	GS2-ICD-BRA-RW-00002
[AD 64]	MIMU ICD	ICDYG9666HA
[AD 65]	CESS Software User Manual	GS2.UM.AED.CESS.0002
[AD 66]	Magnetometer Design Description and Users Manual	GS2-TN-ZAR-MAG-01
[AD 67]	Magnetorquers Design Description and Users Manual	GS2-TN-ZAR-MTR-01

2. OVERVIEW

2.1 Mission

The Sentinel-2 optical mission is part of the GMES system, which is designed to provide an independent and operational information capacity to the European Union to warrant environment and security policies and to support sustainable economic growth. While the mission life of SPOT-5 and Landsat, currently providing numerous services of high strategic importance and economic value, is approaching their end of life, Sentinel-2 shall provide the enhanced follow-on mission, satisfying the growing user demand for higher and faster service quality at utmost reduced servicing and operating costs.

The analysis of user requirements has led to the identification of the need of the concurrent operations of two similar satellites, each servicing a MultiSpectral Instrument (MSI) operating from the visible to the shortwave infrared spectral range to address Land and Emergency user services at medium spatial resolution, but using a large swath for fast revisiting capability, as enhanced continuity to SPOT and Landsat.

A summary of the most important mission objectives are given in the following list:

- Risk Management (floods and forest fires, subsidence and land slides)
- European Land Use/Land Cover State and Changes
- Forest Monitoring
- Food Security/Early Warning Systems
- Water Management and Soil Protection
- Urban Mapping Services
- Natural Hazards
- Terrestrial Mapping for Humanitarian Aid and Development

Table 2.1-1: Sentinel-2 Mission Overview

Mission Concept - Two simultaneous operating satellites - 5 days global revisit time - 10 days revisit with one single satellite - Deployment of 3 to 5 spacecrafts in total - Design-Lifetime of 7,25 years - Additional 5 years for consumables **Mission products** - Vegetation - Urban areas - Food and emergency monitoring **Payload** - Multi Spectral Instrument (MSI) - Laser Communication Terminal (LCT) optionally **Launcher** - VEGA nominal launcher - Rockot as backup	**Mission Data** - Mission lifetime 15 years - FAR of first satellite in 2012 - Sun synchronous orbit - 786 km altitude, 14 + 3/10 rev/day - 10:30 Local Time Descending Node - 290 km swath - 13 spectral bands VNIR&SWIR - spatial resolution 10, 20 and 60 m - Geolocation 20 m 2 σ, 10 m with GCP **Mean Keplerian orbital elements** - Semi-major axis: 7164.256 km - Eccentricity: 0.00115840 - Inclination: 98.498 deg - RAAN: 246.684 deg - Argument of perigee: 90.744deg - True anomaly: 269.283 deg

2.2 Space Segment

The Sentinel-2 Space Segment is built on a constellation of two similar satellites operating simultaneously. The main characteristics of the Sentinel-2 satellite are summarized below:

- **Satellite Configuration, Thermal and Structure:**
  - An aluminium frame composed from aluminium profiles.
  - A baseplate providing the interface to the clampband interface connecting the satellite to the launch vehicle adapter (LVA).
  - An instrument compartment stiffened by an aluminium frame.
  - The Platform unit equipment compartment accommodates by means of 4 sandwich panels the electronic equipment as well as the LCT.

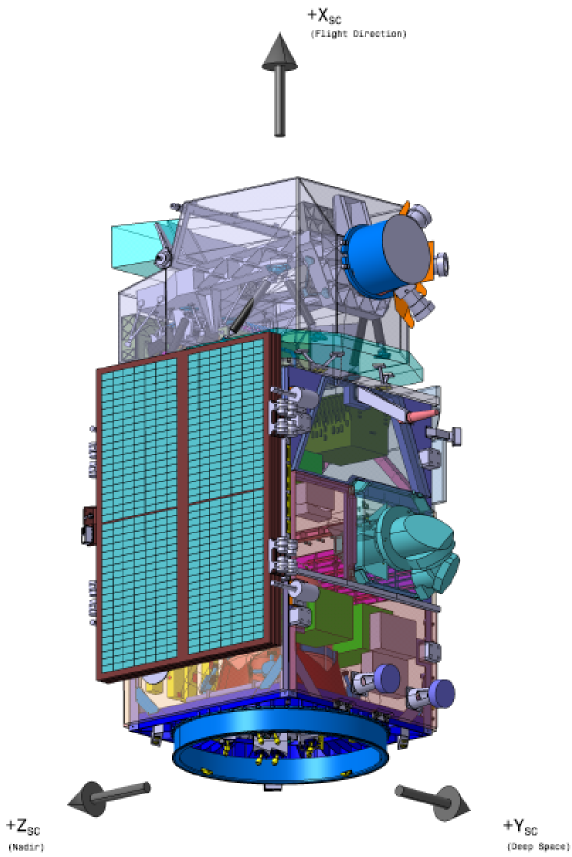

Figure 2.2-1: Stowed Spacecraft Configuration

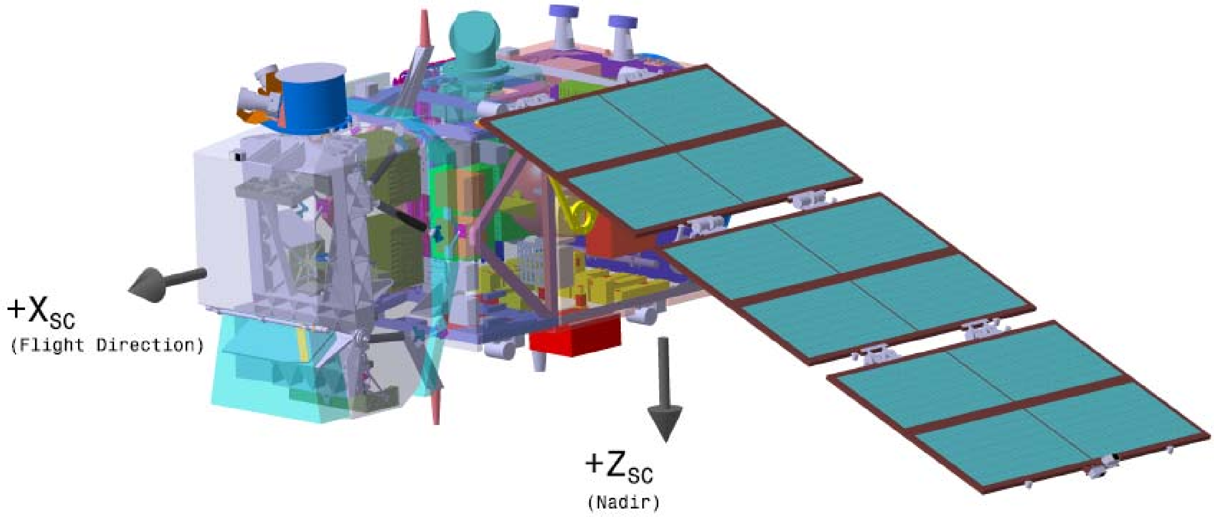

Figure 2.2-2: Deployed Spacecraft Configuration

- **3-axis AOCS stabilized satellite**
  - Star trackers, gyros, CESS, magnetometers and GPS for attitude & positioning knowledge
  - Reaction wheels, magnetorquer and thrusters as actuators
  - Chemical mono-propellant (Hydrazine), "plug in" concept.

- **Power subsystem**
  - Deployable and steerable Solar Array with an area of 8.6m²
  - MPPT PCDU
  - Two 108 Ah Li batteries (BOL capacity)
  - Unregulated 28 V bus.

- **Payload data handling**
  - X Band subsystem with 2 out of 4 channels at 280 Mbps information rate each, based on 8PSK modulation and providing a nominal data rate 560 Mbps (incl. RS encoding) using TWTAs and a fixed isoflux X Band antenna without interference to the Deep Space Network
  - 2.4 Tbit mass memory (EOL capacity), allowing an MSI instrument nominal observation data rate of up to 490 Mbps.

- **TM/TC S-band**
  - 64 kbps uplink data rate PM modulated
  - Nominal 128 kbps SP-L (with simultaneous ranging function) or 2048 kbps OQPSK maximum downlink data rate
  - 2 helix antennas looking Nadir and Zenith.

- **A multispectral high resolution wide swath imager (MSI) with the following key parameters**
  - 290 km swath width at equator, including 6% margin for uncertainties at the edge
  - 13 spectral channels (10 nom. + 3 atm.) VNIR to SWIR incl. 2.2 µm channel in a pushbroom configuration
  - 12 nominal spectral channels with 10m & 20m SSD, 12 bit
  - 2 atmospheric spectral channels with 60 m SSD, 12 bit
  - Channels are compressed with a factor 2 to 4
  - Isostatically mounted star trackers and IMU directly onto MSI structure.

2.3 Ground Segment

The GMES Sentinel-2 Ground Segment supports the mission operations of a system of two Satellites in orbit over a period of 15 years following the launch of the first Satellite. Over that period, the Ground Segment is able to support different Sentinel-2 mission configurations, involving up to three satellites in orbit (either being operational, in commissioning, or in stand-by).

The operational in orbit twin Satellite configuration is monitored and controlled through the following S-Band Ground Stations:

- Kiruna
- Svalbard (for Kiruna blind orbits).

All X-Band Mission and Satellite housekeeping data composite are systematically downlinked over a baseline network of four European and Canadian Core Ground Stations, three of which at high-latitude, and the fourth at mid-latitude. These are (tbc.):

- Kiruna
- Prince Albert
- Maspalomas
- Svalbard (for Kiruna blind orbits).

The GMES Sentinel-2 Ground System encompasses a Flight Operations Segment, a Payload Data Ground Segment, and a Service Segment. More specifically these three major Ground Segment functionalities provide:

a) Flight Operations Segment

- Mission control for commanding and monitoring the Satellites in orbit (up to 3 satellites simultaneously)
- Flight dynamics for manoeuvring one Satellite at a time, for orbit prediction and restitution, and for generation of Ground Stations acquisition data
- Communications with one Satellite at a time
- Simulation of the Satellite for operations rehearsals and training, for LEOP, Commissioning, and routine Operations
- Key management for the implementation of security requirements.

b) Payload Data Ground Segment

- Acquisition of Mission data from the Satellite, decompression, processing, archiving and dissemination of User products.

- Product quality control and instrument calibration
- Mission planning if required.

c) Service Segment

- Production of higher level products
- User access coordination and control.

The FOS is operated by ESA/ESOC in Darmstadt/Germany, whereas the PDGS operations is managed by ESA/ESRIN in Frascati/Italy. The Service Segment, which has no Satellite interfaces, is TBD.

The Mission operations allows for an update of the Satellites mission timeline every 15 days. This time period constitutes therefore a requirement on the Satellite in orbit autonomy. The Satellite telemetry is acquired every orbit in an autonomous manner by the respective TM/TC and X-band Ground stations. Detection of Satellite anomalies by the Flight Operations Segment are therefore be made in quasi real time, in order not to delay the call for urgent support from the Industrial contractor in case of safety/Mission critical Satellite anomaly. The maximum time for generating a Ground Segment commanded recovery of a Satellite anomaly is set to 3 days in the current SRD and in the Ground Segment concept.

The Ground Segment has the capability to prepare and to uplink a plan for Satellite operations, including mass memory playback over core or local user Ground Stations, with less than 72 hours notice for nominal purposes.

The Ground Segment has the capability to prepare and uplink a mission plan containing adhoc real-time downlinks on local user ground stations, in addition to the default downlink plan, with less than 3 hours notice for emergency purposes.

The Ground Segment has the capability to prepare and uplink a mission plan containing adhoc downlinks for mass memory playback of specific segments on local user ground stations, in addition to the default downlink plan, with less than 3 hours notice for emergency purposes.

The Ground Segment has the capability to prepare and uplink a mission plan containing adhoc image acquisition segments, in addition to the systematic image acquisition over the areas of interest, with less than 3 hours notice for emergency purposes.

The Ground Segment has the capability to reschedule in less than 3 hours the programming of Satellite observations, in case of special event, possibly requiring the use of the extended observation mode or/and a different Mission data downlink scenario (new combination of core ground stations and local user ground stations).

3. SATELLITE TO GROUND INTERFACES

3.1 Introduction

The interfaces between the Space Segment and the Ground Segment are shown in the figure below.

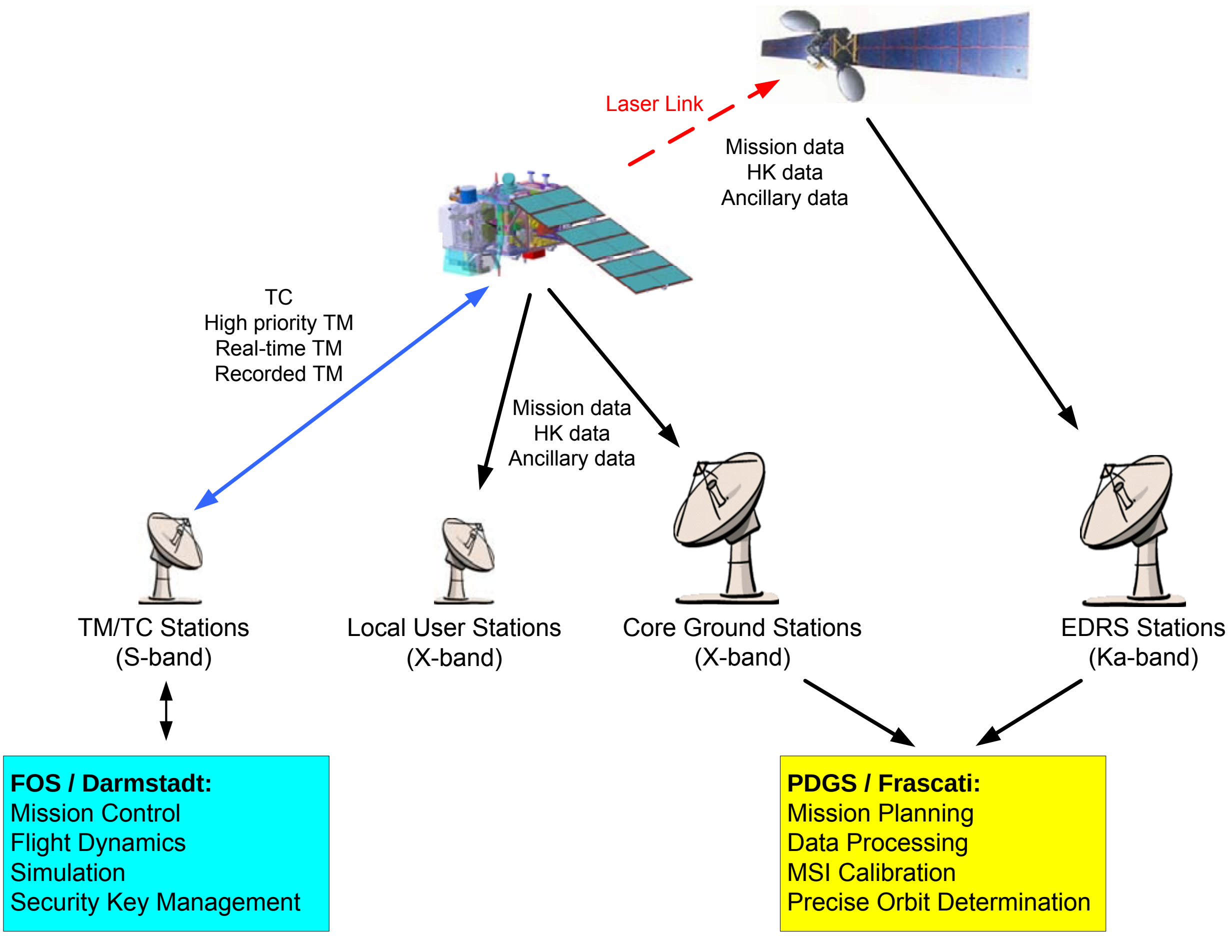

Figure 3.1-1: Satellite to Ground Segment Interfaces

The interfaces between the Space Segment and the Ground Segment are:

S-Band Uplink for the transmission of

- Telecommands.

S-Band Downlink for the transmission of

- Real-time telemetry
- High priority telemetry
- Satellite housekeeping data stored in the OBC packet stores.

X-Band Mission Data Downlink for the transmission of

- Mission data
- System anxillary data
- Image anxillary data.

X-Band Satellite Housekeeping Data Downlink for the transmission of

- Satellite housekeeping data
- Satellite Ancillary Data.

3.2 S-Band

3.2.1 Overview

The S-band interface is shown by the figure below:

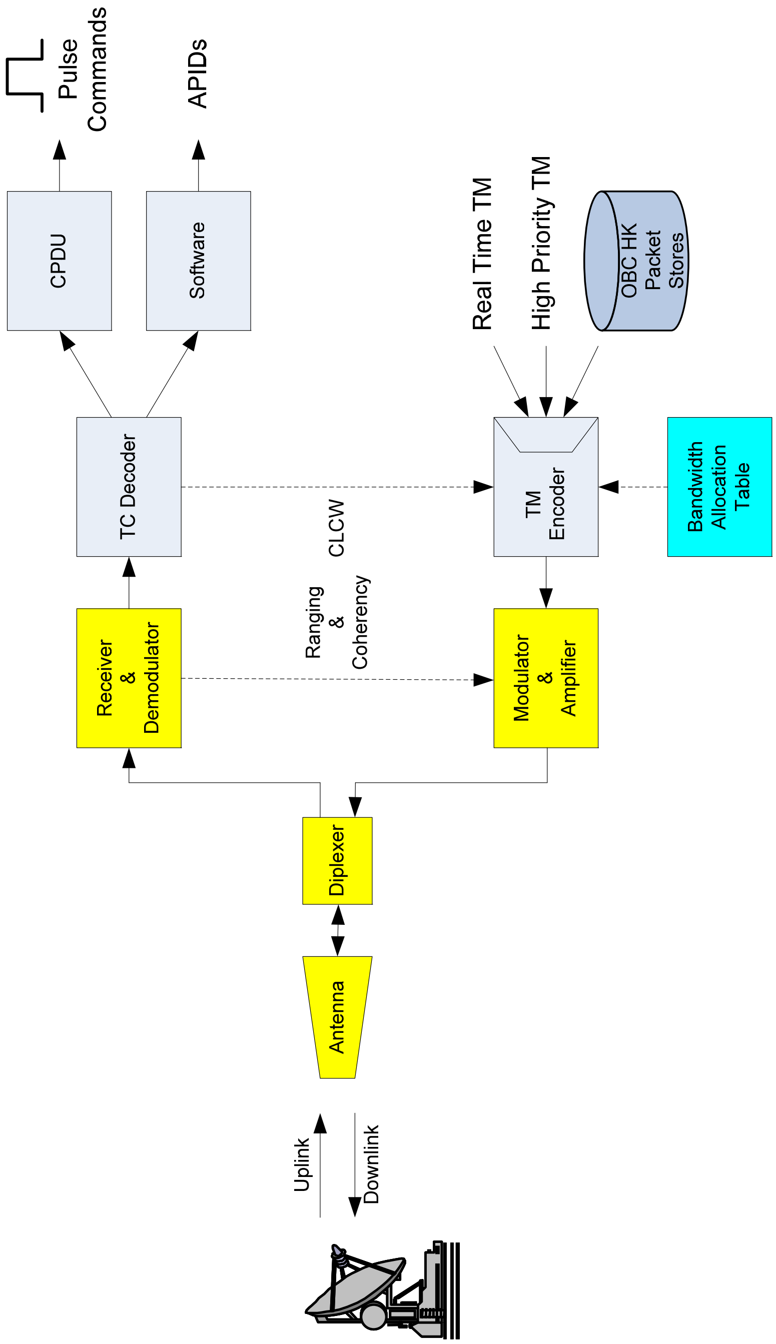

Figure 3.2-1: S-Band Interface

3.2.2 S-Band Uplink

RF Uplink

The S-band Ground Station transmits the modulated RF signal that is received on-board. The uplink carrier is phase modulated by the ranging signal to support range and range-rate (relative Doppler shift) measurements.

The S-band receiver provides the ranging and coherency signal to the S-band modulator.

The demodulator generates the bit stream of Command Link Transmission Units for the telecommand decoder.

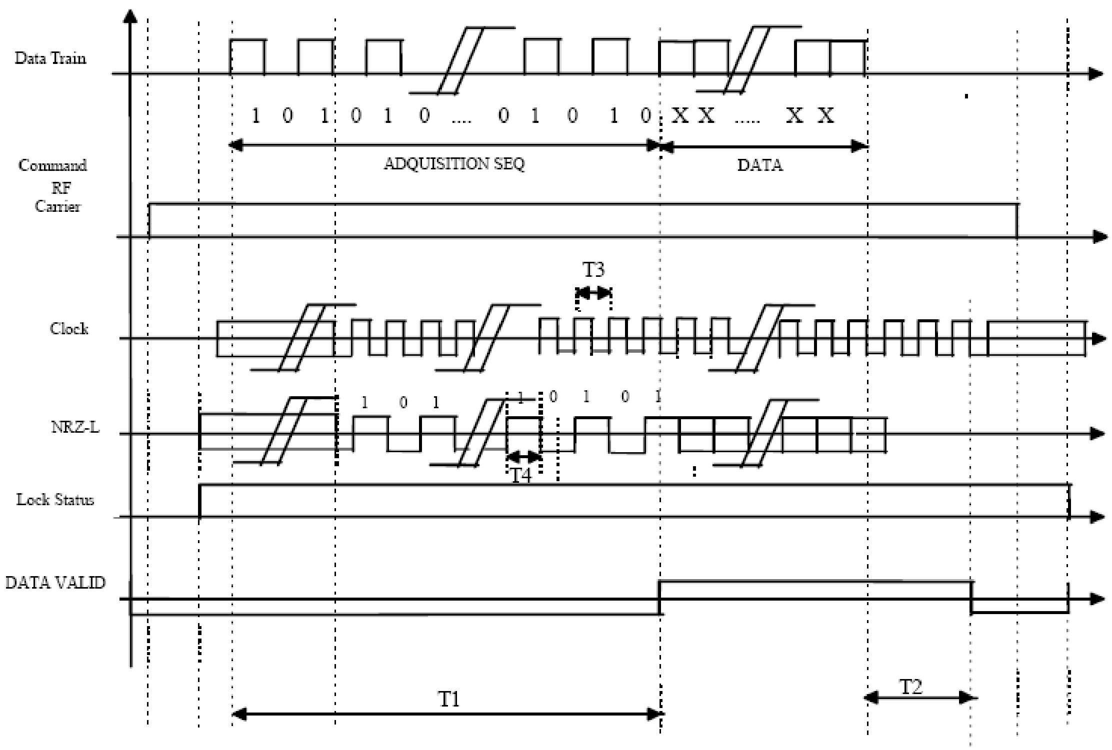

Figure 3.2-2: Acquisition Sequence

To support the locking of the S-band receiver, an acquisition sequence (length = 500 bit) is transmitted by the ground station before the transmission of the actual data (Command Link Transmission Units).

Command Link Transmission Unit

The Command Link Transmission Units are composed of

- Start Sequence
- variable number of Code-blocks
- Tail Sequence.

The decoder searches all input streams simultaneously until a start sequence is detected. Only one of the TC Channel inputs is selected for further processing. On the level of the individual Code-blocks the selected stream is bit-error corrected and the resulting Telecommand Transfer Frame is extracted.

Telecommand Transfer Frame

The Telecommand Transfer Frame is composed of

- Frame Header, including Spacecraft ID and Virtual Channel ID
- Telecommand Segment
- Telecommand Frame Error Control (CRC).

By means of the Spacecraft ID and the Virtual Channel ID the individual satellite TC Decoder is identified. the decoder verifies that the received frame is valid and extracts the Telecommand Segment.

Telecommand Segment

The Telecommand Segment is composed of

- Segment Header, including the MAP ID
- Variable number of TC Source Packets
- Segment Trailer that is used as Authentication Tail.

By means of the MAP ID the Telecommand Segment is either routed to the

- Telecommand Authentication Function (TCAF)
- Command Pulse Distribution Unit
- Central Software.

The Telecommand Authentication Function (TCAF) is part of the TC decoder. After power up, the TCAF is disabled. Once enabled, the validity of the received telecommand segments is checked by means of the authentication tail. Telecommands to the Telecommand Authentication Function (TCAF) itself are always authenticated.

After successful authentication the TC segments are distributed.

From the CPDU Telecommand Packets, High Priority Commands (HPC-1) are extracted and executed as pulse commands.

Nominal TC Source Packets are routed to the Central Software.

Telecommand Source Packet

Telecommand Source Packets are composed of

- Packet Header, including the Application Identifier
- Data Filed Header, including Service Type and Sub-type
- Command Data
- Packet Error Control (CRC).

By means of the Application Identifier the Telecommand Packets are routed to the internal and external applications

- Central Software internal application: System Control, AOCS, Payload Control and MSI Control
- Central Software external applications: GPS, MMFU, Star Tracker.

The effective TC up-link rate is limited by the Central Software. The CSW supports as a minimum:

- 10 telecommands per second
- 10 telecommand packets per second.

These figures result in the following throughput:

Minimum number of TCs per second: 10

	[byte]	[bit]	**[bit/s]**	**[kbit/s]**
Command Data	214			
Data Field Header	4			
Packet Error Control	2			
Packet Data Field	220			
Packet Header	6			
TC Source Packet	226	1.808	18.080	17,7
Segment Header	1			
Segment Trailer (Authentication Tail)	22			
TC Segment	249	1.992	19.920	19,5
Frame Header	5			
Frame Error Control	2			
TC Transfer Frame	256	2.048	20.480	**20,0**

Therefore, an effective TC up-link rate of up to 20 kbit/s is supported.

3.2.3 S-Band Downlink

Telemetry Source Packets

The Telemetry Source Packets are composed of

- Packet Header, including the Application Identifier
- Data Field Header, including Service Type, Sub-type and Time
- Telemetry Data
- Packet Error Control (CRC).

The following Telemetry Source Packets are routed to the Telemetry Encoder:

- High Priority Telemetry (generated entirely by hardware)
- Real-time Telemetry (generated and routed by software)
- Recorded Telemetry (stored in OBC Housekeeping Packet Stores, generated and routed by software).

Transfer Frame

The Transfer Frames are composed of

- Frame Header, including Spacecraft ID, Virtual Channel ID, and the First Header Pointer
- Frame Data Field
- Transfer Frame Trailer.

The Telemetry Source Packets are routed into corresponding Virtual Channels that are identified by a Virtual Channel ID. Virtual Channels are assigned for:

- Real Time Telemetry
- High Priority Telemetry
- Satellite Housekeeping
- Idle Frames.

Each Virtual Channel detects the beginning of a packet and calculates the corresponding First Header Pointer. This First Header Pointer is required for the packet chaining process during the packet de-multiplexing on the ground. It is unlikely that an integer number of packets is exactly contained within a Transfer Frame, some Packets are thus be split between multiple Transfer Frames.

Furthermore, the Command Link Control Word (CLCW) is retrieved from the two Packet Telecommand Decoders and inserted into the Transfer Frame Trailer. Each Transfer Frame Generator shall receives the CLCW alternatingly from the nominal and redundant telecommand interfaces. The CLCW from the nominal TC interface is transmitted in frames with an even Master Channel Frame Count and the CLCW from the redundant TC interface is transmitted with an odd Master Channel Frame Count.

In addition, the command reception status is provided by the following TC decoder register:

- Command Link Control Word (CLCW) status report
- CPDU status report
- Frame analysis report.

Channel Access Data Unit

The Channel Access Data Units are composed of

- Synchronization Marker
- Data Space
- Reed Solomon Check Symbols.

The default virtual channel priority scheme is:

VC0 (Real Time) highest priority

VC1 (High Priority)

VC2 (Playback) lowest priority.

According to a this priority scheme, the Transfer Frames are multiplexed into the CADU Data Space. In case that there are no Telemetry/Housekeeping frames available for transmission, Idle Frames are generated.

The CADU Data Space is protected by Reed Solomon Check Symbols. The Reed-Solomon Encoder generates (255, 223) check symbols with an interleaving depth of I = 5.

For the high data rate (NRZ-L modulation) downlink stream a concatenated coding scheme is applied using the RS code as outer code and an (R=1/2, K = 7) convolutional coding as inner code. There is no convolutional encoding for the low data rate (SP-L modulation). Afterwards scrambling is performed according to CCSDS-131.0-B-1using the following polynomial:

$$h(x) = x8 + x7 + x5 + x3 + 1$$

The sequence generator is initialized to the all-ones state at the start of each transfer frame. The pseudo-random sequence is applied starting with the first bit of the transfer frame.

Finally, a Synchronization Marker is attached for identification of the CADUs on-ground.

RF Downlink

The Channel Access Data Units are routed to the S-band modulator (external telemetry modulation). Independently or simultaneously, the modulator receives the ranging modulation input signal from the associated receiver (internal ranging modulation) in low data rate mode only.

In coherent mode, the transmit frequency is derived from the received (uplink) frequency with a turn-around ratio of 240/221. In non-coherent mode the transmit frequency is derived from an internal reference oscillator.

The modulated signal is amplified and transmitted to ground.

3.3 X-Band

3.3.1 Overview

The X-band interface is shown by the figure below:

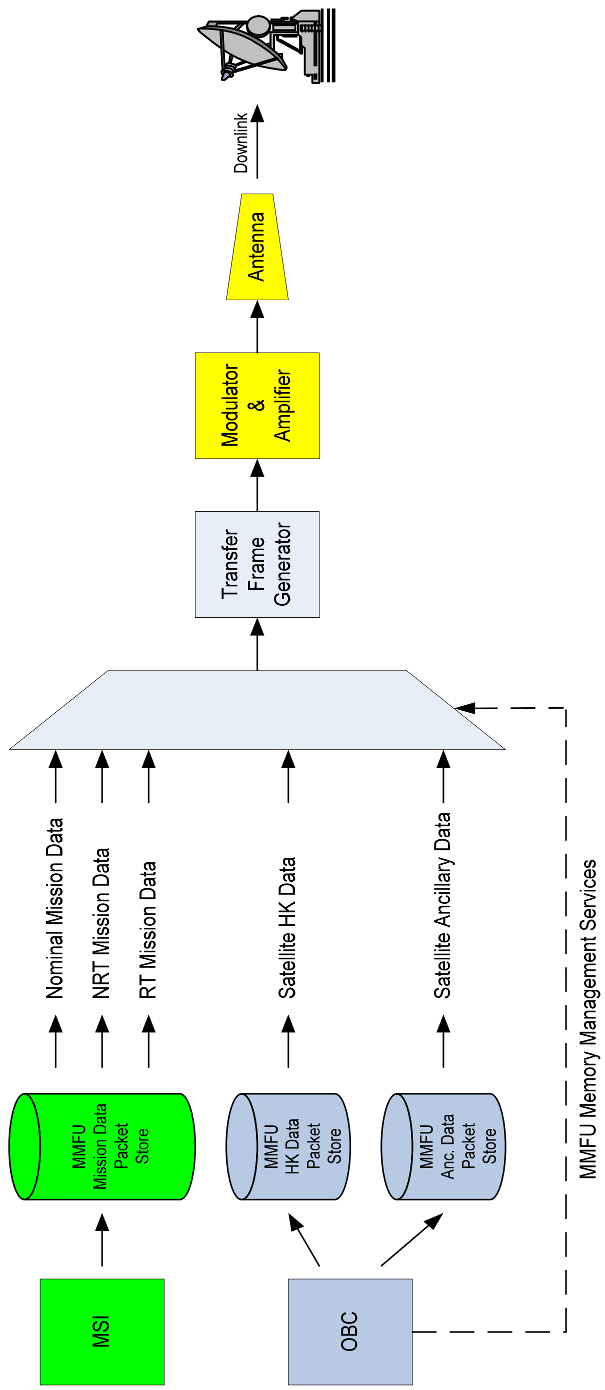

Figure 3.3-1: X-Band Interface

3.3.2 X-Band Mission Data Downlink

Telemetry Source Packets

The Telemetry Source Packets are composed of

- Packet Header, including the Application Identifier
- Data Field Header, including System Ancillary Data and Image Ancillary Data. The Time is included in the System Ancillary Data
- Image Data
- Packet Error Control (CRC).

These telemetry source packets are generated by the Instrument and stored in the MMFU Mission Packet Store.

Transfer Frame

The Transfer Frames are composed of

- Primary Header, including Spacecraft ID, Virtual Channel ID, and the First Header Pointer
- Frame Data Field.

For the MMFU data acquisition, storage, and playback, dedicated MMFU PUS services are available. Following a dedicated playback command, the corresponding Mission data are routed into the corresponding Virtual Channel that is identified by a Virtual Channel ID. Virtual Channels are assigned for:

- Nominal Mission data
- Near Real Time data
- Real Time data
- Idle Frames.

Each Virtual Channel detects the beginning of a packet and calculates the corresponding First Header Pointer. This First Header Pointer is required for the packet chaining process during the packet de-multiplexing on the ground. It is unlikely that an integer number of packets is exactly contained within a Transfer Frame, some Packets are thus be split between multiple Transfer Frames.

Channel Access Data Unit

The Channel Access Data Units are composed of

- Synchronization Marker
- Data Space
- Reed Solomon Check Symbols.

The Transfer Frames are multiplexed into the CADU Data Space. In case that there are no frames available for transmission, Idle Frames are generated.

The data field of the idle transfer frame and idle source packet are randomized according to the polynomial:

$$g(x) = x14 + x13 + x8 + x4 +1$$

The randomizer is initialized with a seed of all-ones for each transfer frame.

The CADU Data Space is protected by Reed Solomon Check Symbols. The Reed-Solomon Encoder generates (255, 239) check symbols with an interleaving depth of I = 8.

Subsequently, the Reed Solomon Code-block is randomized following ECSS-E-ST-50-01C using the following polynomial:

$$h(x) = x8 + x7 + x5 + x3 + 1$$

The sequence generator is initialized to the all-ones state at the start of each transfer frame. The pseudo-random sequence is applied starting with the first bit of the transfer frame.

Finally, a Synchronization Marker is attached for identification of the CADU on-ground.

RF Downlink

The Channel Access Data Units are modulated according to 4 dimensional 8PSK TVM modulation format, amplified and transmitted to ground.

3.3.3 X-Band Satellite Housekeeping and Satellite Ancillary Data Downlink

Telemetry Source Packets

The Telemetry Source Packets are composed of

- Packet Header, including the Application Identifier
- Data Field Header, including Service Type, Sub-type and Time
- Telemetry Data
- Packet Error Control (CRC).

These telemetry source packets are generated by the Central Software and stored in the MMFU Housekeeping Packet Store or in the MMFU Satellite Ancillary Data Packet Store.

All S-band telemetry is also be provided via X-band.

Transfer Frame

The Transfer Frames are composed of

- Frame Header, including Spacecraft ID, Virtual Channel ID, and the First Header Pointer
- Frame Data Field.

For the playback of the Satellite Housekeeping Data and the Satellite Ancillary Data stored in the related MMFU packet stores dedicated MMFU PUS services are available. Following a dedicated playback command, the data are routed into the corresponding Virtual Channel that is identified by a Virtual Channel ID. Virtual Channels are assigned for:

- Satellite Housekeeping Data
- Satellite Ancillary Data
- Idle Frames.

Each Virtual Channel detects the beginning of a packet and calculates the corresponding First Header Pointer. This First Header Pointer is required for the packet chaining process during the packet de-multiplexing on the ground. It is unlikely that an integer number of packets is exactly contained within a Transfer Frame, some Packets are thus be split between multiple Transfer Frames.

Channel Access Data Unit

The Channel Access Data Units are composed of

- Synchronization Marker
- Data Space
- Reed Solomon Check Symbols.

The Transfer Frames are multiplexed into the CADU Data Space. In case that there are no frames available for transmission, Idle Frames are generated.

The CADU Data Space is protected by Reed Solomon Check Symbols. The Reed-Solomon Encoder generates (255, 239) check symbols with an interleaving depth of I = 8. Subsequently, the Reed Solomon Code-block is randomized. Finally, a Synchronization Marker is attached for identification of the CADU on-ground.

RF Downlink

The Channel Access Data Units are modulated according to 4 dimensional 8PSK TCM 2.5b/Hz modulation format, amplified and transmitted to ground.

4. DATA FORMAT AND CONTENT

4.1 Introduction

The subsequent sections provide an overview of the data formats and content. Details are given by the documents listed below:

4.2 S-Band Uplink

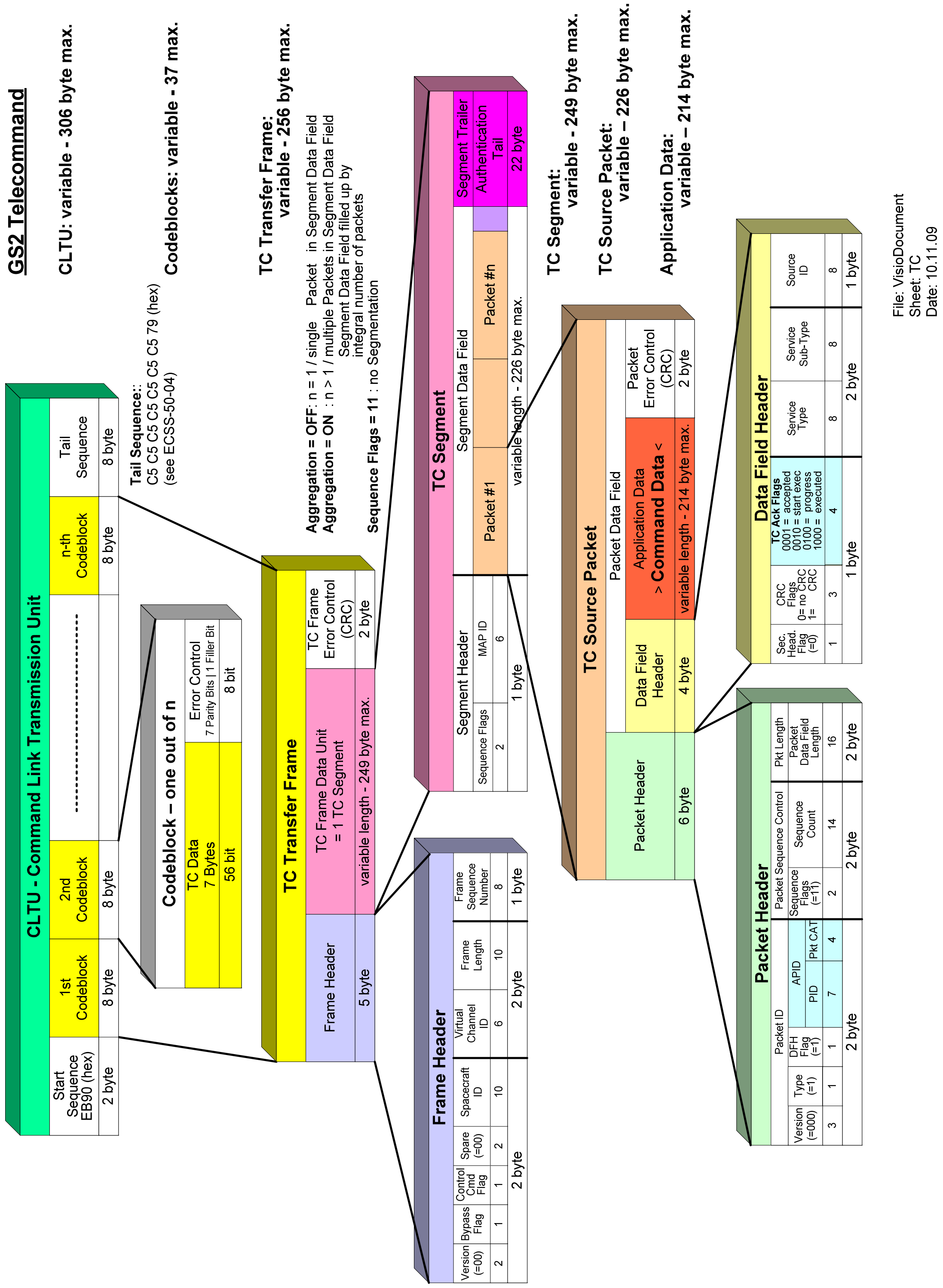

Figure 4.2-1: S-Band Uplink – Data Format and Content

4.3 S-Band Downlink

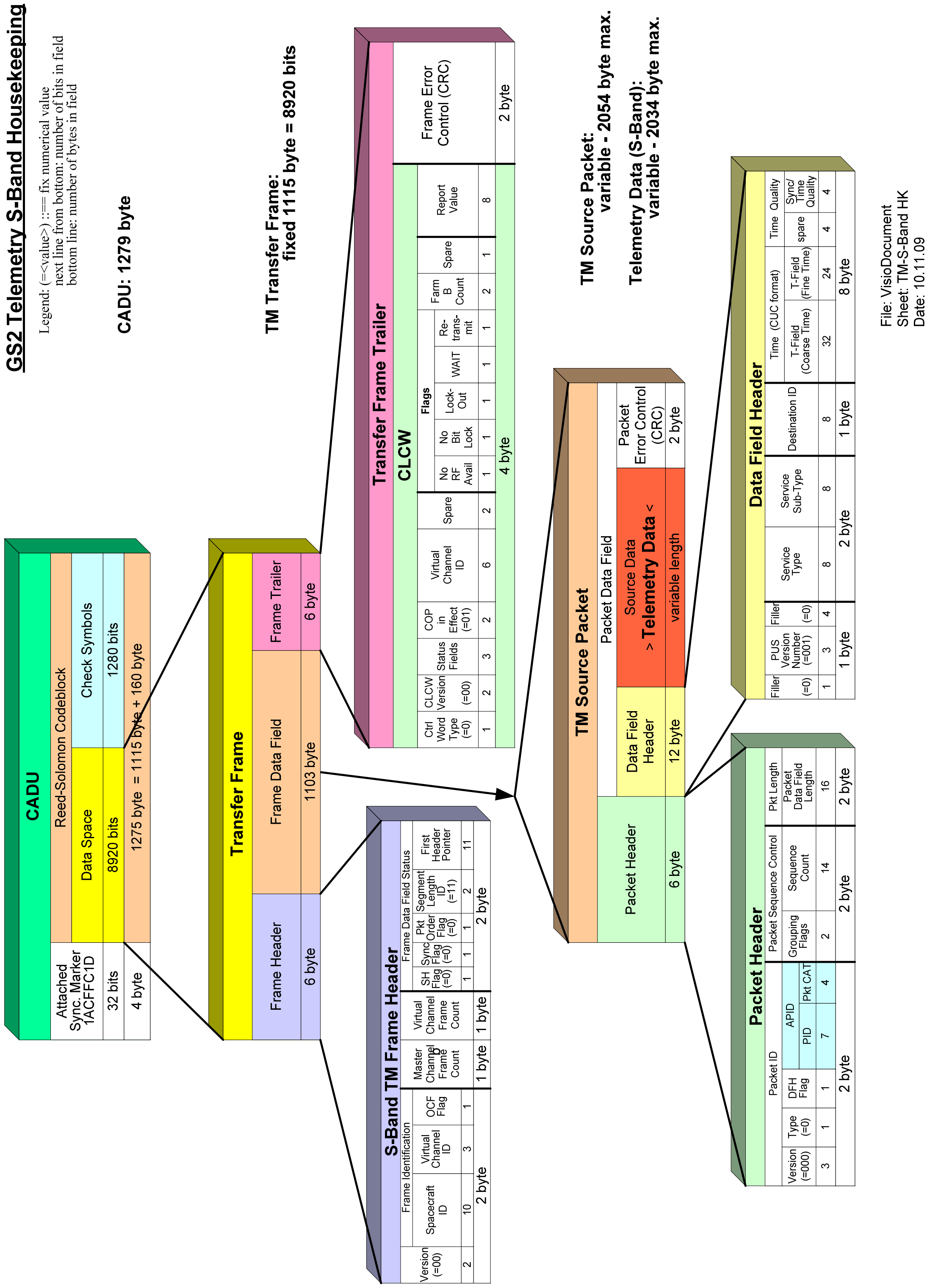

Figure 4.3-1: S-Band Downlink – Data Format and Content

4.4 X-Band Mission Data Downlink

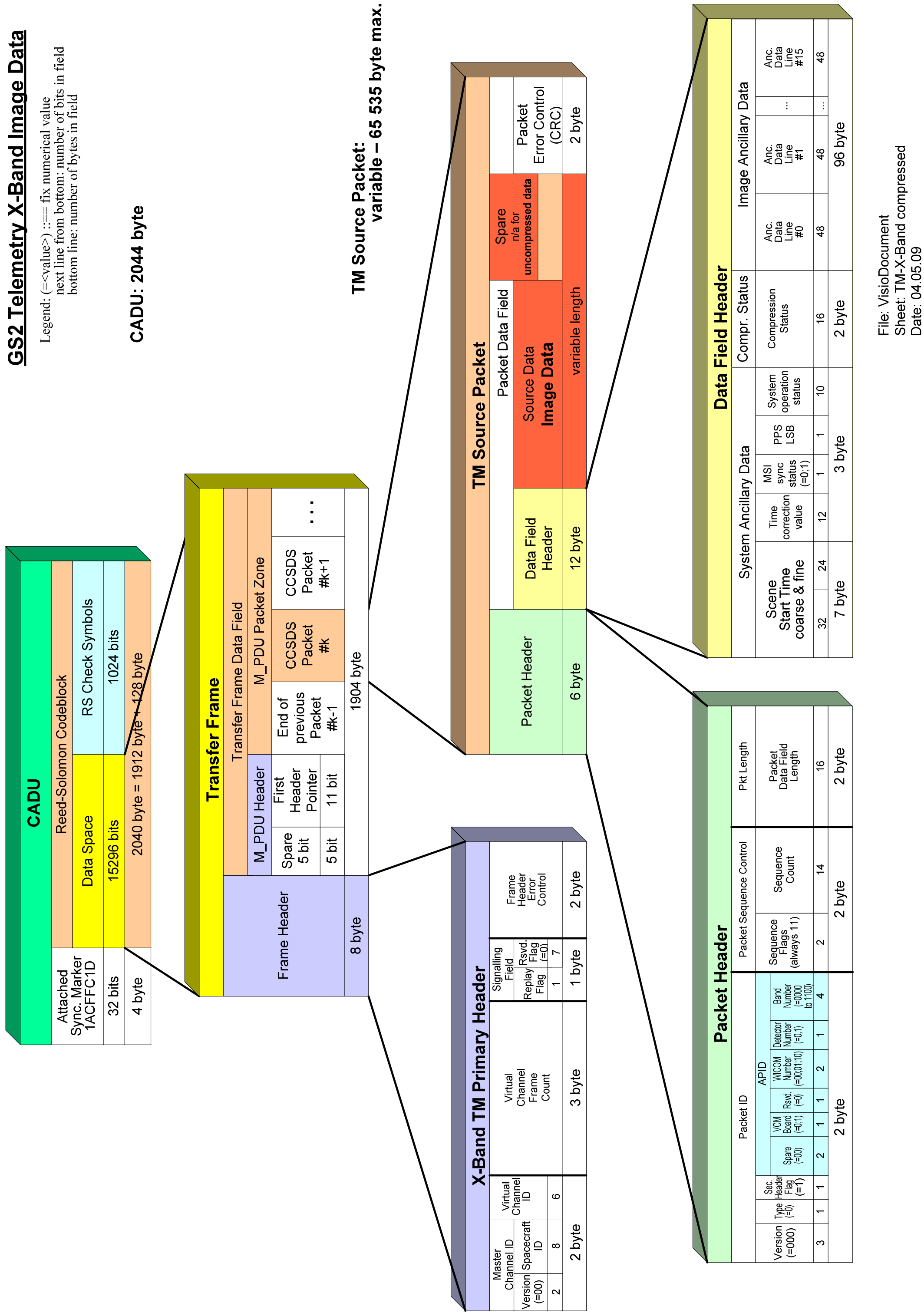

Figure 4.4-1: X-Band Mission Data Downlink – Data Format and Content

The on-board mission data flow from the detectors to the transmission systems is shown below.

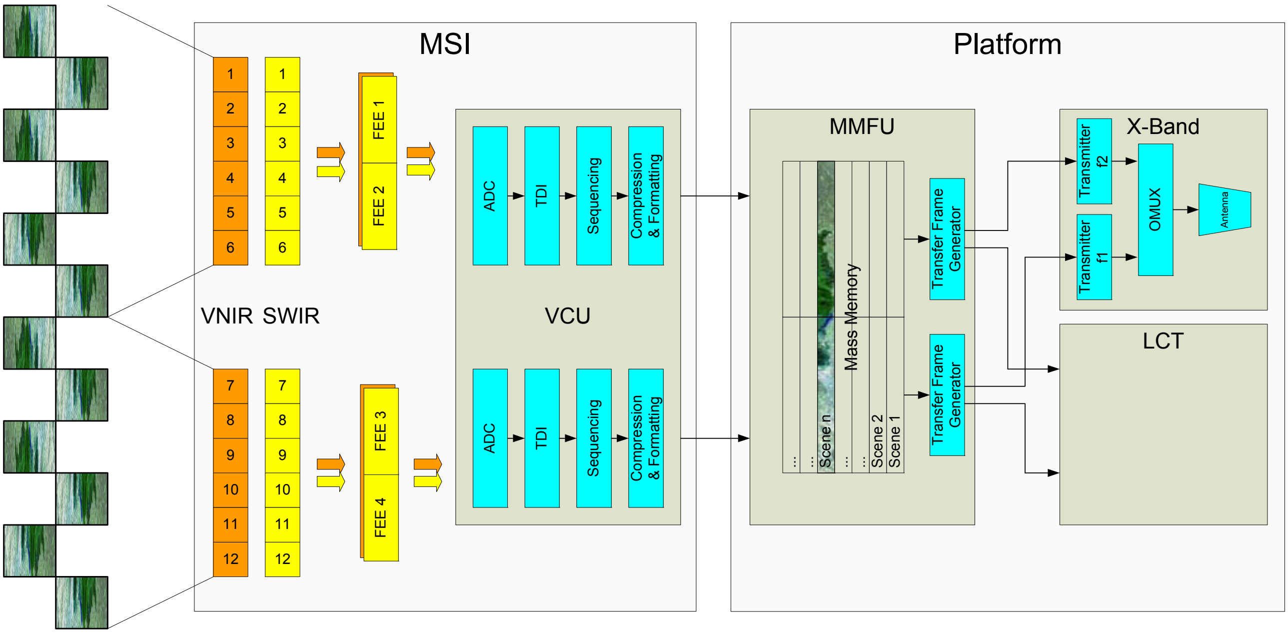

Figure 4.4-2: On-board Mission Data Flow

In view of the instrument data rate, multiplexing at the mass memory input and/or de-multiplexing at the mass memory output would result in considerable design complexity. To avoid this complexity, the mission data is basically acquired and processed by two parallel on-board processing chains.

The data acquired by 6 detectors (corresponding to half of the swath and half of a scene) are processed in parallel by the MSI. Two half-scenes are transmitted via two parallel measurement interfaces to the MMFU.

The MMFU internal data storage is as well organized in scenes respectively half-scenes. The MMFU receives two data streams from the MSI via Channel Link interfaces. Each of these data streams carries one half-scene, but both streams are logically stored within one Mission data packet store. The transfer frame is generated by two active Transfer Frame Generators operated in parallel.

For the X-band downlink half-scene 1 is transmitted with frequency 1 and half-scene 2 is transmitted with frequency 2. As for the X-band, the Transfer Frame Generator output data are routed in parallel to the LCT.

On platform level, the MSI data structure is maintained. Therefore, the description of the CCSDS Source Packet Structure, as well as, the transmitted packets over a scene given in [RD 40] apply also on satellite level.

4.5 X-Band Satellite Housekeeping and Ancillary Data Downlink

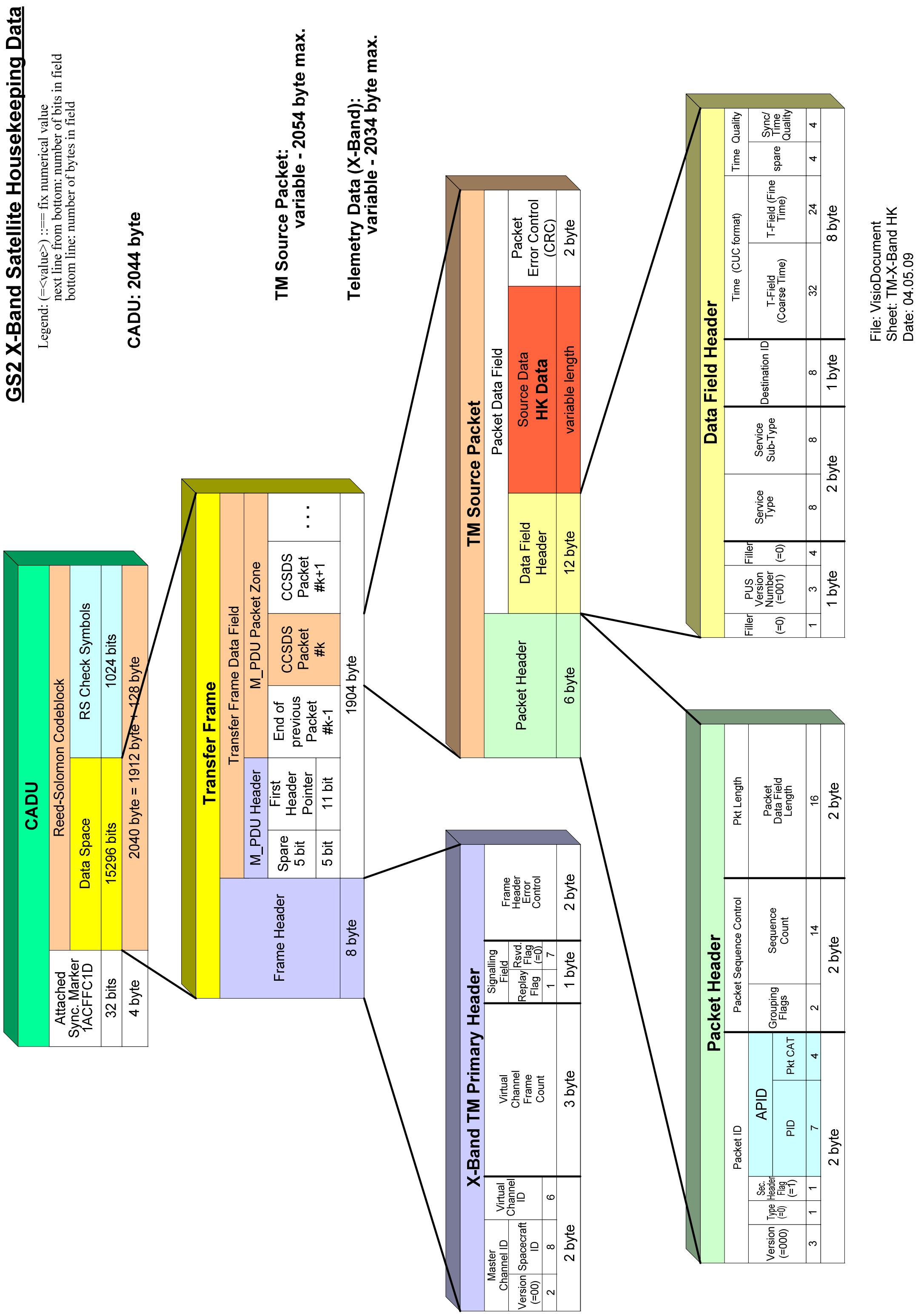

Figure 4.5-1: X-Band Satellite Housekeeping and Ancillary Data Downlink – Data Format and Content

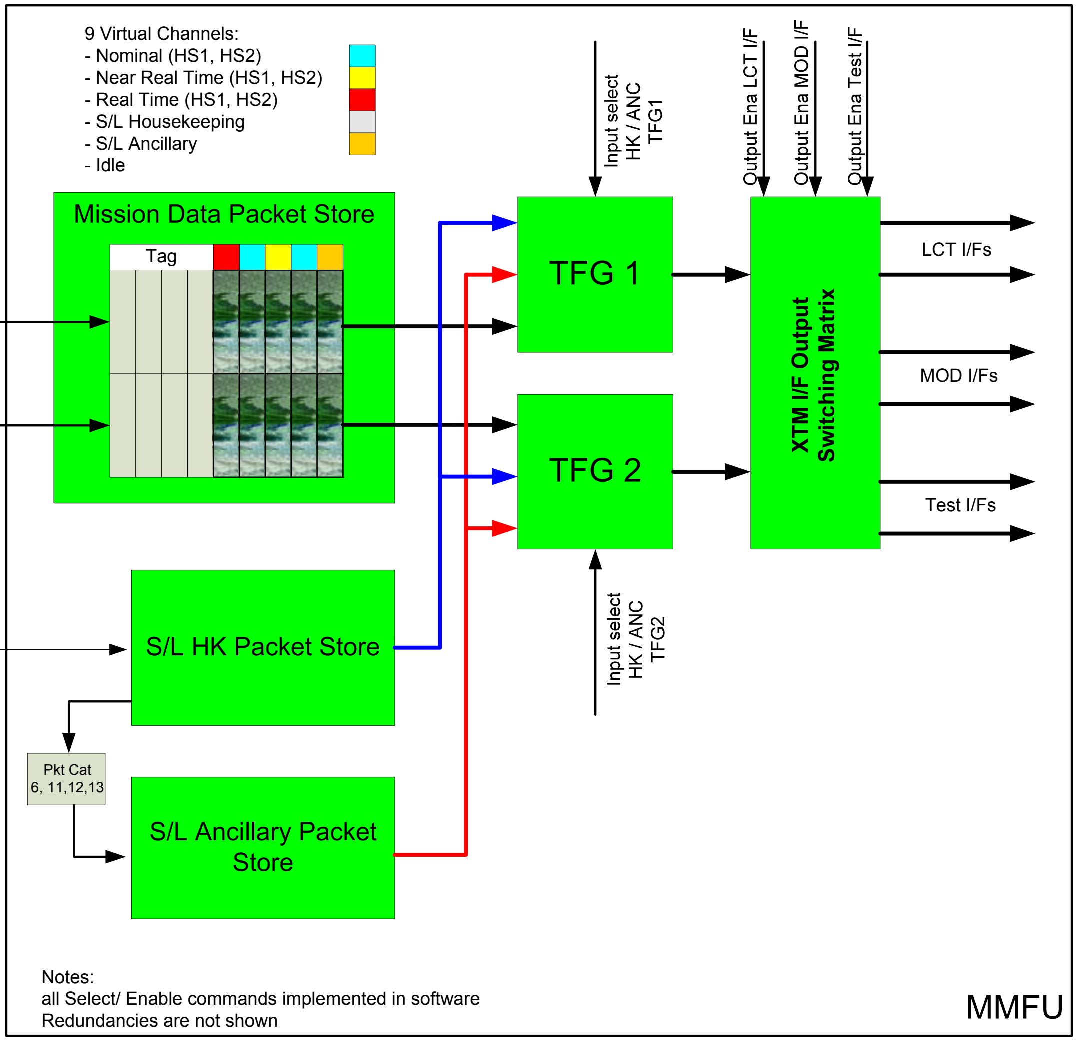

Figure 4.5-2: MMFU Packet Store Routing

In addition to the instrument data, the MMFU receives Satellite HK Data and Satellite Ancillary Data from the OBC via the Mil Bus interface. All data are stored within the Satellite Housekeeping Packet Store. Ancillary Data are required for the on-ground processing of the mission data. Based on their Packet Categories (PCAT = 6, 11, 12, 13) the Ancillary Data are also stored in the Satellite Ancillary Packet Store.

The content of the Satellite HK Data and Satellite Ancillary Data can be downlinked via any Transfer Frame Generator (TFG). Pending on the selected memory module and TFG configuration, both packet stores can also be downlinked in parallel.

5. RF DESCRIPTION

5.1 S-Band

5.1.1 Overview and Characteristics

The layout of Sentinel-2 on-board S-band TT&C system is schematically depicted in Figure 5.1-1. It is designed to have a dual redundancy with the following functional modules:

- Two S-band transponders, each consisting itself of a receiver, a transmitter, a diplexer, a ranging channel and the capability to operate as a coherent or non-coherent system.
- One quadrifilar helix antenna, Right Hand Circular Polarised (RHCP), with hemispherical coverage. It is located on the nadir pointing panel and is used for nominal communications.
- One quadrifilar helix antenna, Left Hand Circular Polarised (LHCP), with hemispherical coverage. It is located on the zenith panel and is used in case of loss of spacecraft attitude (emergency link).
- One 4-port 3 dB hybrid coupler to simultaneously connect the two hemi-spherical antennas to both transponders.
- RF harness and miscellaneous hardware interconnecting and matching the different modules.

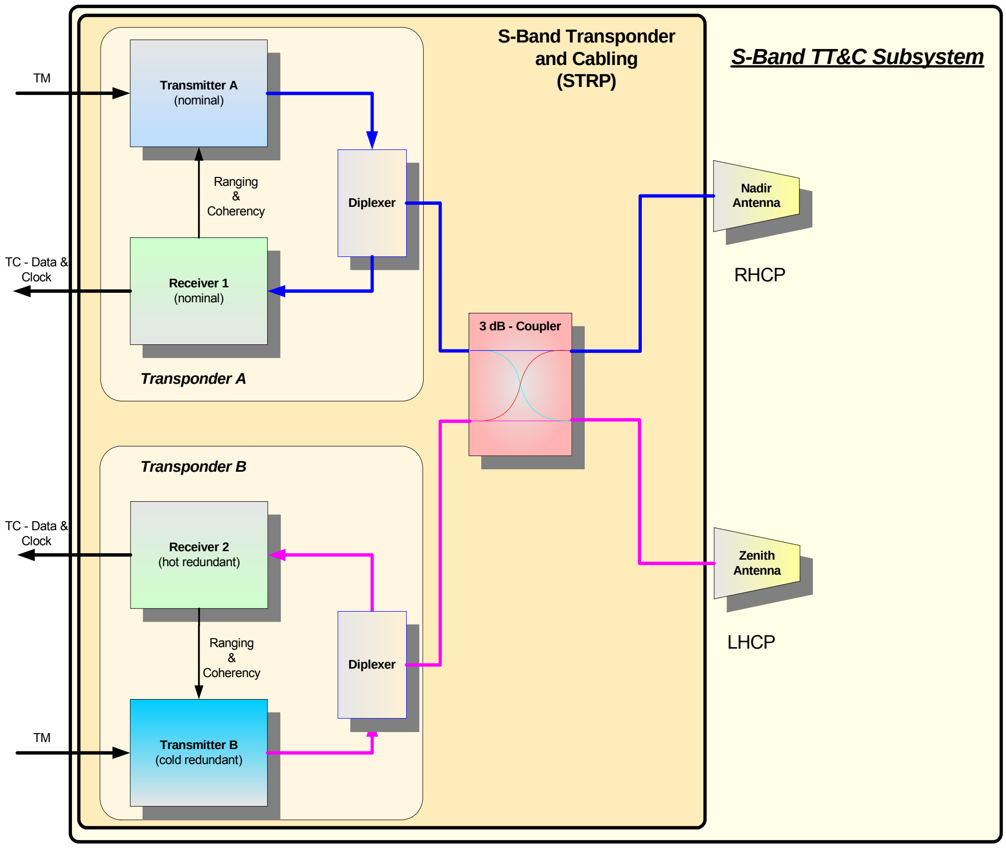

Figure 5.1-1: Sentinel-2 S-Band TT&C Subsystem Block Diagram

The main functions of the S-band TT&C system are:

- To receive and demodulate the S-band up-link signals for telecommand purposes. The uplink data rate is 64 kbps.
- To modulate and transmit the S-band down-link telemetry signals. For downlink a data rate of either 128 kbps or 2048 kbps is selectable.
- To support ranging by extracting the ranging tone signal out of the received telecommand signal and modulating this tone signal additionally onto the transmitted telemetry carrier. (This is only possible with the 128kbps downlink data rate).
- To provide coherent RF links to support range and range rate measurements by the relevant ground station during Launch and Early Orbit Phase (LEOP), during contingency scenarios and as a back-up for on-board GPS navigation.

The Transponder provides the performance data as given in the following tables.

Table 5.1-1: Uplink Performance Data of the S-Band Transponder

S-Band Transponder Uplink Issue	Specification
Uplink Carrier Frequency	2075.650417 MHz
Modulation Scheme	SP-L decoded data will be converted to NRZ-L coding. The SP-L data is directly modulated on the Uplink Carrier. Modulation scheme is BPSK
Data Rate	64 kbps
Telecommand Modulation Index	1 rad
Ranging Modulation Index	0.6 rad
Rest Frequency Stability	20 ppm
Carrier Acquisition Threshold	-128 dBm
Carrier Acquisition Range	-50 dBm … -128 dBm
TC Tracking Range	-50 dBm … -109 dBm
Doppler Tracking Range	± 60 kHz for Locking ± 140 kHz for Hold Lock
Sweep Properties	Max 32 kHz/s
Polarization	Zenith Antenna: LHCP Nadir Antenna: RHCP

Table 5.1-2: Downlink Performance Data of the S-Band Transponder

S-Band Transponder Down link Issue	Specification
Downlink Carrier Frequency	2254.1 MHz
Carrier Frequency Stability	20 ppm
Output Power Variations	< 1.0 dBpp
Low Data Rate	128 kbps (SP-L coded; RS encoded)
Low Data Rate Modulation Scheme	These data will be SP-L filtered and directly phase modulated on the Downlink Carrier. Modulation scheme is BPSK
RF output power at Low Data	25.0 dBm at Transponder output port
Low Data Rate Telemetry Modulation Index	1.2 rad rms
Ranging Tone for Low Data Rate Mode	between 100 kHz and 1500 kHz F_R = 448 kHz
Ranging Modulation Index	0.5 rad
High Data Rate	2048 kbps (NRZ-L coded; RS & Convolutional encoded)
High Data Rate Modulation Scheme	OQPSK, directly modulated onto RF-carrier
SRRC Roll-off factor	0.5
High Data Rate RF output power	25.0 dBm at transponder output port
Residual Carrier Suppression	> -30 dBc
Ranging Modulation Index	None, no ranging with this data rate!
Ranging Tone for High Data Rate Mode	None, no ranging with this data rate!
Polarization	Zenith Antenna: LHCP Nadir Antenna: RHCP
Satellite EIRP	Nom. - 11dBW @ Spacecraft Antenna angle 62°

- The uplink command shall be sent in the same polarization as the received downlink telemetry
- The RF output of the transmitter is switched ON during Ground contact and is switched off the rest of the orbit
- The receiver of the two transponders are in hot redundant conditions; the transmitter are in cold redundant conditions
- It will be possible to switch the transponder to Coherent or non-Coherent as required
- The Transponder coherent turn around ratio is 221 / 240 (f_{up} / f_{down}).

The transponder provides the following operational modes:

Table 5.1-3: Operational Modes of the S-Band Transponder

(Hot redundant) **Receiver Modes**	
Unmodulated Carrier, only	x
Telecommand only	x
Ranging only	x
Telecommand and Ranging	x

(Cold redundant) **Transmitter Modes**	Coherent Mode	Non-Coherent Mode
Modulation Mode 1 (128 kbps data rate)		
Unmodulated Carrier only	Not possible in orbit due to Power Flux Density requirements. Mode for ground testing, only.	
Telemetry only	X	X
Ranging only	Not possible in orbit because telemetry may not be switched off. Mode for ground testing only.	
Telemetry + Ranging	X	X
Modulation Mode 2 (2048kbps data rate)		
Unmodulated Carrier only	Not possible in orbit because telemetry may not be switched off. Mode for ground testing only.	
Telemetry only	X	X
Ranging only	Not possible, due to the high data rate and the OQPSK modulation scheme.	
Telemetry + Ranging		

Ranging

- RF ranging will be the backup to the GPS positioning information
- It will be possible to switch the ranging on or off as required
- The ranging tone is sent to the satellite on the uplink, turned around by the transponder and transmitted on the downlink with telemetry
- Simultaneously telecommand and ranging can be performed
- Ranging tone frequency: 448 kHz.

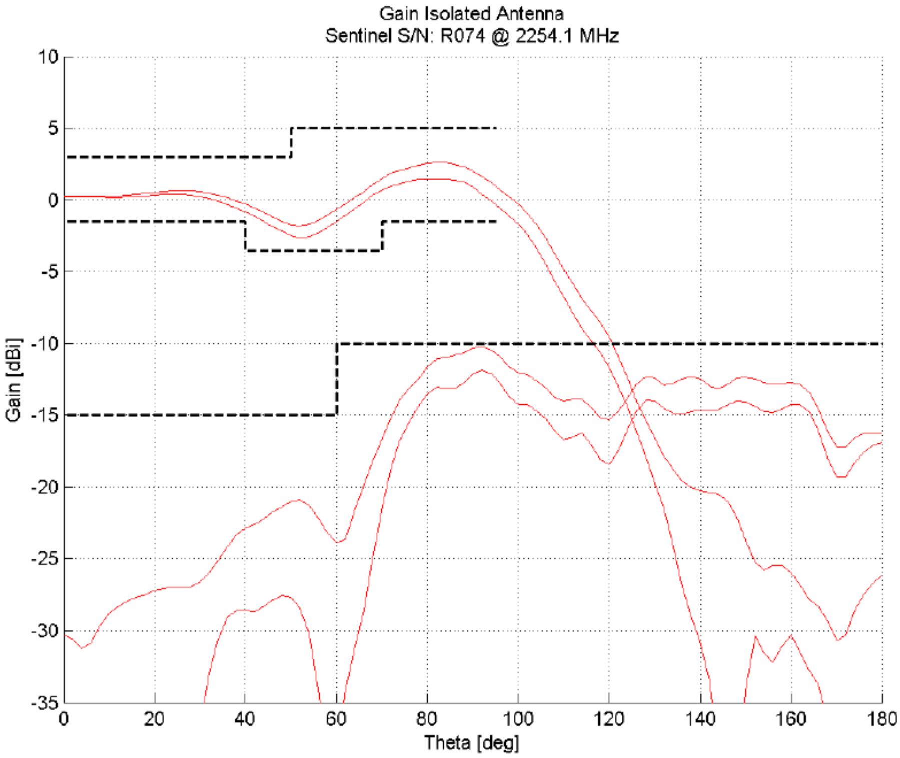

Figure 5.1-2: Uplink Antenna Gain versus Antenna Elevation Angle, measured (S/N R074)

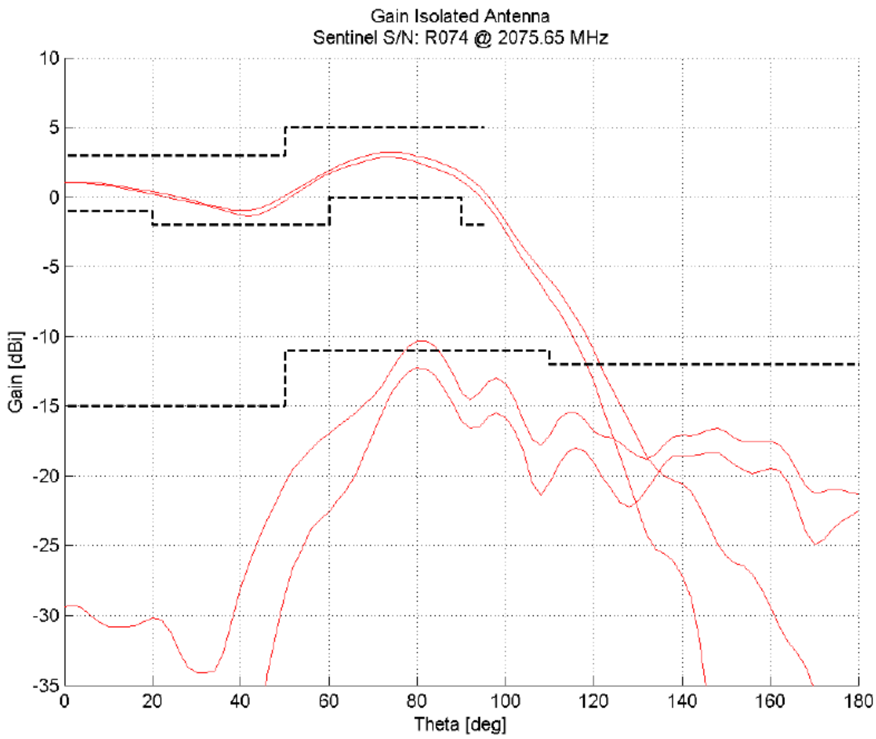

Figure 5.1-3: Downlink Antenna Gain versus Antenna Elevation Angle, measured (S/N R074)

5.1.2 S-Band Ground Station Interface

Kiruna-1, Kiruna-2, Svalbard-3 and Troll are considered as ground stations. The table below shows the G/S parameters.

	Kiruna-1	Kiruna-2	Svalbard-3	Troll
G/S EIRP	63 dBm	63 dBm	63 dBm	53 dBm
G/S G/T at 5° EL	> 27.7 dB/K	> 22.5 dB/K	> 23.0 dB/K	> 19.0 dB/K
G/S Axial Ratio	< 1.5 dB	< 1.5 dB	< 1.5 dB	< 1.5 dB

5.1.3 S-Band Link Budget

The link budgets are given in the Sentinel 2 Engineering Budgets [AD 14].

5.2 X-Band

5.2.1 Overview and Characteristics

The general layout of Sentinel-2 Payload Data Transmission System (PDT) is schematically depicted in Figure 5.2-1. The PDT provides two data channels for the data down link transmission.

The Payload data Transmission System consists of:

- X-Band Transmitter Subsystem (XBS)
- X-Band Antenna.

The X-Band Transmitter Subsystem (XBS) consists of:

- four X-Band transmit chains (two in cold redundancy), each consisting of
  - a X-Band Modulator
  - a Traveling Wave Tube Amplifier (TWTA)
    - Electrical Power Conditioner (EPC)
    - Traveling Wave Tube (TWT)
  - a RF Isolator
    - Circulator
    - High Power Load
- two Wave Guide Switches (WGS)
- a Output Multiplexer (OMUX).

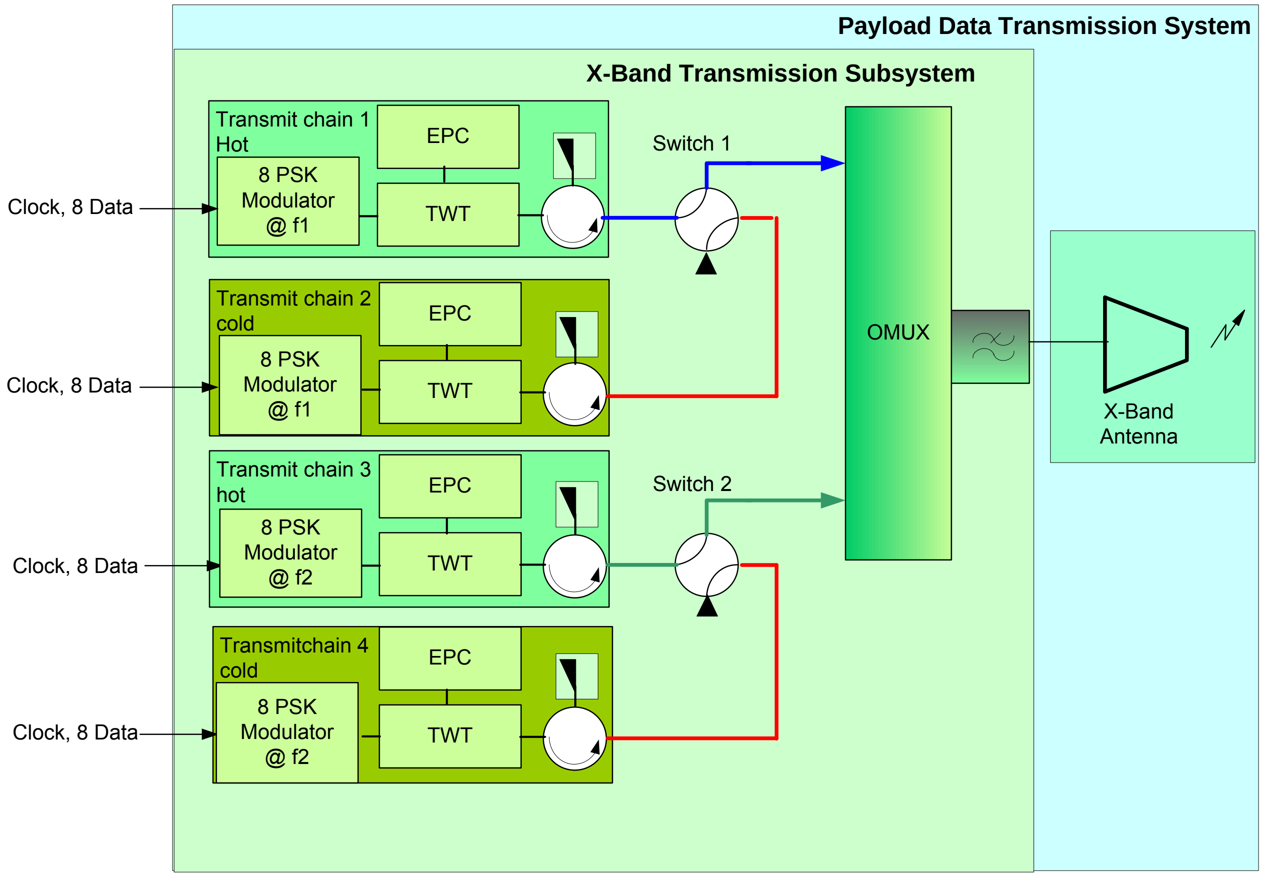

Figure 5.2-1: Sentinel-2 X-Band Subsystem Block Diagram

The fundamental functions of the PDT are

- to encode the both user data streams
- to modulate the two user data streams on two carrier
- to transmit these data in two separate channels.

The PDT architecture shows two cold redundant transmit chains which are operating simultaneously. Each transmit chain is equipped with a 4D TCM 8PSK modulator and a Traveling Wave Tube Amplifier (TWTA). The RF Isolator saves the TWT for unwanted signal back radiation due to open or shortened circuit in a subsequent unit.

The two amplified RF-signals are transmitted via Wave Guide Switches to the two channel inputs of the Output Multiplexer (OMUX). The OMUX combines the two channels and provides an output interface to the subsequent antenna.

The main parameters of the PDT are summarized below.

Table 5.2-1: PDT Parameter

Down link Issue	Specification
Downlink Frequency, channel 1	8095 MHz
Downlink Frequency , channel 2	8260 MHz
Input Symbol Rate per channel; R_S	280 Msps
Transmitted Channel Symbol Rate per channel; R_{chs}	112 MSps
Modulation	4D TCM 8PSK
Coding	Trellis 5/6; 2.5 bit/Hz
Roll-off factor	0.35
Occupied bandwidth	< 300 MHz
Polarisation	RHCP
RF Power at antenna interface per channel	> 15.05 dBW
Satellite EIRP per channel	> 20.6 dBW @ S/C antenna angle 62°
Carrier stability	± 20 ppm
Antenna Coverage	± 62°
Specified Antenna Gain	See Figure 5.2-2 below
RF Output Spectrum	See Figure 5.2-3 below
OMUX Filter characteristics	See Figure 5.2-4 below

The PDT provides the operational modes as listed below.

Table 5.2.1-2: X-Band Operational Modes

Modes	Modulator Mode	TWTA Mode
XBS OFF	OFF	OFF
XBS Standby	Standby	Standby
XBS Operation	Operation	Operation

The XBS is switched OFF during launch. After Launch the XBS is switched on in XBS STANDBY and during Ground contact in XBS OPERATION.

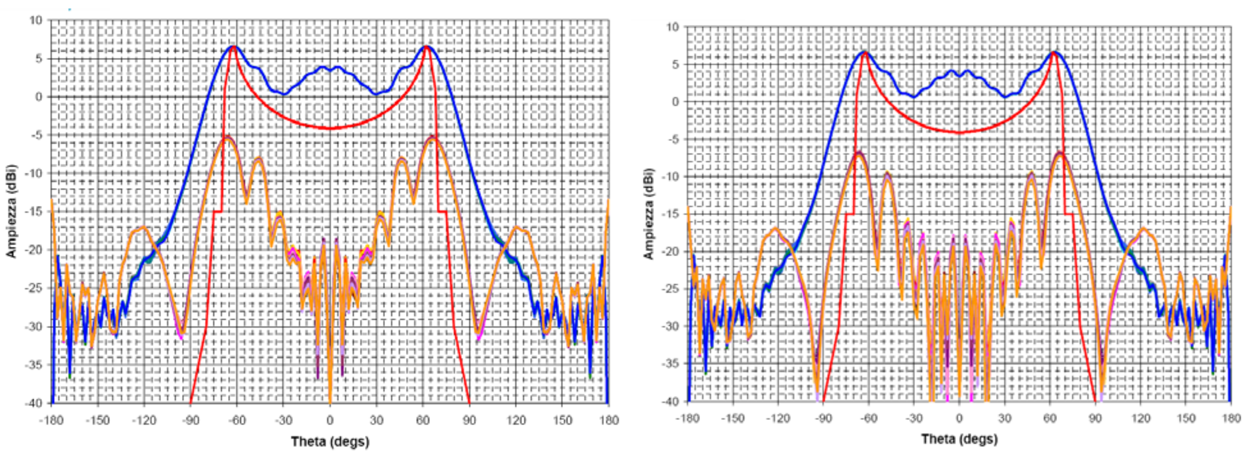

Figure 5.2-2: Antenna Gain versus Antenna Elevation Angle (on right f=8095MHz; on left f=8260 MHz)

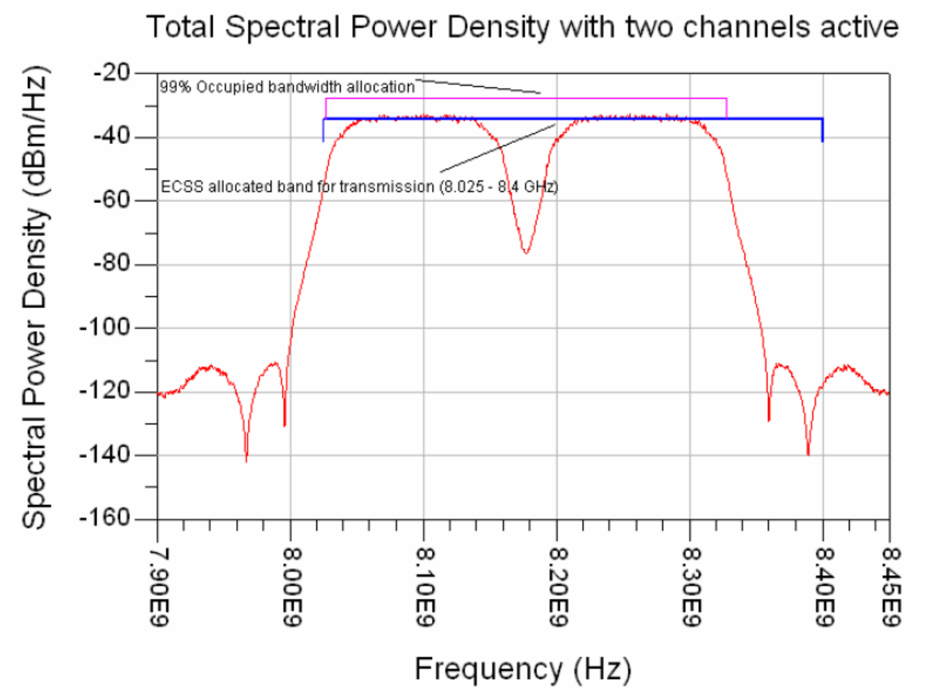

Figure 5.2-3: RF Output Spectrum, simulated

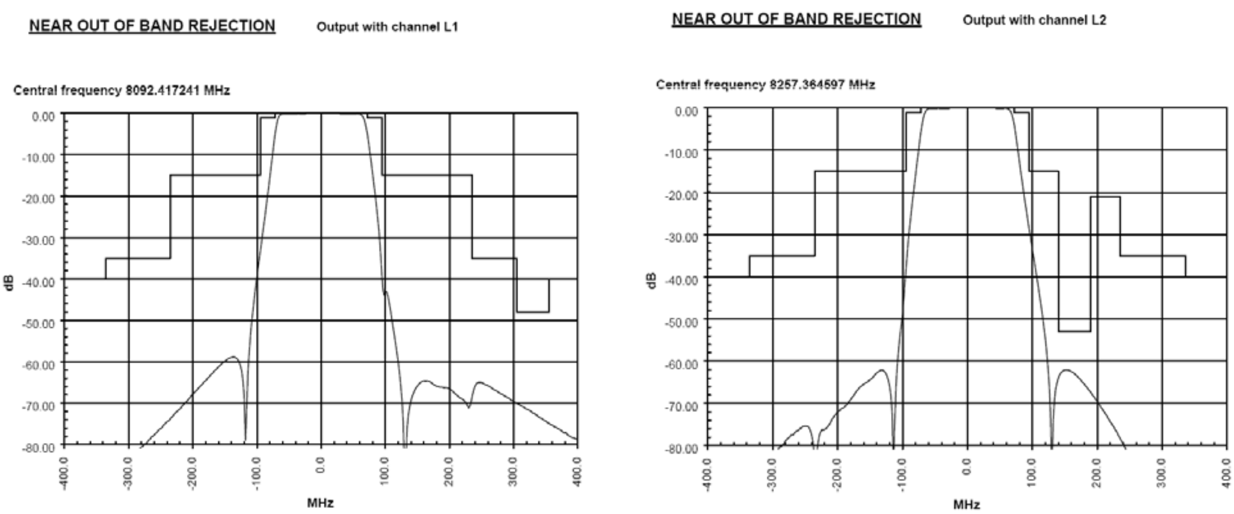

Figure 5.2-4: OMUX Characteristics, measured

5.2.2 X-Band Ground Station Interface

Kiruna, Svalbard, Prince Albert and Maspalomas are considered as ground station. For all G/S the same performance is considered.

The main parameters are

- G/T: > 33.8 dB/K (incl. rain and scintillation losses) according to SRD requirement COM-GE-020
- Axial Ratio: < 1.5 dB
- Demodulation Loss: < 3dB
- Minimum elevation angle: 5°.

5.2.3 X-Band Link Budget

The link budgets are given in the Sentinel 2 Engineering Budgets [AD 13].

Sentinel 2

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