EPS-SG (Metop-SG) Direct Data Broadcast (DDB) Radio Frequency (RF) Space to Ground Interface Control Document (ICD)

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Preface

The EUMETSAT Polar System – Second Generation (EPS-SG) Spacecraft Radio Frequency (RF) Interface Control Document (ICD) defines the X band Direct Data Broadcast (DDB) communication link between EPS-SG Spacecraft and Direct Broadcast Users.

EUMETSAT EPS-SG system team will maintain configuration control of this document through its Configuration Control Board (CCB).

1 INTRODUCTION

1.1 Purpose

This Interface Control Document (ICD) provides performance requirements and defines and controls technical aspects of the Direct Data Broadcast (DDB) communications subsystem interface between the EPS-SG space segment (MetOp-SG satellites) and the Direct Data Broadcast Users worldwide within line-of-sight view.

The DDB provides real-time mission data (live instrument data as it is being sensed by the various instrument payloads) via X band downlink transmission.

This interface can be used by final users gathering local real-time data (e.g. for nowcasting applications) but also for supporting the reception of regional data to the EUMETSAT processing chains via a set of complementary stations.

Users of the Direct Data Broadcast Stations are responsible for meeting the requirements laid out in this ICD.

1.2 Scope

The communications subsystem interface defined and controlled by this ICD is the DDB Radio Frequency (RF) transmission link between the MetOp-SG satellite and the Direct Data Broadcast Users.

The contents of this ICD are extracted from the MetOp-SG Space to Ground Interface Control Document version 6 [RD.1].

This ICD does not include information of other MetOp-SG RF links: S band link for Telemetry, Telecomm and Tracking (TTC) system, Ka band link for Stored Mission Data (SMD) transmission; these are included in separated RF ICD [RD.1]. Figure 1 depicts the RF links between the MetOp-SG and its various interfaces.

The RF link budget calculations contained in Appendix B for the MetOp-SG DDB is included only as supporting data and do not constitute a formal part of the RF ICD.

The Earth-coverage antenna patterns provided in Appendix A are included for information purposes and are also not part of this RF ICD.

2 DOCUMENTS

2.1 Reference Documents

RD No	Document Title	Document Reference
RD.1	MetOp-SG Space to Ground Interface Control Document, version 6	MOS.ICD.ASD.SYS.00796
RD.2	EPS-SG Data Rates, version 6	EUM/LEO-EPSSG/TEN/14/746414
RD.3	Metop-SG PUS Interface Requirements Document	MOS.IRD.ASF.SYS.00835

2.2 Applicable Standards

ND No	Document Title	Document Reference
ND.1	Space Packet Protocol	CCSDS 133.0-B-1
ND.2	AOS Space Data Link Protocol	CCSDS-732.0-B-2
ND.3	Space Data Links - Telemetry Synchronization and Channel Coding	ECSS-E-ST-50-01C
ND.4	Radio Frequency and Modulation	ECSS-E- ST-50-05C

3 OVERVIEW OF EPS-SG MISSION

The EUMETSAT Polar System Second Generation (EPS-SG) is a follow-on programme from EPS and, following the launch of a first MetOp-SG satellite in late 2022, the programme should have an operational lifetime of 21 years.

The overall mission of the EPS-SG System is to provide global observations from which information on variables of the atmosphere and the ocean and land surfaces can be derived, using satellite based sensors from the Low-Earth Orbit (LEO). To fulfil its mission it is required to deploy sustained capabilities to acquire, process, and distribute environmental data to down-stream application users and second tier processing centres. The data covers a broad spectral range (from UV to MW), are related to different spatial coverage (global and regional), and are characterized by a variety of different time scales, in order to continue and enhance the services offered by the EPS system.

There are three high level mission services:

- The Global mission for product generation and distribution of information acquired by the on-board instruments over the full globe.
- The Regional mission for product generation and distribution with improved timeliness for a regional area (Europe and the North Atlantic).
- The Local mission for distribution of "live" instrument data to user stations at any location with visibility of the satellites.

In order to support the different mission services and to monitor and control the MetOp-SG satellites, the EPS-SG system architecture is composed of four physical Space-to-Ground EPS-SG interfaces:

- TTC links, including transmission of telecommands, reception of housekeeping telemetry and retransmission of ranging/Doppler tracking signals for orbit determination. TTC links are implemented in S band.
- Stored Mission Data (SMD) downlink, supports the Global mission service as the main link for transmission of stored instrument data acquired by the on-board instruments to the relevant ground stations. SMD link is implemented in Ka band.
- Direct Data Broadcast (DDB), supports the Regional and Local mission services, for transmission of live instrument data as it is being sensed by the various instrument payloads. This interface can be used by final users gathering local real-time data (e.g. for nowcasting applications) but also for supporting the reception of regional data to the EUMETSAT processing chains via a set of complementary stations. DDB link is implemented in X band.
- Implementation of the support missions, including the corresponding transponders for relaying the data collected by the distributed platforms to the associated control centres/reception stations.

The space segment comprises two satellites (MeOp-SG A, and MeOp-SG B), both satellites will be operated simultaneously (though their orbits will be phased) and will have the same orbit as to the EPS MetOp spacecraft.

Each MetOp-SG satellite consists of satellite platform and payload. All of the MetOp-SG satellites are based on a common satellite platform design with only minor differences between the two satellite types (A and B). The Payload is composed of the instruments on board the satellites (i.e. the set of observation missions) and is different in the A and B satellites. This is specified in the following Table 1.

Payload	Mission	Sat
IASI-NG (Infrared Atmospheric Sounding Interferometer –New Generation)	Provides atmospheric temperature and humidity profiles, as well as monitors ozone and various trace gases (High vertical resolution temperature and water vapour profiles in clear sky atmospheric trace gases).	A
METimage	Visible and infrared imager to provide information on clouds, cloud cover, land surface properties, sea, ice and land surface temperatures, etc. (High horizontal resolution cloud products. Atmospheric water vapour gross profile at high horizontal resolution. Vegetation, snow coverage, fire monitoring and aerosol products).	A
S-5 (Sentinel-5)	Provides ozone profiles and columns, monitor various trace gases, monitor air quality and support climate monitoring (Ozone profile and total column. Total column of SO2, NO2, H2O, CO, CH4).	A
MWS (MicroWave Sounder)	Provides atmospheric temperature and humidity profiles (Temperature and water vapour profiles in clear and cloudy air).	A
3MI (Multi-viewing, Multi-channel, Multi-polarization Imager)	Provides information on atmospheric aerosols (High quality imagery of aerosols parameters. Optical depth, particle size and shape. Surface albedo, cloud characterisation, ocean colour).	A
RO (Radio Occultation sounder)	Provides atmospheric temperature and humidity profiles, as well as information about the ionosphere (Atmospheric temperature in the troposphere and stratosphere. Humidity profiles in the lower troposphere).	A&B
MWI (MicroWave Imager)	Provides precipitation monitoring as well as sea ice extent information (Precipitation and liquid cloud products including bulk microphysical parameters. All weather surface imagery: sea ice coverage and type, snow coverage)	B
ICI (Ice Cloud Imager)	Monitors clouds and cloud ice particles (Cloud ice products including bulk microphysical parameters)	B
SCA (SCAtterometer)	Provides ocean surface wind vectors and land surface soil moisture.	B
ADCS-4 (Advanced Data Collection System)	Collection and transmission of observations and data from surface, buoy, ship, balloon or airborne data collection platforms (Collection of in-situ oceanographic and meteorological data).	B

Table 1: Overview of the EPS-SG mission services

Complementary to the direct observations summarised above and yet essential to satisfy key user needs, the following services have to be fulfilled by EPS-SG:

- Product generation;
- Near-Real Time Data Dissemination & Relay services to users;
- Direct Broadcast and Data Dissemination;
- A-DCS Data Relay service;
- Non-NRT dissemination services;
- Long term archiving in the *EUMETSAT Data Centre*;
- *Archived dataset* retrieval services to be provided by the *EUMETSAT Data Centre*;
- User support services.

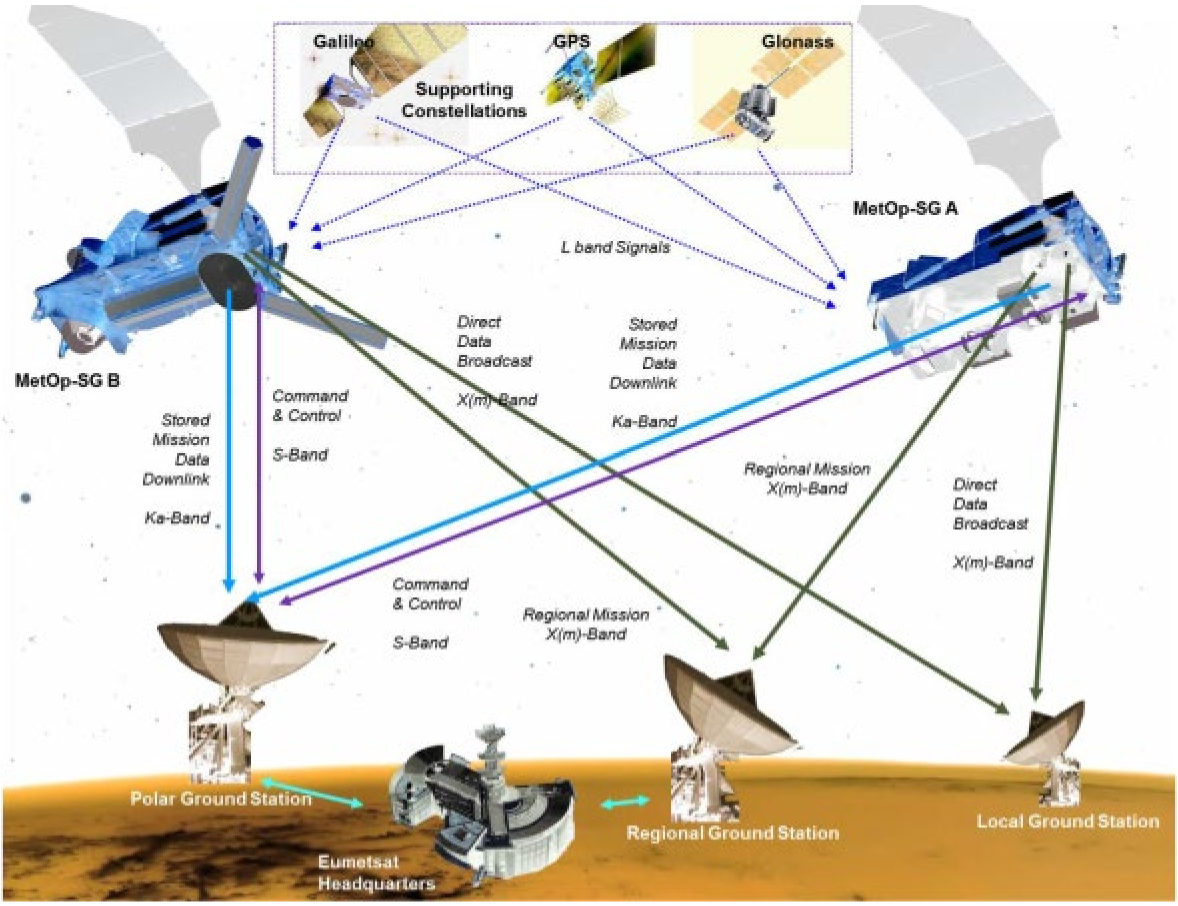

Figure 1: Overview of the ESP-SG Space-to-Ground Interfaces

4 DDB LINK INTERFACE CHARACTERISTICS

4.1 Overview

MetOp-SG satellites will use X band to downlink the Direct Data Broadcast (DDB) data in quasi-real time i.e. the most recently collected data. The DDB services contains the following type of data:

- Science data from all the instruments (except IASI-NG ASD Data);
- Ancillary data from platform and instruments;
- Housekeeping TM from platform and instruments (including NAVATT);
- Multi-Mission Administrative Message.

MetOp-SG satellites will use isoflux radiation pattern antenna to provide equally good link performance independently of receiving Direct Broadcast Users ground station location. Antenna patterns are shown in Appendix A for reference.

The information data rate is 80 Mbps. Data is formatted, coded and modulated into a downlink carrier frequency of 7825 MHz. The DDB data will be formatted in accordance with ECSS AOS standard [ND.2] as outlined in section 4.3. In normal operations broadcast data will operate continuously providing real-time data to the Direct Data Broadcast Users. The data is transferred to the ground within 10 sec. after generation by the instruments.

The Direct Data Broadcast User Terminal demodulates and decodes the RF signal received from MetOp-SG communication subsystem. The satellite to Earth station link distance ranges from 2890 km, at a ground station elevation angle of 5 degrees to 850 km at a station elevation angle of 90 degrees. Direct Broadcast Station support is dependent on favourable radio line-of-sight conditions when Direct Broadcast Station antenna elevation angle is greater than 5 degrees (above the local horizon).

The Direct Broadcast Stations must be able to handle a maximum Doppler shift of +/- 172.5 kHz at an elevation angle of 5 degrees, and a Doppler shift rate of 1.55 kHz/sec at an elevation angle of 90 degrees.

4.2 DDB Link Implementation

The DDB link is organised in a set of independent layers which are described in the following sections. A space link protocol is associated with each one of the layers, see Figure 2.

An overview of the layers and of the services they offer is presented in the following text.

For a set of data issued from the satellite, the data passes through the protocol layers in the following order:

4.2.1 Network Layer:

This layer has the function of routing the application data through the entire data system that includes both on board and ground subnetworks.

- The protocol used for DDB system in this layer is the CCSDS Space Packet Protocol, CCSDS 133.0-B-1 [ND.1].

4.2.2 Data Link Layer:

This layer has two sublayers: the Data Link Protocol Sublayer and the Synchronization and Channel Coding Sublayer.

- 4.2.2.1 Data Link Protocol Sublayer, which transfers the data from the network layer over the space link using Transfer Frames as data unit
  - The protocol used in this layer for DDB is the CCSDS AOS Space data link protocol, CCSDS-732.0-B-2 [ND.2].

- 4.2.2.2 Synchronization and Channel Coding Sublayer, which provides the methods for reliably transferring Transfer Frames over noisy space links; these include methods of delimiting and synchronization of Transfer Frames and methods of error correction and/or detection.
  - The protocol used in this layer for DDB is the ECSS Telemetry synchronization and channel coding ECSS-E-ST-50-01C [ND.3].

4.2.3 Physical Layer:

The physical layer involves the Radio Frequency Transmission process. The Standard ECSS-E-ST-50-05, Radio Frequency and Modulation [ND.4] is applied for DDB.

For a set of data acquired on ground, the data passes through the protocol layers in the opposite order.

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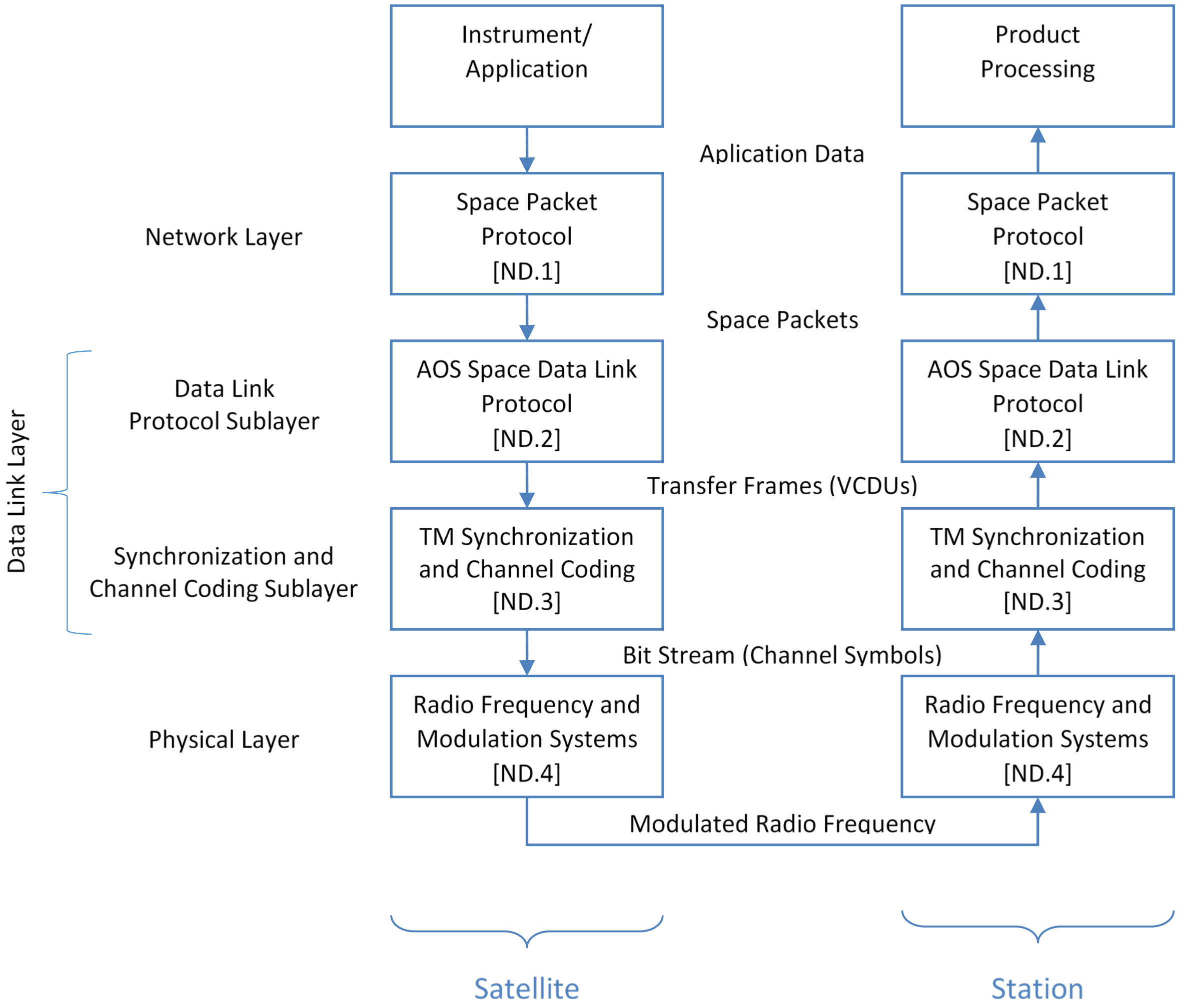

Figure 2: OSI (Open System Interconnection) Reference Model, Layers implemented for DDB space link and associated protocols

4.2.1 Network Layer

DDB uses Space Packet Protocol as defined in [ND.1].

Space missions use this protocol to transfer space application data over a ground-to-space or space-to-space communications link. The Protocol Data Units (PDU) employed by this protocol are Space Packets (unless otherwise stated, the term ‘Packet’ in this document refers to the Space Packet).

The structure of the standard Space Packet tailored for Metop-SG DDB [RD.3] is depicted in the following Figure 3.

The Space Packet is of variable length with a maximum 65 536 bytes.

The structural components are: Packet Primary Header (fixed length, 6 bytes), Secondary Header (fixed length, 12 bytes), Useful Data (variable, maximum length 65 516 bytes) and a Checksum (fixed length, 16 bits).

The Primary Header (Packet Header) of the Packet contains the Application Process Identifier (APID, 11 bits) which for Metop-SG is composed of two parts:

- PRID (7 bits): Process ID, it is set to a value according to Table 3;
- PCAT (4 bits): Packet Category. It is set CAT = 0, for instrument ancillary data, for the rest of data types it is set CAT > 0. In total 15 CAT values available allowing to distinguish between different data types, these are defined individually for each instrument.

The Secondary Header is not present in all the packet types, as is the case for the following packet types:

- TIME packet (PRID 0x00 PCAT 0x00, see Table 3): no secondary header;
- IDLE packet (PRID 0x7F PCAT 0x0F, see Table 3): no secondary header.

If the Packet is not an Idle Packet, then the User Data Field contains application data. If the Packet is an Idle Packet (PRID 0x7F, PCAT 0x0F, see Table 3), the User Data Field contains Idle Data. The structure of the Idle Packet is shown in Figure 4.

Packet Primary Header								Packet Data Field										
Packet Version Number	Packet Identification				Packet Sequence Control		Packet Data Length	Packet Secondary Header									User Data Field	
			APID											Time CUC				
	Packet Type	Secondary Header Flag	Process ID	Packet Category ID	Grouping or Segment Flags	Source Sequence Count		Spare	TM Source Packet PUS Version Number	Spare	Service Type	Service Subtype	Destination ID	Coarse Time (seconds)	Fine Time (subseconds)	Time synchronization status	Source Data	Packet Error Control Field
"000"	"0"	"0" PUS(9,2) /HPTM/idle "1" rest						"0"	"001"	"0000"							Variable (up to 65516 bytes)	
3 bits	1 bit	1 bit	7 bits	4bits	2 bits	14 bits	16 bits	1 bit	3 bits	4 bits	8 bits	8 bits	8 bits	32 bits	24 bits	8 bits		16 bits
2 bytes					2 bytes		2 bytes	12 bytes									variable	
6 bytes								12 bytes									variable	
18 to 65536 bytes																		

Figure 3: DDB Space Packet Structure

<table>
<tr><th colspan="10">Idle Packet</th></tr>
<tr><th colspan="8">TM Source Packet Primary Header</th><th colspan="2">TM Source Packet Data Field</th></tr>
<tr><th colspan="5">Packet Identification (ID)</th><th colspan="2">PACKET SEQUENCE CONTROL</th><th rowspan="3">Packet Data Length (no. of packets in TM Source Packet Data Field -1)</th><th rowspan="3">Scrambled Idle Data</th><th rowspan="3">Packet Data Length (no. of packets in TM Source Packet Data Field -1)</th></tr>
<tr><th rowspan="2">Version Number (=000)</th><th rowspan="2">Type (=0, TM)</th><th rowspan="2">TM Source Packet 2nd'ry Header Flag (=1b)</th><th colspan="2">APID</th><th rowspan="2">Segmentation Flags (Grouping Flags) = 11b</th><th rowspan="2">Source Packet Sequence Count = 0000h</th></tr>
<tr><th>PID = 7Fh</th><th>PCAT = Fh</th></tr>
<tr><td>3 bit</td><td>1 bit</td><td>1 bit</td><td>7 bit</td><td>4 bits</td><td>2 bit</td><td>14 bit</td><td>16 bit</td><td></td><td>16 bit</td></tr>
<tr><td>000b</td><td>0b</td><td>1b</td><td colspan="2">7FFh</td><td>11b</td><td>0000h</td><td>variable</td><td>Variable</td><td>CRC</td></tr>
</table>

Figure 4: DDB Idle Packet Structure

For IDLE packets only: The CRC is computed over the data zone of the Idle packet. The packet's primary header is not included in the CRC computation.

4.2.2 Data Link Layer

The Data Link Layer is composed of two sublayers:

- 4.2.2.1 Data Link Protocol Sublayer, which transfers the data from the network layer over the space link using Transfer Frames as data unit;
- 4.2.2.2 Synchronization and Channel Coding Sublayer, which provides the methods for reliably transferring Transfer Frames over noisy space links, these include methods of delimiting and synchronization of Transfer Frames and methods of error correction and/or detection.

4.2.2.1 Data Link Protocol Sublayer

For the Data Link Protocol Sublayer, DDB uses AOS Space Data Link Protocol [ND.2].

The Space Packets received from the Instruments and the On Board Computer (OBC) are downlinked according to their Application Process Identifier (APID) into one Virtual Channel (VC) filling the Transfer Frame Data Field. By design, all the mission data (i.e. all APIDs) from a given Instrument are downlinked with the same VCID.

The Transfer Frame structure and format is as defined in [ND.2] and it is depicted in Figure 5.

The Transfer Frame length is of constant length 892 bytes.

The structural components are: Primary Header (6 bytes) and Data Field (or M_PDU, 886 bytes):

The Transfer Frame Primary Header's first two octets correspond to Master Channel ID (first 10 bits), followed by the Virtual Channel ID (VCID, next 6 bits):

- The Master Channel ID is composed of the Transfer Frame Version Number ('01') and the Spacecraft ID. Table 2 defines the spacecraft IDs for each of the different satellite models;
- The Virtual Channel (VC) allocation concerning the DDB downlink is shown in Table 3.

The Transfer Frame Data Field contains the Multiplexing Protocol Data Unit (M_PDU) or Idle Data:

> The M_PDU is composed of the M_PDU Header (2 bytes) and the M_PDU Packet Zone (884 bytes) which contains the Packets (inserted contiguously and in forward order). To keep the transfer frame length constant (892 bytes), Idle Packets are generated to fill the M_PDU Packet Zone when there are not enough application Packets. The structure of the Idle Packet is shown in the previous Figure 4.

To keep the downlink data rate constant, when there are no Transfer Frame Data Field available for transmission at release time for a Transfer Frame, a Transfer Frame with a Data Field containing only Idle Data (pseudo random sequence pattern) is transmitted. Such a Transfer Frame is called an Idle Transfer Frame and it is transmitted with a specific VCID (see Table 3). The structure of the Idle Frame is shown in Figure 6.

A specific improved round robin arbiter is implemented for the DDB virtual channels. The arbiter is a normal round robin arbiter which keeps the priorities on each VC the same as long as no VC contains more than 3 Mbit of data content. Each VC filled with more than 3 Mbit of data will receive a higher priority. This ensures that the heterogeneous data rates of the instruments are handled in a way in which the DDB utilization time corresponds directly to the instrument data rate needs. Therefore, Packets are downlinked in the same order that they were sent from the instrument and received by the mass memory and formatting unit.

Satellite Name	Spacecraft identifier [hex]	Spacecraft identifier [bin]
MetOp-SG A1	0x003	0b 0000 0000 0011
MetOp-SG A2	0x01B	0b 0000 0001 1011
MetOp-SG A3	0x030	0b 0000 0011 0000
MetOp-SG B1	0x042	0b 0000 0100 0010
MetOp-SG B2	0x046	0b 0000 0100 0110
MetOp-SG B3	0x047	0b 0000 0100 0111

Table 2: Metop-SG satellite Spacecraft Identifiers (SCID)

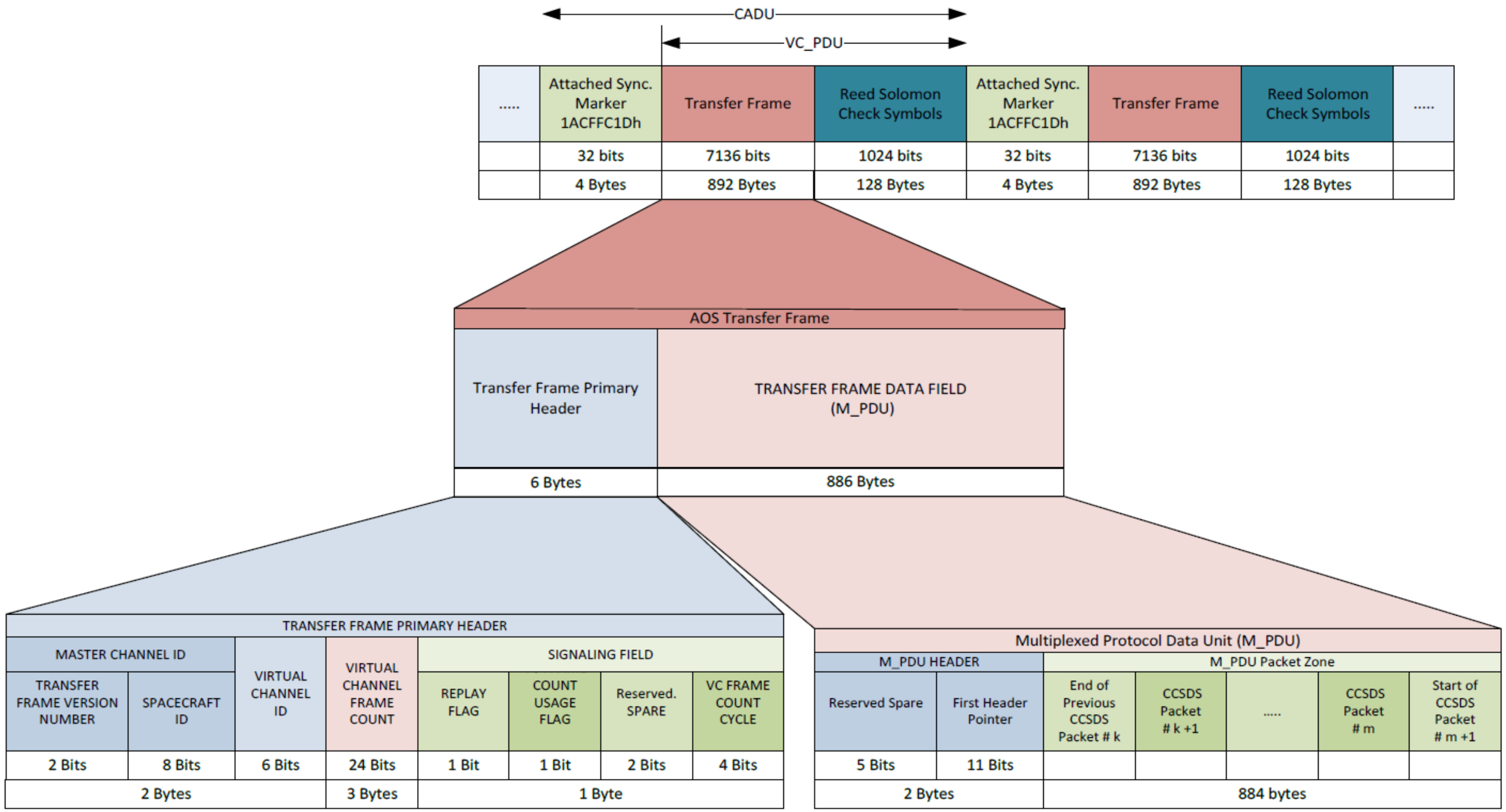

Figure 5: DDB Transfer Frame Structure

Idle Frame (spans ASM through Error Control)
VC_PDU (spans Transfer Frame Primary Header through Error Control)
Transfer Frame (spans Transfer Frame Primary Header through M_PDU)

ASM	TRANSFER FRAME PRIMARY HEADER								Multiplexed Protocol Data Unit (M_PDU)	Error Control
	MASTER CHANNEL ID				SIGNALING FIELD					
Attached Sync. Marker	TRANSFER FRAME VERSION NUMBER	SPACECRAFT ID	VIRTUAL CHANNEL ID	VIRTUAL CHANNEL FRAME COUNT	REPLAY FLAG	COUNT USAGE FLAG	Reserved. SPARE	VC FRAME COUNT CYCLE	Scrambled Idle Pattern	Frame Error Control Field
1ACFFC1Dh	01b	Fix value	3Fh	Counter	0b	0b	00b	0000b		
32 bits	2 Bits	8 Bits	6 Bits	24 Bits	1 Bit	1 Bit	2 Bits	4 Bits	7088 Bits	1024 bits
4 Bytes	2 Bytes			3 Bytes	1 Byte				886 Bytes	128 Bytes

Figure 6: DDB Idle Frame Structure

Data Content	PRID	CAT	VCID	Satellite
Platform and Instruments HK-TM Data: all BOOT software and Application Command & Control PRID's	0x00, 0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x029, 0x2F, 0x32, 0x35, 0x36, 0x3C, 0x3D, 0x43, 0x44, 0x4A, 0x4B, 0x51, 0x52, 0x58, 0x59	(1)	8	A & B
Platform Ancillary Data (NAVATT)	0x24	0x00	9	A & B
ADMIN DDB message (MMAM)	0x24	0x01	10	A & B
RO				
RO Science data	0x37	(2)	11	A & B
RO Calibration	0x38	(2)	11	
IASI-NG				
IASI-NG NSD data	0x3E	(2)	12	A
IASI-NG Check mode	0x3F	(2)	12	
MWS				
MWS Science data	0x45	(2)	13	A
MWS Calibration	0x46	(2)	13	
3MI				
3MI Science data	0x4C	(2)	14	A
3MI Calibration	0x4D	(2)	14	
Sentinel 5				
S5 Science data	0x53	(2)	15	A
S5 Calibration	0x54	(2)	15	
METImage				
METimage Science data	0x5A	(2)	16	A
METimage Calibration	0x5B	(2)	16	
SPARE				
Spare	0x5F	(2)	17	A
Spare	0x5F	(2)	22	B
Spare	0x3E	(2)	17	B
Spare	0x3F	(2)	17	B
MWI				
MWI Science data	0x45	(2)	18	B
MWI Calibration	0x46	(2)	18	
ADCS				
ADCS Science data	0x4C	(2)	19	B
ADCS Calibration	0x4D	(2)	19	
SCA				
SCA Science data	0x53	(2)	20	B
SCA Calibration	0x54	(2)	20	
ICI				
ICI Science data	0x5A	(2)	21	B
ICI Calibration	0x5B	(2)	21	
Idle				

Data Content	PRID	CAT	VCID	Satellite
Idle Packets	0x7F	F	-	A & B
Idle Frames	-	-	63	A & B

Table 3: Virtual Channels and PRID assignment for DDB

(1) CAT range [0...F], PRID generating commands or non-science telemetry, typically BOOT software and Application.
(2) CAT range [0…F], CAT are defined by the instrument provider and are individual for each instrument.

4.2.2.2 Synchronization and Channel Coding Sublayer

For the Synchronization and Channel Coding Sublayer, DDB uses ECSS Telemetry Synchronization and Channel Coding Standard (ECSS-E-ST-50-01C) [ND.3].

This standard provides the following functions, see Figure 8:

- Error Correction Scheme: Reed-Solomon Coding concatenated with the basic Convolutional Coding; this is using Reed-Solomon code as the outer code and the Convolutional code as the inner code;
- Pseudo-randomization: Cyclic Pseudo-noise Sequence;
- Frame Synchronization: Attached Synchronous Marker, ASM.

The data unit that consists of the ASM (4 bytes), the Transfer Frame (892 bytes) and the Reed-Solomon Check Symbols (128 bytes), is called the Channel Access Data Unit (CADU).

The complete length of the CADU is 1024 bytes. After the ASM insertion, the CADUs are convolutional encoded with rate = ½. The Figure 9 shows the DDB CADU structure.

4.2.2.2.1 Reed-Solomon Encoding

The transfer frame is protected by Reed-Solomon (R-S) Check Symbols in the Frame Error Control (FEC) Field.
The R-S (255,223) coding with E=16 is generated as specified in [ND.3] (chapter 6) with an interleaving depth of I = 4.

4.2.2.2.2 Pseudo-randomization

To ensure sufficient transitions a pseudo randomizer is applied as specified in the [ND.3] standard (chapter 9). The pseudo-randomization is performed in each CADU after RS encoding and before ASM attachment and convolutional encoding.

4.2.2.2.3 The Attached Sync Marker (ASM)

The attached synchronous marker is defined as follows (hexadecimal):
1ACFFC1Dh.

4.2.2.2.4 Convolutional Coding

The convolutional encoding is performed as specified in the [ND.3] standard (chapter 5.3) with a code rate = ½ bit per symbol and constraint length = 7 bits. The following Figure 7 shows the encoder block diagram according to the [ND.3] standard.

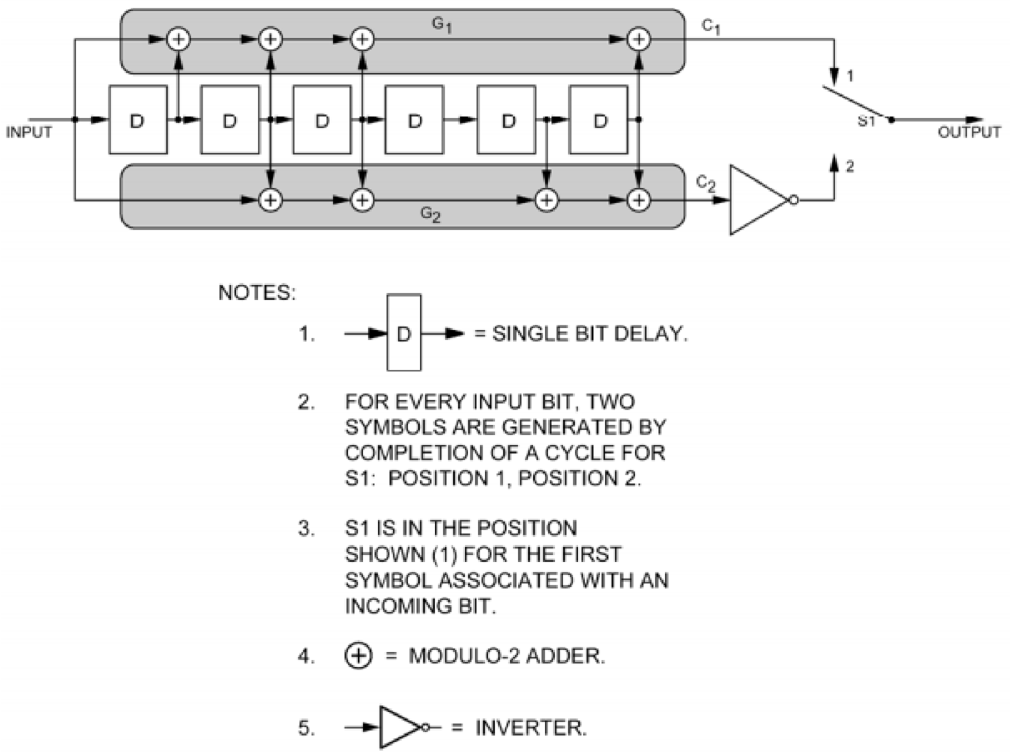

Figure 7: [ND.3] Convolutional encoder block diagram

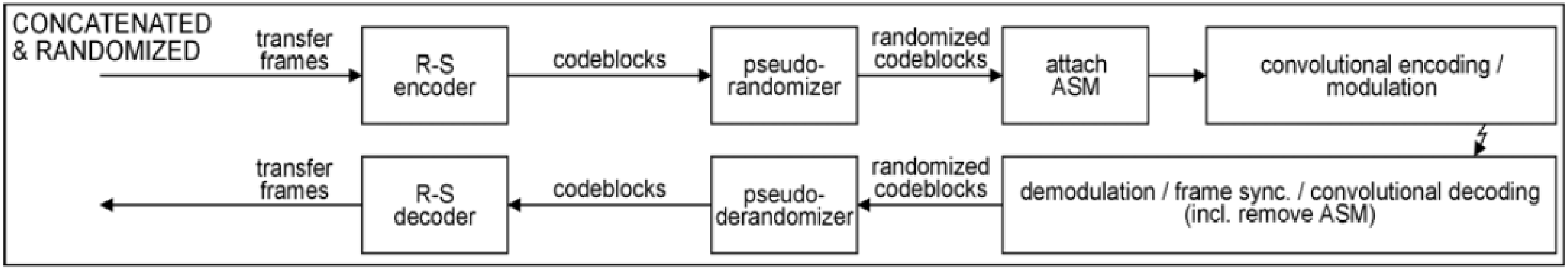

Figure 8: [ND.3] Coding, Randomization and Synchronization at the sending and receiving end

CADU
VC_PDU
Transfer Frame

ASM	TRANSFER FRAME PRIMARY HEADER								Multiplexed Protocol Data Unit (M_PDU)							Error Control
Attached Sync. Marker	MASTER CHANNEL ID		VIRTUAL CHANNEL ID	VIRTUAL CHANNEL FRAME COUNT	SIGNALING FIELD				M_PDU HEADER		M_PDU Packet Zone					Frame Error Control Field
	TRANSFER FRAME VERSION NUMBER	SPACECRAFT ID			REPLAY FLAG	COUNT USAGE FLAG	Reserved. SPARE	VC FRAME COUNT CYCLE	Reserved Spare	First Header Pointer	End of Previous CCSDS Packet # k	CCSDS Packet # k +1	.....	CCSDS Packet # m	Start of CCSDS Packet # m +1	
1ACFFC1Dh	01b	Fix value	variable	Counter	0b	0b	00b	0000b	00000b	calculated						
32 bits	2 Bits	8 Bits	6 Bits	24 Bits	1 Bit	1 Bit	2 Bits	4 Bits	5 Bits	11 Bits	variable	variable	variable	variable	variable	1024 bits
4 Bytes	2 Bytes			3 Bytes	1 Byte				2 Bytes		884 bytes					128 Bytes

Figure 9: DDB CADU structure

4.2.3 Physical Layer

The physical layer describes the radio frequency channel parameters. The DDB physical layer is implemented according to, and fulfilling the ECSS Radio Frequency and Modulation Standard (ECSS-ST-50-05C) [ND.4].

The DDB data is transmitted in the MetSat X band (7750-7900 MHz) with a downlink carrier frequency of 7.825 GHz and a occupied bandwidth (99 % of power) of less than 150 MHz.

The X band carried is modulated employing Hard keyed QPSK (no shaping filter) scheme and it is transmitted using RHCP circular polarization.

The DDB uses isoflux (Earth coverage) antenna on the satellite, with a cross polar isolation better than 12.9 dB over the coverage.

The satellite EIRP is of 24.6 dBW; this is considering the satellite antenna gain when the ground station antenna is at 5 degree elevation.

The DDB link is designed to guarantee a minimum of quality at ground reception of 10^{-6} Frame Error Rate (FER) under the conditions defined in Appendix B.

4.3 Summary DDB Characteristics

The following Table 4 summarises the physical layer parameters of the DDB downlink, it also includes coding parameters and data rate figures.

Parameter	MetOp-SG A	MetOp-SG B
Information Data Rate (Mbps) *Excluding formatting and coding*	80	23
Data Rate (Mbps) *Expanded width idle frames, excluding formatting and coding*	80	80
Downlink Data Rate (Mbps) *Including 2% formatting and coding*	186.6	186.6
PCM Code	NRZ-L	
Error Correction Coding	Concatenated coding (convolutional and Reed-Solomon coding with E=16)	
Pseudo randomizer	YES	
Modulation	QPSK	
Downlink Frequency (GHz)	7.825	
99 % Bandwidth Occupancy (MHz)	< 150	
EIRP (dBW)	24.6 (Note 1)	
Polarization	RHCP	
Cross polar isolation	≥ 12.9 dB (for $0° \leq \theta \leq 62°$)	
Satellite antenna axial ratio	< 4 dB	
Required Frame Error Rate	10^{-6}	

Table 4: Summary DDB characteristics

Note 1: Design value. It considers antenna gain at 62° from boresight which is the antenna point of view angle when the elevation is 5° to G/S (ground Station).

4.4 Instruments Data Rates

The following table provides the individual instruments data rate and the gross total information data rate for both satellites A and B.

[RD.2] The estimated DDB information data rate to be used for X band link dimensioning is the PEAK value required by Satellite-A in routine mode: **79.76 Mbps.** The Satellite-B DDB physical channel will have the same data rate as Satellite-A, therefore fill data will be transmitted together with the science data to fill the channel bandwidth.

ADMIN message data rate is not accounted in this budget because it is considered negligible. Margins are added to account for any possible data rate evolution.

MetOp-SG A Instruments Data Rate (Kbps)			
	DAY	NIGHT	PEAK
METImage	18	9	25
MWS	0.06	0.06	0.33
IASI-NG	6	6	7
3MI	7.8	0.1	9.88
RO	1.76	1.76	3.52
Sentinel-5	21.2	4.4	25
HKTM	0.055	0.055	0.055
Net total	54.87	21.37	70.78
Margin	6.96	2.71	8.98
Gross total	**61.83**	**24.08**	**79.76**
MetOp-SG B Instruments Data Rate (Kbps)			
SCA	13.2	13.2	13.2
MWI	2.2	2.2	2.42
ICI	0.55	0.55	0.55
RO	1.76	1.76	3.52
Argos-4	0.08	0.08	0.08
HKTM	0.053	0.053	0.053
Net total	17.84	17.84	19.82
Margin	2.68	2.68	2.97
Gross total	**20.52**	**20.52**	**22.8**

Table 5: [RD.2] MetOp-SG A and B instrument data rates

5 APPENDIX A: EARTH-COVERAGE ANTENNA PATTERN

This chapter presents the antenna gain radiation pattern of the DDB on-board X band antenna. The gain pattern corresponds to the standalone antenna and does not consider the distortions caused by the antenna's installation in the spacecraft.

The radiation pattern is presented for the minimum and maximum operation frequencies of the antenna. The RF power losses between the transmitting system and the antenna foot are not considered in the plots. The co over cross polarization discrimination plots are also included.

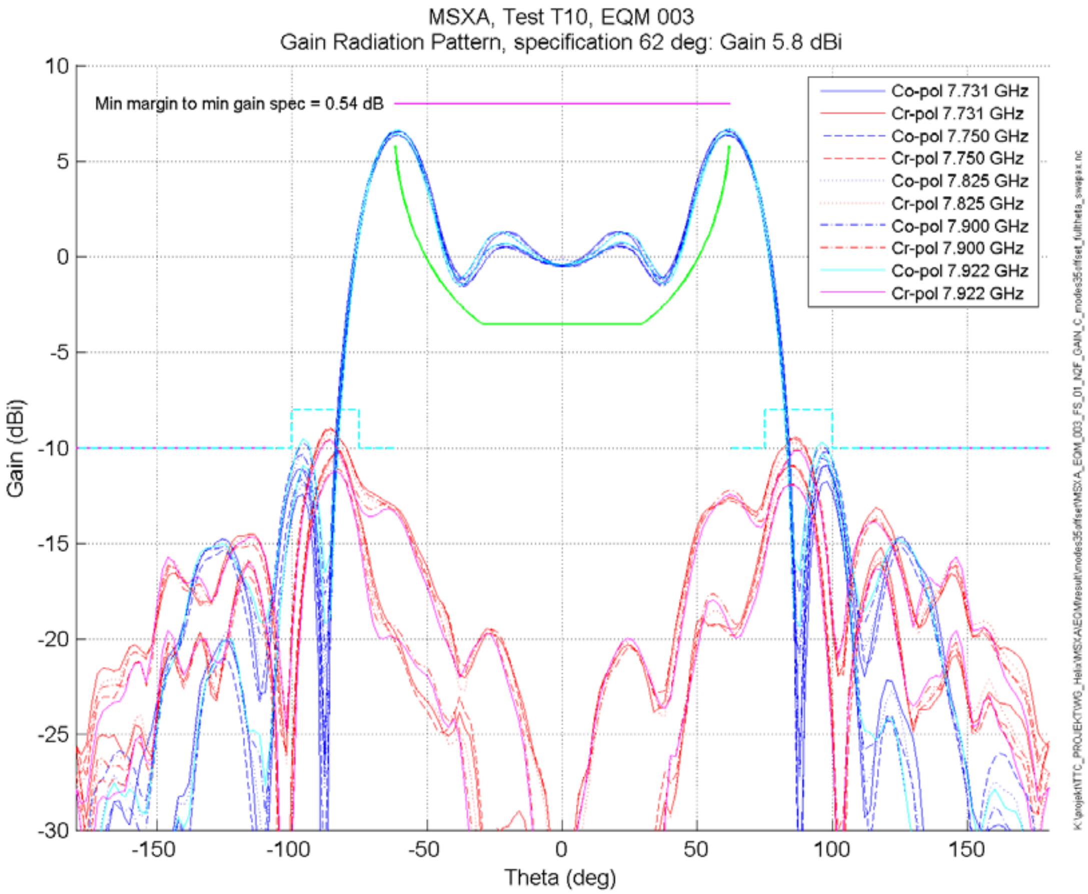

Figure 10: Co and Cross polarization X band antenna gain radiation pattern

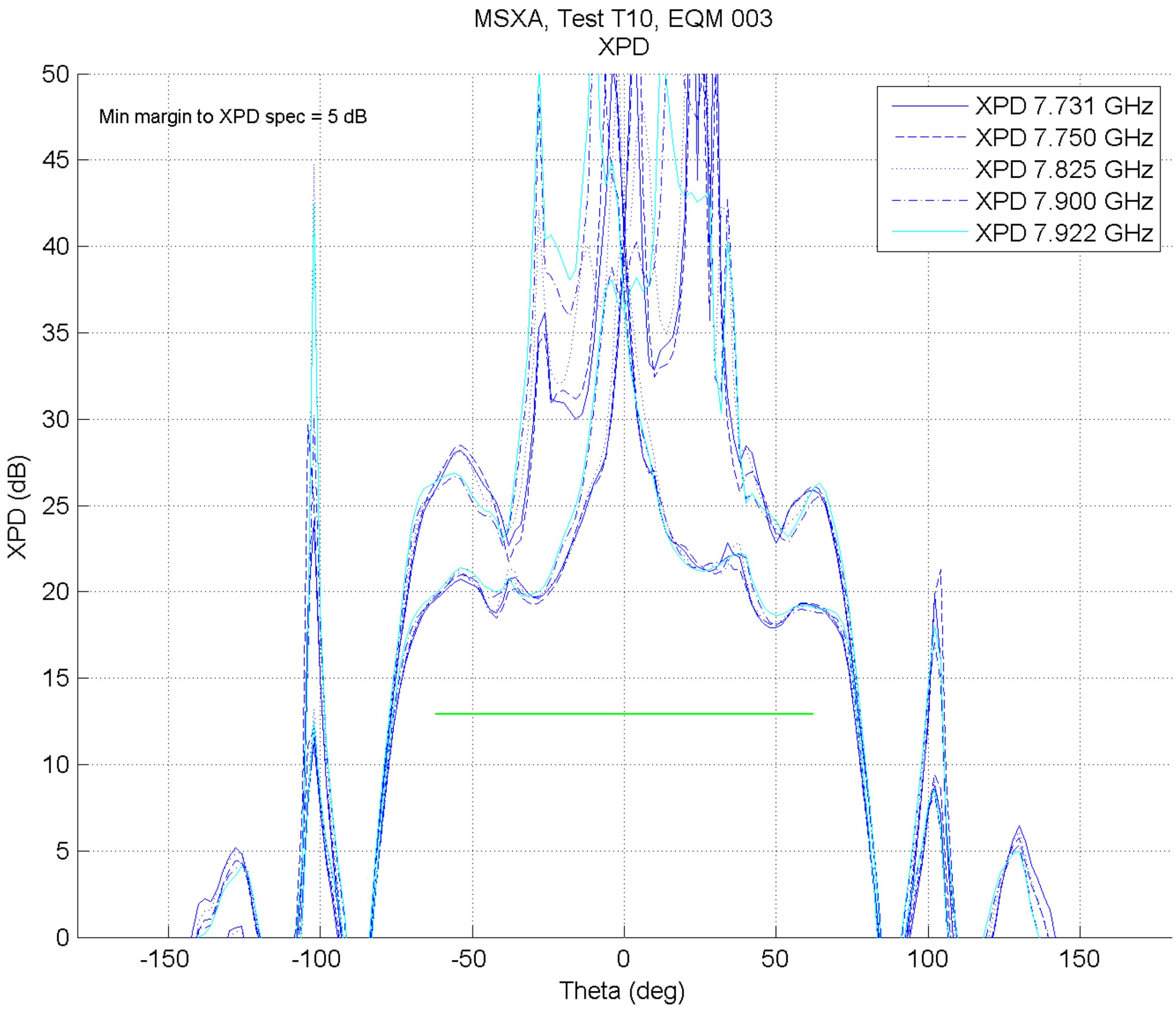

Figure 11: Co over Cross polarization discrimination X band antenna gain radiation pattern

6 APPENDIX B: RF LINK CALCULATIONS

The DDB X band communications link has been design to be compatible with worst case link budget for a ground station performance G/T (station gain over noise temperature ratio) of 22.7 dB/K defined at 5 deg. elevation and clear sky conditions.

The G/T degradation due to worst weather conditions (rain) and pointing losses has to be accounted in the link budget.

The link calculation presented in this section considers the ground station is located at Lannion (France), and atmospheric degradation have been computed accordingly using ITU models.

Local users will have to analyse the worst weather attenuation for their station location and choose the antenna implementation according to this.

The following Table 6 summarizes the worst case DDB link budget with a 5 deg field-of-view.

Key parameters for the nominal case are:

- Link quality FER: 10^{-6};
- Ground station reference location: Lannion (France);
- Carrier frequency: 7.825 GHz;
- Information data rate: 80 Mbps;
- Modulation: Hardkeyed QPSK;
- Coding: Concatenated coding (Reed-Solomon (255,223) + convolutional coding rate ½);
- TWTA RF output power: 98.40 W;
- S/C Antenna gain: 6.5 dBi at end of coverage, 5° (isoflux antenna);
- Resulting Power Flux Density margin: 9.04 dB;
- Requirement of link availability due to weather conditions: 99.9 % pass-averaged over year;
- Atmospheric attenuation incl. rain (99.9% link ava. pass-avg over a year): 2.8 dB;
- Ground station performance:
  - G/T at 5 deg. Elevation and clear sky weather conditions: 22.7 dB/K;
  - G/T degradation due to worst weather conditions: 2.2 dB losses;
  - Worst case antenna pointing: 1 dB.

Local DDB users will have to analyse the worst weather attenuation and their availability requirement for their station location and chose the antenna implementation according to this.

- Resulting link margin: 4.6 dB (3 dB required).

Link Budget EPS-SG: DDB - User Station at Lannion

	EPS-SG SPACE - EARTH: DDB - X BAND	Orbit Max Heigh (Km): 850 Weath. Ava (%): 99.90 Station location: Lannion		Modulation: HardKeyed QPSK Coding: RS(255/223)+Conv 1/2 Rb (Mb/s): 81.60		Link Budget ID: EPS-SG:DL-DDB-UserStation Revision: 6.0 Date: 22/08/2019
		UNITS	DESIGN VALUE	FAV VALUE	ADV VALUE	REMARKS
	S/C TRANSMITTING DATA CHANNEL					
1	Information Bit Rate	Mbit/s	80.00	80.00	80.00	Excluding formatting and coding
2	Bit rate including formatting	Mbit/s	81.60	81.60	81.60	2 % formatting
3	Transfer Frame Length	bits		7,136		CCSDS 130.1-G-2, table 6-1.
4	Required FER	bits		1.00E-06		
5	Coding Scheme			RS(255/223) + Conv 1/2		RS(255,223), I =4 + Conv (7, 1/2)
6	Code Rate			2.29		
7	Bit rate including Coding	Mbit/s	186.62	186.62	186.62	
8	Required Eb/No	dB	3.08	3.08	3.08	
9	Data Format			NRZ-L		
10	RF Carrier Modulation Scheme			HardKeyed QPSK		
11	Occupied Bandwidth	MHz	139.00	139.00	139.00	
	S/C TRANSMITTING RF CARRIER CHANNEL					
12	Transmitter Power	W	98.40	101.39	94.84	
13	Transmitter Power	dBW	19.93	20.06	19.77	
14	Transmitter Frequency	GHz		7.825		Signal center frequency
15	Antenna Circuit Loss	dB	1.85	1.85	2.20	
16	VSWR (overall)	:1	1.07	1.07	1.22	
17	VSWR Losses	dB	0.005	0.005	0.044	
18	Antenna Gain	dBi	6.50	6.50	5.80	
19	Antenna Axial Ratio	dB	1.29	1.29	4.00	
20	Effective Gain	dBi	4.65	4.65	3.56	
21	EIRP	dBW	24.58	24.71	23.33	
	SPACE -TO-EARTH-PATH					
22	E/S Antenna Elevation Angle	deg		5.00		
23	Slant Range	Km		2890.00		
24	Free Space Loss	dB	179.54	179.54	179.54	
25	Weather Availability (pass-avg. over a year)	%		99.90		
26	Atmospheric Model Uncertainty	%		25.00		
27	Station Location			Lannion (France)		
28	Atmospheric Loss	dB	2.88	2.88	3.85	Losses computed for a link availability due to weather conditions of 99.9% pass-averaged over a year, and considering Lannion as reference location
29	Polarisation Mismatch Loss	dB	0.07	0.07	0.23	
30	Total Propagation Loss	dB	182.49	182.49	183.61	
31	Power Flux Density at E/S	dBm/m^2	-85.63	-85.50	-86.88	
32	Power Flux Density at E/S	dBW/m^2	-115.63	-115.50	-116.88	
33	Power Flux Density in 4 KHz Bandwidth	$dBW/m^2/4KHz$	-161.04	-162.29	-160.91	
34	Power Flux Density in 4 KHz Bandwidth Limit	$dBW/m^2/4KHz$	-152.00	-152.00	-152.00	ITU PFD limit
35	**Power Flux Density Margin**	**dB**	**9.04**	**10.29**	**8.91**	
	E/S RECEIVING RF CARRIER CHANNEL					
36	E/S Receiving G/T	dB/K	22.70	22.70	22.70	G/T at 5 deg. antenna elevation and clear sky conditions
37	G/T degradation due to worst case weather conditions	dB	2.20	2.20	2.60	Losses computed for a link availability due to weather conditions of 99.9% pass-averaged over a year, and considering Lannion as reference location
37	Multipath Loss	dB	0.20	0.20	0.20	
38	Antenna Pointing Loss	dB	1.00	1.00	1.00	Expected worst case performance
39	**Received S/No**	**dBHz**	**90.00**	**90.12**	**87.22**	
	E/S RECEIVING DATA RECOVERY					
40	Demodulator Implementation Loss	dB	3.18	3.18	3.22	Includes TX distorsion, phase noise and receiver imperfections (2.5 at G/S Rx plus 0.72 dB for Tx)
41	Bit Rate with Formatting (excluding coding)	Mbits/s	81.60	81.60	81.60	Excluding coding
42	Bit Rate with Formatting (excluding coding)	dBHz	79.12	79.12	79.12	
43	Received Signal Eb/N_0	dB	7.70	7.82	4.88	
44	Required Eb/N_0 ($FER=10^{-6}$)	dB	3.08	3.08	3.08	Including decoder implementation losses
45	**Data Recovery Margin**	**dB**	**4.62**	**4.74**	**1.80**	Required Margin: Nom ≥ 3dB
46	Permisible level of external interference S/I	dB	18.07	18.07	19.52	RFI Computed ITU-R SA.1022 (Factor Q = 0.1)
47	Losses due to external interference	dB	0.46	0.47	0.18	RFI Computed ITU-R SA.1022 (Factor Q = 0.1)
48	**Telemetry Margin including RFI losses**	**dB**	**4.16**	**4.27**	**1.62**	Required Margin: Nom ≥ 3dB

Table 6: DDB link budget computation

7 APPENDIX C: ACRONYMS

ADMIN	Administrative Message
APID	Application Process Identifier
ASM	Attached Synchronous Marker
CADU	Channel Access Data Unit
CCB	Control Change Board
DDB	Direct Data Broadcast
EIRP	Equivalent Isotropic Radiated Power
EPS-SG	EUMETSAT Polar System -Second Generation
FEC	Frame Error Control
FER	Frame Error Rate
G/S	Ground Station
G/T	Station Gain over noise Temperature Ratio
HKTM	House Keeping Telemetry
ICD	Interface Control Document
MetOp	Meteorological operational satellite
MMAM	Multi Mission Administrative Messages
ND	Normative Document
OBC	On board Computer
OSI	Open System Interconnection
PCAT	Packet Category
PDU	Protocol Data Unit
PRID	Process Identifier
RD	Reference Document
RF	Radio Frequency
RHCP	Right Hand Circular Polarization
S/C	Space Craft
SMD	Stored Mission Data
TC	Telecommand
TM	Telemetry
TTC	Telemetry and Telecommand
VC	Victual Channel
VCID	Virtual Channel Identifier

Table 7: List of acronyms