Title

METOP SPACE TO GROUND INTERFACE SPECIFICATION

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Annex3	02										
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REFERENCE DOCUMENTS

ESA DOCUMENTS

RD ESA1	Metop Satellite to Ground Segment Interface Requirements MO-IS-ESA-SY-0025
RD ESA2	Packet Utilisation Standard ESA-PSS-07-101
RD ESA3	Telemetry channel coding standard ESA-PSS-04-103 (Issue 1 September 89)
RD ESA4	Ranging standard ESA-PSS-04-104 (Issue 2 March 91)
RD ESA5	Radio frequency and modulation standard ESA-PSS-04-105 (Issue 1 December 89)
RD ESA6	Packet Telemetry standard ESA-PSS-04-106 (Issue 1 January 88)
RD ESA7	Packet Telecommand standard ESA-PSS-04-107 (Issue April 92)
RD ESA8	Telecommand Decoder Specification ESA-PSS-04-151 (Issue 1 September 93)

CCSDS DOCUMENTS

RD CCSDS1	CCSDS - Advanced Orbiting Systems Network and Data Links Architectural Specification CCSDS 701.0-B-2 (Blue Book Nov 92)
RD CCSDS2	CCSDS - Time codes formats CCSDS 301.0-B-2 (Blue book April 90)
RD CCSDS3	CCSDS - Packet Telemetry CCSDS 102.0-B-3 (Blue book Nov 92)
RD CCSDS4	CCSDS - TM channel coding CCSDS 101.0-B-3 (Blue book May 92)

EUMETSAT DOCUMENTS

RD EUM1	HRPT/LRPT direct broadcast services Specification MO-DS-ESA-SY0048 or EPS/SYS/SPE/95413
RD EUM2	Encryption System Specification EPS/SYS/SPE/95424 MO-DS-ESA-SY-0049
RD EUM3	S&R , DCS System Specification MO-RS-ESA-IN-0087 Draft 1 October 96

REFERENCE DOCUMENTS (Cont'd)

MMS DOCUMENTS

RD MMS1	Environment Specification MO-RS-MMT-SY.0002
RD MMS2	LEOP sequence criticalities MO-TN-MMT-SY.0024
RD MMS3	Metop S Band link budgets (SRR version) MO-NT-MMT-SY-0012
RD MMS4	Metop X Band link budgets (SRR version) MO-RP-DOR-PM-0015
RD MMS5	User Manual Vol TBD "TMTC list" Ref TBD
RD MMS6	Central Flight Software Description MO-TN-00000.0004-MMT
RD MMS7	EDR Specification MO-RS-MMT-SV.0008
RD MMS8	CCU SW TC reception implementation MO-RS-MMT-SY.0011
RD MMS9	Space to ground Standard communications procedures MO-NT-MMT-SY.0043
RD MMS10	Metop Communication Scenarii Analysis MO-NT-MMT-SY.0035
RD MMS11	Compliance Matrix to PSS-04-105 MO-LI-MMS-SY.0009
RD MMS12	SVM TMTC Data Definition ICD MO-IF-MMT- SV.0003
RD MMS14	Detailed European Instrument Source Packet Layout To be provided later
RD MMS15	Detailed NOAA Instrument Source Packet Layout To be provided later
RD MMS17	Content of the EDR Recovery LAC at Power on. MO-NT-MMT-SV-0024 & Fax MO-FX-MMT-0097-97

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ANNEXES

1 INTRODUCTION

1.1 SCOPE AND PURPOSE

The purpose of this document is to specify the interfaces between the METOP satellite and the dedicated EPS ground segment. Within the Metop project, a strong emphasis has been put upon space segment heritage re-use. Therefore, because it belongs to the Mark III family, Metop, and in particular the Service Module, is not fully compatible with the CCSDS standards and the set of ESA PSS specifications. Moreover, these standards are generic and include a lot of requirements which are not applicable to Metop. Consequently, the Metop Space to Ground Interface Specification shall be a self-content specification gathering all the necessary requirements.

In the METOP mission, the data streams are the following :

- Global Data Stream : overall SVM, PLM and payload instruments data on X Band direct to the ground station,
- High Resolution Picture Transmission (HRPT) Data direct broadcast on L Band to meteorological local users ground stations but also to the EPS ground segment,
- Low Resolution Picture Transmission (LRPT) Data direct broadcast on VHF Band to meteorological local users ground stations but also to the EPS ground segment,
- Satellite Command and Monitoring Data with :
  - Omni-directional TT&C up and down link on S Band directly from/to ground stations.
  - up and down ranging links which support range and range-rate measurements.

In addition, the payload provides the following links :

- Uplink on VHF Band from Data Collection transmitters towards the CRA antenna for A-DCS,
- Direct broadcast on VHF Band from the advanced DCS instrument, via the DTA antenna, to the Argos centers
- Uplink on VHF Band from Search and Rescue beacons towards the CRA antenna,
- Direct broadcast on L Band via the SLA antenna to Search and Rescue reception ground stations.

The present document only addresses the S band and the X band Space to ground interfaces, which are specified at different levels, from radio frequency level until logical exchanged data level.

The HRPT/LRPT broadcast services and the Search & Rescue and Advanced DCS links are specified in dedicated documents (RD EUM1 and RD EUM3) under ESA/Eumetsat joint responsibility. Such a specific document also addresses the Encryption aspects (RD EUM2).

1.2 DOCUMENT STRUCTURE

This document is structured as follows:

A brief overview of the Metop system is provided in paragraph 2 while paragraph 3 focuses over the characteristics of the ground stations involved in the S and X band links.

Paragraph 4 defines the Service module space to ground interfaces which include telecommand, telemetry and ranging links.

The Global data stream , i.e the X Band link is described in paragraph 5.

Requirements driven by the on-board time/ground time synchronisation methodology are presented in paragraph 6.

At last, specific operational requirements are described in paragraph 7 while constraints related to the compatibility tests (performed on ground) are described in paragraph 8.

The structure of the telemetry, the telecommands and the different kind of tables which may be downlinked to the ground upon request are presented in separated dedicated documents: RD MMS12 for the SVM and RD MMS13 for the PLM. The detailed layout of the instruments source packet application data fields is presented in RD MMS 14 for the European instruments and in RD MMS 15 for the NOAA instruments.

All remaining details are part of the Metop Reference Database. Bit conventions are recalled in annex 1, rules for the Protection of Deep Space and Radio Astronomy are available in annex 2 and a summary table of all the TBD's and TBC's is presented in the annex 3.

Note that a more detailed description of some ESA Space to Ground procedures as defined by the PSS standards is provided in a separate technical note (RD MMS9). This note is not a specification, its purpose being purely practical. Any update of the standards supersedes its content.

The link budgets are also provided in separate technical (RD MMS3 and RD MMS4).

2 GENERAL DESCRIPTION OF THE METOP SYSTEM

2.1 THE MISSION

Metop is flying a sun-synchronous orbit whose altitude is about 820 km which makes a little more than 14 revolutions per day. The precise orbital parameters are provided in the environment specification (RD MMS1). Thanks to the on-board storage capacity (SSR) and the X Band reception stations visibility profile (Kiruna and Fairbanks, as a baseline), the Global Mission Data acquired over one orbit can be dumped often enough so that the data are dumped no later than 1 orbit after recording.

2.2 THE METOP SATELLITE

2.2.1 Generalities

The platform is sub-structured in 2 major modules :

- the Service Module (SVM) in charge of attitude and orbit control, telecommand and control link with the ground S Band, monitoring and control, power generation, energy storage and power distribution, interfaces with the launcher.
- the Payload Module (PLM) is a self-contained entity which can be designed and tested as a separate element, in parallel to the SVM. Its configuration is tailored in order to accommodate the instruments within their specific constraints. It also provides the following functions : payload level command distribution, monitoring and control, electrical distribution, thermal control, instruments data processing, global data on-board storage, X Band, LRPT and HRPT communication links.

The satellite data Management System is composed of:

- a TTC function permitting a direct and omni-directional link from and to ground station, for telecommanding, housekeeping telemetry and ranging.
- a command and control subsystem under the responsibility of the SVM Central Computer Unit (CCU) only which interfaces with the PLM Management Computer (PMC).

The current Mark II and Mark IIP design undoubtedly suits Metop needs w.r.t on-board communication capacity, programming and software capacity. Nevertheless, some modifications have been implemented in order to satisfy most of the PSS communication standards and provide packet telecommands and telemetry.

2.2.2 Telemetry routing :

The SVM housekeeping data is provided to the ground, through the S Band housekeeping telemetry via one unique packet elaborated by the CCU.

The CCU acquires HK data from the SVM subsystems via the SVM OBDH bus. It then merge these data with those acquired from the PMC and generates the complete S Band frame which is sent to the S band transponder for down-link. The same S Band frame is also sent to the PMC using the Level 3 protocole, for recording on the SSR together with payload measurement data.

The PMC acquires housekeeping data from PLM subsystems and instruments ICUs via the PLM OBDH bus for :

- delivery to the SVM CCU for direct downlink to ground via S Band ,
- delivery to the SVM CCU which forwards back the complete satellite HK information data, to the PMC for storage in the SSR and transmission with the Global X Band Data Stream and the LRPT/HRPT direct broadcast links.

INSTRUMENT	GLOBAL DATA STREAM	LRPT	HRPT
AVHRR/3 HR	YES	NO	YES
AVHRR/3 LR	YES	YES	NO
AMSUA1	YES	YES	YES
AMSUA2	YES	YES	YES
HIRS/4	YES	YES	YES
DCS/2	YES	NO	YES
SEM	YES	YES	YES
ASCAT	YES	NO	YES
GRAS sounder	YES	NO	YES
IASI	YES	NO	YES
MHS	YES	YES	YES
GOME	YES	NO	YES
GRAS position	YES	YES	YES
SL packet (SL HK + filler data)	YES	YES	YES
Admin messages	YES	YES	YES

TABLE 2.2/1 : PAYLOAD DATA VS DOWNLINK STREAM

The fact that a set of AOCS ancillary data was previously transmitted to the PMC by the CCU is an Envisat heritage but these data are not actually needed by the Metop instruments. So this capability is no more used. Hence, in order to minimise the design modification, the PMC still receives a set of so-called "AOCS ancillary data" whose content is zero's but does not use them. In particular, they are not acquired by any ICU for inclusion in the Ancillary data field of the instruments source packets.

The table 2.2/1 presents the set of information downlinked via the different links.

The instrument ICU's themselves acquire the HK data from the instruments and format them for transfer to the PMC via the PLM OBDH bus. To acquire of these data, the PMC uses the same interfaces as those used for transferring MCMDs to the instrument ICU's.

All HK data acquired by the PMC are transmitted to the CCU in "TM data packets" via the SVM OBDH on a 1 Hz exchange basis following the Level 3 Protocol standard.

Instruments Measurement Data are acquired from the instrument ICU's (including the NIU ICU) under the form of CCSDS instrument source packets. Packetisation is done at instrument level for the European instruments and by the NOAA Interface Unit (NIU) for the American instruments. The NIU is also in charge of the AVHRR data compression for LRPT.

The **Payload Data Handling Subsystem** buffers, formats (according to CCSDS standards) and multiplexes these data onto Coded Virtual Channel Data Units (CVCDU) under the responsibility of the Formatting and Multiplexing Unit (FMU) for:

- direct downlink through the HRPT and the LRPT link (subset of the Payload Measurement Data together with the housekeeping data) to meteorological local users ground stations,
- storage in the SSR and downlink via the X Band Global Data Stream (all the payload measurement data and the SVM, PLM and instruments housekeeping data).

The PMC provides a function for the encryption of the data field of selectable VCDUs for the HRPT and LRPT data streams. An encryption function is inserted into each data stream (LRPT, HRPT-Q, HRPT-I) and the encryption scheme is updated according to encryption keys up-linked from ground.

All instruments operate continuously over the orbit. The PLM manages the meteorological instruments, the climatology instruments and GRAS (GPS/Glonass Receiver for Atmospheric Sounding). Note that S&R data are transmitted via a separated link using a dedicated antenna.

2.2.3 Telecommand routing

The command link uses the S Band uplink and a 2 Kbps transmission rate. Packet telecommands are all received at SVM level by the EDR and forwarded to the CPDU or the CCU. Packets telecommands received by the CCU can be executed within the SVM or forwarded to the PMC via the SVM OBDH bus. The CCU performs no control nor change to the commands forwarded to the PMC.

A telecommand packet may therefore contain only CPDU commands or commands addressed to the CCU, which are called TCH.

These TCH may be functionally dedicated to:

- SVM programmation,
- Individual software data loading (previous TCH according to SPOT terminology),
- actions by-passing the CCU interpretation before execution:
  - OBDH interrogation and DHSA registers load actions (previous TCi and TCx according to SPOT terminology)
  - Patch TCH
- PLM programmation.

This is illustrated on figure 2.2/2 and detailed herebelow.

CPDU commands

CPDU commands are direct packet telecommands (previous DTC) for direct execution by the EDR. All CPDU commands are executed immediately.

SVM Programmation TCH (so called "global TCH")

This TCH is interpreted by the CCU and is able to include several *individual software data load TCHs* and *OBDH interrogation and registers load TCHs*. It can be for immediate or time-tagged execution.

Individual Software Data Load TCHs

These TCH are interpreted by the CCU and may consist in CCU data loading but also in actions upon the other equipments. Note that the PMC is switched ON/OFF by the ground via a SVM M/L command. Some memory load commands addressed to the CFS can not be time-tagged if not planned beforehand, at TC definition level. The CCU memory loads commands addressed to the LVPROM cannot be time-tagged.

Examples of such TCH are : MCO orbit control TCH, Patch TCH, CFS mode change TCH, transmitter switch ON/OFF TCH...

TCH by-passing the CCU interpretation:

- **SVM OBDH interrogation and DHSA register Load TCH**

  This TCH contains a sequence of "operations" which may be OBDH interrogations, DHSA register loads, controls or delays. It is not interpreted by the CCU before execution.

  OBDH interrogations are transmitted to the SVM OBDH bus for immediate execution within the SVM. They may consist in acquisitions or commands.

  DHSA Registers operations are used at CCU level for on-board H/W registers loading.

  This TCH can be immediate or time-tagged when executed by the CFS. It is for immediate execution only when processed by the LVPROM.

- **Patch TCH**

  This TCH permits to load data within the memories without preliminary interpretation by the CCU.

PLM programmation TCH

This TCH contains a sequence of PLM macro-commands (MCMD) meant to control the PLM avionics and the instruments. They are transferred from the CCU to the PMC via a dedicated protocol (different from CCSDS) called : OBDH level 3 protocol.

All macrocommands can be executed immediately(IM-MCMD) or in time-tag (TT-MCMD).

Macro-commands are forwarded from :

- the PMC towards the PLM avionics,
- the PMC towards the instruments via the ICU's.

The macrocommands sent to the PLM avionics are **Low Level Protocol commands** going through the PLM OBDH bus. Those received by the instruments ICU's (including the NIU ICU) are **High Level Protocol** commands.

2.3 MONITORING AND CONTROL CONCEPT

2.3.1 Overview

The satellite is designed to manage autonomously "short-term" activities such as equipment switching and error recovery by the on-board software. "Long-term" activities, for instance, AOCS ephemeris updating, payload activity plan loading and fine failure analysis, are under ground operations. This concept limits the on-board software complexity and allows the ground to maintain complete control of the satellite while relieving the ground control centre from intensive low-level operations.

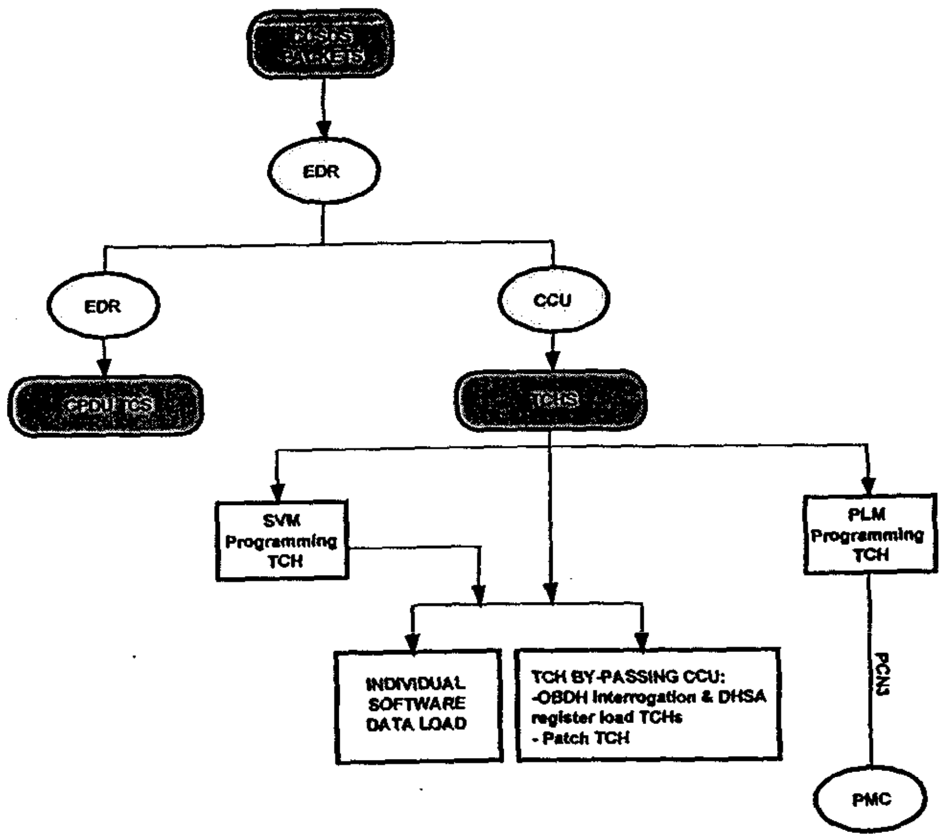

FIGURE 2.2/2 : PACKET TELECOMMAND ROUTING

To achieve this the satellite permits pre-programming of nominal operations for up to 36 hours, by up-linking from ground a set of time-tagged CCSDS packets commands which, as a sequence, control all operations in orbit.

It is the responsibility of the ground to ensure that the uplinked commands are compliant with the satellite's energy and thermal capabilities and all the operational constraints defined in the Satellite's User's Manual. If a fault inducing a transitory switch to the CFS MTDP mode (Mode de Traitement de Panne) is detected on-board, all the time-tagged buffers are reset. They are also reset if the ground send a PU SET or RESET CPDU command. Depending on the anomaly, automatic reconfiguration may occur to put the satellite in a safe state and operations are suspended until further ground commands are sent.

Failure detection isolation and recovery is also shared between the satellite and ground. The satellite undertakes actions to detect and recover from the failures which have short term effects, whereas the ground performs the same functions for the failures which have long term effects.

2.3.2 Ground Operations

Ground monitoring and control shall be performed using the direct to ground S Band links. The major ground operations relating to monitoring and control are :

- acquisition and evaluation of real time and report formats during each coverage,
- acquisition of test and dump formats in failure cases,
- correlation of on-board time to ground related time,
- ranging of the satellite orbit, prediction of following orbits and restitution of the recent orbits,
- generation and uplink of time-tagged packet commands,
- generation and uplink of predicted orbit information,
- in failure cases the ground may have to control the satellite through single commands which are immediately and directly distributed on-board without software control.

In addition acquisition and evaluation of replayed housekeeping data may be performed on the ground as a support to satellite monitoring and control.

The S Band ground station specified for use in the routine phase is the Eumetsat dedicated northern latitude station, assumed to be located in Kiruna. The satellite shall be nominally controlled during the routine phase from only one station (Kiruna). Fairbanks is nominally only used for downlinking X Band data.

The following typical nominal operation sequence shall be applied during a pass over the nominal TT&C station, i.e Kiruna (baseline) :

- acquire and track carrier,
- synchronise on S Band frame,
- receive and monitor several real time frames, evaluate if the satellite parameters are as expected, and correlate off line on-board to ground related time,
- send commands to request CCU, PMC and ICU reports information in the S Band frame variable part,
- receive and monitor CCU, PMC and ICU report information and confirm whether histories are as expected,
- continue to receive and monitor real time frames while:
  - sending commands to reset on-board history areas,
  - sending the payload operation profile in the form of packets commands containing PLM macro-commands and verify from the telemetry they have been received correctly,
  - sending packet commands to control the platform and verify from the telemetry they have been received correctly.

Ranging shall normally also be done by the Kiruna ground station and will be used for orbit prediction and restitution.

S Band ranging shall generally be performed in those parts of ground station passes not required for telecommanding although simultaneous ranging and commanding shall be possible.

3 GROUND SEGMENT CHARACTERISTICS

3.1 OVERVIEW

The EPS ground segment concept (architecture and operations) specification lies under Eumetsat responsibility. Therefore, detailed information can be found in Eumetsat documentation not part of the Metop satellite project documentation.

The EPS ground segment comprises a high northern latitude main PCDA (Polar Command and Data Acquisition) station for HK TM acquisition, TC uplink and ranging during the nominal mission phases. Another PCDA station is also in charge of acquiring the Global stream of data dumped from the SSR. The PCDA stations are complemented locally by LRPT/HRPT ground stations.

In addition, the NOAA ground station of Fairbanks can also perform Metop monitoring and control and acquire the global measurement data which cannot be dumped over the european PCDA station.

During the LEOP or in contingency conditions, the routine PCDA stations will be complemented by an additional network in order to ensure a larger coverage.

3.2 TT&C STATIONS

Table 3.2/1 summarises the characteristics of the stations to be used during the LEOP and the routine phase. Note that the term *Horizon for AOS* defines the earliest geometrical possibility for Acquisition of Signal. The term *Horizon for LOS* defines the latest geometrical possibility for transmission before Loss Of Signal. For stations located in a mountainous area, such as Svalbard and Fairbanks, the horizon for AOS may be well over 5° for some particular azimuth ranges, as defined in figure 3.2/2 and table 3.2/3.

3.2.1 LEOP network :

At this stage of the project, the philosophy for the choice of the LEOP network is to remain as close as possible to the ERS2 one, provided some stations may be used in priority by CNES in case of a dual launch with SPOT5, and then have to be replaced. Another working hypothesis is that stations previously used for Spot3 will be re-used for Spot5.

The LEOP network is therefore composed of a set of baseline stations which may be completed by additional ones if needed :

- Eumetsat dedicated northern latitude station considered to be located in Kiruna in the frame of phase B studies (Kiruna site also used for Spot5)
- Svalbard
- Kourou (several S Band stations available => site also used for Spot5)
- Wallops (several S Band stations available => site also used for Spot5)

- Villafranca (used for ERS2 but not for Spot3)
- Poker Flats (used for ERS2 but not for Spot3)
- Perth (used for ERS2 and but for Spot3)
- Santiago de Chile (if needed)
- Okinawa (if needed)
- Cuiaba (if needed)
- Mauritius (if needed)
- Carnicobar (if needed)
- Godstone (if needed for coverage over southern - may be required for the SPOT5 LEOP with higher priority).

After the first (TBC) day of LEOP, if everything is nominal, this network will be reduced to a sub-set of stations still TBD for the next TBD days.

STATION	HORIZON FOR AOS	HORIZON FOR LOS	ALTITUDE (M)	LATITUDE (°)	LONGITUDE (°)
LEOP					
Kiruna	5° elev.	5° elev.	352 m	67.857 N	20.964 E
Svalbard	see routine network				
Kourou	5° elev.	5° elev.	0 m	5.3 N	52.8 W
Wallops	5° elev.	5° elev.	0 m	37.9 N	75.5 W
Villafranca	5° elev.	5° elev.	0 m	40.5 N	4.1 W
Poker Flats or other	5° elev.	5° elev.	0 m	65.12 N	147.47 W
Perth	5° elev.	5° elev.	0 m	31.8 S	115.8 E
Santiago de Chile	TBD by ESA				
Okinawa	TBD by ESA				
Cuiaba	TBD by ESA				
Mauritius	TBD by ESA				
Carnicobar	TBD by ESA				
Goldstone	5° elev.	5° elev.	0 m	35.3 N	116.9 W
ROUTINE					
Kiruna	5° elev.	5° elev.	352 m	67.857 N	20.964 E
Tromsö	5° elev.	5° elev.	0 m	69.5° N	19.00 °E
Fairbanks	see table 3.2/2 & 4	see table 3.2/2 & 4	300 m	64.97°N	147.52°W
Svalbard Mine 7	see table 3.2/3 & 4	see table 3.2/3 & 4	0 m	78°13'27" N	15°22'27"E

TABLE 3.2/1 : METOP Ground S tations Characteristics

AZIMUTH (°)	ELEVATION (°)	AZIMUTH (°)	ELEVATION (°)
0 (= North)	15	175	16
5	14	180	16,6
10	11,2	190	13
12	8,8	195	9,5
20	8,8	205	8,3
30	8,5	210	7,1
40	8,2	220	7,1
50	7,6	230	6,5
60	5,3	240	4,7
70	4,7	250	3,6
80	4,1	260	2,4
90	3,5	270	3,6
100	4,7	280	4,7
110	5,9	290	5,3
120	7,1	300	5
130	8,3	310	5,3
140	8,3	320	6,5
150	8,3	330	7,7
160	8,6	340	8,3
166	9,5	347	9,5
170	13,6	350	11,8

Fairbanks horizon shall be taken as the maximum value between 5° and the elevation above.

TABLE 3.2/2 : Fairbanks Orographic data

Azimuth (°)	Elevation (°)	Azimuth (°)	Elevation (°)
0 (north)	< 3.0	165	6.8
30	< 3.0	170	5.8
60	< 3.0	175	4.7
90	< 3.0	180	3.3
120	< 3.0	190	< 3.0
130	< 3.0	210	< 3.0
140	< 3.0	240	< 3.0
150	4.5	270	< 3.0
155	5.5	300	< 3.0
160	5.8	330	< 3.0

Svalbard horizon shall be taken as the maximum value between 5° and the elevation presented above.
Note that the phase B sizing analysis have been performed with an elevation profile provided by ESA and which was much worse than this one. This profile has been updated by ESA/EUM for the phase CD proposal.

TABLE 3.2/3 : SVALBARD Mine 7 Horizon

3.2.2 Routine network

Three routine networks shall be considered:

- Kiruna + Fairbanks as a nominal pair of reception stations
- Tromsö + Fairbanks as another nominal pair of reception stations
- Svalbard alone as an option.

For a nominal set of stations, the on-board design shall be such that data can be downlinked no later than 1 orbit after recording.

For the optional case, i.e Svalbard alone, it is accepted to delay the dump of some data recorded by more than one orbit, if necessary.

In other words, the nominal cases are the sizing parameters for the determination of the SSR Maximum User Capacity and the necessary X Band rate.

In order to account for signal synchronisation, acquisition preamble, SSR data access time and margin, the data transmission shall start and stop as specified in the table 3.2/4 below.

STATIONS	KIRUNA TROMSØ	SVALBARD FAIRBANKS
DATA TRANSMISSION START	AOS (horizon of table 3.2/1, i.e 5° el) + 5 seconds (signal synchronisation) + 1 second (preamble) + 1 second (SSR data access time)	AOS (horizon of table 3.2/2 or 3) + 5 seconds (signal synchronisation) + 1 second (preamble) + 1 second (SSR data access time) + 0.5° elevation (margin)
DATA TRANSMISSION END	LOS (LOS horizon of table 3.2/1 i.e 5° el)	LOS (LOS horizon of table 3.2/1, i.e 5° el) + 0.5° elevation (margin)

TABLE 3.2/4: Data transmission end/start

3.2.3 Emergency network

A network similar to the LEOP one may be used in case of emergency necessitating an extended coverage (TBC). An on-call contract with a CNES station is also being studied by ESA/Eumetsat (still TBD).

The phase B assumption is that, in case of contingency, more than 10 minutes continuous coverage will be provided.

3.3 VISIBILITY PROFILES

The coverage provided by the baseline LEOP network is presented in RD MMS 2 (LEOP sequence criticalities).

The complete analysis of the communication scenarii during the drift and the routine phases is provided in RD MMS10.

4 SERVICE MODULE SPACE TO GROUND INTERFACES

4.1 TELECOMMAND

4.1.1 Overview

The METOP packet telecommand system shall be organised in a set of 5 independent layers described in details in the following paragraphs. An overview of the layers and of the services they offer is presented in figure 4.1.1/1. For a set of data issued from the ground, they are chronologically: the packetisation layer, the segmentation layer, the transfer layer, the coding layer and the physical layer. Figure 4.1.1/2 presents a summary of the different protocols units structure.

4.1.2 Packetisation layer description

The system shall allow the user to optimise the size and structure of his application data set with a minimum of constraints imposed by the ground-to-spacecraft communication system. The protocol data unit which makes this independence possible is the **Telecommand Packet**. User data are encapsulated within the packet by pre-fixing them with a standard label (the Packet Header) and attaching at the end an Error Control Field, so that end-to-end transport services of the packetisation layer can be provided (i.e application process identification, sequencing, error detection...).

4.1.2.1 TC Packet structure

The TC packet format structure is presented in the figure 4.1.2/1 below. It is composed of two major fields : the Packet Header (6 octets) and the Packet Data Field (at most 16384 bits i.e 1024 words among which 1022 are useful data-1).

PACKET HEADER							PACKET DATA FIELD		
Packet Identification				Packet Sequence Control		Packet length	Data field header	Appli. data	Packet Error Control
Version Number	Type	Data field header flag	Applic. process ID	Sequ. Flag	Packet Name		Not for CPDU TC		
3 bits	1 bit	1 bit	11 bits	2 bits	14 bits	16 bits	16 bits	at most 1022 wd	16 bits
000	1	0 or 1	01h, 08h or 09h	11	VAR	VAR	VAR	VAR	VAR

FIGURE 4.1.2/1 : TC Packet Structure

The minimum TC packet length is 8 octets (no Data Field Header nor Application Data) and its maximum length is 1027 words (2054 octets).

1 Previously, the Application data field was limited to 252 words, which was sufficient to cover the CPDU, PLM and SVM programming TCH needs. In fact, there is no reason to constrain ourselves to such a small data field, when new commands may highly benefit of a larger one. Hence, after having submitted this idea to ESA/EUM, MMS has reflected this in the Space to ground Interface Specification. The maximum data field size is now 1022 words. Nevertheless the application data field for PLM programming TCH still remains at 252 words.

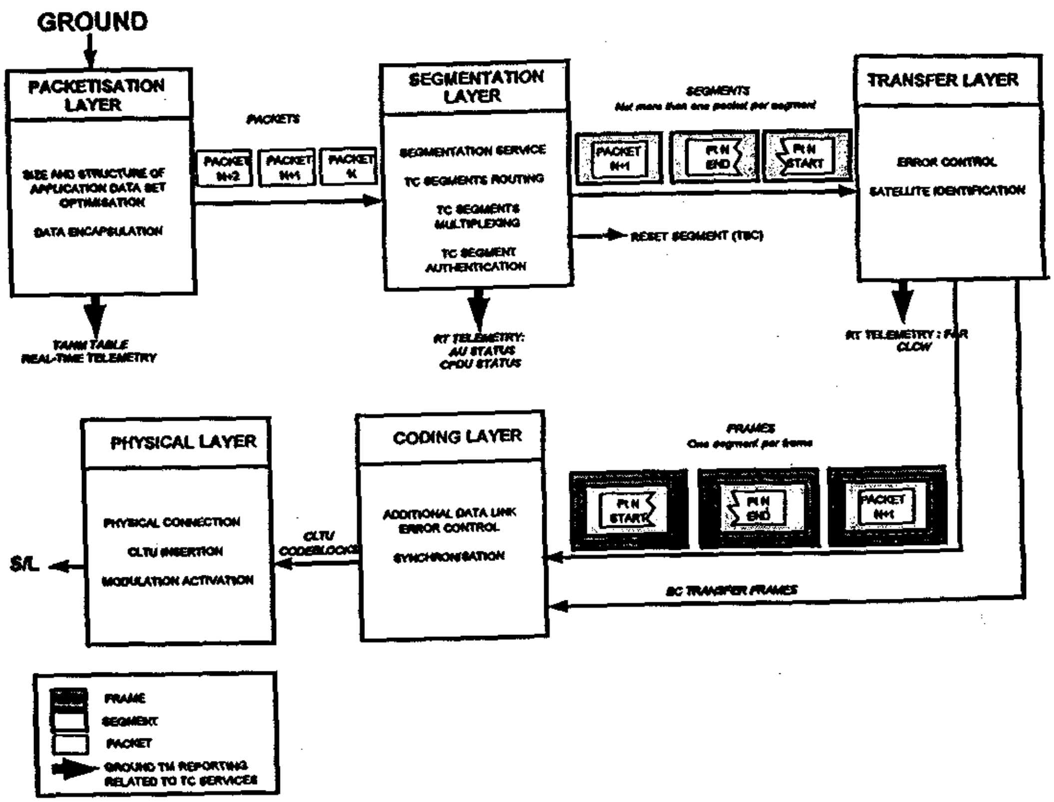

FIGURE 4.1.1/1 : Telecommand system layers and services (Metop case)

4.1.2.2 TC packet Header

The packet header occupies 48 bits (6 octets) of the TC packet format and is composed of the fields described below.

Version Number:

It corresponds to the PUS version number. The only authorised version today is version zero and this field is therefore frozen to "000".

Type :

In this case, the type to identify is the telecommand type. Therefore this field is frozen to "1' (Telemetry type is identified by "0").

Data Field Header Flag :

This field indicates the absence ("0") or presence ("1") of the Data Field Header within the Packet Data Field.

The CPDU TC's have no Data Field Header	"0"
Other commands have a Data Field Header	"1"

Application Process Identifier:

This field identifies the Application Process to which the TC packet is sent. Metop design comprises three applications : the EDR, the CCU and the PMC.

The value of the APID's are :

• CPDU (written in PROM):	**00000001001 (009 h)**
• CCU (CFS + LVPROM):	**00000000001 (001 h)**
• PMC (written in RAM):	**00000001000 (008 h).**

Packet Sequence Flag2:

This field identifies whether this packet is the first, the last or an intermediate component of the command sequence addressed to one particular application Process.

For the Metop mission, it shall be frozen to "11" (which corresponds to stand-alone TC packets) because no control of the packet sequence flag is realised.

Nevertheless, note that other types of control are performed by the CCU and the CPDU. They are described in the RD MMS7 and RD MMS8, respectively for actions of the CPDU and of the CCU (CFS & LVPROM).

2 Note that there is also a "Segment Sequence Flag"

Packet Name :

This field reflects the sequence counter status. This counter is a wrap-around counter of size 16384 (2^{14}). It permits to identify the position of the TC packet w.r.t the others occurring within a TC session. No consistency checking shall be performed on-board over this counter value. It shall be used only for identifying a given command addressed to the CCU and its APID if necessary (ex: If a CRC failure is detected and has to be reported to the ground).

Packet length :

This field permits to identify the length of the Packet Data Field. The value of this field is defined as follows : *Number of octets in the TC Packet Data Field - 1*

Therefore, the actual length of the complete TC Packet is 7 octets longer (packet header + 1) and this field can take odd values from a minimum of 1 octet (Packet Error Control only) to a maximum of 2047 octets.

Note that CPDU commands shall not be transported over several segments. Therefore, one packet containing CPDU commands shall be contained within one segment, i.e its Application Data Field shall fill at most 115 words. Consequently, the first byte of the Packet length, for a packet containing CPDU commands, shall be : "00000000".

4.1.2.3 TC Packet Data Field

The TC Packet Data Field contains information specific to the destination on-board Application Process. Its length is an even integer number of octets limited to 1024 words, i.e 2048 octets.

Data Field Header:

This field was originally meant to insert ancillary information within the first octets of the Packet Data Field (see RD ESA2 page 41). In the Metop design, its length is taken down to 16 bits because the CCU uses an 16-bit processor[3] and the first byte would have no added value.

For the Metop mission, this field contains the **Command Identifier** written on 16 bits (identical to the SPOT/ERS TCH Identifier) which will specify all the commands contained in the packet, i.e the function and structure of the Application Data Field. Note that CPDU commands do not have a data field header.

The values taken by this field are described in the Metop Reference database.

3 The first 8 bits of the standard 24 bits are suppressed : the PUS version number is already not provided, the checksum type is always CRC, the acknowledgement capacity is not permitted by the Metop design. The Service type and sub-types covering the standard last 16 bits are not provided either.

Application Data:

This field contains the user data in the form of a sequence of octets, forming an even number of octets.

- For a packet addressed to the CPDU, this field is made of one or several double-octets command instructions. Each double octet is formatted as follows : 64 on the nominal HPCI and 64 on the redundant HCPCI

The first octet specifies one of the 128 command pulse outputs.

The second octet specifies the delay between two command pulses. The 5 MSB will be normally set to 0 and they shall be ignored by the CPDU. The 3 LSB specify the delay between two pulses as follows :

n		
000	= 1 x D	The delay between two pulses is : n x D + 3 ms where 000 ≤ n ≤ 111 and where D is a fixed time value of 16 ms ± 0.5 ms
001	= 2 x D	
010	= 4 x D	
011	= 8 x D	
100	= 16 x D	
101	= 32 x D	
110	= 64 x D	
111	= 128 x D	

TABLE 4.1.2/1 : CPDU commands pulse duration

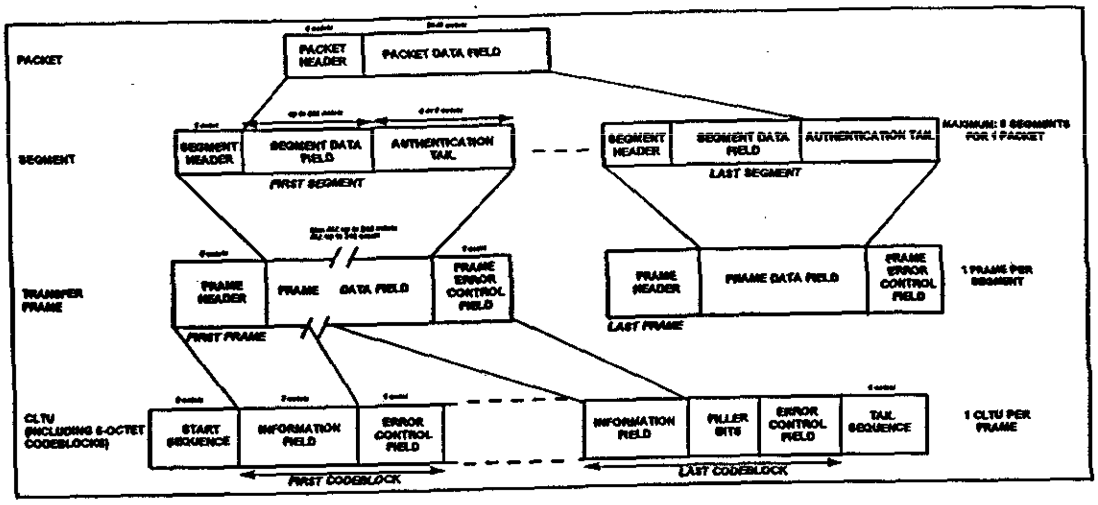

FIGURE 4.1.1/2: Summary of the S Band Protocol units structures (Metop Case - Authenticated commands)

- For a packet addressed to the CCU, this field contains the specific data related to the type of TC commands contained in the packet : SVM dedicated commands (for DHSA registers load, SVM memory load, SVM OBDH interrogation) and PLM dedicated commands also called macro-commands. The commands are described in detail in RD MMS12 for SVM, in PLM data sheets and in the Metop Reference Database for PLM.

Packet Error Control;

This field contains a CRC error detection code : the EDR (for CPDU commands) and the CCU (for the other TC's) can then verify that the integrity of the complete TC packet structure has been preserved and that this packet is available and correct in the memory of the application process. A packet shall be rejected as soon as an anomaly is detected.

The Cyclic Redundancy Code (CRC) is defined as follows :

- the generator is polynomial : $g(x) = x^{16} + x^{12} + x^5 + 1$
- on the ground, the CRC is calculated over the TC Packet Header and the TC Application Data Field, i.e excluding the Packet Error Control Field
- on-board, the CRC is calculated over the TC Packet Header and the complete TC Packet Data Field, i.e including the Packet Error Control Field: a correct packet leads to a result equal to "zero"
- both encoder and decoder are initialised to "all one's" state for each TC Packet.

4.1.3 Segmentation Layer

In order to be able to manage the data flow in an orderly manner, the following mechanisms are provided within the Segmentation Layer.

The first one is the **segmentation service** which, after segmentation of the packets too large for direct insertion into transfer frames, encapsulates a TC packet (or a portion of it if the TC packet length exceeds the maximum allowed for one segment) within a telecommand segment structure. Note that a CPDU command(s) packet shall always be included within one segment. The ground shall provide an optimised packet segmentation method, minimising the number of segments. Therefore, due to the relative size of the TC packet and the TC segment data field, a TC packet shall be split into at most 9 telecommand segments

The **multiplexing service** allowing to multiplex different streams of TC packets onto a single virtual channel is not used for Metop where there is only one TC source.

The **Segmentation Layer** provides several service access points multiplexed at segment level : the Multiplexer Access Points (MAPs).

Metop design is such that 4 MAP's identifiers are available :

- one MAP for both CPDU's (nominal and redundant)
- one MAP for the CCU (internally redunded) indicating that the segment contains one (or part of a) command packet addressed to the CCU .
- one MAP dedicated to the PAC (Packet Assembly Controller of the CCU) indicating that the segment is a control segment (see § 4.1.3.2)
- one MAP (called MAP 63) dedicated to Authentication Control Commands when Authentication is disabled, or carrying authenticated commands if authentication is enabled.

Another function is the **Authentication sub-layer** between the Segmentation layer and the Transfer layer, which provides data protection services at TC segment level, applicable to CPDU TC but not to the Transfer Layer Control frames ("Unlock" and "Set V(R)"). It is a "plain-text-with-appended-signature" system whose algorithm is specified in RD MMS7.

That part of the decoder concerned with the Authentication, and the Frame Acceptance as well, is the Frame Acceptance Unit (FAU). The FAU has two functioning modes, with authentication enabled or disabled. If the authentication is disabled, the Transfer Layer directly sends the frames to the Segmentation Layer. Note that once an authentication process has started, it shall not be interrupted, even upon arrival of a new TC segment transferred by means of a BD or AD frame.

Authentication is nominally always used except for the following exceptions:

- automatic inhibition when following a BCG order,
- manual inhibition by ground commanded CPDU TC upon mission request,

If the authentication is enabled, it is possible to select the MAP which shall be used. The MAP's selection system is based on MAP pointers which points at (see RD MMS 9/ § 8 for more details):

- the last pair of MAP ID that carries authenticated TC segment ,
- or MAP 63 alone.

The pairs associate MAPi and MAPi+32, counting from [MAP0, MAP32] onwards. When the pointer indicates MAPi, it means that the first (i+1) MAP pairs are expected to carry authenticated segments.

Authentication Control Commands are used to reconfigure the FAU, for key management and recovery operations. Their specific structure is described in § 4.1.3.5.

4.1.3.1 TC Segment structure

The TC segment structure is presented in the figure 4.1.3/1 below. It is composed of the 8-bit Segment Header, of the Segment Data Field and of the Segment Trailer containing the authentication data (empty if authentication inhibited or 9-octet long when commands are authenticated).

WITH AUTHENTICATION

SEGMENT HEADER			SEGMENT DATA FIELD	AUTHENTICATION TAIL
	MAP ID			
Segment Sequence Flag	Control Flag	MAP address		
2 bits VAR	1 bit 0:normal 1:reset	5 bits 00h:CPDU 01h:CCU 1Fh:AU CC	up to 238 octets VAR	9 octets VAR

WITHOUT AUTHENTICATION

SEGMENT HEADER			SEGMENT DATA FIELD
	MAP ID		
Segment Sequence Flag	Control Flag	MAP address	
2 bits VAR	1 bit 0:normal 1:reset	5 bits 00h:CPDU 01h:CCU 1Fh:AU CC	even number of octets up to 248 octets VAR

Figure 4.1.3/1 : TC SEGMENT STRUCTURES

4.1.3.2 TC Segment Header

The TC Segment Header written on the first 8 bits of the TC segment, is composed of the 3 following fields : the Sequence Flag, the Reset Flag and the MAP Address. The Reset Flag and the MAP address make up the MAP identifier (6 bits).

The Authentication Control Command are distinguished by an 'all-ones" segment header.

The Segment Sequence Flag:

This 2-bit field indicates the sequential position of the segment w.r.t the complete user TC packet. It shall take the following values :

- **01** ➔ First segment
- **00** ➔ Continuation segment
- **10** ➔ Last Segment
- **11** ➔ Unsegmented (entire TC packet) or stand-alone

The sequence flag check performed on-board is based on the matrix presented on table 4.1.3/2.

Previous value / Present value	FIRST	CONTINUOUS	LAST	UNSEGMENTED/ STAND-ALONE
FIRST	NOK	NOK	OK	OK
CONTINUOUS	OK	OK	NOK	NOK
LAST	OK	OK	NOK	NOK
UNSEGMENTED/ STAND-ALONE	NOK	NOK	OK	OK

TABLE 4.1.3/2 : Sequence flag check-out matrix

The Control Flag:

This field indicates on 1 bit whether the segment contains packet telecommands data in the Segment Data Field or corresponds to the unique Control Segment, also called *PAC Reset Command.*

When this bit is equal to "0", the command is to be received by the CPDU for direct execution or by the CCU for processing or transfer to the PMC.

When it is equal to "1", the command is a specific Control Command:

- the Control Segment (single octet) used to reset the PAC to a "completed" state and therefore unlock the Packet Assembly Controller of the TC reception function (processed by CCU),
- one of the 7 authentication Control Commands (processed by EDR).

The MAP Address:

Five last bits provide the MAP address value which, in METOP case, can be :

- **"00000"** for the CPDU
- **"00001"** for the CCU
- **"11111"** for AU (Authentication Unit) control Commands (processed by the EDR).

The **control segment** or "*PAC Reset Command*" contains only one octet, the segment header, with no segment data field. The value of the segment header is as follows : **"11100001"**, where the five last bits represent the MAP address of the PAC, i.e of the CCU. Note that it may be transferred using AD or the BD transfer frames (see § 4.1.4.1 & 4.1.4.3).

4.1.3.3 TC Segment Data Field

In order to provide the CCU software with 16-bit words, the useful data transported by the segment, i.e all except the Segment Header and the Authentication Tail if any, shall be constituted of an even number of octets:

- the Segment Data Field of non authenticated commands can go up to 248 octets,
- the Segment Data Field of authenticated commands can go up to 238 octets.

There is no Segment Data Field when the command transmitted is the Control Segment, i.e the Reset Command.

4.1.3.4 TC Segment Trailer

For Metop, authentication is required and is performed on-board by the Frame Acceptance Unit (FAU). The authentication tail is composed of 9 octets describing the Logical Authentication Channel (LAC-4 octets) and the Signature Field (5 octets) as shown on figure 4.1.3/3. The signature is a string built-up on-ground by the authentication algorithm, using the secret key, the command data and the ground LAC counter value. The Metop AU first compares the received LAC value with the one maintained by the on-board LAC.

Then, if the check is successful, it compares the received digital signature with the one it has constructed on-board, using the same algorithm and the on-board counter value.

LOGICAL AUTHENTICATION CHANNEL (LAC)		SIGNATURE
4 octets		5 octets
LAC ID 2 bits	LAC COUNT 30 bits	 5 octets

FIGURE 4.1.3/3 : AUTHENTICATION TAIL STRUCTURE

LAC ID :

In the Metop design, there are three LAC's (Logical Authentication Channels), two for the normal TC stream and one for recovery. The recovery LAC content is a fixed value: after temporary power loss or at EDR switch-on, the recovery LAC counter value is fixed and pre-defined[4].

The purpose of the LAC ID is to identify the LAC used by the sending end and, consequently, the LAC register to be selected for final authorisation of a TC segment.

The LAC Identifiers are :

- Principal LAC ID : 00
- Auxiliary LAC ID : 01
- Recovery LAC ID : 10

LAC count :

This field provides the count number issued from the ground 30-bit counter: the ground increments this counter by one every time a TC segment is successfully sent.

The 30 bits of the Principal and the Recovery on-board LAC count registers are maintained and also fully programmable from ground.

The 22 first bits of the Recovery LAC count register are forced to "1", on-board and on the ground and the remaining 8 bits are set to a fixed value after temporary power loss or at EDR switch-on. This fixed value is "00000000" (TBC).

The roll-over principle implies that the variable bits go back to "00...00" after "11..11". This is true for all bits of the principal and auxiliary LAC and for the last 8 bits of the recovery LAC.

Signature :

The digital signature is a 5-octet string built up by the authentication algorithm described in RD MMS9 (§ 3).

4.1.3.5 Authentication Control Commands

To differentiate TC segments containing Authentication Control Commands required to reconfigure the FAU, the specific segment structure is used. There are seven AU Control Commands split into three groups, as shown in the table 4.1.3/4.

4 The non-volatile recovery LAC required by the standard has not been implemented in agreement with ESA for design simplification (see RD MMS 17).

GROUP Nb	AU CONTROL COMMAND ID	AU COMMAND NAME
GROUP 1	0000 0000	• DUMMY SEGMENT
	0000 0101	• SELECT FIXED KEY
	0000 0110	• SELECT PROGRAMMABME KEY
	0000 0111	• LOAD FIXED KEY IN PROGRAMABLE KEY MEMORY
GROUP 2	0000 1001	• SET NEW LAC COUNT VALUE
GROUP 3	0000 1010	• CHANGE PROGRAMMABLE KEY BLOCK "A"
	0000 1011	• CHANGE PROGRAMMABLE KEY BLOCK "B"

Table 4.1.3/4 : LIST OF AUTHENTICATION CONTROL COMMANDS

Details about the effect and the utilisation constraints of these Control Commands are provided in RD MMS 9, § 9.

SEGMENT HEADER	AU CONTROL COMMAND ID	AU CONTROL COMMAND DATA FIELD	AUTHENTICATION TAIL (LAC+SIGNATURE)
8 bits	8 bits	Group1 : nothing Group2 : 4 octets Group3: 8 octets	9 octets
11111111	see table 4.1.3/4	VARIABLE	see § 4.1.3.4

Figure 4.1.3/5 : AU CONTROL COMMANDS SPECIFIC SEGMENT STRUCTURE

4.1.4 Transfer layer

In order to transfer the TC segments to the spacecraft without error, omission or duplication and in their original sequence, two other layers shall be implemented : the transfer and the coding layers.

The transfer layer provides the mechanisms for the **transmission of protocol data units called Telecommands Frames.** Each TC segment is embedded in one TC Transfer Frame.

There are three types of transfer frames : the AD frames and the BC frames belonging to the Sequenced-controlled Service and the BD frames belonging to the Expedited Service.

4.1.4.1 The AD Frames

The AD frames transport TC segments dedicated to nominal spacecraft operations. "A" stands for *Acceptance Check* and "D" for *Data transportation*. The functions and protocols required to achieve this service are those defined as COP-1 (Command and Operation Procedure One) detailed in RD MMS9 (§ 4) and summarised below :

- the service includes an "Automatic Request for Retransmission" (ARQ) of the "Go-back N" type,
- sequence control mechanisms are implemented on-board and on-ground to ensure that the TC segments will be delivered in the same sequential order in which they were received from the segmentation layer,
- a standard data report, the Command Link Control Word (CLCW), is downlinked in the telemetry (see § 4.1.7.3 and RD MMS9/§ 7).

4.1.4.2 The BC Frames

The frames transporting control instructions dedicated to the on-board configuration of the AD service are called Control Frames or BC Frames, where "B" stands for *Bypass Acceptance Check* and "C" for *Control*. The service is ensured with simpler means than for the AD frames :

- the ARQ is a "Transmit-One, Stop-and-Wait" procedure,
- no sequence control mechanism is applied on-board,
- a standard data report, the Command Link Control Word (CLCW), is downlinked in the telemetry (see RD MMS9 / § 7).

4.1.4.3 The BD Frames

The BD frames transport TC segments used for exceptional spacecraft communications, such as : recovery in absence of TM downlink (i.e no CLCW) or TC system lockout. Hence, it permits the recovery of a blocked Channel or Application, which, in the case of Metop, can only be the CCU because the CPDU is by definition never blocked. Access to the CCU can be blocked at two levels : the PAC, unlocked by the Reset Segment, and the Packet Reception function, unlocked by a dedicated CCU memory load command.

These particular frames are called By-Pass Frames or BD Frames where "B" stands for *Bypass Acceptance Check* and "D" for *Data Transportation*. The BD service is ensured simply, without any ARQ procedure (frames are transmitted once and forgotten), without sequence control and without telemetry reporting from the Transfer Layer apart from the CLCW which contains a BD counter (2 bits).

4.1.4.4 Transfer Frame structure

The Transfer Frame structure is presented in figure 4.1.4/1. It is composed of the Frame Header written on 5 octets, the Frame Data Field written on up to 249 octets and the Frame Error Control Field which occupies the 2 last octets. For the Metop mission, the Frame Data Field shall never contains more than 248 octets when in authenticated mode.

FRAME HEADER	FRAME DATA FIELD	FRAME ERROR CONTROL FIELD
5 octets	1 to 249 octets	2 octets

TABLE 4.1.4/1 : Transfer Frame Structure

The Frame length varies from 8 octets, when the embedded segment is only composed of a segment header (no data field and no authentication), up to 256 octets. For the Metop mission, the Frame length shall never exceed 255 octets when in authenticated mode.

4.1.4.5 Transfer Frame Header

The Frame Header is composed of 40 bits providing COP-1 and spacecraft specific information via the 9 fields presented in figure 4.1.4/2.

FRAME HEADER								
Version number	Bypass Flag	Control Command Flag	Reserved Field A	Spacecraft ID	Command Chain ID	Reserved Field B	Frame Length	Frame sequence number
2 bits	1 bit	1 bit	2 bits	10 bits	6 bits	2 bits	8 bits	8 bits
00	VAR	VAR	00	VAR	A:000000 B:000111	00	VAR	VAR
2 octets					1 octet		2 octets	

FIGURE 4.1.4/2 : Transfer Frame Header

Version Number :

This field identifies on 2 bits the formal structure of the Transfer Frame, according to CCSDS definitions. The Metop Transfer Frame structure has the version number : "00".

By-pass and Control Commands Flags:

These 2 bits identify the type of frame, as defined in paragraphs 4.1.4.1 to 4.1.4.3.

The **By-pass bit** is set to "0" (= A for Acceptance check) when the sequence control mechanisms is used on-board. It is set to "1" (= B for By-pass Acceptance Check) otherwise.

The **Control Command bit** is set to "0" (= D for Data) when the Transfer Frame carries data and it is set to "1" (= C for Control) when it carries Control Commands.

In summary, this field can take the values :**00**, **10** and **11**.

BYPASS FLAG	CONTROL COMMAND FLAG	INTERPRETATION
0	0	**AD Frame :** data carried with sequence control
0	1	**Illegal combination :** Control Frames are not sequence-controlled
1	0	**BD Frame :** data carried without sequence control
1	1	**BC Frame :** Control Command information without sequence control

Reserved Field A :

This 2-bit field, reserved for future CCSDS applications, is frozen to : "00".

Spacecraft Identifier :

This 10-bit field identifies the spacecraft to be commanded. Its value is provided by ESA and shall be different for the 3 Metop and for the simulator. Their values are :

METOP 1	→	**00 0000 1011**
METOP 2	→	**00 0000 1100**
METOP 3	→	**00 0000 1101**
METOP simulator	→	**00 0000 1110**

Command Chain ID 5:

This 6-bit field identifies the on-board command chain to be used. In the Metop case, it takes the following values :

EDR chain A	→	000000
EDR chain B	→	000111

Reserved Field B :

This 2-bit field, reserved for future CCSDS applications, is frozen to : "00".

Frame Length :

This 8-bit field permits to know the number of octets contained in the entire TC Transfer Frame. It is defined as follows :

Total Number of octets - 1

Therefore its binary value varies from 7, when the embedded segment is only composed of the segment header (no data field and no authentication), up to:

- 254 octets in authenticated mode,
- 255 in non authenticated mode.

Frame Sequence Number:

This 8-bit field, denoted N(S), has a value depending on the type of frames transmitted.

When AD frames are prepared for transfer, its value corresponds to the "Transmitter Frame Sequence Number", also noted V(S), maintained by the ground counter according to the FOP-1 procedure (see RD MMS9 / § 4).

It is set to "all-zeros" for BC and BD frames.

4.1.4.6 Transfer Frame Data Field

For AD and BD Transfer Frames types, the Transfer Frame Data Field carries the entire TC segment without interpreting it. For BC Transfer Frames, the data field contains Control Commands generated within the Transfer Layer (therefore not authenticated) and aiming at the on-board FARM-1 configuration (see RD MMS9 / § 4). There are two possible control commands. A control frame shall only contain one at the time :

- the UNLOCK control command, OR
- the SET V(R) control command.

---

5 Warning: the satellite cannot manage independently both command chains. It is then up to the ground not to uplink commands to both chains simultaneously (i.e in less than 2 seconds time).

UNLOCK Control Command:

This command stands on one octet where all bits are set to zero :

"00000000".

Its purpose is to reset the lock-out condition of the on-board FARM-1 service.

SET V(R) Control Command :

This command stands on 3 octets encoded as follows :

" 10000010 00000000 XXXXXXXX "

The last octet corresponds to the V(R) value set by the ground, i.e the desired on-board value for the next expected Frame Sequence Number (see RD MMS9 / § 4).

4.1.4.7 Transfer Frame Error Control Field

This 16-bit field contains a CRC detection code for detection of errors which may have been introduced by the coding and physical layers. The encoding and decoding procedures are described in RD MMS9 / § 1.

The Cyclic Redundancy Code (CRC) is defined as follows :

- the generator is polynomial : $g(x) = x^{16} + x^{12} + x^5 + 1$
- the CRC is calculated over the TC Transfer Frame Header and the TC Transfer Frame Data Field
- both encoder and decoder are initialised to "all one's" state for each TC Packet.

4.1.5 Coding Layer

The coding layer provides the **Forward Error Correction** (and detection) capability as well as a **synchronisation** service for the Physical Layers. Each Transfer Frame is embedded in the Coding Layer whose basic protocol data unit is the **Command Link Transmission Unit (CLTU)**. The CLTU is essentially made of one or more telecommands Codeblocks containing the information bits making up one TC transfer Frame.

Searching for the Start Sequence, the on-board Coding Layer service finds the beginning of a CLTU and decodes the TC Codeblocks. As long as no error is detected or errors are detected and corrected, the on-board Coding Layer passes clean octets to the on-board Transfer Layer. Note that the Start sequence is not transmitted to the on-board Transfer Layer which only receives candidates TC Frames.

Should any Codeblock contain a uncorrectable error, this Codeblock is abandoned, no further data octet is passed and the on-board Coding Layer returns to the Start Sequence searching mode until it detects one.

The CLTU decoding Procedure to be applied on-board is detailed in § 6 of RD MMS9.

4.1.5.1 CLTU Structure

The CLTU structure, presented on figure 4.1.5/1 below, is composed of three elements : the Start Sequence written on 2 octets, one or several TC Codeblocks, each of them occupying 8 octets, and the Tail Sequence written on 8 octets.

START SEQ	FIRST CODE BLOCK			...	LAST CODE BLOCK			TAIL SEQ
	Inform. Field	Error Control Field			Inform. Field	Error Control Field		
		Parity bits	Filler Bit			Parity bits	Filler Bit	
2 octets	7 octets	7 bits	1 bit		7 octets	7 bits	1 bit	8 octets
EB90	VAR	VAR	0		VAR	VAR	0	0101...01

FIGURE 4.1.5/1 : CLTU structure

4.1.5.2 CLTU Start Sequence

The Start Sequence written on the first 16 bits marks the beginning of the first TC Codeblock within a CLTU, and therefore of the Transfer Frame.

Its value is frozen to "EB90", i.e :

"1110 1011 1001 0000".

4.1.5.3 CLTU Codeblocks

The CLTU codeblocks encoding the Transfer Frames have a fixed selected length of 8 octets among which 7 are dedicated to Information and 1 to Error Control.

Information Field :

When the Transfer Frame is encoded, the 7 first octets of the Transfer Frame are placed in the first Codeblock of the CLTU.

When the Transfer Frame length does not match exactly that of the codeblock sequence, i.e when the last octet of the TC Frame does not coincide with the last octet of the last codeblock information field, fill octets are added to the last Codeblock information field by the Coding Layer.

The pattern of a fill octet is an alternating sequence of zero's and one's as follows :**"01010101"**.

These fill octets shall be removed by the on-board Transfer Layer Service.

Error Control Field :

• The block coding procedure processes the 56 bits of the information field and generates 7 parity check bits for each codeblock. These bits are positioned in the 7 first bits of the Error Control Field.

The code is a (63,56) modified (single error correction) Bose-Chaurhuri-Hocquenghem (BCH) code which uses the following polynomial generator to produce the 7 parity bits, when checking a set of 56 bits (see RD MMS9 / § 5):

$$g(x) = x^7 + x^6 + x^2 + x^0$$

The code generator implementation is shown on figure 4.1.5/3.

• The last bit of the Error Control Field, and therefore of the Codeblock, is a filler bit always set to "0".

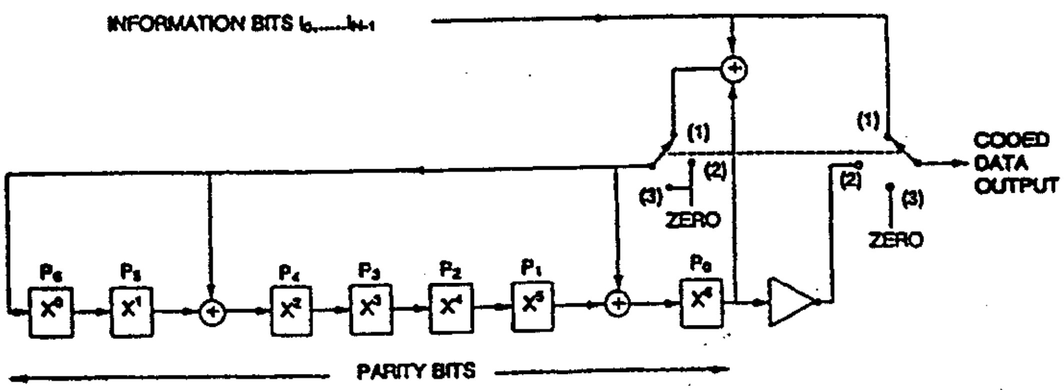

FIGURE 4.1.5/3 : Modified BCH Code Generator

4.1.5.4 CLTU Tail Sequence

The Tail Sequence marks the end of the TC Codeblock Field within the CLTU. Its length is identical to the Codeblock one, i.e 8 octets.

Its pattern is frozen and alternates zero's and one's (ending with a one) as follows :

"01010101 .... 01010101"

4.1.6 Physical layer

This layer specifies the physical connection between the transmitting ground station, i.e Kiruna, and Metop. It controls the activation and deactivation of the physical connection by invoking the PLOP-2 Physical Layer Operation Procedure consisting in a sequential application of several Carrier Modulation Modes (CMM), as shown on figure 4.1.6/1 :

- CMM1 : the unmodulated carrier
- CMM2 : the carrier modulated with an Acquisition Sequence
- CMM3 : the carrier modulated with one CLTU
- CMM4 : the carrier modulated with an Idle Sequence.

4.1.6.1 Coding and Physical Layers Interface

On ground, the Coding Layer may send two requests to the Physical Layer :

- Transmit Request for CLTU
- Abort Request.

If the Physical Layer accepts the Transmit Request, it has stored the CLTU data which will be transmitted as soon as the preceding CLTU data has been transmitted.

If the Physical Layer rejects the Transmit Request, it is because there is no more space to store the CLTU data.

An Abort Request shall erase the CLTU's queuing in the layer but not the one being currently transmitted.

On-board, the Coding Layers accepts the Physical Layer data bit by bit, as soon as bit modulation is detected and bit lock is achieved.

4.1.6.2 Unmodulated carrier

This mode concerns the establishment of the RF part of the physical connection. In this state, the lock status of the satellite transponders shall be downlinked in the telemetry data to Kiruna and be set to "0".

This lock status is described by a flag of the CLCW, more precisely the bit 16 of the CLCW denoted the "No RF Available Flag" (see RD MMS9 / § 7).

CLCW Bit 16 = 1 --> RF connection not available through both transponders
CLCW Bit 16 = 0 --> RF connection available through at least one transponder

4.1.6.3 Acquisition Sequence modulation

This mode concerns the establishment of the modulation part of the physical connection. The procedure requires that a 128-bit Acquisition sequence is transmitted and that a performance quality indicator is downlinked in the telemetry data to Kiruna.

This quality indicator is described by a flag of the CLCW, more precisely the bit 17 of the CLCW denoted the "No Bit Lock Flag".

CLCW Bit 17 = 1 →
none of the 2 METOP EDR demodulators has achieved bit lock

CLCW Bit 17 = 0 →
at least one of the 2 METOP EDR demodulators has achieved bit lock.

The standard length of the Acquisition Sequence is 128 bits, which may be lengthened by idling, as described in paragraph 4.1.6.5. The Acquisition Sequence bit pattern is of NRZ-L type, alternating zero's and one's and ending with a one when immediately followed by an Idle Sequence.

In practice, if time critical, no acquisition sequence is uplinked.

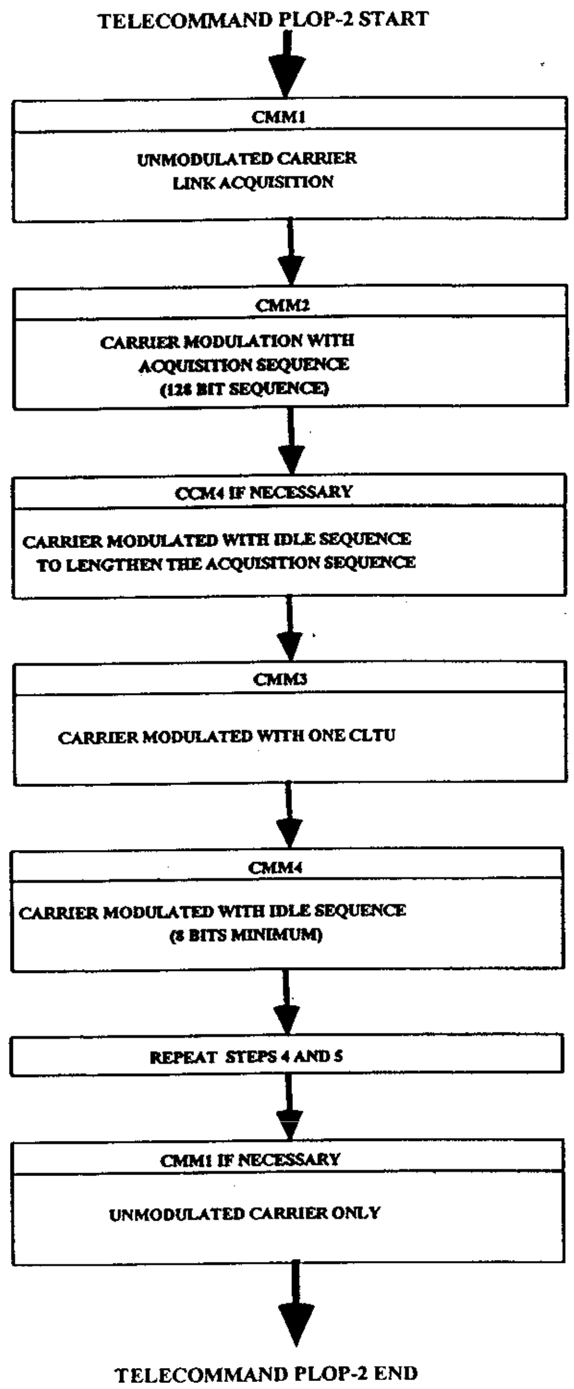

FIGURE 4.1.6/1 : PLOP-2 Sequence Of CMM'S

4.1.6.4 CLTU modulation

This mode is used for transferring the CLTU's issued from the Coding Layer.

4.1.6.5 Idle Sequence Modulation

This mode is used for maintaining the modulation part of the physical connection while not transferring CLTU's. In particular, it may be useful for avoiding buffer bottle-neck situation if a short frame follows a long frame. Also, it was intended to be used in order to ensure that no command is uplinked before CPDU TC with long execution time are completed. The length of the Idle Sequence varies in function of its position in the CMM sequence.

If it is used between the Acquisition Sequence and the first CLTU, it will increase the length of the acquisition sequence.

Between two successive CLTU's, there shall always be at least 8 bits of Idle Sequence. In practice, any length over 8 bits can be used (not even an integer number of octets or an even number of bits) and the maximum length of the Idle Sequence is dictated by the timing of the commanded operations. The bit pattern is always beginning with a "zero".

4.1.6.6 Physical Layer numerical characteristics

This paragraph describes the physical characteristics to be used for the establishment of the S Band TC link budgets. All parameters given here are worst case EOL values, unless otherwise specified. The Metop G/T is not provided here because the budgets shall determine the G/T value permitting to fulfil the margins requirements. The adequate value of all the G/T the components are provided in the link budgets.

More precisely, these budgets shall be computed for :

- the S Band Eumetsat station, i.e Kiruna, whose geographical characteristics are presented at § 3.2,
- a 5° minimum elevation,
- the reference (whole possible range) and drift orbits defined in RD MMS1,
- 3 dB margin for typical cases,
- 1 dB margin in worst cases
- the RF spectrum mask of a trapezoidal form as shown on figure 4.1.6/3 (typically, the band between the -15 dB points corresponds with the occupied bandwidth for this mask).

The attenuation due to atmospheric phenomena i.e rain, clouds, gas, scintillation which is not exceeded for 99.9% of the time shall be considered in the link budget.

Note that in today's link budgets, the value specified for the total channel degradation accounts for the technological losses for TC recovery (or implementation losses)[6].

[6] If not satisfactory for ESA, ESA shall provide the terms of the channel degradation.

The other characteristics are presented in table 4.1.6/2. Note that the TC and the Carrier modulation loss being derived from the modulation index, only the modulation index value is provided. Also, the on-board antenna axial ratio being function of the Metop Receiver antenna gain, is not provided either.

KIRUNA CHARACTERISTICS7	
Carrier Frequency	2053.4583 MHz
EIRP (worst case)	59 dBW
Antenna Polarisation	Earth facing antenna : LHCP Other antenna : RHCP
Kiruna Axial Ratio	< 1dB
Data rate	2000 bps
Data modulation	NRZ-L/PSK
Carrier Modulation	PM
Carrier Modulation Index (*) TC only (for information) simultaneous TC and ranging (for budget)	 ESA standard : >0.6 rad pk precise value : TBD by MMS TC: ESA standard >0.6 rad pk precise value: TBD by MMS Ranging: see § 4.3.4.1
Sub-carrier Frequency	8 KHz sinewave
Spectral Mask for TC signal	see figure 4.1.6/3
G/S spurious radiations	According to RR article 28, section II and III

(*) MMS shall determine modulation indexes values compatible with the limits imposed by the ESA standards and with the link budget margins to achieve.

LINK CHARACTERISTICS	
Link Quality	BER < 10^{-5} (i.e SPOT) probability of rejected Frame (PFL) < 10^{-5} probability of undetected Frame error < 10^{-19}
Total Channel Degradation	2.6 dB

METOP CHARACTERISTICS	
Metop G/T (receiver) composed of : *Receiver antenna gain* *Hybrid coupling* *Cables mismatches & hybrid losses* *System Noise temperature*	To be determined by the link budgets

TABLE 4.1.6/2 : TC Physical Link Characteristics

7 Today's version of the link budgets (i.e SRR version) account for the previous characteristics available at the time of the SRR. In particular, since the ground station EIRP has been significantly decreased, the margins announced in the SRR budgets have to be decreased by several dBs.

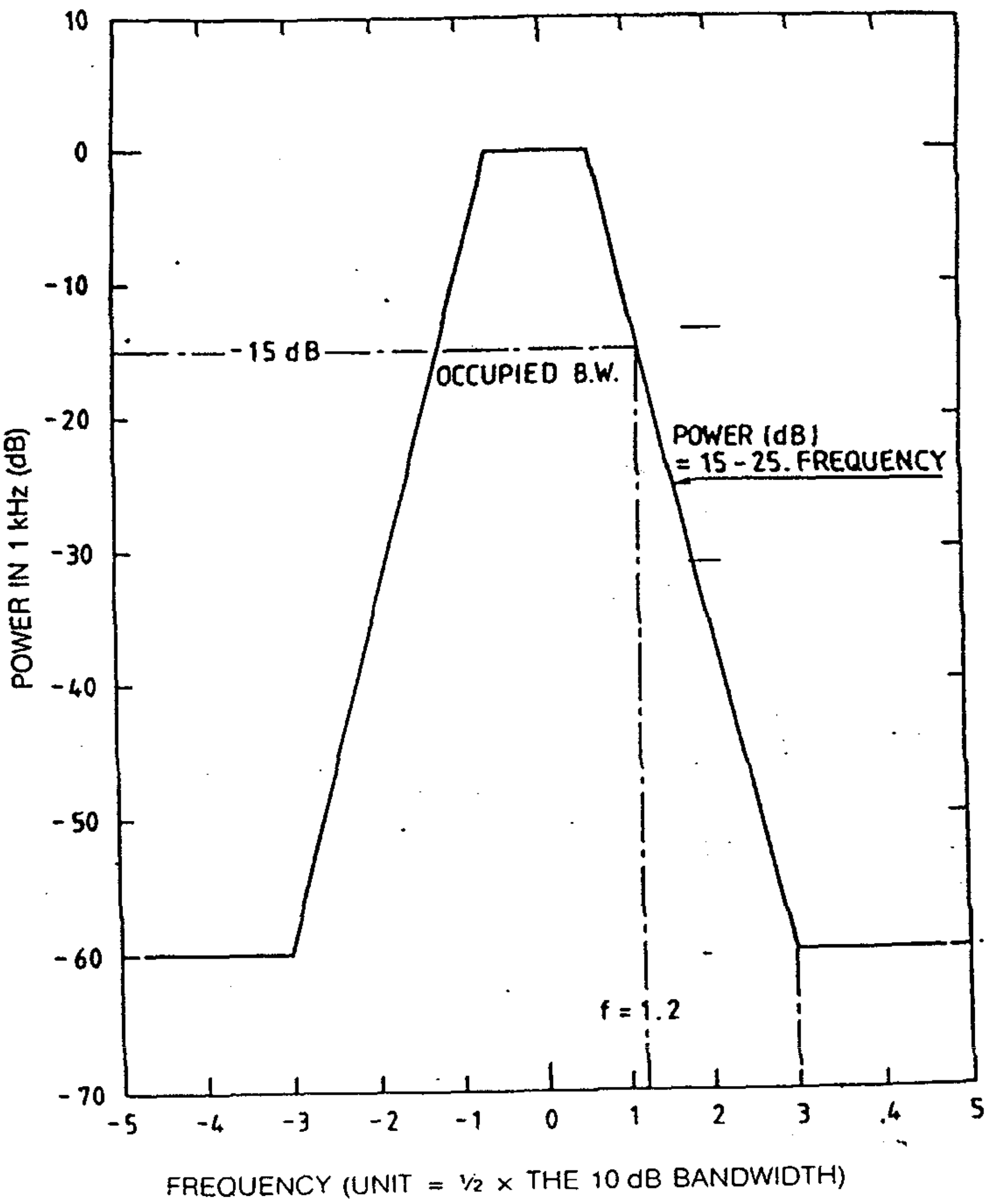

TABLE 4.1.6/3 : TC Radio Frequency Spectral Mask
(from ESA RF modulation standard)

4.1.7 Telemetry reporting of the TC reception

Each layer shall provide a report to the ground station via telemetry, within the layer structure (CLCW in the Frame Trailer) or via normal S Band telemetry (fixed part and dumped tables). In particular, the EDR produces report messages at a fixed 1 Hz frequency, which are included by the CCU software in the S Band telemetry Frame 8.

The TC report is available only if the TC channel is active.

4.1.7.1 Packet Layer

The Packet Layer reports unambiguously the status of all TC packets via :

- the anomaly table (TANM) downlinked on-request in the variable part of the S Band frame9but not available in Safe Mode
- several telemetries downlinked in the SVM real-time part of the S Band frame.

In **TANM**, one will find information related to the occurrence of an anomaly, typically: the on-board time of anomaly occurrence, the number of that anomalous packet (= SPOT TCH identifier), the type of anomaly, the data causing problem ... The TANM structure is defined in RD MMS12 and the anomalies codes and signification can be found within the Metop Satellite Database.

In the **real-time telemetry**, one finds :

- the last TC packet report (number of the last received packet, may it be correctly received or not, related Sequence count ...)
- the last anomaly code
- counter of anomalies
- the PAC report: re-assembly status (Packet completed or in Progress), PAC Lockout status (PAC lockout or No Lock-out) and the MAP-ID of the TC packet in progress of receipt,
- the TC execution lock-out status,
- the counter of the TC packets received correctly.

More detail about the real-time TM report can be found in RD MMS12 (SVM TMTC data definition).

4.1.7.2 Segment Layer

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8 According to the standard, the EDR shall produce a report for each CLTU received (FAR, AU, CPDU reports): it is then up to the user to use it or not. The CCU accepts these report but cannot feed the telemetry frames at more than 1 Hz. Therefore, although the EDR could produce them at a higher frequency, only the last reports received within the second will be downlinked.

9 Note that if the TC reception log is implemented, the corresponding table will contain all the anomalous TC errors type together with the attached sequence count values. This log is not retained by ESA/Eumetsat for the phase CD proposal.

The segment layer reports the Authentication status and the CPDU status in the SVM part of the S Band telemetry frame. A precise description of the CDPU status report written over 16 bits (one for each CPDU commands sent) and of the AU status report, written over 80 bits (one for each authenticated commands received) is provided in § 11 of RD MMS9.

4.1.7.3 Transfer Layer

The Transfer Layer reports (TM report n°1) the Command Link Control Word (CLCW) and the Frame Analysis Report (FAR).

FAR:

The **FAR** is a 32-bit field of survey data downlinked in the SVM fixed part of the S Band telemetry Frame. Table 4.7/1 presents an overview of the FAR fields description while more details about the FAR is provided in § 10 of RD MMS9.

BITS	MEANING
0	STATUS OF SURVEY DATA
1,2,3	FRAME ANALYSIS
4,5,6	LEGAL/ILLEGAL FRAME QUALIFIER
7 through 12	COUNT OF ACCEPTED CODEBLOCKS PER CLTU
13,14,15	COUNT OF SINGLE ERROR CORRECTIONS PER CLTU
16,17	LEGAL FRAME QUALIFIER
18,19,20	SELECTED CHANNEL INPUT
21 through 26	LAST MAP ADDRESS
27	RESERVED BY ESA = 0
28,29,30	AUTHENTICATION PROCESS ANALYSIS
31	RESERVED BY ESA = 0

Table 4.7/1: FAR FIELD DESCRIPTION

CLCW:

The CLCW is a 4-octet word generated by FARM-1 and telemetred back in the trailer of the S Band telemetry transfer Frames, as described at § 4.2.3.5. The format of the CLCW is briefly described in figure 4.1.7/2 and detailed in the RD MMS9 (§ 7).

CLCW OCTETS 1 AND 2					
Control Word Type "CLCW"	CLCW Version Number	Status Field	COP in effect	Command Chain	Reserved Field
1 bit	2 bits	3 bits	2 bits	6 bits	2 bits
0	00	000	01	A:000000 B:000111	00

CLCW OCTETS 3 AND 4							
No RF available	No Bit Lock	Lock-out	Wait	Retransmit	FARMB Counter	Report Type	Report Value
1 bit	1 bit	1 bit	1 bit	1 bit	2 bits	1 bit	8 bits
VAR	VAR	VAR	VAR	VAR	VAR	0	VAR

FIGURE 4.7/2 : CLCW Format

4.1.7.4 Coding Layer

No standard reporting data is defined for the operational activities of the Coding Layer.

4.2 TELEMETRY

4.2.1 Overview

The METOP packet telemetry S Band link shall be organised in a set of 3 independent layers described in details in the following paragraphs. An overview of the layers and of the services they offer is presented in figure 4.2.1/1. For a set of data issued from the satellite, they are chronologically: the **Packetisation Layer**, the **Transfer Layer** and the **Physical Layer**. Note that the **Segmentation Layer** is not used in the Metop S Band link.

Figure 4.2.1/2 presents a summary of the different protocols units structure.

4.2.2 Packetisation layer description

The METOP CCU produces source data including housekeeping telemetry of the SVM and of the PLM. The **Packetisation Layer** shall transform the source data into a source packet.

In the Metop mission, the source packet maximum length is such that there is no need for a segmentation system in order to turn the source packet into a telemetry packet. The telemetry packet, protocol data unit to be provided to the Transfer Layer, is in fact the unsegmented Source Packet.

In addition to the source data, the Source Packet carries a minimum of information needed by the ground for acquisition, storage and distribution of the source data to the end user, unique for S Band data in the EPS system.

4.2.2.1 Source Packet structure

The housekeeping TM source packet structure is presented in the figure 4.2.2/1. It is composed of two major fields : the Packet Header (6 octets) and the Packet Data Field (490 octets). The total length of the Housekeeping Source Packet is 496 octets.

One can choose to downlink two different types of HK TM format via ground command : the **Real-Time Format** (RTF) or the **Table Emptying Format** (TEF). Depending on the chosen format, the Packet Data Field differs as follows :

- in the RTF, the Packet Data Field is split into four parts: the Data Field Header, the SVM real-time HK data, the PLM real-time HK data and the programmable part,
- in the TEF, unless for the Data field Header and a limited SVM fixed part containing HK telemetry, the whole Packet Data Field is programmable and used to transmit large on-board tables.

PACKET HEADER							PACKET DATA FIELD
Packet Identification 2 octets				Packet Sequence Control 2 octets		Packet length 2 octets	REAL-TIME OPTION OR TABLE EMPTYING OPTION
Version number	Type	Data field header flag	Applic. process ID	Segment Flag	Source Sequence count		
3 bits	1 bit	1 bit	11 bits	2 bits	14 bits	16 bits	490 octets
100	0	1	01h or 07 h	11	VAR	VAR	VAR

FIGURE 4.2.2/1 : Housekeeping TM Source Packet Structure

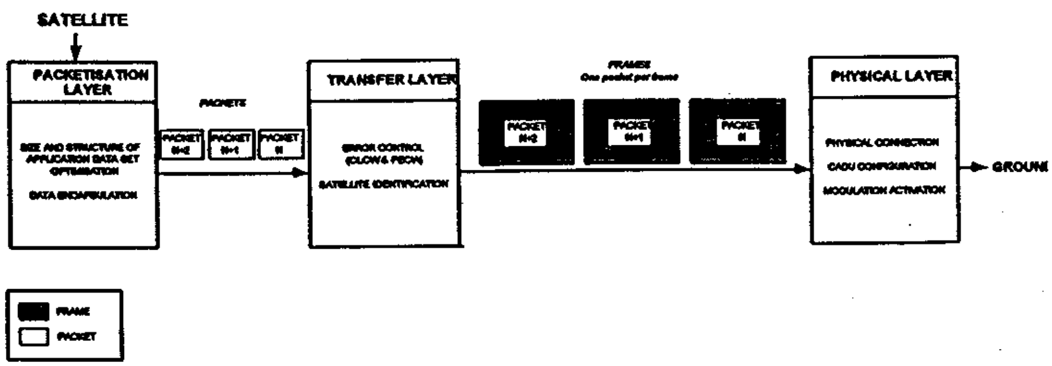


FIGURE 4.2.1/1 : S Band Telemetry system layers and services (Metop Case)

4.2.2.2 TM Source Packet Header

The Packet Header occupies 48 bits (6 octets) of the TM packet. It provides the standardised control information required during the Metop-to-ground transport process, i.e : the identification of the data source, the sequence numbering and the Packet Data Field Length. It is identical for the RTF and the TEF and composed of the following fields.

Version Number:

This version number is defined by the CCSDS. The only authorised version describing such TM packets today is version "two" and this field is therefore frozen to "100".

Type :

In this case, the type to identify is the telemetry type. Therefore this field is frozen to '0" (Telecommand type is identified by "1").

Data Field Header Flag:

This field indicates the absence ("0") or presence ("1") of the Data Field Header within the Packet Data Field.

It shall be set to "1" to indicate that there is a Data Field Header in the Metop S Band TM packet, whatever the format (RTF or TEF).

Application Process Identifier:

This field identifies both the physical source (sub-system, instrument) and the application process within the physical source, which created this packet.

In the Metop case, there are two physical source/Application processes :

- the satellite with the LVPROM (SAFE Mode): "00000000111" (0007 h),
- the satellite with the CFS : "00000000001" (0001 h).

Segmentation Flag:

This field shall always be set to "11" to reflect the non segmented character of the source packets.

Source Sequence count:

This field contains a straight sequential count (modulo 16384) of each packet generated by each data source application process of Metop, i.e the CFS and the LVPROM. This will allow the ground to control the continuity of packets delivery, apart from the discontinuities occuring in S band between two visibility passes.

The CFS count is frozen upon switch from a nominal mode to Safe Mode. When going back to a nominal mode and except for some few particular cases where it goes back to Zero, the CFS count starts again from the value it had before switching toSAFE Mode.

When entering Safe mode, the LVPROM count shall start from its initialisation value, i.e Zero.

Packet length :

This field permits to identify the length of the TM Source Packet Data Field. The value of this field is defined as follows :

Number of octets in the TM Packet Data Field - 1 =

489 octets = 01E9 hexa

Therefore, the actual length of the complete TM Packet is 7 octets longer (length of the packet header+1) than the value of this field.

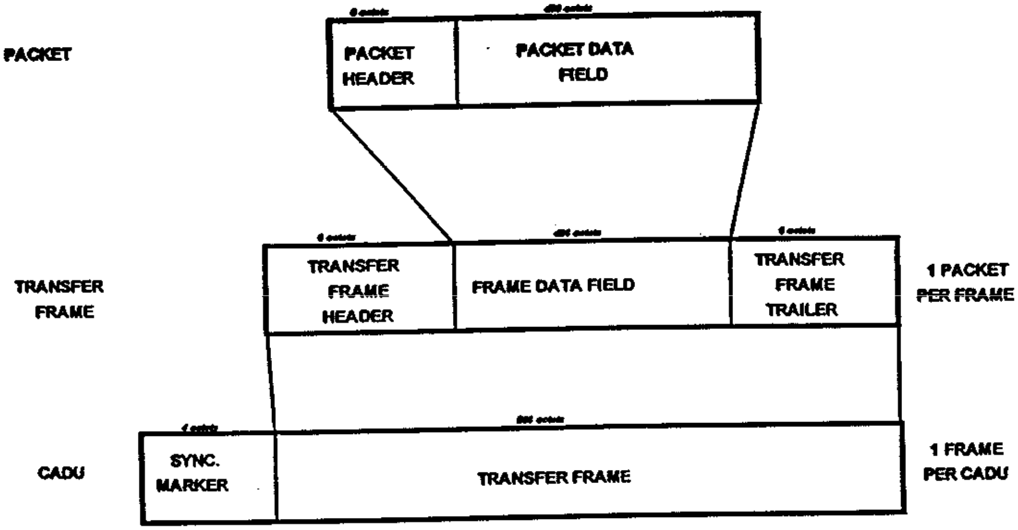


Figure 4.2.1/2 : Summary of the S Band Telemetry System Protocol Units Structure

4.2.2.3 TM Packet Data Field of the RTF

Within the RTF S Band TM Packet Data Field (490 octets), the data are organised in four parts : the data field header (7 octets), the SVM real-time part (137 octets), the PLM real-time part (89 octets) and the programmable part (257 octets) as described on figure 4.2.2/2. Note that the Packet Data Field Header only contains SVM generated data, i.e the time information and the satellite mode.

PACKET DATA FIELD OF THE REAL-TIME FORMAT (RTF)									
DATA FIELD HEADER		USER DATA							
		SVM RT PART			PLM RT PART		PROGRAMMABLE PART		
CCU Time	SL Mode	SVM HK data	SVM Phase Nb	SVM RT Data	PLM Phase Nb	PLM RT Data	Prog. Part Phase Nb	On-request Table ID	Progr. Data
4 octets	3 octets	12 octets	1 octet	124 octets	1 octet	88 octets	1 octet	2 octets	254 octets
VAR	VAR	VAR	VAR	VAR	VAR	VAR	VAR	VAR	VAR

FIGURE 4.2.2./2 : RTF Format Packet data Field

Phase numbers:

Each part of the frame contains a Phase Number, written on 1 octet, allowing the ground to recognise the parameters contained in this frame. The transmission of the whole data necessitates several seconds.

The three parts of the RTF do not require to downlink the same number of frames to constitute on ground a complete "format": 16 frames for the SVM RT part but maybe more for PLM RT part if Test formats are downlinked. Nevertheless, in order to provide flexibility for future evolutions, and independence between the different parts of the S Band frame, note that the three phase numbers may be generated independently.

Note that in Safe Mode (LVPROM used), the PLM phase number is equal to the SVM phase number.

Data Field Header:

• Both the RTF and the TEF have the same Data Field Header.

• The first 4 octets of the Data Field Header are dedicated to the **on-board time** information. This time is in fact the time of the TM frame emission: the SVM RT parameters of the TM frame have been acquired 2 seconds before the beginning the TM frame transmission to ground.

The *on-board time sampling rate* and the *on-board time format* (P-Field) are not provided in the TM source packet.

The on-board time code is defined according to the T-Field standard, i.e it is constituted by four contiguous elements, each of them written over one octet (see RD MMS8). It has a 1/256 second resolution for a capacity higher than 6 months ($2^{32}/2^8$ seconds exactly) and is common to the CCU, the PMC and the ICU's.

SATELLITE ON-BOARD TIME (LSB = 1/256 second)

4TH BYTE	3D BYTE	2D BYTE	1ST BYTE

LSB OF SECOND BYTE = 1 second

• The last 3 octets contains the satellite mode, i.e reflect the TM mode, the flight SW mode, the memory recopy mode, the SVM mode and the PMC mode as seen from the CCU.

Note that when the satellite is in Safe Mode, the SVM part keeps the same structure but most of it is empty. Only a minimum set of data (critical information) is downlinked providing the bus couplers have been switched back on by the ground. The ground is then also able to modify the default SAFE mode format and require additional telemetry to be downlinked within the RTF.

Real Time SVM part:

The SVM real-time part occupies 137 octets and is split into three sub-fields:

- 12 octets of *SVM HK data* containing basic SVM HK information, other than the on-board time and the satellite mode: format type, CFS mode, anomaly counter, PAC report ...
- 1 octet for the SVM phase number,
- and the remaining 124 octets for real-time SVM **housekeeping data** .

The ***housekeeping data*** sub-field is also present in the TEF format.

Real Time PLM part:

The PLM real-time part, 89 octets long, contains the PLM phase number and 88 octets of real-time PLM housekeeping data.

Note that when the satellite is in Safe Mode, the PLM part keeps the same structure but it is completely empty, unless when SVM on-request data are commanded by the ground.

Programmable part:

This last part occupies 257 octets and is split into three sub-fields:

- the programmable part phase number on 1 octet,
- the on-request table ID on 2 octets,
- the programmable data on 254 octets.

On-Request Table ID:

This field identifies which on-board data are downlinked in the programmable part of the S Band Frame.

The table 4.2.2/3 describes the possible SVM on-request data and provides their ID.

When PLM data are downlinked in the programmable part, the 16 bits of the On-Request Table ID are structured as follows:

0 3	4	5	6	7 10	11 15
FIELD TYPE	PL VALID FLAG	F1 VALID FLAG	F2 VALID FLAG	ICU or NIU ICU FORMAT NUMBER	ICU or NIU ICU FRAME COUNTER
see table 4.2.2/4	1	1 or 0	0 or 1	PLM FRAME COUNTER	

Therefore, only the first 6 bits are provided in table 4.2.2/4. The ICU numbers are provided in table 4.2.2/5. More details, in particular about the meaning of F1 and F2, is provided in the PMC Software User Manual.

Programmable Data:

This part contains either SVM data or PLM data, as described in table 4.2.2/3. Note that when the satellite is in Safe Mode, only SVM data can be downlinked in the programmable part.

SVM ON-REQUEST DATA REPORTS IN NOMINAL MODE (WITH CPS)	
Content	ID 10
Extension of SVM RT parameters Default data of "acquisition" type : gyros IDVA + pyro data + SA deployment data	000E h
Extension of SVM RT parameters Default data of "routine" type: gyros IDVA + STD transitions	000C h
SVM Report data (3 tables) 11: Anomalies (TANM) + Modes changes (TCMD) + Particular Events (THIST)	0003 h
Acquisition frozen upon anomaly (TACQ)	0002 h
Differed data (TDIF1)	0004 h
Differed data (TDIF2)	0005 h
Extrema Table (TEXTR)	0001 h
Real Time Data Table (TDTR12)	TBD
Decentralised Memory Dump: PMC1 Dump	00F1 h
Decentralised Memory Dump: PMC2 Dump	00F2 h
CCU Memory dumps	0080 h
SVM ON-REQUEST DATA REPORTS IN SAFE MODE (WITH LVPROM)	
Content	ID
Default data of "Safe mode" type: Extension of SVM RT parameters	8000 h
Memory comparison (TCRCM) (result of a ground test sequence)	C000 h
RAM1 control (TCRP1)	A000 h
RAM2 control (TCRP2)	B000 h
RAM Memory checksum calculation (TCRCK)	9000 h
CCU Memory dumps	0080 h

Detailed data is provided in RD MMS2 (SVM TMTC data definition) and in the database

TABLE 4.2.2/3 : SVM RTF On-request data

10 These codes are those of PPF/Envisat. They may be revised for Spot5 and therefore for Metop.

11 There may be different ID's for each table.

12 This table is the one created in order to answer the real-time oversampling need expressed by ESA/EUM in phase B.

PLM ON-REQUEST DATA		
F1 DATA	F2 DATA	TYPE
PLM avionics Nominal RT format	ICU Nominal RT format	1001
PLM avionics Nominal RT format	PLM avionics RT Test format	1010
PMC Report format	PMC Report format	0101
PMC Table format	PMC Table format	0110
ICU Memory Dump Data	ICU Memory Dump Data	0111
PMC SW Nominal Data	PMC SW Nominal Data	0000
ICU Real-time Test Format	ICU Real-time Test Format	0001
ICU Report Format (first 4064 octets)	ICU Report Format (first 4064 octets)	0010
ICU Report Format (remaining octets)	ICU Report Format (remaining octets)	0100
ICU Secondary processor Dump Format	ICU Secondary processor Dump Format	0011

ICU includes NIU ICU. Detailed data in the PMC software user manual

TABLE 4.2.2/4 : PLM RTF On-request data

INSTRUMENT	ICU NUMBER
ASCAT	TBD
IASI	TBD
MHS	TBD
GOME-2	TBD
GRAS	TBD
AVHRR/HIRS	TBD
AMSUA1/SEM	TBD
AMSU A2/DCS/NIU	TBD
SARP/SARR	TBD

Detailed data in the PMC software user manual

TABLE 4.2.2/5 : ICU Format Numbers

4.2.2.4 TM Packet Data Field of the TEF

The TM Packet data Field of the Table Emptying Format contains :

- the TM Packet Data Field Header, common to the RTF and the TEF, dedicated to some basic SVM HK information such as the On-board time, the SVM phase number, the format type, SW parameters ...,
- a large programmable part (up to 470 octets) used to transmit large SVM on-board tables with a data rate higher than the one provided by the RTF.

The structure of the TEF Packet Data Field is described on figure 4.2.2/6 .

PACKET DATA FIELD OF THE TEF						
DATA FIELD HEADER		USER DATA				
		SVM RT PART		PROGRAMMABLE PART		
CCU Time 4 octets VAR	SL Mode 3 octets VAR	SVM HK data 12 octets VAR	SVM Phase Nb 1 octet VAR	Prog. Part Phase Number 1 octet VAR	On-request TM ID 2 octets VAR	SVM Table 467 octets VAR

FIGURE 4.2.2/4 : TEF Packet data Field

Phase Number:

The phase number, written on one octet, has the same purpose than in the RTF Packet data field.

Data Field Header:

It is identical to the one of the RTF.

RT SVM part:

The SVM RT part occupies 13 octets and is split into two sub-fields:

- the *SVM HK Data* identical to those of the RTF,
- the SVM phase number.
- Therefore, within the TEF format, only basic SVM HK data are downlinked in a fixed manner.

SVM Programmable part:

This part occupies 470 octets and is split into three sub-fields, as for the programmable part of the RTF: - the programmable part phase number,

- the On-request TM ID,
- the SVM programmable data over 467 octets occupied by the dumped tables.

On-request TM ID:

This field identifies which table is written in the large programmable part.

SVM ON-REQUEST DATA	
Content	*ID*
Acquisition frozen upon anomaly (TACQ)	TBD
Differed data (TDIF1) (not with LVPROM)	TBD
CCU Memory dumps	TBD

SVM Table:

The present design only permits to downlink three tables in the TEF Packet Data Field: the Acquisition Table (TACQ), the Differed Data Table (TDIF1) and Dumped Memory Areas.

4.2.3 Transfer layer

This layer acts on the Telemetry Packets which are equivalent to the unsegmented Source Packets in the Metop mission. It provides a mechanism for optimal transmission of its protocol unit, the Transfer Frame. Each Telemetry Packet is encapsulated in a Transfer Frame for transmission through the downlink data channel.

4.2.3.1 HK TM Transfer Frame Structure

The Transfer Frame structure is 508 octets long. Preceded by a 4 octets Synchronisation Marker, it becomes the Channel Access Data Unit (CADU), protocol data unit of the physical layer.

As shown on figure 4.2.3/1, the Header is written on 6 octets, the Transfer Frame Data Field is written on up to 496 octets (i.e the telemetry source packet) and the Transfer Frame Trailer occupies the 6 last octets.

No Reed-Solomon or convolutional encoding is performed at Transfer Layer Level.

←=========================== CADU ===========================→

←================== TRANSFER FRAME ==================→

SYNC MARKER	TM TRANSFER FRAME HEADER				TM TRANSFER FRAME DATA FIELD	TM TRANSFER FRAME TRAILER	
	FRAME ID	MC FRAME COUNT	VC FRAME COUNT	FRAME DATA FIELD STATUS		CLCW	FECW
4 octets	2 octets	1 octet	1 octet	2 octets	496 octets	4 octets	2 octets
1ACFFC1D (hex)	VAR	VAR	VAR	1800 (hex)	VAR	A:0100 B:011C	VAR

FIGURE 4.2.3/1 : S Band Telemetry Transfer Frame Structure

4.2.3.2 Attached Synchronisation Marker

The Synchronisation Marker delimits the boundaries of the fixed-length Transfer Frames. Care should be taken that although this marker does not routinely appear in any other portion of the Transfer Frame, occasional random presence of this pattern elsewhere in the Frame is not precluded.

The 32-bit Synchronisation marker immediately precedes each Transfer Frame and is defined as follows:

"0001 1010 1100 1111 1111 1100 0001 1101"

i.e

"1ACFFC1D (hexa)"

4.2.3.3 HK TM Transfer Frame Header

The Transfer Frame Header permits to detect missing frames (Master Channel Frame Count), to identify the satellite (Satellite ID), to identify frames sequences (Virtual Channel Id and Frame Count) and to provide control information (Frame Data Field Status) to enable the extraction of the telemetry packet on the ground. Its detailed structure is presented on the figure 4.2.3/2 .

TM TRANSFER FRAME HEADER										
FRAME IDENTIFICATION				MC FRAME COUNT	VC FRAME COUNT	FRAME DATA FIELD STATUS				
Version nb	SL ID	VC ID	Operat. Control Field Flag			Second. Header Flag	Synchr. Flag	Packet Order Flag	Segment Length ID	First Header Pointer
2 bits	10 bits	3 bits	1 bit	1 octet	1 octet	1 bit	1 bit	1 bit	2 bits	11 bits
00	VAR	000	1	VAR	VAR	0	0	0	11	all 0's

FIGURE 4.2.3/2 : TM Transfer Frame Header

Frame Identification:

This field, split into 4 sub-fields, identifies which satellite created the frame and the presence of the Virtual Channel.

→ **Version Number :**

This 1-bit field is frozen to "00" corresponding to the only CCSDS version recognised in this standard, i.e version 1.

→ **Satellite Identifier:**

This 10-bit field identifies the satellite itself and the physical link used for downlinking these transfer frames. Its value is provided by ESA and shall be different for the 3 Metop and for the simulator. Their values are :

METOP 1	→	**00 0000 1011**
METOP 2	→	**00 0000 1100**
METOP 3	→	**00 0000 1101**
METOP simulator	→	**00 0000 1110**

→ **Virtual Channel Identifier:**

Only one virtual channel is foreseen for the Metop S Band telemetry. Therefore, the VC ID value is : "000".

→ **Operational Control Field Flag:**

This 1-bit field signals the presence (= 1) or absence (=0) of the CLCW in the Transfer Frame Trailer. It is therefore set to "1" to indicate that the Operational Control Field (CLCW) is implemented and shall appear at each frame transmitted.

Master Channel Frame Count:

This field provides an 8-bit sequential up-count (modulo 256) of each Transfer Frame generated by Metop. The same discontinuities than those occurring for the Packet Source Sequence Count appear in case of switch from Nominal to Safe Mode and vice-versa

Virtual Channel Frame Count:

This field provides an 8-bit sequential up-count (modulo 256) of the frames assigned to the virtual channel defined by the Virtual Channel ID. As far as there is only one VC used for the Metop S Band, this field is equal to the Master Channel Frame Count.

Frame Data Field Status:

This field, split into 5 sub-fields, provides control information to enable the ground to extract the Telemetry Packets from the Frame Data Field.

➔ **Secondary Header Flag:**

This 1-bit field indicates the presence (=1) or absence (=0) of the optional Secondary Header. The Secondary Header is not retained for the Metop mission and therefore this flag is set to "0".

➔ **Synchronisation Flag:**

This 1-bit flag reflects the synchronisation status of the packets inserted in the Frame Data Field. For the Metop mission, it is set to "0", indicating that the TM packets are standard packet synchronously inserted, one after the other. The Frame octets boundaries coincide with those of the Packet octets boundaries.

➔ **Packet Order Flag:**

During Metop real-time S Band transmission to the ground, the order of the TM packets inserted within the Transfer Frames is 'forward" justified (most significant bit transmitted first and sequence counter incrementing increasingly). Therefore, this 1-bit field in set to "0" reflecting that the Packet Sequence Order is Forward, which is the only option recognised by the present PSS standard for Synchronously inserted Packets.

➔ **Segment Length Identifier:**

This 2-bit field identifies, for a given virtual channel, the selected maximum data field length of the standard TM packets inserted in the Transfer Frames.

In the Metop mission, the TM packets are unsegmented and therefore this field is set to "11": a maximum of 65536 octets is authorised but a TM packet shall never exceed 496 octets for the Metop mission. Note that, for each VC, this field shall remain fixed for a well defined mission phase.

➔ **First Header Pointer:**

Because the S Band TM packets are synchronously inserted in the frames and because the frames are ACTIVE (VC transmitted and frame data field not empty), this 11-bit field contains a binary value, called 'P'. 'P' specifies the number of the octets within the Frame Data Field which contains the first octet of the first Packet Header structure, starting at octet n°0 (beginning with the first bit of the Frame Data Field).

In the Metop case, there is one HK TM packet by Transfer Frame and therefore, the 11-bit 'P' equals "00000000000".

4.2.3.4 HK Transfer Frame Data Field

This field contains one entire and only one HK TM Source Packet, and is therefore 496 octets long.

4.2.3.5 HK Transfer Frame Trailer

The Transfer Frame Trailer provides a mechanism for inserting the two following information in the last 6 octets of the Transfer Frame : the CLCW on 4 octets and the Frame Error Control Word on 2 octets.

Command Link Control Word (CLCW):

The CLCW inserted in this Operational Control Field is the 4-octet word generated by the Telecommand Transfer Layer for standard real-time reporting of TC related on-board error detection (see § 4.1.7.3 and RD MMS9/§ 7 for details). Its presence is mentioned by the Operational Control Field Flag within the Transfer Frame Header. The CLCW reporting enables the ground to implement automatic TC retransmissions.

Each EDR chain generates its own CLCW. For a given chain, the 2 first octets of the CLCW are constant. Each CLCW will be sent to the ground, 1 frame out of two:

EDR chain A CLCW (2 first octets) = 0100 h

EDR chain B CLCW (2 first octets) = 011C h

Frame Error Control Word (FECW):

This 16-bit field permits to detect errors which may have been introduced during the transmission through the downlink channel. No attempt should be made to use it for error correction. It is mandatory because no Reed Solomon encoding is planned for the Metop mission S Band data. The value of the Satellite Identifier, within the Transfer Frame Header, shall indicate the presence of this word. The standard encoding/decoding procedure (see RD MMS9 / § 1) produces a Frame Check Sequence placed in the FECW.

Its characteristics are those of a CRC, generally expressed as follows :

- the generator is polynomial : $g(x) = x^{16} + x^{12} + x^5 + 1$
- the CRC is calculated over the TM Transfer Frame less the final FECW and less the Attached Synchronisation Marker
- both encoder and decoder are initialised to "all one's" state for each Transfer Frame

The CRC has the following capabilities:

- All error sequences composed of an odd number of bit errors will be detected
- All error sequences containing two-bit errors anywhere in the encoded block will be detected
- If a random error sequence containing an even number of bit errors (>= 4) occurs within the block, the probability that the error is undetected is about 2^{-15}
- All single error bursts spanning 16 bits or less will be detected provided no other error occur within the block.

4.2.4 Physical layer

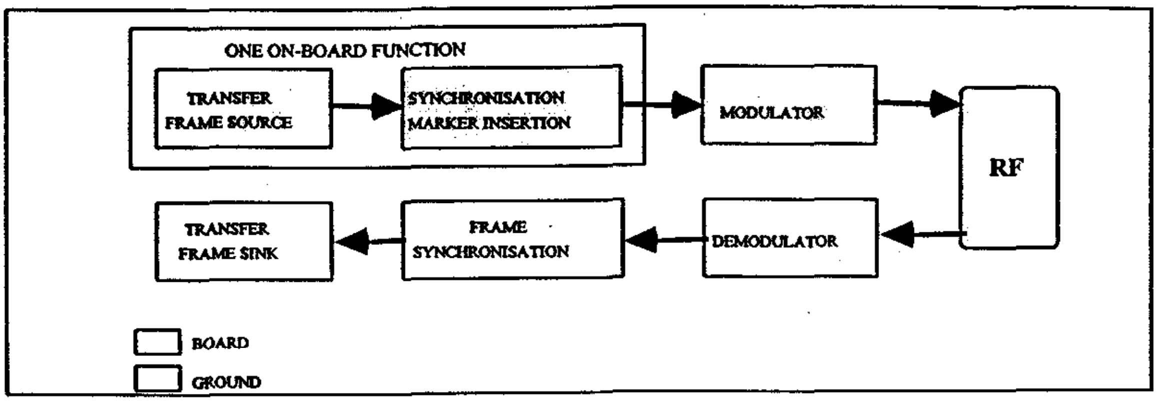
This layer specifies the physical connection between the transmitting end, i.e Metop, and the receiving ground station, i.e Kiruna. The S Band frames transmission is permanently activated. The protocol data unit of the physical layer is the Channel Access Data Unit (CADU).

4.2.4.1 CADU configuration

The figure 4.2.4/1 below shows the CADU (Channel Access Data Unit) configuration chosen for Metop: the CADU is the assembly of a synchronisation marker with the Transfer Frame.

No encoding is performed.

Because of the SPL modulation which ensures a sufficient symbol transition, the Randomiser function mentioned in RD ESA3 is not required.



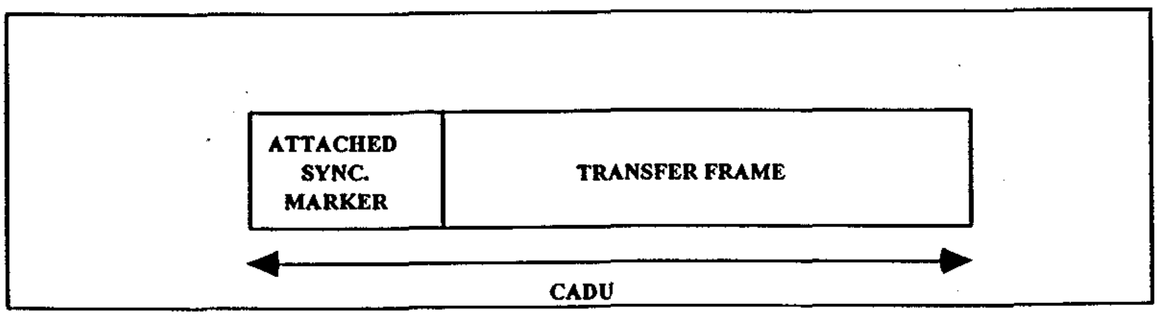


Figure 4.2.4/1 : CADU configuration

The value of the Synchronisation Marker is :

1 A C F F C 1 D hexa

4.2.4.2 TM Packet telemetry mechanism

This paragraph presents briefly the TM packet mechanisms at work. More details are provided in RD MMS9 (§ 2). There are four main procedural steps in the ground data capture process:

- Transfer Frame Acquisition
- Virtual Channel Demultiplexing
- Telemetry Packet Extraction.

The Source Packet Reconstruction is not needed because the Telemetry Packet is equal to the Source packet (no segmentation).

Transfer Frame Acquisition:

The Transfer Frame Acquisition Processor shall test the incoming Transfer Frames and each frame is passed to the next process with a quality label : GOOD or BAD.

The procedure ends by processing the Primary Headers of all GOOD frames.

Virtual Channel Demultiplexing:

After acquisition, GOOD Transfer Frame enter the VC Demultiplexing processor. For each incoming frame, the following on-line process take place:

- Read-out VC ID,
- VC Frame count sequence verification,
- Read-out Synchronisation Flag.

Telemetry Packet Extraction:

The Telemetry Packet Extraction processor will extract synchronously the Telemetry Packets from the Frames. For each incoming frame, the following Frame Data Field Status fields are processed on-line:

- Packet Order Flag
- Segment length ID
- First Header Pointer.

The chaining process is straightforward because the S Band TM Packets are unsegmented.

4.2.4.3 Physical Layer numerical characteristics

This paragraph describes the physical characteristics to be used for the establishment of the S Band TM link budgets. The Metop EIRP is not provided here because the budgets shall determine the EIRP value permitting to fulfil the margins requirements. In particular, the EIRP calculation has to consider:

- the worst case gain values with antenna mounted on SL structure,
- the minimum RF power values (at EOL and considering also the transmission losses, ie modulation losses, amplifier losses, filtering losses and transmission cabling losses,
- the amplifier thermal variation : - 0,5 dB (TBC).

More precisely, these budgets shall be computed for :

- the S Band Eumetsat station, i.e Kiruna (TBC), whose geographical characteristics are presented at § 3.2.
- a 5° minimum elevation ,
- the reference (whole range) and drift orbits defined in RD MMS 1,
- 3 dB margin for typical cases,
- 1 dB margin in worst cases,
- the RF spectrum mask of a trapezoidal form as shown on figure 4.2.4/3 (typically, the band between the -15 dB points corresponds with the occupied bandwidth for this mask)

The attenuation due to atmospheric phenomena i.e rain, clouds, gas, scintillation which is not exceeded for 99.9% of the time shall be considered in the link budget.

The other characteristics are presented in table 4.2.4/2. All parameters of this table are worst case EOL values, unless otherwise specified.

METOP CHARACTERISTICS 13	
Carrier Frequency	2230.0000 MHz
EIRP	*to be determined by link budgets*
Carrier Polarisation (*) nadir zenith	Earth facing antenna : LHCP Other antenna : RHCP
Axial Ratio	□5.5 dB for 0<□90°
Data rate	4096 bps
Data modulation	SP-L/PSK
Carrier Modulation	PM
Sub-carrier Frequency	65.536 KHz sinewave
Modulation index (**) TM only (for information) simultaneous TM & ranging & TC (for budget)	 *ESA standard: > 1rad pk* precise value TBD by MMS TM: 1.3 rad +/- 10% Ranging: see § 4.3.4.2 TC: 0.2 rad +/- 10%
Spectral mask for TM signal	see figure 4.1.6.2

(*) Assumption is made that ground station will use a combiner for reception of both co-polarised and cross-polarised signals as emitted by the satellite.

(**) MMS shall determine or has determined modulation indexes values compatible with the limits imposed by the ESA standards and with the link budget margins to achieve.

LINK CHARACTERISTICS	
Link Quality	BER < 10[illegible] (i.e SPOT) probability of frames with errors < 10^{-6}
Maximum power allowed for DSN and Radio Astronomical bands protection	See annex 2
Maximum PFD (*)	-154 dBW/m^2. 4 KHz for 0<□5 -154+0.5(□5)dBW/m ^{2}.4 KHz for 5<□25 -144 dBW/m^2. 4 KHz for 25<□90

(*) Following assumptions shall be used in the PFD calculation:
- peak of TX spectrum density including possible residual carrier,
- typical values for TX power and antenna gain over elevation,
- average values for antenna gain along azimuth,
- path loss : 0 dB.

KIRUNA CHARACTERISTICS	
G/T	21 dB/K at 5° elevation
Techno losses for TM & carrier recovery	1.5 dB
Carrier Acquisition Bandwidth (PLL)	*100 Hz*
Axial Ratio	1 dB

TABLE 4.2.4/2 : TM Physical Link Characteristics

13 Today's version of the link budgets (i.e the SRR version) account for the previous value of the downlink frequency provided by ESA, i.e 2215 MHz.

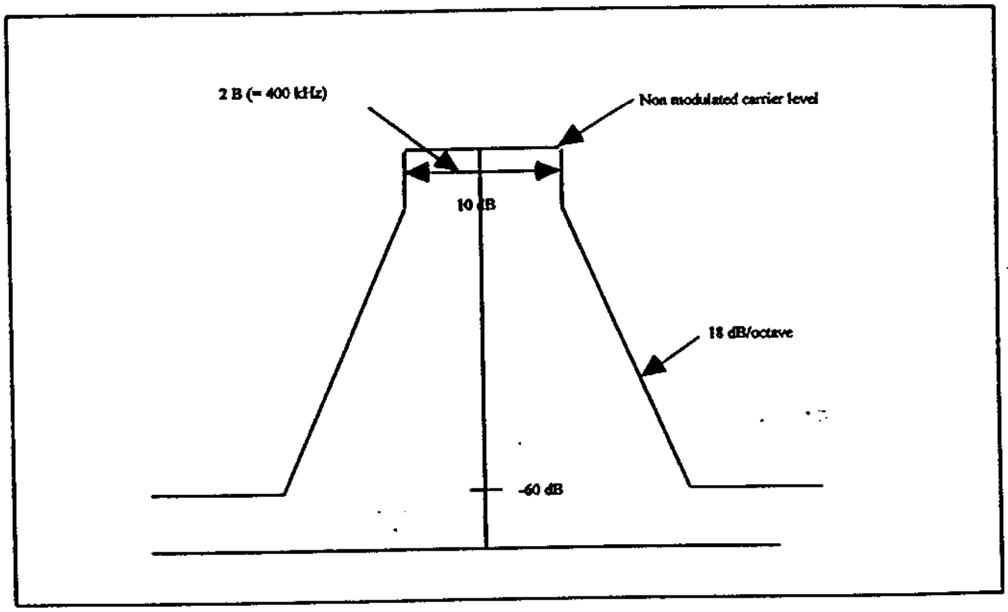


TABLE 4.2.4/3 : TM Radio Frequency Spectral Mask
(PCM with sub-carrier)

4.3 RANGING

4.3.1 Overview

The purpose of this paragraph is to:

- ensure compatibility between the Metop transponder and the Range and Doppler facilities of the ESA ground network to be used for Metop,
- provide criteria for those Metop equipments which may influence the accuracy of the measurements. This accuracy is not to be confused with the performance of the overall orbit reconstitution process, which is also influenced by effects such as : the modelling of gravitational and non gravitational forces, the modelling of propagation effects, the pre-processing and screening of data, the performance of the ground softwares ...

Note that the requirements addressing the ground facilities capacities are not included in this document.

The same spacecraft transponder shall be used for ranging, receiving commands and transmitting telemetry. Moreover, it shall be possible to perform simultaneously ranging and commanding or telemetry downlink.

The five main functions of a global range and Doppler Tracking system are:

-1-the Earth-to-Space link function, employing communication, process control from ground, signal generation and Earth-to-Space communication;

-2-the Metop transponder functions (ground calibrated);

-3-the Space-to-Earth link function, employing Space-to-Earth communication, Doppler measurement, replica generation, correlation, process control and interfacing to the telemetry processing;

-4-the link-control function, resident partly in the Space-to-Earth and Earth-to-Space communication and partly in the process control;

-5-the data acquisition function concerned with collection, measurement, processing and transfer of data to the control centre.

4.3.2 Metop transponder Functional requirements

Metop transponder function shall consist in:

- reception of the RF signal,
- coherent down-conversion and phase tracking of the remnant carrier,
- phase demodulation of ranging and telecommand signals,
- independent AGC of the remnant carrier and baseband video signal chain,

- selection of the Space-to-Earth link frequency source, between a free running oscillator (not coherent mode) and the phase-locked reference frequency (coherent mode) of the receiver,
- selection of the modulating source between, ranging only and ranging-and-telemetry,
- modulation of the downlink carrier by TM video signal and turn-around ranging signal,
- upconversion of the carrier to the assigned Space-to-Earth frequency, i.e TBD Hz (within 2200 MHz - 2290 MHz),
- transmission to Earth.

4.3.3 Frequency and spectrum requirements

4.3.3.1 Spectral requirements

A/Sinewave Tone:

The ranging baseband signal consists in a 114.688 kHz sinewave (tone-TBC), which is phase modulated by a series of codes, used for ambiguity resolution. The tone frequency has been defined by ESA in order to be compatible with the Metop transponder ranging bandwidth (noise bandwidth = 300 kHz) and the frequency selection rules defined in B/.

Each code is synchronised to the tone and can be derived from it by means of the following expression:

$$C_n = Q_1 \oplus Q_2 \oplus Q_3 \oplus \dots\dots\dots Q_n$$

where:	C_n	is the n-th code
	n	1, 2, 3 ...13 (codelength = 2^{13})
	$\oplus$	stands for Exclusive OR
	Qi	are squarewaves at frequencies 2^{-i} x ft (i varying from 1 to 13) They may be generated as the outputs of a divide-by-two flip-flop chain driven by the tone.
	f_t	is the tone frequency, i.e 114.688 kHz (TBC)

A simple way to transmit the code C_n is to transmit the previous code C_{n-1} followed by its logical complement. Each code is transmitted for a fixed period of time to perform correlation and phase alignment at the receiving site, i.e Metop transponder.

The RF carrier is phase modulated with this baseband signal.

The ranging signal spectrum changes during the ambiguity resolution process, owing to the different transmitted codes. The spectrum produced when the tone alone modulates the carrier has discrete lines at the carrier frequency plus or minus integral multiples of the tone frequency. During the acquisition process, the code number increases and the code power is spread over an increasing number of lines. When the last step of the ambiguity resolution is completed, the code has created a quasi-continuous baseband spectrum which extends (between first nulls) from 0 Hz to twice the tone frequency.

B/ Frequency selection Rules:

The tone frequency shall be compatible with the requirements related to the interference between ranging and telemetry and between ranging and telecommand.

Interference between ranging and telemetry

In order to minimise this interference, the following conditions should be met:

$|f_t - f_{sc}| \geq 2.5 f_{symb}$

$|f_t - 3 f_{sc}| \geq f_{symb}$

$|K f_{symb} - f_t \times D| \geq 5$ Hz

where:

f_t		= tone frequency 114.688 kHz (TBC)
f_{symb}		= telemetry symbol rate
		= f_{sc} because of SPL modulation
f_{sc}		= telemetry subcarrier frequency, i.e 65.536 kHz
K		= any integer value
D		= one-way Doppler factor = $\frac{\sqrt{1-v/c}}{\sqrt{1+v/c}}$
v		= Metop radial velocity (worst case, 5° elevation)
c		= speed of light

Note that the interference level is strongly dependent on the ranging signal-to-noise density ratio in the Metop transponder. The above guidelines are applicable to transponders with a high S/N_0 ratio[14].

14 The precise definition of a "high S/No" ratio is TBD by ESA.

Interference between ranging and telecommand

Because simultaneous ranging and command shall be possible, the following conditions shall be met:

$$|2\,m\,f_{TC} - f_t \times D| \geq 5\ \text{Hz}$$

$$|(2n-1)\,f_{TC} - f_t \times D| \geq 2\,f_{bTC}$$

where:	f_t	= tone frequency 114.688 kHz (TBC)
	f_{bTC}	= command bit rate, i.e 2 kbps
	f_{TC}	= telecommand subcarrier frequency, i.e 8 kHz
	m,n	= any integer values
	D	= one-way Doppler factor = $\frac{\sqrt{1-v/c}}{\sqrt{1+v/c}}$
	v	= Metop radial velocity (worst case, 5° elevation)
	c	= speed of light

One shall consider that, once the above rules are met, no additional signal degradation due to interferences will be considered in the link budget[15].

4.3.3.2 Modulation requirements

Modulation technique

The modulation on both Earth-to-Space and Space-to-Earth links shall be PM.

Modulation indexes

Modulation indexes shall be determined by MMS so that they remain in the limits specified by ESA (standard values) and permit a compliant link budget.

These values are summarised in the § 4.3.4.1 and 4.3.4.2.

It is important to note that the link budgets could be improved if these values are optimised.

Telecommand and ranging

Telecommand and ranging can be carried out either in time sharing or simultaneously. For normal operations, and if the link performance permits this approach, simultaneous ranging and telecommand shall be adopted to avoid scheduling conflicts. The following constraints shall be taken into account:

- the telecommand signal will form part of the demodulated (baseband) signal in the spacecraft transponder and will therefore appear in the Space-to-Earth link. Telecommand retransmission

15 TBC by ESA

might create undesirable effects on the transmitted spectrum, owing to power sharing and spectrum overlap.

- overmodulation of the Space-to-Earth link and telemetry signal loss may occur owing to the slow response of the on-board baseband AGC when the telecommand signal appears in an essentially noise-limited amplifier. These effects can generally be avoided operationally, by ensuring the presence of a ranging signal in the ranging channel for the whole period in which this is operational.

For periods where the link performance makes continuous ranging operations undesirable, the mission should be designed to operate ranging and telecommand in time sharing 16.

4.3.4 Earth Stations requirements

This paragraphs lists some ground requirements necessary to assess the compatibility of the Metop transponder with the whole set of ranging specifications. Note that the axial ratio are those specified for the HK TM and TC physical layers.

Budgets shall be performed with worst case modulation indexes, i.e simultaneous ranging & TC or TM.

4.3.4.1 Earth-to-Space link

Tone frequency (f_t)	114.688 kHz (TBC by ESA)
Code period Code length	$2^{13}/f_t$ 2^{13}
Modulation scheme	PCM/PSK/PM
Tone modulation index	45° during ambiguity resolution 28° during measurement phase
Carrier modulation index (*) ranging only (for information)	ESA standard: < 1.2 rad precise value: TBD by MMS
ranging and telecommand (for budget)	ESA standard : Combined index < 1.4 rad pk precise value: TBD by MMS
Spurious signals	< -60 dBc
Phase noise density: for 10Hz < f < 1 MHz: for f > 1 MHz:	 - 48 - 10 log(f) dBc/Hz < -108 dBc/Hz
Reference frequency stability	+/- 3 10^{-5}
Group delay variation vs time	20 ns/12 hours

(*) MMS shall determine modulation indexes values compatible with the limits imposed by the ESA standards and with the link budget margins to achieve.

4.3.4.2 Space-to-Earth link

The following applies to the remnant carrier modulation case.

16 It is still unknown if such periods exist.

Carrier phase noise	< 5° RMS
Remnant power in modulated carrier (function of modulation indexes)	> - 10 dBc
Modulation induced power, integrated over +/- 800 Hz around carrier	> - 30dBc Note that this is not specified to the transponder manufacturer
Induced discrete spectral lines	> -30 dBc within carrier frequency +/- 60 kHz, due to carrier modulation by ranging
Carrier modulation index (*) Ranging only (for information)	ESA standard: > 0.1 rad pk and < 0.7 rad pk precise value: TBD by MMS
Ranging and telemetry (for budget)	Ranging: 0.4 rad +/- 10% TM: see table 4.2.4/2

(*) MMS shall determine or has determined modulation indexes values compatible with the limits imposed by the ESA standards and with the link budget margins to achieve.

4.3.5 Other Metop transponder requirements

4.3.5.1 Range and Range Rate operations

The transponder shall be of coherent type, i.e the Space-to-Earth link carrier shall be derived coherently from the Earth-to-Space link carrier, through multiplication by the turn-around-ratio : 240/221.

The ranging signal shall be demodulated in the transponder from the Earth-to-Space link carrier, and then be remodulated on to the Space-to-Earth link carrier.

Two independent mode selections shall be accessible by ground command:

- Transponder coherent/non coherent
- Ranging ON/OFF.

4.3.5.2 Group delay

The group delay of the ranging channel shall be constant within +/- 50 ns for the chosen tone frequency from the residual carrier as seen from the transponder interface.

This specification applies over the nominal range of Doppler, input level, power supply, temperature and life time.

If required by mission analysis, it shall be possible to know the total on-board delay at any time to a TBD17 accuracy (at most +/- 5 ns), by means of telemetred data of voltage, temperature and predicted Doppler.

Calibration data18 of group delay measured at the tone frequency versus Doppler, input level, temperature and voltage shall be produced by the manufacturer, unless he can demonstrate that the data are insensitive to one of these parameters.

4.3.5.3 Transponder monitoring

In order to verify the correct functioning of the transponder, the following telemetry information shall be downlinked:

- operation mode
- receiver AGC
- receiver static phase error (SPE)

---

17 This is TBC by ESA: no specific mission analysis requirement exists today. Accounting for such a requirement implies that the transponder manufacturer shall be fitted with the necessary facilities (cost impact).

18 ESA shall provide a precise definition of the expected calibration data.

- lock status
- receiver and transmitter temperatures
- secondary voltages of receiver and transmitter DC/DC converters
- transmitter output power.

4.3.5.4 Amplitude response

The amplitude response of the ranging channel (RF in to RF out) shall be +/- 0.5 dB, in the bandwidth today TBC by MMS.

The noise bandwidth shall be ≤ 300 kHz.

4.3.5.5 Phase Modulation

A positive phase shift on the Earth-to-Space link shall give rise to a positive shift on the Space-to-Earth link.

4.3.5.6 Baseband AGC

An AGC system in the video ranging channel, working to keep constant RMS or average level of signal-plus-noise, shall be employed. The AGC response time shall be less than 30 ms.

4.3.5.7 Carrier phase stability

The following value is applicable to the complete assembly of the transponder.

For the combined influence of temperature and supply voltage over the operational range, input power over any 10 dB within the transponder dynamic range and uplink frequency shifts of +/- 3 10^{-5} [RD ESA4], the peak-to-peak phase shift[19] of the transmitted carrier shall not exceed Π/2

4.3.5.8 Effective modulation index

As specified in § 4.3.4.

Link design shall ensure that the effective Space-to-Earth link ranging modulation index is always > 0.01 rad.

---

19 Note that this 3 10-5 value is different from the ones provided in RD ESA5 where one finds: +/- 2 10-5 for the transmitter and +/- 1.7 10-5 for the receiver.

4.3.5.9 Ranging performances

Range measurement accuracy must not be confused with the orbit determination accuracy. This paragraph presents minimum requirements for those aspects which determine the end-to-end performance of the ranging system. The accuracy of the range measurement is affected by several error sources. Those related to the satellite are described below.

On-board transponder error:

An error may be introduced by the uncertainty of the delay, when going through the on-board transponder. This error is proportional to the instability of the transponder group delay.

In the absence of calibration requirements, the specified overall group delay stability must be taken, i.e 50 ns leading to 7.5 m (see § 4.3.5.2).

If a specific calibration requirement is provided, the error shall be derived from the allowed calibration accuracy[20].

Thermal noise:

The error due to the influence of the thermal noise at the input of the Earth-to-Space link receiver may also affect the ranging performance. No specification related to the on-board receiver is available yet[21].

4.3.5.10 Input signal range

Correct functioning of the transponder, for ranging purposes, shall be possible over an input signal range of -115 dBm to -50 dBm (300K noise input).

20 No mission-specific calibration requirement exists today.

21 RD ESA4 (PSS-104) only specifies the ground receiver.

5 MEASUREMENT DATA DOWNLINK

5.1 DATA FORMATTING AND COMMUNICATION MODEL

5.1.1 Space-to-ground links

The Measurement Data are downlinked via 3 space-to-ground links: the X-band for the global data, the VHF band for the LRPT link and the L band for the HRPT link.

5.1.1.1 Global Data

The Global Data link, in X Band, is intended for the dump of the data recorded on-board, in the SSR. It includes the instruments measurement data within the instruments source packets, the satellite packet and the administrative packet multiplexed on 10 virtual channels. All the packets transporting HK-like information (ADMIN packet, SL packet and GRAS position and time packets) are downlinked on the same virtual channel.

The SSR dump periods are dictated by the coverage achieved on each orbit, when using the baseline routine network. When downlink is requested, data transmission is performed in a FIFO mode.

5.1.1.2 LRPT & HRPT

The LRPT and HRPT links are meant to provide local users with real-time data, directly routed from the FMU to the transponders.

Both LRPT and HRPT links include the satellite packet, the GRAS position and Time packets and the ADMIN packet. They only differ by the choice of the instruments source packets. The HRPT link transmits all the instruments sources packets whereas the LRPT link does not transmit AVHRR HR data, A-DCS, IASI, ASCAT, GRAS Tracking, GRAS Occultation and OMI. Most of the Virtual channels of both links are encrypted.

The Space to Ground specifications for the HRPT and LRPT links are provided in a separate document: RD EUM1.

5.1.2 CCSDS generalities

5.1.2.1 Overview and definitions 22

The space-to-ground measurement data flows are supported by the CCSDS network concept. This network is composed of several layers:

- the Application Layer for producing the instruments data
- the Network Layer (called Path layer in the RD ESA09) routing the instruments packets in function of their Application Process ID's
- the Data link Layer (called Space Link layer in the RD ESA09) multiplexing the instruments packets onto Virtual Channels Data units (VCDU), transformed into Coded Virtual Channels Data units (CVCDU) and organised onto Virtual Channels (VC) for transmission to the ground,
- the Physical Channel Layer, supporting the physical data transfer to the ground.

Figure 5.1/1 provides an overview of the Space-to-Ground Measurement data flow. It only shows the CCSDS services and functions applicable to the Metop mission. Its understanding requires the definition of several concepts: Service Data Unit (SDU), Protocol Data Unit (PDU) and Primitive.

A **SDU** is a Data Unit which is provided as an input to a service, or which is an output by that service.

A **PDU** is a data structure which operates across a layer within a distributed system in order to implement the service offered by that layer. A summary of the X band PDUs is presented on figure 5.1/2.

22 The nomenclature used in this specification is that of the RD ESA1 although it is different from the one used in the CCSDS document ESA RD11. This choice has been advised by ESA in order to remain coherent with NASA terminology of RD NASA1 (MSG and GOES-NEXT generation).

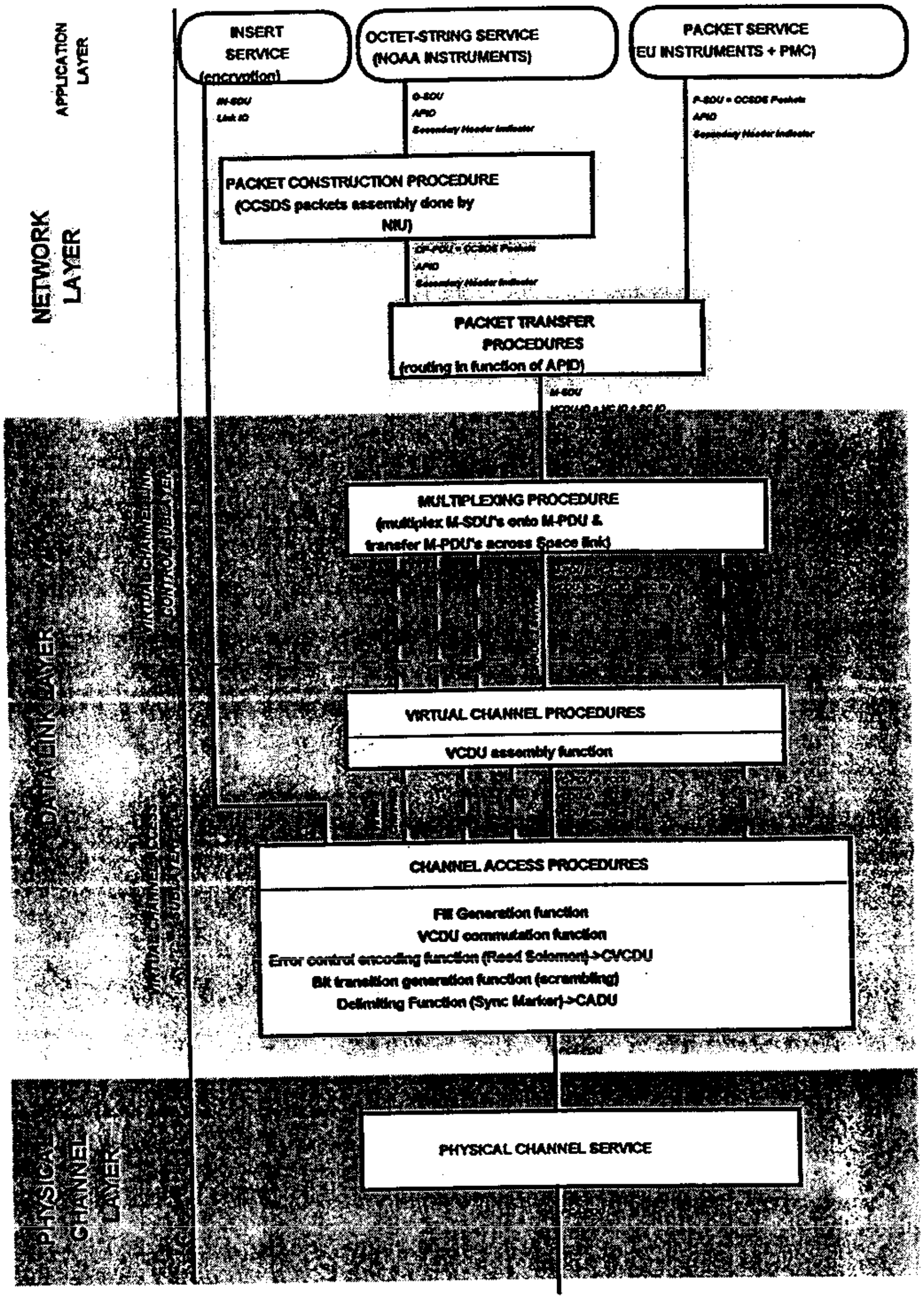


Figure 5.1/1 : Metop Space-to-ground Measurement Data flow

A **"primitive"** is an abstract model of the logical exchange of user data and control information between network layers or sublayers.

5.1.2.2 Network Layer (= Path layer)

The Network Layer provides efficient, high throughput, unidirectional data transfer between single Source User Applications to the Destination User Applications. The protocol Data unit within the Network layer is the CCSDS Source Packet.

Above this service, the Application Layer provides the input to the network layer:

- the ICU instruments (IASI, MHS, ASCAT, GOME-2, GRAS) directly provide their data as CCSDS Standard Source Packets,
- the NOAA instruments (AVHRR, HIRS, AMSUA1/A2, SEM, A-DCS) provide their data (Octet-string service) to an interface unit, the NIU, which applies a Packet Construction Procedure (within the NW layer), in order to generate standard CCSDS Source packets,
- the PMC directly provides the satellite housekeeping data within one standard CCSDS packet, called the Satellite Packet,
- the PMC also directly provides the administrative messages within one standard CCSDS packet,
- the PMC extracts data from the GRAS ICU format and creates two additional packets dedicated to position and time.

No segmentation is applied to the X Band packets. The NW layer transfers the CCSDS packets to the Data link Layer, via the M-SDU containing CCSDS packets immediately following each other. The M-SDU are transmitted together with the following necessary information: the Application Process ID (AP ID) and the Virtual Channel Data Unit ID (VCDU-ID).

For the Metop mission, 30 different packets available (corresponding to 30 different APID) are available for downlink via the X Band link:

- the Satellite Packet transporting the full S band frame,
- the ADMIN packet transporting the administrative messages,
- 2 GRAS Time and Position packets,
- 12 ICU instruments packets,
- 14 NOAA instruments packets.

5.1.2.3 Data Link Layer (= Space Link Layer)

The Data link layer is organised in two sub-layers: the Virtual Channel Link Control Sublayer and the Virtual Channel Access Sublayer.

Via a multiplexing procedure, the **Virtual Channel Link Control Sublayer** multiplexes the CCSDS packets which have to be delivered over the same Virtual Channel and breaks them into blocks which fit exactly the data field of the next layer Protocol Data Unit, i.e the VCDU (VC-PDU). The different streams are routed in different Packet Channels, identified by the APID's present in the CCSDS packets header. The protocol Data Unit within this sublayer is the M-PDU.

Within the **Virtual Channel Access Sublayer**, the VCDU assembly function organises the M-PDU into Virtual Channel Data Units (VCDU) and then into error protected Coded Virtual Channel Data Units (CVCDU). The Channel Access procedure provides the functions to switch all of the individual virtual channels into several Channel Access Data Units (CADU's) and then into one Physical Channel Access Protocol Data Unit (PCA-PDU).

5.1.2.4 Physical Channel Layer

This layer is defined by the physical characteristics of Metop and the ground receiving stations supporting the transfer of the PCA-PDU's through the Space medium.

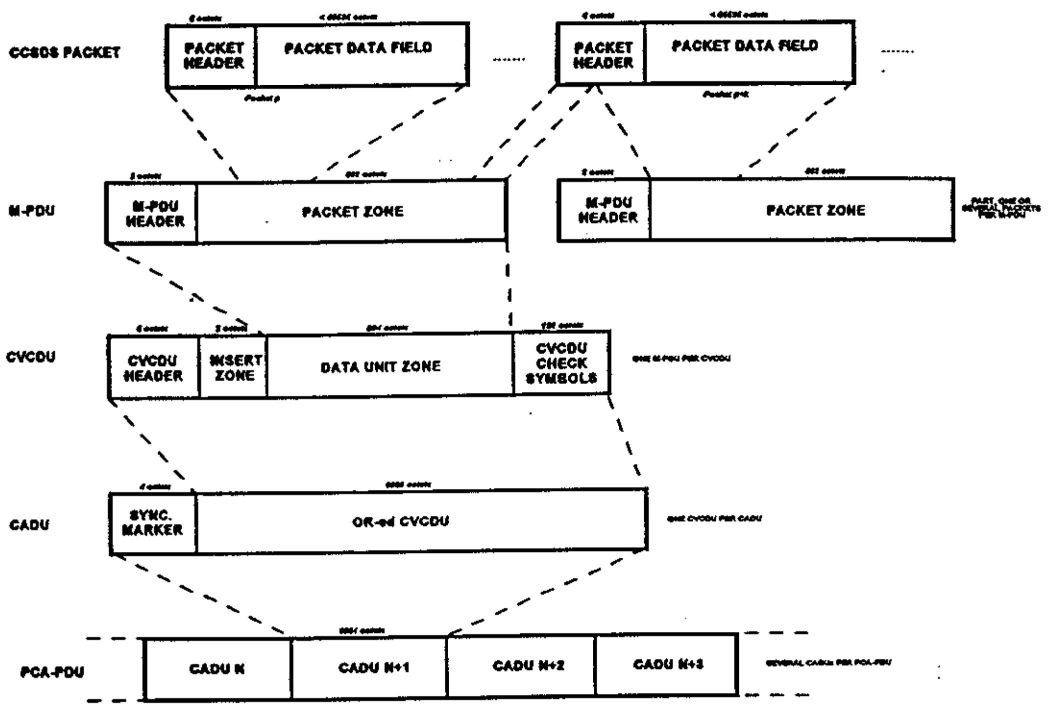


Figure 5.1/2 : Metop X Band PDUs summary

5.1.2.5 Network layer (= Path Layer)

In the frame of Metop, the Network Layer offers, within the Space-to-ground link, two services supported by 2 procedures.

5.1.2.6 Network Layer Performance

The baseline performance required from the Network layer is that:

- the probability of a bit error in a packet shall be less than 10^{-9} (TBC),
- the probability of a packet loss (error in header) shall be less than 10^{-6} (TBC)[23].

This applies to errors generated by on-board PDH.

5.1.2.7 Network Layer Services

The Network Layer offers two services relying on the use of a pre-configured route between the Source User Application and the Destination User Applications: this route is uniquely identified by the Application Process Identifier (APID).

5.1.2.7.1 Octet-String Service

This service transmits delimited strings of user octets, the Octets Service Data Units (O-SDU) produced by the NOAA instruments, across the CCSDS network and build them into CCSDS Packets on the user's behalf by the Packet Construction Procedure. In the Metop case, this is performed by the NIU.

5.1.2.7.2 Packet Service

This service transfers the Packet Service Data units (P-SDU), i.e the CCSDS packets, preformatted by the European instruments ICU's, intact across the CCSDS network. The MPU modifies the MHS CCSDS packets by inserting the UTC time stamp and updating the PEC. No additional formatting is required from the Network procedures.

23 Note that this requirement is not to be fulfilled simultaneously with the the VCDU loss probability requirement (§ 5.1.3.1.2): these two specifications are meant to control 2 different possible sources of data quality degradation, i.e errors introduced by the NIU and the FMU in 2 different steps of the data formatting.

5.1.2.8 Network Layer Services Primitives

The parameters for the Network service primitives are:

- O-SDU : The Octet Service Data Unit, a delimited octet-oriented data unit whose content and format are unknown to the Network Layer.
- P-SDU : The Packet Service Data Unit, identical to the CCSDS standard Source packet.
- APID : The Application Process Identifier, mandatory parameter used to uniquely qualify the route of the CCSDS packets.
- Secondary Header Indicator :

  Indicates the presence of the secondary header, used to provide Time information in the Metop case.
- Path ID: Identical to the APID in the Metop case.

5.1.2.9 Packet Construction Procedure

This procedure provides the Packet assembly function which builds-up the headers of the created CCSDS Packet by generating information such as the secondary header flag and the sequence counter.

5.1.2.10 Packet Transfer Procedure

This procedure provides the Transfer function, which uses the APID to route the CCSDS packet to the Data Link Layer. It generates the Transfer Frame envelope for transmitting packetised data over a noisy Space to ground channel.

5.1.3 Data Link Layer

5.1.3.1 Data Link Layer Performance

5.1.3.1.1 Grades of Service

Three grades of Services are offered within the Data Link Layer. Because of the use of CVCDU's on Metop, user data receive a Grade 2 Service : service data units are delivered through the Data Link Layer, possibly incomplete, but with their sequence preserved and with a very high probability of containing no error induced by the Data Link Layer. Within this grade, the performance probabilities are improved by the error-correcting capabilities of the Reed-Solomon Code. The probability that a VCA-SDU is missing shall be inferior to 10^{-7} for the Grade 2 Service.

5.1.3.1.2 VCA Performance

The error probability for on-board errors generated by the PDH are specified in the PLM Requirement Specification.

5.1.3.2 Virtual Channel Link Control Sublayer

In the frame of Metop, the Virtual Channel Link Control Sublayer offers, within the Space-to-ground link, one service supported by 1 procedure.

5.1.3.2.1 Multiplexing service

The multiplexing service permits to transfer the multiplexed CCSDS Packets across the Data Link Layer. The multiplexed packets, i.e the VCDUs, are to be downlinked within the same specified virtual channel.

In the case of Metop, this service is performed by the NIU in a FIFO manner: the packets are stored in an internal FMU buffer until the full VCDU packet zone is filled up.

5.1.3.2.2 VCLC Service Primitives

The parameters for the Network service primitives are:

- M-SDU : The Multiplexing Service Data Unit whose header content is known and used by the VCLC sublayer.
- PC ID : The Packet Channel Identifier, locally expressed by the AP ID, for which some values are reserved to assignment and administration by CCSDS.
- VCDU-ID : The Virtual Channel Data Unit Identifier, consisting in the concatenation of the Spacecraft Identifier and the Virtual Channel Identifier.

5.1.3.2.3 Multiplexing Procedure

The Data Protocol Unit of the Multiplexing procedure is the M-PDU, created by the Multiplexing function. This function multiplexes M-SDUs together into an M-PDU for transfer. It constructs separate M-PDU for each VC, as specified by the VCDU-ID parameter. The M-PDU shall be used as input for the Data Field for the next layer Protocol Data Unit, i.e the VCDU (or VC-PDU).

The M-PDU has a fixed length of 884 Octects (M-PDU Header plus Packet Zone), identical for all VC, and specified in order to match the data field of the VCDU.

A "First Header Pointer" field is set by the multiplexing function, to indicate the location of the first octet of the first M-SDU.

5.1.3.3 Virtual Channel Access Sublayer

In the frame of Metop, the VCA sublayer offers, within the Space-to-ground link, two services supported by 2 procedures.

5.1.3.3.1 VCA Service

The VCA service is used to transfer VCA-SDUs across the Data link Layer. The VCA sublayer constructs VCDU and CVCDU from the VCA-SDUs, serialises them, delimits them and transmits them using the services of the Physical Channel Layer.

5.1.3.3.2 Insert Service

This service is used to transfer isosynchronous Insert SDU's (IN-SDUs) by carrying them within an Insert Zone placed in every transmitted VCDU. In the case of Metop, it shall be used for encryption purpose. It exists but is not used for the X band packets because the global stream data are not ciphered.

5.1.3.3.3 VCA Service Primitives

The parameters for the VCA service primitives are under revision, but the preliminray definition is given below:

- VCA-SDU : The VCA Service Data Unit passed on a particular VC to and from users of the VCA service
- VCDU : Virtual Channel Data Unit (See VCLC primitives)
- CVCDU : Coded Virtual Channel Data Unit (Reed Solomon)
- VCDU-ID : Virtual Channel Data Unit Identifier
- Link-ID : Used to identify the PCA-PDU containing the stream of CVCDUs which carries the IN-SDU's.

- VCDU Loss Flag : Used to notify the user at the destination end of the VCA service that a sequence discontinuity has been detected and that one or more VCDU and/or CVCDU's have been lost. It is mandatory in recognition of its importance in the Multiplexing procedure.

5.1.3.4 Virtual Channel Procedure

The Protocol Data Unit of the Virtual Channel procedure is the VC-PDU, i.e the Virtual Channel Data Unit (VCDU). The VCDUs are composed of a Primary Header, an Insert Zone, a Data Unit Zone and a VCDU Trailer.

This procedure includes the VCDU assembly function, used to build the structure and Primary header of the VCDUs for transmission on each VC.

The VCDUs are assembled by placing a single M-PDU (set of multiplexed packets) in each VCDU Data Unit zone. The length of the M-PDU (equal for all all M-PDU's on Metop) must be equal to the length of the Data Unit zone for the VC identified by the VC ID.

The VCDU-ID is generated and placed in the VCDU header.

A sequential count is generated independently for each VC and placed into the Primary Header.

There is one VCDU-ID per VC.

5.1.3.5 Channel Access Procedures

These procedures provide the functions necessary to switch all of the individual VC together for commutation into one PCA-PDU. The PCA-PDU is then transmitted using the services of the Physical Channel Layer.

5.1.3.5.1 VCDU commutation function

This function generates a queue of VCDUs (received from the Virtual Channels Procedures) for commutation into the PCA-PDU in an appropriate order. If necessary to preserve the continuity of the transmitted stream, the VCDU commutation function requests "fill data" from the Fill Generation function.

5.1.3.5.2 Fill generation Function

If requested by the VCDU commutation function, the Fill Generation function creates a Fill VCDU and has its VCID set on the reserved value of "all ones".

It is not required to maintain a sequential count for fill VCDUs but for the Metop mission, the fill VCDU are transmitted via a dedicated virtual channel. Hence, because a VCDU counter is implemented for each VC, this counter is applicable for fill VCDUs as well.

5.1.3.5.3 Insert Injection Function

The Insert Injection function places the IN-SDU into the Insert Zone of the VCDU, preserving octet alignment. No encryption being applied over the X Band data, this function simply fills the insert zone with zeros.

5.1.3.5.4 Error Control Encoding Function

In order to get error-protected VCDUs, this function applies a Reed Solomon encoding scheme. The VCDU is transformed internally into a Coded VCDU (CVCDU) by appending a block of "Reed Solomon Check Symbols" to the end of the VCDU, thus forming a CVCDU.

Note that since CVCDU and VCDU are always of the same fixed length in a particular PCA-PDU (1020 octets in the case of Metop), the Data unit zone of the CVCDU is shortened by an amount equal to the length of the Reed Solomon Check Symbols.

5.1.3.5.5 Bit transition generation function

In order to ensure adequate bit transition, a modulation scheme shall be implemented via a randomisation function performing an exclusive OR with the 8160 bits of the CVCDU. It is applied before the delimiting function, i.e before insertion of the Synchronisation Marker. Such a pseudo-noise pattern shall be generated using the following polynomial sequence:

$$h(x) = x^8 + x^7 + x^5 + x^3 + 1$$

This sequence shall repeat after 255 bits and the sequence generator shall be re-initialised to "all ones" state during each Synchronisation Marker period. The first 40 bits of the pseudo noise sequence are showed below. The left most bit shall be the first bit of the sequence and be exclusively ORed with the first bit of the CVCDU:

1111 1111 0100 1000 0000 1110 1100 0000 1001 1010

FF 48 0E C0 9A hexa

5.1.3.5.6 Delimiting function

The VC-PDUs are transmitted through the Physical Channel as a serial string of VCDUs. Therefore, the delimiting function creates the PCA-PDU, which is clocked out synchronously at the transmitted bit rate of the physical channel, by prefixing a 32-bit Synchronisation Marker to each fixed length VCDU (-> CADU) and thus forming a continuous stream of CADUs. In absence of instruments data, the constant data rate shall be kept by inserting idle CADU's (i.e Synchronisation Marker + VCDU Data Unit Zone filled with dummy data) into the output data stream.

The PCA-PDU, streams of CADUs, is then submitted to the Physical Channel Layer.

5.2 NW LAYER PROTOCOL DATA UNIT: CCSDS SOURCE PACKET

The structure of the CCSDS source packets is first presented in paragraph 5.2.1 and the different User data fields are then detailed in paragraph 5.2.2. The precise layout of each instrument source packet data field is provided in RD MMS 14 for the European instruments and in RD MMS15 for the NOAA instruments. The description of the ADMIN message packet and the Gras Time and Position Real-time and Reduced Packets is included in this ICD.

A summary table of the main packets characteristics is provided on table 5.2.2/5.

5.2.1 Source Packet structure

The CCSDS source packets carry, in addition of the source data (measurements data and ancillary data), all the information needed for the acquisition, storage and distribution of the source data to the end user.

It is composed of 2 major mandatory fields: the Packet Primary Header (6 octets) and the Packet Data Field (from 1 to at most 65536 octets). The packet structure, presented on figure 5.2.1/1, consists of at least 7 and at most 65542 octets.

PACKET PRIMARY HEADER (6 octets)							PACKET DATA FIELD (max. 65536 octets)			
								SOURCE DATA		
Packet Identification				Packet Sequence Control		Packet length	Sec hdr	User Data		Error Control
Version number	Type indic.	Second hdr flag	AP ID	Sequ. flags	Packet Sequ. count		Time stamp	Ancill. Data	Applic. data	PEC
3 bits	1 bit	1 bit	11 bits	2 bits	14 bits	16 bits	48 bits 64 bits	even nb of octets	even nb of octets	16 bits
000	0	VAR	VAR	11	VAR	VAR	VAR	VAR	VAR	VAR

Table 5.2.1/1 : CCSDS Source Packet Structure

5.2.1.1 CCSDS Source Packet Primary Header

The Source Packet Primary Header occupies 6 octets of the packet format and is composed of the fields described hereafter 24.

24 Note that in RD ESA1 and RDESA9, the version number is part of the Primary Header, although in RDESA12 it is a stand-alone field. MMS has been advised by ESA to follow RD ESA1.

5.2.1.1.1 Packet Identification

Version number:

For the Metop mission, this field shall be set to "000", signifying the Version-1 CCSDS TM Packet.

Type indicator:

This field reflects the type of data unit. It is not used within the CCSDS Advanced Orbiting System Standards and shall therefore be set to "0".

Packet secondary Header Flag:

This field indicates the presence of Secondary Header within the TM packet : "0" for absence and "1" for presence. Unless for the ADMIN packet (structure still TBD), it shall therefore be set to "1" to indicate the presence of a secondary header.

Note that this flag is static w.r.t the APID throughout the mission phase.

Application Process Identifier:

For the Metop mission, the APID alone defines the Source User Application, the Destination User Application and the route between them, i.e the route of the CCSDS packets. The different APID's used for the Metop mission are provided in table 5.2.1/2.

APPLICATION PROCESS	APID	COMMENT
NOAA INSTRUMENTS		
AVHRR HR	 103 104	1 packet at the time among: Channel 3A data (day) & Channel 3B data (night)
AVHRR LR	 64 or 65 66 or 67 68 or 69 70	4 packets at the time among Channel 1 or 2 data Channel 3A or 3B data Channel 4 or 5 data Calibration data
AMSU-A1	39	1 packet
AMSU-A2	40	1 packet
HIRS/4	38	1 packet
SEM	37	1 packet
A-DCS	35	1 packet
EUROPEAN INSTRUMENTS		
MHS	34	1 packet
IASI	 128 132 134 136 138	1 packet at the time among Spectrum packet Image packet Spectrum verif. packet Image Verif. packet Auxiliary packet [APID possible range : 128..191]
ASCAT	 TBD TBD TBD	1 to 3 packets at the time among Nominal packet: Echo Nominal packet: Noise Raw data packet (for ground testing only) [APID possible range : 192..255]
GOME-2	384	1 packet [APID possible range : 384..447]
GRAS - Tracking packet	448	1 packet [APID possible range : 448..479]
GRAS - Occultation packet	480	1 packet [APID possible range : 480..511]
HOUSEKEEPING INFORMATION		
GRAS - pos & time	 2 3	1 packet at the time among Real-time Reduced
SATELLITE PACKET	1	S band frame
ADMIN PACKET	6	1 packet

Table 5.2.1/2 : Network Layer Primitives: AP Ids

Note that different APIDs may be associated to different operation modes of the same upon selection by ground or on-board means.

5.2.1.1.2 Packet Sequence Control

The Packet Sequence Control field provides a sequential count of the packets generated with the same Application Identifier.

Sequence Flag:

This flag indicates if the packet is the segment of a larger set of application data, i.e if it is a *continuation segment* ("00"), a *first segment* ("01"), a *last segment* ("10") or an *unsegmented set* of user data ("11").

For the Metop mission, this flag is set to "11" to indicate that only unsegmented packets are used within the network.

Note that, for packets constructed from the octet-string service, the flag is also set to "11", since segmentation is not allowed within the Network Layer.

Packet Sequence Count:

This field provides the sequential binary continuous count (modulo 16384) of each source packet generated by an application process identified by its unique APID. Its purpose is to order this packet w.r.t the other packets generated by the same AP, even though their natural order may have been disturbed during transport to the ground. It will normally be used in conjunction with the Time Stamp Field of the Secondary Header (archiving, sorting, processing, correlation with other data set).

A resetting of this count before reaching 16383 shall not take place unless it is unavoidable.

5.2.1.1.3 Packet Length

This field shall contain a binary number which permits to identify the length of the User Data and Error Control Fields. Its value is defined as follows:

number of octets of the Packet Data Field - 1

In order to inherit the Envisat developments in the most cost effective manner, the actual size of the packets produced by the PMC (i.e Satellite packet, Gras Position And Time packet and ADMIN packet) shall be a multiple of 32 octets. This has a direct impact over the size of the Packet Data Field (and hence the packet length) which shall be completed with filler zeros as appropriate.

5.2.1.2 CCSDS Source Packet Data Field

The Source Packet Data field occupies 65536 octets of the packet format and is composed of two sub-fields : the Packet secondary header and the User Data (or Source Data). The User Data field is itself split into 3 sub-fields: the Ancillary data, the Application data and the Packet Error Control Field as described hereafter.

The detailed content (i.e parameter by parameter) of each instrument Ancillary and User Data Field is provided in RD MMS 14 for the European instruments and in RD MMS 15 for the NOAA instruments.

5.2.1.2.1 Packet Secondary Header

For the Metop mission, the Packet Secondary Header contains the UTC Time Stamp. The time stamp is associated to known time preceding the event measured and is compliant to RD CCSDS 301-B2, "Level 1" Time Code .

The time stamp consists of

- 2 octects indicating the number of days with reference to the uplinked date
- 4 octects indicating the milliseconds of the day
- 2 octects indicating the microseconds of the millisecond

5.2.1.2.2 Ancillary data

This field contains in the first six octects a secondary time stamp and optionally data required by the instruments for on-board or on-ground processing reasons –i.e. instrument mode, instrument calibration data, redundancy. They are PLM/Instrument housekeeping information and may be different for each instrument [25]. Its size – an even number of octects – depends on the instrument requirments.

The secondary time stamp consists of

- one octects filled with "0"
- 3 octects of coarse time (seconds)
- 2 octects of fine time (2^{-16} seconds). Within this field a number of the LSB's (depending on the source) up to a maximum of 8 may be set to "0".

The reference time of the secondary time stamp (epoch) is known and defined by the Satellite Control Centre. A counter rollover happens every 2^{24} seconds (half year). This is equivalent to a modification of the epoch. The secondary time stamp is synchronised with the time stamp in the Packet secondary header.

25 Note that AOCS ancillary data (mostly zeros) are still provided by the CCU to the PMC but are not any longer processed by the PMC. Hence, they are not provided any longer in the Satellite Packet and nor are they included within the instrument packet ancillary data.

5.2.1.2.3 Application data

This field is composed of an even number of octets. The Application data field contains the data provided by the application source.

If the application source is an instrument, the application data are the measurement data completed, in some cases, by some instrument housekeeping data. In particular, the NOAA instrument measurement data, called Digital A data, also contain some of the housekeeping information necessary for ground calibration. Digital instrument housekeeping data, Digital B data, is provided to the PMC for inclusion in the Satellite packet. The NIU will acquire only Digital A data for inclusion in the User Data.

If the application source is the PMC, the application data shall be completed by filler zeros as necessary, in order to obtain a packet size multiple of 32 octets.

The detailed description of this field for each Global stream packets is presented in § 5.2.2.3.

5.2.1.2.4 Packet Error Control Field 26.

This 16 bits long field is optional: if required by the user, it shall contain one of the following checksum:

Cyclic Redundancy Checksum:

The Cyclic Redundancy Checksum (CRC) is computed over all the octets composing the CCSDS packet (except the PEC). The generator of the polynomial shall be:

$$G(x) = x^{16} + x^{12} + x^5 + 1$$

Both encoder and decoder shall be initialised with "all ones" state for each packet.

Vertical Parity Checksum:

The vertical Parity Checksum is calculated by performing an Exclusive-OR over all the other octets-pairs which compose the packet.

26 Note that the Error Control field is not mentionned in the CCSDS documents RD ESA11 and 12 but is considered in RD ESA1 as a stand-alone field following the User Data field.

5.2.2 X-Band source packet User's data

Although the instruments source packets follows the CCSDS recommendations, the Packet User Data field structure is specific to each instrument. These specificities (time stamp, ancillary data, application data, packet generation rate and Packet Error Control) are presented hereafter.

5.2.2.1 Secondary header: time stamps

The table 5.2.2/1 defines more precisely the time stamp for each CCSDS packet of the Global stream. It is identical for all packets issued from a same application.

APPLICATION	TIME STAMP DEFINITION
NOAA INSTRUMENTS	
AVHRR HR	It shall contain the UTC computed according to formula below
AVHRR LR	It shall contain the UTC computed according to formula below
AMSU-A1	It shall contain the UTC computed according to formula below
AMSU-A2	It shall contain the UTC computed according to formula below
HIRS/4	It shall contain the UTC computed according to formula below
SEM	It shall contain the UTC computed according to formula below
A-DCS	It shall contain the UTC computed according to formula below
EUROPEAN INSTRUMENTS	
MHS/MPU	It shall contain the UTC computed according to formula below
IASI	It shall contain the UTC computed according to formula below
ASCAT	It shall contain the UTC computed according to formula below
GOME-2	It shall contain the UTC computed according to formula below
GRAS: Tracking packet	TBD
GRAS: Occultation packet	TBD
HOUSE KEEPING INFORMATION	
GRAS: position & datation	It shall contain the UTC computed according to formula below
SATELLITE PACKET	It shall contain the UTC computed according to formula below
ADMIN PACKET	It shall contain the UTC computed according to formula below

Note: UTC is computed using the following formula:

$$UTC = UTC_0 + (SBT - SBT_0) * T_S$$

where SBT_0 is reference SBT, UTC_0 is reference UTC and T_S is period of SBT increments.

Table 5.2.2/1 : Source Packets Time Stamps Definition

5.2.2.2 Ancillary Data

Table 5.2.2/2 indicates for each instrument the presence and the length of the ancillary data field. Precision about the content and layout of the ancillary data fields are provided in the subsequent sub-paragraphs.

APPLICATION PROCESS	ANCILLARY DATA CONTENT	ANCILLARY DATA FIELD LENGTH
NOAA INSTRUMENTS		
ALL EXCEPT AVHRR LR	OBT	6 Octects
AVHRR LR	OBT	6 octets
EUROPEAN INSTRUMENTS		
MHS/MPU	MHS OBT	6 octects
IASI Spectrum Image Spectrum Verif. Image Verif. Auxiliary	 TBD TBD TBD TBD IASI OBT	 TBD TBD TBD TBD 6 octects
ASCAT Nominal data Raw data (ground use) Auxiliary	 HK generated by ICU and ASCAT DPU ASCAT OBT	 124 octets 64 octets 6 octects
GOME-2	GOME-2 OBT	6 octects
GRAS TRACKING	content TBD	TBD
GRAS OCCULTATION	content TBD	TBD
HOUSE KEEPING INFORMATION		
GRAS POS & TIME Real-time Reduced	 PMC OBT PMC OBT	 6 Octets 6 Octets
SATELLITE PACKET	PMC OBT	6 Octets
ADMIN PACKET	PMC OBT	6 octets

Note: SARR/SARP do not deliver OBT

Table 5.2.2/2 : Ancillary Data Field

5.2.2.2.1 European instruments ancillary data

The European instruments requiring, for on-board or on-ground processing, data other than those provided in the Application Data Field, gather them within this ancillary data field.

Today's assumption is that no SVM, PLM or instrument HK information shall be added to the instrument source packets.

MHS: Note that the MHS application data already contain HK data necessary for processing purposes. The MHS ancillary data field is today empty but this may change, depending on the need expressed by the box MPU, today TBD. The MPU delivers HK data to the PMC which are not included in the application data.

IASI

Among the 5 IASI packets, all except the Auxiliary packet have an Ancillary Data Field.

Spectrum Packet Ancillary Data Field

[illegible] number	step number	scan position	pixel number	cube direction	spectrum quality index	spare
16 bits	6 bits	6 bits	2 bits	1 bit	105 bits	24 bits

Image Packet Ancillary Data Field

[illegible] number	step number	scan position	image quality index	spare
16 bits	6 bits	6 bits	22 bits	14 bits

Spectrum Verification Packet Ancillary Data Field

[illegible] number	step number	scan position	pixel number	target number	cube direction	processing step	spare
16 bits	6 bits	6 bits	3 bits	2 bits	1 bit	3 bits	11 bits

Image Verification Packet Ancillary Data Field

[illegible] number	step number	scan position	processing step	spare
16 bits	6 bits	6 bits	3 bits	9 bits

ASCAT

Both ASCAT Source Packets structures contain an Ancillary Data Field.

Nominal Source Packet Ancillary Data Field (Echo or Noise)

	Word number [27]
Tag Field (kind of application data supplied) & Ground Processor Flag	6
PRI count : first PRI which contributed to the User data collection.	7
PRI count at time tag : derived from ASCAT master clock	8
DPU SW configuration ID	9
ASCAT Mode and redundancy configuration (set of active units)	10
ASCAT status	11
SFE temperature 0-5	12 to 17
Antenna temperature 0-11	18 to 29
RFU Receiver Gain	30
Overflow count : number of main ADC out of range events	31
Integrated transmitted Power 1-4 during PRI where applic. data acquired	32 to 35
Integrated Reflected Power 1-4 during PRI where application data acquired	36 to 39
Integrated Calibration power 1-4 during PRI where application data acquired	40 to 43
Calibration Power 1-4 during PRI where application data acquired	44 to 67

Raw Data Source Packet Ancillary Data Field (packet used for ground testing purpose only)

	Word number
Tag Field and Ground Processor Flag	6
PRI count :number of PTI during which the User data were collected	7
PRI count at time tag	8
DPU SW configuration ID	9
ASCAT Mode and redundancy configuration	10
ASCAT status	11
SFE temperature 0-5	12 to 17
Antenna temperature 0-11	18 to 29
RFU Receiver Gain	30
Overflow count	31
Integrated transmitted Power 1-4	32
Integrated Reflected Power 1-4	33
Integrated Calibration power 1-4	34
Number of echo samples	35
Number of calibraion samples	36
Number of Noise samples	37

GOME

27 Words 0 to 5 of the Source packet are those of the Primary and Secondary Header. The first word of the Ancillary data field is therefore word n°6 of the source packet (16-bit words).

GOME User data field layout shall be provided at a later stage: it is not sure yet that it will contain an ancillary data field.

GRAS

Only the Tracking and the Occultation GRAS packets, i.e those directly generated by the GRAS ICU, contain an ancillary data field whose layout shall be provided at a later stage.

Tracking Packet

TBD

Occultation Packet

TBD

5.2.2.2.2 NOAA instruments ancillary data

There is no Ancillary field in the NOAA instruments source packets except for AVHRR LR. The content of the AVHRR LR packets ancillary data field is still TBD.

One shall nevertheless note that a few uncertainties have been pointed out regarding additional needs in terms of HK data, for the ground processing of AVHRR and HIRS data.

The possibility of providing AVHRR channel 3A/3B status and two temperatures in the TM for ground processing is under investigation. HIRS needs are still unclear.

AVHRR LR

Measurement Packets

TBD

Calibration Packet

TBD

5.2.2.2.3 PMC generated Packets

The ancillary data field of the PMC generated packet contains the PMC time with the following lay-out:

- 1 octet filled with "0"
- 3 octets with coarse time (seconds)
- 1 octet with fine time (2^{-8} seconds)
- 1 octet filled with "0"

5.2.2.3 Application Data

Table 5.2.2/5 recalls the Application Data Field length of each instrument packet. Precision about the Application Data Field layout are provided in the next sub-paragraphs.

APPLICATION	PACKET APPLICATION DATA SIZE
NOAA INSTRUMENTS	
AVHRR HR Channel 3A (Day) Channel 3B (night)	Channel 3A : 12944 octets Channel 3B: 12944 octets
AVHRR LR Channels data Calibration	Variable : 2048 octets average 160 octets
AMSU-A1	2080 octets
AMSU-A2	1120 octets
HIRS/4	2304 octets
SEM	640 octets
A-DCS	7440 octets
EUROPEAN INSTRUMENTS	
MHS	1286 octets
IASI Spectrum Image Spectrum verification Image Verification Auxiliary	TBD TBD TBD TBD TBD
ASCAT raw data nominal data	11048 octets 512 octets
GOME-2	TBD
GRAS TRACKING	250 octets TBC
GRAS OCCULTATION	1250 octets TBC
HOUSE KEEPING INFORMATION	
GRAS pos & time Real-time Reduced	178 octets (TBC; subject to GRAS design consolidation)* 50 octets (TBC; subject to GRAS design consolidation)*
SATELLITE PACKET	530 octets)*
ADMIN PACKET	8018 octets)*

Note: *) This may include filler data to reach the multiple of 32 bytes for the overall packet length

Table 5.2.2/3: Application Data Fields

5.2.2.3.1 NOAA instruments Application Data

AVHRR HR

The AVHRR HR source packet contains the results of one scan, the scanning rate being 360 rpm: hence, the packet generation rate is 6 packets per second.

The Application data field shall then contain the samples associated to one line in each of the five optical channels running together with the calibration data.

AVHRR HR APPLICATION DATA FIELD	SIZE
Deep Space	500 bits
Ramp Calibration	50 bits
Video Data for 5 channels	102400 bits
TLM: IR target temperature	50 bits
TLM: Patch temperature	50 bits
Back Scan	500 bits
Filler bits at "0"	2 bits
TOTAL	*12944 octets*

AVHRR LR

The first packet of an AVHRR LR downlink sequence will be APID 64 or APID 65 (channel 1 or 2). The second will be either APID 66 or APID 67 (day or night). The third will be either APID 68 or APID 69 (Channel 4 or 5). The sequence is closed by APID 70 (calibration data) and then repeated.

The nominal sequence is:

APID 64 ➔ APID 66 and 67 alternatively ➔ APID 68 ➔ APID 70.

Measurement Packets:

Data compression is performed on the Earth view data samples acquired for AVHRR Low rate data stream.

Earth view data of one AVHRR channel grouped into 8 subsequent AVHRR lines are defined as a strip, and 8 adjacent pixels of 8 lines are a block.

The compressed data of one strip, called "scan", are put into the User data Field of the measurement packets (APID 64 to 69) corresponding to the compressed AVHRR channel.

AVHRR LR CHANNELS APPLICATION DATA FIELD	SIZE
ENCODED CHANNEL STRIPE HEADER	12 bits
SEGMENT 1	3 octets of header + M_1 MCUs+Bit Padding
SEGMENT 2	3 octets of header + M_2 MCUs+Bit Padding
......	...
SEGMENT N	3 octets of header + M_N MCUs+Bit Padding
BIT PADDING FIELD (to get an even number of octets for the User Data Field)	variable
TOTAL	*variable: 2048 octets average*

An Encoded Channel Stripe contains any number N of Segment and each Segment contain any number M_i of Minimum Coded Units, provided that the global number of MCUs per packet is 256. Each Segment corresponds to a strip (8 lines), each MCU corresponds to the compressed data of one block and the size of the packet is variable with an average of 2048 octets.

A line of data being produced every 1/6 second, such 3 packets are produced every 8/6 second.

The packet generation rate is : 3 packets per 8/6 second.

Calibration Packet: The calibration packet contains data from all 5 active channels sub-sampled once every stripe and formatted in a non compressed CCSDS packet.

A line of data being produced every 1/6 second, such packets are produced every 8/6 second.

The packet generation rate is : 6/8 packet per second.

AVHRR LR CALIBRATION APPLICATION DATA FIELD	SIZE
RESERVED FOR FUTURE USE	34 bits
CHANNEL 1 ANCILLARY DATA	230 bits
CHANNEL 2 ANCILLARY DATA	230 bits
CHANNEL 3A or 3B ANCILLARY DATA	230 bits
CHANNEL 4 ANCILLARY DATA	230 bits
CHANNEL 5 ANCILLARY DATA	230 bits
TOTAL	*198 octets*

Note: The PLM will not remove fill words

AMSU-A1

Each AMSU-A1 source packet contains one line of scanned data, one scan being performed every 8 seconds. Therefore, the packet generation rate is: 1/8 packet per second.

AMSU-A1 intermingles measurement data with fill words whose value is "0001 hex", and which are recognised as non measurement data. Then, AMSU-A1 provides the NIU ICU with 13 16-bit words every 100 ms, which will constitute, after 8 seconds, the User Data Field. The packet application data field size is then 2080 octets.

Depending on the instrument mode, the set of data sequentially written in the Application Data field varies. Its length is always inferior to the constant 2080 octets Application Data field, as follows:

AMSU-A1 MODE	SIZE OF THE REPEATED SET OF MEASUREMENT DATA
FULL SCAN MODE	1240 octets
WARM CALIBRATION MODE	1120 octets
COLD CALIBRATION MODE	1120 octets
NADIR MODE	1120 octets

AMSU-A2

Each AMSU-A2 source packet contains on line of scanned data, one scan being performed every 8 seconds. Therefore, the packet generation rate is: 1/8 packet per second.

AMSU-A2 intermingles measurement data with fill words whose value is "0001 hex", and which are recognised as non measurement data. Then, AMSU-A1 provides the NIU ICU with 7 16-bit words every 100 ms, which will constitute, after 8 seconds, the User Data Field. The packet data filed size is then 1120 octets + 6 octets OBT.

Depending on the instrument mode, the set of data sequentially written in the Application Data field varies. Its length is always inferior to the constant 1120 octets Application Data field, as follows:

Note: The PLM will not remove fill words.

AMSU-A2 MODE	SIZE OF THE REPEATED SET OF MEASUREMENT DATA
FULL SCAN MODE	316 octets
WARM CALIBRATION MODE	288 octets
COLD CALIBRATION MODE	288 octets
NADIR MODE	288 octets

HIRS/4

The application data field contains the data corresponding to one scan, one scan being performed every 6.4 seconds. Therefore, the packet generation rate is : 1/6.4 packet every second.

HIRS generating 64 elements of 36 8-bit words for each scan, the Application Data Field size is 2304 octets.

HIRS/4 APPLICATION DATA FIELD	SIZE
Earth scan data or target data during calibration sequences	Elements 0 to 55 : 2016 octets
Retrace data	Elements 56 to 63 : 288 octets
TOTAL	*2304 octets*

SEM

SEM acquisition data rate is based on the 32 seconds NOAA N/N' Major frame. The packet generation rate is therefore : 1/32 packet every second.

SEM APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*640 octets*

A-DCS

DCS will provide 93 octets of data to the NIU every 100 ms. The application data field size being 7440 octets, the packet generation rate is: 1/8 packet every second.

A-DCS APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*7440 octets*

5.2.2.3.2 EU instruments Application Data

MHS

MHS provides a source packet to the FMU every scan, i.e every 8/3 seconds. The packet generation rate is therefore: 3/8 packet every second.

In modes which do not generate measurement data, all fields are filled with "0", except the "Full HK data field".

MHS APPLICATION DATA FIELD	SIZE (octets)
Full HK data Mode and subcommutation mode Telecommand Acknowledgement and fault code Switch status Temperature data Raw current consumption data	39 1 5 3 24 6
Status word	1
Signal processing status / DC offsets	9
Earth view data	1080
Space view data	48
OBCT View data	48
OBCT temperature data	16
Spares (set to "0")	45
TOTAL	*1286 octets*

IASI

The IASI instrument measurement acquisition cycle is based on the 8 seconds scan period. This scan period is divided into 37 subcycles of 216 ms, one packet being generated at each subcycle. The global IASI packets generation rate is then : 37 packets every 8 second, i.e 37/8 packet per second.

Image and Spectrum packets: Observation data are acquired and processed during sub-cycles 1 to 30 and the corresponding source packets (Spectrum and Image) have an Application data field of TBD octets.

IASI IMAGE APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*TBD octets*

IASI SPECTRUM APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*TBD octets*

Image Verification, Spectrum Verification and auxiliary packets: Verification and Auxiliary data are transmitted during the last 7 sub-cycles. The corresponding source packets have a an Application data field of TBD octets.

IASI IMAGE VERIFICATION APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*TBD octets*

IASI SPECTRUM VERIFICATION APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*TBD octets*

IASI AUXILIARY APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*TBD octets*

ASCAT

The ASCAT instrument generates two structures of source packets in order to convey three types of data: Echo data, Noise data and Raw data. The Nominal Source Packet structure contains processed Echo or Noise data and the Raw Data Source Packet, used for ground testing purpose only, contains raw data.

Nominal Packet:

During the nominal measurement mode of ASCAT, only Nominal Source Packets are generated. Echo and Noise data packets are interleaved in a way programmable by the ground. Typically:

- 6 Echo packets (one per antenna) are generated every 824.16 ms (i.e every 24 PRI),
- 6 Noise packets (one per antenna) are generated every 8241.6 ms (i.e every 240 PRI).

The Echo Packet generation rate is : 7.28 packets (250/PRI) every second.

The Noise Packet generation rate is : 0.728 packets (25/PRI) every second.

Nominal Packets Application data fields have a fixed length and contain processed Echo or Noise data. In case of Noise data, part of the ancillary data is not relevant. The Application data field size is 512 octets.

ASCAT NOMINAL APPLICATION DATA FIELD	SIZE
PROCESSED ECHO OR NOISE SAMPLES	512 octets
TOTAL	*512 octets*

Raw Packet (ground testing purpose only): During the Test measurement mode of ASCAT, Nominal and Raw Data Source Packets are generated. Unprocessed raw data and the corresponding processed Echo and Noise data packets are interleaved. This mode may be selected by the ground for check-out and trouble-shooting.

Typically, one raw data packet is generated every 2.06 s (60 PRI), 1 processed Echo packet is generated every 16.48 s (480 PRI) and 1 processed Noise packet is generated every 82.41 s (2400 PRI).

The Echo Packet generation rate is : 0.48 (1/60/PRI) packet every second.

The Noise Packet generation rate is : 0.06 (1/480/PRI) packet every second.

The Raw Packet generation rate is : 0.012 (1/2400/PRI) packet every second.

The raw data Packet Application data field has a variable length. Its length varies in function of the echo samples (n1), the noise samples (n2) and the calibration samples (n3) selected by the ground, as reflected in the ancillary data. Its maximum length, 11048 octets (TBC), is given by the available buffers within the ASCAT PDU which are specified to keep : 4500 echo samples, 512 noise samples and 512 calibration samples (each sample = 2 octets). The Raw data packet contains at least 1 sample of each type (N1=N2=N3=1), which leads to a minimum User Data Field size of 6 octets.

ASCAT RAW APPLICATION DATA FIELD	SIZE
N1 ECHO SAMPLES (max 4500 samples)	2 N_1 octets
N2 CALIBRATION SAMPLES (max 512 samples)	2 N_2 octets
N3 NOISE SAMPLES (max 512 samples)	2 N_3 octets
TOTAL	*$N_1 + N_2 + N_3$ octets (min: 6 octets and max : 11048 octets)*

GOME

Detail shall be provided at a later stage.

GOME RAW APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*TBD octets*

GRAS/Tracking

The Tracking packet generation rate is: 1 packet per second.

The Application data field size is 250 octets (TBC).

GRAS TRACKING APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*250 octets*

GRAS/Occultation

The Occultation packet generation rate is variable. At most, it reaches: TBD packet per second.

The Application data field size is 1250 octets (TBC).

GRAS OCCULTATION APPLICATION DATA FIELD	SIZE
TBD	TBD
TOTAL	*1250 octets*

5.2.2.3.3 GRAS position & time Application Data

The PMC extracts the Time and Position data from the ICU format generated by GRAS. The PMC acquire these data every 16 seconds and format them into two kinds of CCSDS source packets, depending on the ICU format type: Real-time Position and Time Source Packet (if Real-Time ICU format) or Reduced Position and Time Source Packet (If Reduced ICU format). When GRAS is providing Report or Dump formats, no CCSDS Source Packet is generated. When GRAS is providing an ICU Test Format, the Real-Time Source packet shall be generated.

The Time and Position Source Packet generation rate is: 1/16 packet every second.

Real-time Position and Time Source Packet: This packet is created using the data from the GRAS ICU real-time format. The Application Data field size is 178 octets (TBC) so that the packet size is a multiple of 32 octets and the Application Data field remain below 246 octets[28].

GRAS POSITION AND DATA REAL-TIME APPLICATION DATA FIELD	SIZE
PMC Time	6 octets TBC
Useful data : TBD	172 octets TBC
Filler data: zeros	0 octets TBC
TOTAL	*178 octets TBC*

28 In RD ESA1, the Application data field size is 160 octets, which is not compatible with the "packet-size-multiple-of-32-octets" requirement. We understand that the need is 160 octets of useful data and have completed with filler data.

Reduced Position and Time Source Packet: This packet is created using the data from the GRAS ICU real-time format. The Application Data field size is 50 octets (TBC) so that the packet size is a multiple of 32 octets and the Application Data field remain below 42 octets[29].?????

GRAS POSITION AND DATA REDUCED APPLICATION DATA FIELD	SIZE
PMC Time	6 octets TBC
Useful data : TBD	44 octets TBC
Filler data: zeros	0 octets TBC
TOTAL	*50 octets TBC*

5.2.2.3.4 Satellite Packet Application Data

The Satellite Packet Application Data Field shall contain the complete S band frame as received from the SVM (i.e includes the Synchronisation Marker and the Frame Header) and filler data (zeros) in order to obtain a packet size multiple of 32 octets. AOCS ancillary data are not any longer transmitted in the Satellite Packet.

The Satellite Packet generation rate is : 1 packet per second.

SATELLITE PACKET APPLICATION DATA FIELD	SIZE
PMC Time	6 octets
S BAND FRAME	512 octets
FILLER DATA ("0")	12 octets
TOTAL	*530 octets*

For information, note that:

- the Orbit State Vector shall be uplinked by the ground and broadcasted via the Administrative message,
- the Equator crossing flag shall be uplinked to the PMC via a time-tagged Macrocommand.
- the Day/Night Flag required by AVHRR shall also be uplinked via a time-tagged macro-command (sub-satellite D/N flag).

29 In RD ESA1, the Application data field size is 28 octets, which is not compatible with the "packet-size-multiple-of-32-octets" requirement. We understand that the need is 28 octets of useful data but if we want to stick another requirement expressed by ESA and limit the application data field to 42 octets, we cannot add filler data to the 28 octets: this would lead to 52 octets. We then have to reduce the application data field to 20 octets without filler data.

5.2.2.3.5 ADMIN Packet Application Data

The Administrative message shall be distributed every 32 seconds. The ADMIN packet will contain information generated by the Polar Mission Centre, such as calibration coefficients, warning of planned orbit manoeuvres or change in configuration status (i.e coolers decontamination. It might as well contain orbit and attitude information data or the update of the Huffman and quantisation tables used for AVHRR data compression, as provided by the Polar Mission Control Centre.

This Administrative message will be updated regularly by the ground segment. The update of the ADMIN message shall be mission or event dependant, thus decided in the Ground Segment (from every 12 hours to every week).

The ADMIN message shall be stored on-board in the SSR for distribution through the X Band link.

Operationally, one ADMIN message shall always be ready for distribution. That means that, during transition from an old packet "n-1" to a new packet "n", the older ADMIN packet shall be distributed up to the time where the new packet is requested for distribution. Thus, a ping-pong buffer will allow the storage of both the old "n-1" and the new "n" ADMIN packets.

The size of the Application data field is 8018 octets so that the ADMIN Packet Size is a multiple of 32 octets. The detailed layout is as follows:

ADMIN PACKET APPLICATION DATA FIELD	SIZE
PMC Time	6 octets
ADMINISTRATION Data	8000 octets
FILLER DATA ("0")	12 octets
TOTAL	*8018 octets*

5.2.2.4 Packet Error Control

The Packet Error Control field is optional and may be of two types: CRC or Vertical Parity Checksum (VPC).

All packets generated by the NIU are fitted with a Vertical Parity Checksum PEC field.

The table below precise the presence and the type of PEC for each packet of the X Band stream.

APPLICATION PROCESS	PACKET ERROR CONTROL
NOAA INSTRUMENTS	
AVHRR HR Channel 3A (Day) Channel 3B (night)	 VPC VPC
AVHRR LR Channels data Calibration	 VPC VPC
AMSU-A1	VPC
AMSU-A2	VPC
HIRS/4	VPC
SEM	VPC
A-DCS	VPC
EUROPEAN INSTRUMENTS	
MHS	VPC
IASI Spectrum Image Spectrum Verif. Image Verif. Auxiliary	 TBD TBD TBD TBD TBD
ASCAT Nominal data Raw data	 YES but type TBD YES but type TBD
GOME-2	CRC (as per ICD)
GRAS TRACKING	CRC
GRAS OCCULTATION	CRC
HOUSE KEEPING INFORMATION	
GRAS POS & TIME Real-time Reduced	 NONE NONE
SATELLITE PACKET	NONE
ADMIN PACKET	NONE

Table 5.2.2/4 : Packet Error Control

5.2.2.5 Packets Characteristics Summary table

The table below summarises, for each packet of the X Band stream, the corresponding APID, packet generation rate, packet size, Application data field size, ancillary data presence and size and PEC presence.

Most of the time, the Packet Size is TBD because the presence/size of the Ancillary Data Field and/or the PEC field is unknown yet.

PACKET	APID	Generation rate (pck/sec)	Packet size (octets)	Application data size without ancillary (octets)	Ancillary data size (octets)	PEC
NOAA INSTRUMENTS						
AVHRR HR						
Channel 3A	103	6	12958	12944	NONE	VPC
and 3B	104	6	12958	12944	NONE	VPC
AVHRR LR	5 channel + cal	globally: 3ch				
Channel 1	64	6/8	var: 2014 av	var: 2000 av	NONE	VPC
Channel 2	65	6/8	var: 2014 av	var: 2000 av	NONE	VPC
Channel 3A	66	6/8	var: 2014 av	var: 2000 av	NONE	VPC
Channel 3B	67	6/8	var: 2014 av	var: 2000 av	NONE	VPC
Channel 4	68	6/8	var: 2014 av	var: 2000 av	NONE	VPC
Channel 5	69	6/8	var: 2014 av	var: 2000 av	NONE	VPC
Calibration	70	6/8	111	97	NONE	VPC
AMSU-A1	39	1/8	2094	2080	NONE	VPC
AMSU-A2	40	1/8	1134	1120	NONE	VPC
HIRS/4	38	1/6.4	2318	2304	NONE	VPC
SEM	37	1/32	654	640	NONE	VPC
A-DCS	35	1/8	2574	2560	NONE	VPC
EUROPEAN INSTRUMENTS						
MHS/MPU	34	3/8	1308	1286	NONE	VPC
IASI		globally: 37/8				
Spectrum	128	30/8	TBD	TBD	20	TBD
Image	132		TBD	TBD	8	TBD
Spect. Verif.	134	7/8	TBD	TBD	6	TBD
Image Verif.	136		TBD	TBD	5	TBD
Auxiliary	138		TBD	TBD	NONE	TBD
ASCAT	[192..255]					
Nominal	TBD	Echo 7.2 or 0.4	650	512	124	type TBD
	TBD	Noise: 0.7 or 0.06	650	512	124	type TBD
Raw (grd)	TBD	Raw: 0.012	84 to 11126	6 to 11048	64	type TBD
GOME-2	[384..447]	TBD	TBD	TBD	TBD	presence TBD
GRAS TRACKG	448	1	TBD	250 TBC	TBD	CRC
GRAS OCCULT.	480	VARIABLE	TBD	1250 TBC	TBD	CRC
HOUSEKEEPING INFORMATION						
GRAS POS & TIME						
Real-time	2	1/16	192	172 TBC	6	NONE
Reduced	3	1/16	64	44 TBC	6	NONE
SL PACKT	1	1	544	524	6	NONE
ADMIN	6	1/32	8032	8012	6	NONE

Table 5.2/5 : Source Packet Characteristics Summary Table

5.3 DATA LINK LAYER PROTOCOL DATA UNITS

5.3.1 VCLC Sublayer Protocol data unit: M-PDU

The generic structure of the M-PDU is presented in § 5.3.1.1, each M-PDU field is described in § 5.3.1.2 and 3 and the primitives of the VCLC Sublayer (APIDs, VCIDs) are provided in § 5.3.1.4.

5.3.1.1 M-PDU structure

An M-PDU is the input to a VCDU data unit zone. It is composed of the M-PDU Header followed by the M-PDU Packet Zone, as shown on figure 5.3.1/1. For each Virtual Channel, the length of the M-PDU is fixed, since it has to fit exactly the fixed-length data space of the VCDU.

VCDU DATA UNIT ZONE = M-PDU						
M-PDU HEADER (2 octets)		M-PDU PACKET ZONE (882 octets)				
Spare	First Header Pointer	End CCSDS Packet N°K	CCSDS Packet N° K+1	....	CCSDS Packet N° M	Start of CCSDS Packet N° M+1
5 bits	11 bits					
00000	VAR					

Figure 5.3.1/1 : M-PDU structure

5.3.1.2 M-PDU Header

The M-PDU Header is a 2-octet field composed of 5 spare bits and the First Header Pointer over 11 bits.

Spare:

This five-bit spare field being currently undefined by CCSDS, it is set to the reserved value of "00000".

First Header Pointer:

The First Header Pointer delimits variable length CCSDS packets contained within the M-PDU Packet Zone by pointing directly to a known reference location within the first CCSDS Packet. CCSDS Packets may spill over into the Packet Zone of the next consecutive M-PDU.

Therefore, this 11-bit field contains a binary count "P" (modulo 2048) which, when incremented by "1", points directly to the number of the octet within the M-PDU Packet Zone that contains the first octet of the first CCSDS Packet Header. The count "P" is expressed as :

$$P = \text{Number of the octet} - 1$$

By convention, the count starts at octet number 1, which begins at the first bit of the Packet Zone.

If the M-PDU Packet Zone contains CCSDS Packet data but no CCSDS Packet Header (long packet), the First Header Pointer shall be set to the value of "all ones".

If the VCDU is a fill VCDU generated by the FMU, the Packet Zone contains a fill pattern (all zero's) and the First Header Pointer shall be set to the value of "all zeros".

If a CCSDS Packet Header is split between successive M-PDU, the handling rules are as follows:

→ If the first Packet Header starts at the end of the M-PDU$_n$ Packet Zone and spills over into the M-PDU$_{n+1}$ Packet Zone, the First Header Pointer of M-PDU$_n$ indicates the start of this Packet Header.

→ If any Packet Header is split between M-PDU$_n$ and M-PDU$_{n+1}$, the First Header Pointer of M-PDU$_{n+1}$ ignores the residue of the split Packet Header and indicates the start of any subsequent new Packet Header within M-PDU$_{n+1}$.

5.3.1.3 M-PDU Packet Zone

The M-PDU packet zone is a fixed length (882 octets) field which may contain one or several CCSDS Packets, the first and the last packets not being necessarily complete. If necessary, a Fill Packet of appropriate length is inserted in order to complete the M-PDU Packet Zone.

5.3.1.4 VCLC primitive ID's: VCDU ID & AP ID

The Table 5.3.1/2 summarises, for each packet of the X Band stream, the primitives for the VCLC sublayer, i.e the AP IDs and the VCDU IDs. On Metop, the X Band data are downlinked via 10 Virtual Channels.

APPLICATION PROCESS	APID	VCID
NOAA INSTRUMENTS		
AVHRR HR	103 104	9
AVHRR LR	64 or 65 66 or 67 68 or 69 70	5
AMSU-A1	39	3
AMSU-A2	40	3
HIRS/4	38	3
SEM	37	3
A-DCS	35	27
EUROPEAN INSTRUMENTS		
MHS	34	12
IASI	128 132 134 136 138	10
ASCAT	[192..255] TBD TBD TBD	15
GOME-2	[384..447]	24
GRAS - Tracking packet	448	29
GRAS - Occultation packet	480	29
HOUSEKEEPING INFORMATION		
GRAS - position & datation	2 or 3	34
SATELLITE PACKET	1	34
ADMIN PACKET	6	34
OTHER		
FILL VCDU	N/A	63

Table 5.3.1/2 : VCLC Primitives - APID and VCIDs

5.3.2 VCA Sublayer Protocol data units

5.3.2.1 VCDU and CVCDU structures

As shown on figure 5.3.2/1, a Metop VCDU is 892 octets long and is composed of 3 main fields: the VCDU Header, the VCDU Insert Zone and the VCDU Data Unit Zone. In support of the grade 2 service, a block of Reed Solomon Check symbols is appended to the VCDU to form a 1020-octet CVCDU. Each field is detailed in the subsequent paragraphs.

<========================= V C D U =======================>

<============================ C V C D U ============================>

VCDU PRIMARY HEADER (6 octets)						VCDU INSERT ZONE	VCDU DATA UNIT ZONE	CVCDU CHECK SYMBOLS
Version nb	VCDU ID		VCDU counter	Signalling Field				
	SC ID	VC ID		Replay Flag	Spare			
2 bits 01	8 bits VAR	6 bits VAR	24 bits VAR	1 bit 0	7 bits All 0s	2 octets All 0s	884 octets VAR	128 octets VAR

Figure 5.3.2/1 : VCDU/CVCDU Structure

5.3.2.1.1 VCDU Primary Header

Version number:

This 2-bit field indicates Version 2 which identifies the CCSDS VCDU structure. It is therefore set to "01".

VCDU ID:

This 14-bit field contains the SC ID over 8 bits and the VCID over 6 bits.

The SC IDs are provided by ESA and shall be different for the 3 Metop and for the simulator. Their values are :

METOP 1	→	00 0000 1011
METOP 2	→	00 0000 1100
METOP 3	→	00 0000 1101
METOP simulator	→	00 0000 1110

The VCID are as defined in table 5.3.1/2.

Note that a fill VCDU is identified by setting the VCID to "all ones" (= 63).

VCDU Counter:

This 3-octet field provides individual accountability for each of the Virtual Channel. It contains a sequential count (modulo 16777216) of the total number of VCDUs which may have been transmitted on each VC. It is used in association with the VCID to maintain a separate counter for each VC.

Signalling Field:

This 1 octet field is composed of the 1-bit Replay Flag and of spare bits. The Replay Flag indicates if the VCDU downlinked are real-time or replay data. In Metop case, this flag is set to "0" to indicate Real-time data.

The Spare bits are all set to "0" by convention.

5.3.2.1.2 VCDU Insert Zone

The Insert Zone is filled-in by the Insert Service if encryption is performed, which is done only for the LRPT/HRPT direct broadcast links. Therefore, for any packet of the X Band link, this 2-octet field is set to **"all zeros"**.

Note that the fill VCDUs are never encrypted.

5.3.2.1.3 VCDU Data Unit Zone

The VCDU Data Unit Zone is the 884 octets **M-PDU** described in figure 5.3.1/1.

When no valid M-PDU are available for transmission at VCDU release time, a **Fill VCDU** is released: its Data Unit Zone contains a project specific "fill pattern", in Metop case "**all Zeros**". It is associated to the VCID "all ones (63)".

5.3.2.1.4 CVCDU Check Symbols

This 128-octet field permits error correction and contains the Reed-Solomon check symbols, generated according to the procedures described in RD MMS9, with an interleaving depth of 4. It is calculated over the VCDU Primary Header and the VCDU Data Unit Zone.

5.3.2.2 CADU structure

As shown on figure 5.3.2/2, a Metop CADU is 1024 octets long and consists in the CVCDU, OR-ed with a bit transition generator (see § 5.1.4.5.5), and prefixed by a 32-bit Synchronisation Marker.

SYNCHRONISATION MARKER	CHANNEL ACCESS SLOT = OR-ed CVCDU
4 octets 1ACFFC1D hex	1020 octets

Figure 5.3.2/2 : CADU structure

5.4 PHYSICAL CHANNEL LAYER

Note that the document RD ESA5 (Radio frequency and modulation standard) is not applicable to the X band and the LRPT and HRPT links. Contrarily to the S band, no compliance matrix of the design versus this specification has been established. The only applicable requirements relating to RF and modulation are those contained in this paragraph.

5.4.1 Physical Channel Layer Protocol Data Unit

Across the space medium, CADUs are transported within PCA-PDUs, i.e sequences of CADUs, as shown below:

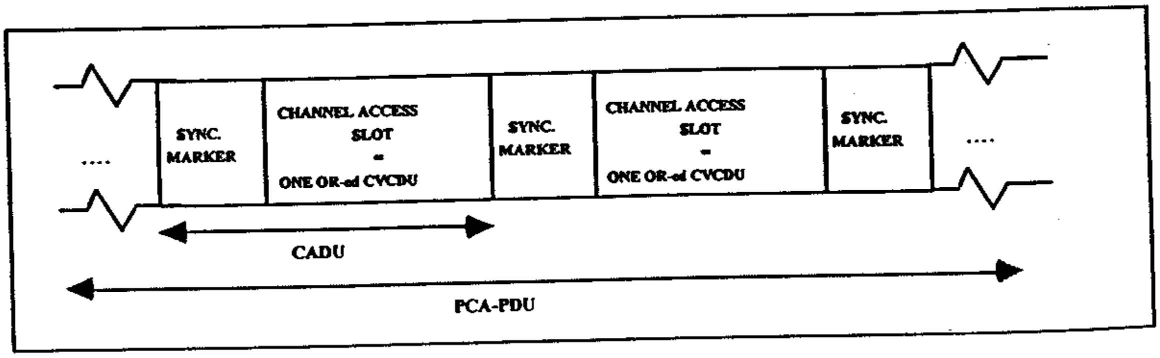


Figure 5.4.1/1 : PCA-PDU Structure

At least four modes of operation shall be provided by the X Band sub-system to convey these CADUs:

1. OFF MODE: No RF and no data is provided
2. SYNC MODE: RF will be switched ON and CADUs are provided for RF lock, bit and frame synchronisation of the ground segment. The CADUs downlinked during this phase will be either old CADUs (i.e those already downlinked earlier) or Fill CADUs.
3. DUMP MODE: Previously stored CADUs will be downlinked, until the SSR does not contain further data, or the Dump Mode will be stopped by ground command. This mode shall last as long as the visibility period. In order to reconstruct packet which have not been completely downlinked during the last visibility period since they spilled over subsequent CADUs, a set of old CADUs may be re-dumped during this mode.
4. TRAILER MODE: Fill CADUs will be transmitted after the termination of the Dump Mode and before switching off the RF carrier. The duration of this mode will be below TBD seconds.

5.4.2 X Band Physical Layer Numerical Characteristics

This paragraph describes the physical characteristics to be used for the establishment of the X Band TM link budgets. The Metop EIRP is not provided here because the budgets shall determine the EIRP value permitting to fulfil the margins requirements. In particular, the EIRP calculation has to consider:

- the worst case gain values with antenna mounted on SL structure,
- the minimum RF power values (at EOL and considering also the transmission losses, i.e. modulation losses, amplifier losses, filtering losses and transmission cabling losses,
- the amplifier thermal variation : - 0,5 dB .

More precisely, these budgets shall be computed for :

- the potential X Band Eumetsat stations whose geographical characteristics are presented at § 3.2: Kiruna, Fairbanks, Tromsö and Svalbard,
- a 5° minimum elevation,
- the reference (whole range) orbit defined in RD MMS 1,
- 3 dB margin for typical cases,
- 1 dB margin in worst cases for worst case orbit height.

The RF spectrum mask are provided in figure 5.4.2/3.

The other characteristics are presented in table 5.4.2/1. All parameters of this table are worst case EOL values, unless otherwise specified.

METOP CHARACTERISTICS	
Frequency band (99% of RF power)	63 MHz
Carrier Frequency (*)	7.80 GHz
EIRP	to be determined by link budgets
Carrier Polarisation	RHCP
Axial Ratio	to be determined by antenna measurement
Data rate	70 Mbps
Coding	Reed-Solomon encoding
Carrier Modulation	Hard Keyed QPSK signal filtered by masks of figure 5.4.2/3
Spectral mask for TM signal	see table 5.4.2/3

LINK CHARACTERISTICS	
Link Quality	FER < 10^{-6}
Atmospheric attenuation : rain, clouds, gas, scintillation (*)	see table 5.4.2/2
Maximum power allowed for DSN and Radio Astronomical bands protection	See annex 2
Maximum PFD (**)	-152 dBW/m^2. 4 KHz for 0<□5 -152+0.5(□5)dBW/m^2.4 KHz for 5<□25 -142 dBW/m^2. 4 KHz for 25<□90

(*) The link budgets shall consider attenuation due to atmospheric phenomena which is not exceeded 99.9 % of the time.

(**) Following assumptions shall be used in the PFD calculation:

- peak of TX spectrum density including possible residual carrier,
- typical values for TX power and antenna gain over elevation,
- average values for antenna gain along azimuth,
- on-board loss : 0 dB.

GROUND STATION COMMON CHARACTERISTICS	
G/T	32 dB/K at 5° elevation
Pointing loss worst case	< 0.4 dB
Technological Demodulation loss	2.5 dB
Axial Ratio	1 dB

Table 5.4.2/1 : X Band TM Physical Link Characteristics

KIRUNA AND TROMSO						
SL elevation (°)	5	10	20	40	60	90
Attenuation (dB)	2.0	1,0	0,4	0,3	0,2	0,2
FAIRBANKS						
SL elevation (°)	5	10	20	40	60	90
Attenuation (dB)	2,0	1,0	0,4	0,3	0,2	0,2
SVALBARD						
SL elevation (°)	5	10	20	40	60	90
Attenuation (dB)	2,0	1,0	0,4	0,3	0,2	0,2

Figure 5.4.2/2 : Foreseen Atmospheric Attenuation

Figure 5.4.2/3 : X Band TM Spectrum Mask (to be provided upon XBS acceptance test)

6 TIME SYNCHRONISATION REQUIREMENTS

6.1 OVERVIEW

The on-board ultra-stable oscillator provides a clock signal for the CCU clock counter from which the SVM OBDH bus clock is derived. The PLM OBDH bus clock and PMC clock counter are synchronised to the SVM OBDH bus clock via a frequency synchronised oscillator in the PMC. The ICU clocks are derived from the PLM OBDH bus clocks and drive clock counters in the ICU's.

The CCU clock counter also provides a 1 second synchronisation for software, hardware and packet exchanges. This is sent as a broadcast pulse (BCP2) to the PMC. BCP2 coincides with the start of the non-exchange period and the start (bit 0 of octet 0) of each TM frame. Similarly, the PMC sends its version of BCP2 via the PLM OBDH bus as 1 second synchronisation to the ICU's.

On-board time is held in time registers located in the CCU, the PMC and the ICU's. The CCU time register is incremented by a 256 Hz clock from its clock counter. The PMC and ICU's time registers are incremented by 65536 Hz clocks from their clock counters. Due to the on-board oscillator drift, the ground has to regularly re-correlate on-ground, the on-board and the ground Universal time.

6.2 CCU

The CCU time is FREE-RUNNING and bears no relationship to Universal time on the ground. The CCU time is the satellite master Time: it is read by the CCU at the BCP2 pulse and placed in the header of each S band telemetry frame, which is then transmitted to the ground.

6.3 PMC

The PMC time counter is read on request from the ground. A DHSA register command causes the CCU to issue a BCP4 via the SVM OBDH bus. This sets up the PMC to read its time counter at the next BCP2. This is then transferred to ground via telemetry. The ground segment shall calculate the equivalent Universal Time at which the SVM BCP2 was sent and can therefore determine any error in the PMC time.

The PMC register is updated whenever requested to do so from the ground.A DHSA register command causes the CCU to issue a BCP3 via the SVM OBDH bus. This sets up the PMC to reset its time register to zero and to start incrementing again at the next BCP2. The CCU automatically put the 24 most significant bits of its on-board time in the first TC packet and this is read by the PMC and used to update the 24 most significant bits of the PMC on-board time. The PMC will read the Master Satellite Time from the first TC packet one second after it was set by the CCU. Therefore, the PMC on-board time is the same as the CCU Master Satellite Time. In this way, the PMC on-board time is always synchronised to the Master Satellite Time.

6.4 ICU

The procedure for reading and updating the ICU time registers is similar to that of the PMC except that in this case, the BCP2, 3 and 4 are issued on the PLM OBDH bus by the PMC. The specific ICU to be read and updated must be identified by the ground. The ICU on-board time may differ from the Master Satellite time by an offset loaded from the ground via a MCMD specifically to the individual ICU. This enables the on-board time of each ICU to be set and monitored by the ground. Care must be taken that time register updating is not performed when time tagged commands are stored in an ICU and which therefore could be affected by the updating process.

7 SPECIFIC OPERATIONAL REQUIREMENTS

7.1 ROUTINE REQUIREMENTS

7.1.1 COP-1 procedures

It is important to note that the COP-1 procedure, specifying the TMTC links standards according to ESA recommendations, provides a new guarantee w.r.t to the previous principles: it ensures totally space-to-ground error free links. The automatisms included take care of operational errors: if no anomaly message is downlinked, the uplinked data are correctly loaded unless in case of an error introduced on-board. Of course, the ground is still responsible for verifying the coherency of the set of data sent to the satellite.

7.1.2 Delays management

The SVM LVPROM (used in satellite SAFE mode) and the PMC accept commands with a maximum rate of 1 packet per second. The CCU can cope with any higher TC rates and is only limited by the size of its internal buffer.

Any other delay constraint related to the uplink of telecommand is mentioned in the S/L operation normal.

7.1.3 Command uplink modes

Generally, three ways of uplinking commands are implemented at Control Centre level:

- Manual Mode: command are sent one-by-one by the ground, upon operator action,
- Automatic Step-by-step Mode: the command is automatically sent by the Control Centre upon verification of a predefined telemetry condition by the ground,
- Automatic burst Mode: the command is sent automatically after the predecedent one, sent by the Control Centre without any particular condition verification.

If such a burst mode exists, delays between commands can be managed via :

- delays part of the automatic command sequence or
- via the use of the CPDU NOP, NOP standing for No OPeration,
- via the use of the TCH NOP30, NOP standing for No OPeration.

30 This feature shall also be implemented on Envisat, Spot4 only being fitted with a NOP Direct command (CPDU).

This NOP TCH can contain up to 1022 words of idle data whose transmission duration provides the necessary delay: the delay is hence function of the amount of idle data loaded by the ground. Upon reception of the TCH NOP, the CFS performs standard checks but executes no real action. This TCH NOP cannot be used with the LVPROM, when in Satellite Safe Mode

In routine, the ground could generally use such a burst mode, providing the burst sequence includes commands whose execution is not dangerous in case of non-execution of a precedent command.

In contingency cases, manual mode should be privileged. A burst mode should be used only if the recovery operations are subject to very strong time constraints or if the manual mode presents no interest (no possibility of correct command execution verification other than the standard acknowledgements).

7.1.4 Authentication management

Today's baseline includes an automatic switching off the authentication if no TC is received within 12 hours, this specific delay being requested by Eumetsat. Note that the delay constraint cannot be inhibited but is modifiable in-flight from the ground via a patch TCH and can take very large values (16-bit word with a 1 hour LSB!).

This may turn out constraining because the autonomy of the satellite is larger, 36 hours: the ground shall be aware that Metop may have switched back to Clear mode.

7.1.5 Satellite Identifiers

Each Metop satellite and the simulator have a different spacecraft Identifier (present at transfer frame/VCDU level).

But, the same spacecraft identifiers values shall be used for all the models of a same satellite and all the versions of the simulator (avoid sending a command meant for the simulator to a Metop satellite).

7.1.6 TC packet size constraints

7.1.6.1 Operations planning

Limiting the TC packet size to 252 words of useful data may induce that the uplink of some delicate operations are spread over several packets. As described by MMS in a technical note (MO-NT-MMT-SY.0032) and a complementary fax (MO-FX-MMT-0425.96), some problems may occur if the uplink sequence is interrupted, for example because of a ground station unavailability. Hence, MMS has specified a larger telecommand Packet Data Field (up to 1022 words) while remaining compliant with the maximum size imposed by the PSS standard.

Should this size still turn up too small in some cases, the ground shall plan the operations in order to minimise such risks: a possibility is to time-tag such operations sufficiently in advance so that the ground would have enough uplink opportunities between potential failure occurrence and actual TC execution.

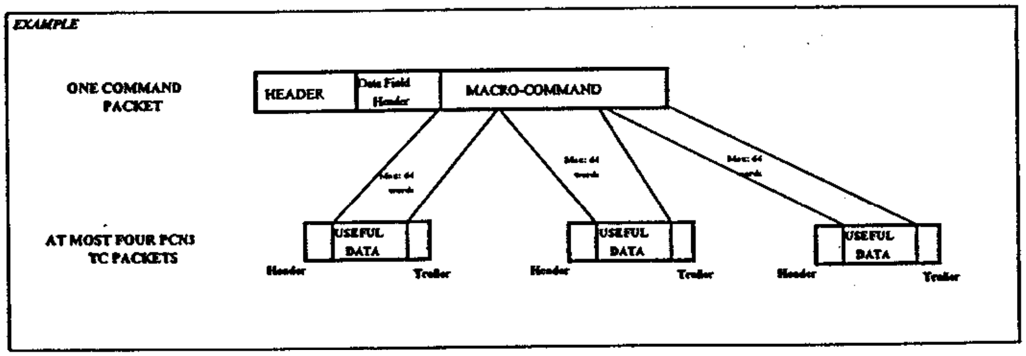
Also, this kind of problem can most of the time be solved, thanks to the implementation of the so-called "global TCH", i.e the SVM programmation TCH. Among other things, this TCH permits to time-tag any other TCH.

7.1.6.2 Ground packetisation task

The PMC reception function is such that it cannot receive more than 256 words of useful data per second. Commands forwarded by the CCU to the PMC are transported via at most 4 PCN3 TC packets. Each PCN3 TC packet is 67 words long, among which 64 words are useful data.

The maximum size of the TC packet application data field being 1022 words, any command addressed to the PMC and whose Application Data Field exceeds 256 words will not be entirely received by the PMC.

This may be the case for the Administrative messages: an ADMIN may contain up to 7986 octets of information. It should then be split into 16 parts, each of them being uplinked within one TC packet. Hence, the ground shall take care of this situation, when creating such command packets.



7.1.7 TC segment data field size

Nominally, a TC segment shall include, apart from the header:

- up to 238 octets of data lengthened by 9 octets of authentication tail if the authentication is enabled,
- up to 248 octets of data if authentication is not enabled

The ground shall be aware of operational errors related to the length of the data fields. Several situations may occur depending on the Authentication status.

These cases are summarised in the table 7.1/1.

	ON-BOARD STATUS	
GROUND ACTION	AUTHENTICATION ON	AUTHENTICATION OFF
AUTHENTICATED SEGMENT	Nominal situation	• The EDR accepts the AU tail and forwards them to the SW • The SW interprets the AU tail as data • The SW detects a packet length error and blocks the TC reception at packet level
NON AUTHENTICATED SEGMENT : 238 octets of data	• The Frame is accepted by the EDR • The EDR controls the 9 last octets of the segment data field and detects an error • The EDR does not forward the data to the SW • The LAC counter of the AU status and the TC packet counter of the RTF HK data are not incremented • The EDR blocks the TC reception at transfer frame level	Nominal situation
NON AUTHENTICATED SEGMENT : more than 238 octets of data		CCU accepts more than 238 octets (up to the buffer maximum size) --> Nominal situation

7.1.8 Use of BD Frames

- BD frames shall be used in particular for recovery in a case of TM downlink absence. In such a case, no CLCW is transmitted to the ground (no N(s)). Therefore, the ground shall be aware that, if two consecutive commands are sent via BD frames and if the first one is not executed, the second one may be executed anyway : the lock-out system is not activated.
- In order to avoid unclean situation, one should not use BD frames when the authentication is ON, unless for telemetry recovery. The Authentication layer maintains the sequence which is incoherent with the BD frames concept: BD frames would be rejected.

7.1.9 Commands acknowledgement

The ground can acknowledge the execution of a telecommand in several ways : the verification of parameters directly reflecting this execution (relay, bias...) and those defined in § 4.1.7: *Telemetry reporting of TC reception*.

7.1.10 CPDU TC reception observability

The ground shall be aware that the observability of the CPDU commands reception has some limitations:

- some CPDU commands are used for modifying the EDR, or the CCU configuration when the CCU is in Reset mode, i.e when to telemetry is available, i.e when no CPDU report is available,
- if two CPDU TC are sent within less than second, there shall not be any CPDU report nor associated execution verification telemetry for the first CPDU command.

7.1.11 CPDU TC particularities

In general, the sequence of CPDU commands shall start by a CCU RESET, also realised by a CPDU command. It shall then end by sending two CCU SET CPDU commands (sent to two different addresses to cope with some failure cases).

Some CPDU commands nevertheless escape this rule.

Therefore, the Metop Reference Database provides, for each CPDU command, the need for an associated CCU RESET/SET. When the RESET/SET is needed, the ground should make sure to group the CCU RESET, the CPDU(s) and the CCU SET commands within the same packet, in order to cope with a potential TC link failure occurring after the CCU RESET.

7.1.12 Status Report availability

According to the standard, the EDR shall produce a report for each CLTU received (FAR, AU, CPDU reports): it is then up to the user to use it or not. The CCU accepts these reports but cannot feed them in the telemetry frames at more than 1 Hz. Therefore, although the EDR could produce them at a higher frequency, only the last reports received within the second will be downlinked.

7.1.13 TC reception blockage

Depending on the error detected, the TC reception blockage occurs or not, and is reset by different means.

If the error occurs at Packet level, it is detected by the SW (packet length check or CRC for example). The SW blocks the TC reception at packet level and a dedicated TCH is necessary to unlock it.

If the error occurs at Segment level, it is detected by the SW (sequence flag check for example). The SW blocks the TC reception at segment level and the Reset Segment is necessary to unlock it.

If the error occurs at **Frame level** (Frame sequence count or CRC for example), it is detected by the EDR. Depending on the difference between the on-board and the uplinked frame counter values, the EDR reacts as follows (see FARM-1 window and state table of the EDR Specification- RD MMS7):

- the EDR rejects the commands and sends a request for retransmission message,
- the EDR blocks the TC reception at packet level and a dedicated Unlock BC frame is necessary to unlock it.

If the error occurs at **CLTU level** (parity check), it is detected by the EDR. If it has not been corrected, the EDR abandons the codeblock and indicates "End of candidate Frame" to the Transfer Layer. It then goes back to SEARCH mode. Note that as far as the corresponding frame has not been transmitted to the Transfer Layer, a frame Sequence Count Error shall be detected at Transfer Layer level, at reception of the next frame.

7.1.14 Command chains

The satellite cannot manage independently both command chains. It is therefore up to the ground not to uplink commands to both chains simultaneously, i.e within less than 2 seconds.

7.1.15 CFS actions impacting the operations

One shall note that when the CFS is initialised after a CCU SET, the processor reads the DHSA configuration registers C1 and C2 and analyses their differences w.r.t to their respective content before the CCU SET. In case of difference, the processor switches to failure processing mode and executes some actions. In particular, if the MASP bit is modified (one has switched to the redundant memory), the automatic recopy over the nominal memory is abandoned.

7.1.16 ADMIN packets management (TBC)

Operationally, one ADMIN message shall always be ready to be distributed, thanks to an on-board ping-pong buffer. The new ADMIN packet may be released upon ground request (MCMD) or at a given time (i.e it is uplinked with a time-tagged execution time).

7.2 LEOP SPECIFIC REQUIREMENTS

7.2.1 Authentication management

As requested by ESA and Eumetsat, baseline operations plans for the authentication disabled at launch. This suppresses the concern about the possibility to automatically switch the authentication off upon a Safe Mode order, even if the BCG order is inhibited within the EDR (i.e before solar array deployment).

7.3 EMERGENCY SITUATION SPECIFIC REQUIREMENTS

7.3.1 Safe Mode Format

When the satellite enter Safe Mode, the packet downlinked in S band corresponds to the Safe Mode Format. This format only includes SVM information, whose default value is a very limited set of data. Moreover, this format is available only when the ground has switch the bus couplers back on. The ground can then request manually the update of this default format, i.e:

- additional data which has to be downlinked in real-time,
- request for table downlink.

Note that one could load by TCH another default Safe Mode Format on the launch pad, using the RAM data of the LVPROM.

7.3.2 SVM Time-tag command management

In case of SVM anomaly provoking the activation of the Failure Management mode and generally the modification of the SVM configuration, all time-tagged command buffer for command packets already received by the CFS are deleted. The command packets whose reception is in progress, may they contain SVM or PLM commands, are also deleted.

Hence, no conflict is raised between the action of these commands and the new SVM configuration induced by the failure management.

7.3.3 PLM Time-tag command management

In case of individual EQ-SOL sent to the payload instrument, the buffered commands are removed from the queue when their execution time is reached.

If the STAND-BY MCMD is sent to an ICU, the time-tag buffer of this ICU is cleared-out.

In case of PLM avionics problem leading to PLM Safe mode, the PMC time-tag buffer is automatically reset when the PMC is restarted.

8 COMPATIBILITY TESTS REQUIREMENTS

The compatibility tests loop shall include the satellite, the Control Centre, the ground station Front End with the TMTC Front End as mailbox, as shown on figure 8/1. The satellite EGSE is only connected to the satellite, in order to monitor through the TM the correct execution of the commands sent by the Control Centre, or to pre-configure the satellite as necessary for the tests. A TC echo shall allow the logging of the TCs for investigation purposes.

The purpose of the Compatibility tests are multiple:

- participate in the validation of the Control Centre database and maybe part of the Flight operations Procedures,
- check that the action of the telecommands over the satellite are as expected, through the end-to-end checks of both TM and TC links (example: verify that the correct thruster is commanded),
- validate the Ground Station Front End equipment chain.

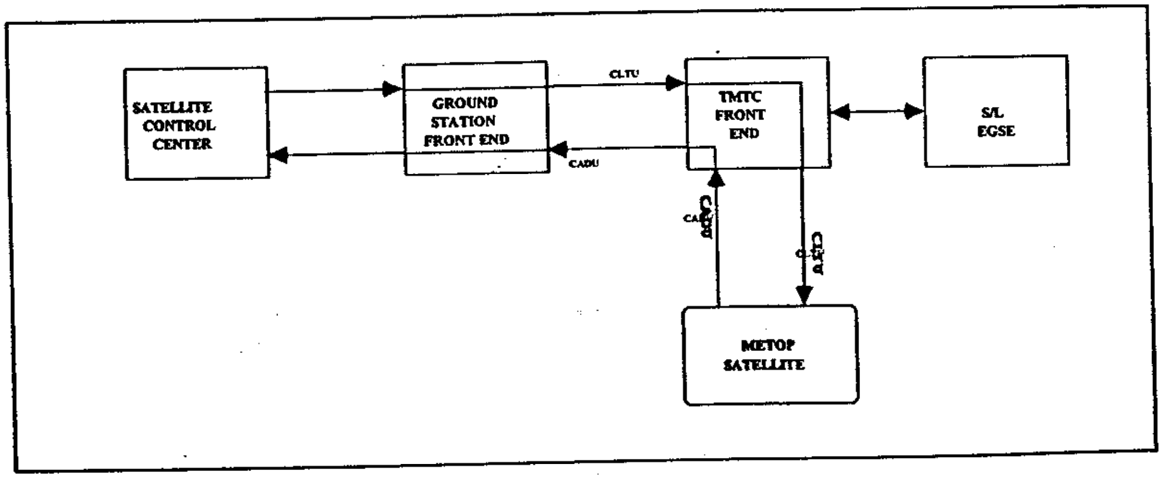


Figure 8/1 : Compatibility tests Chain

It is still TBD today whether the commutation from TC packet to CLTUs and the decommutation from CADUs to TM packets shall be made at Control Centre or at Ground Station Front End level.

Detailed requirement concerning the compatibility tests shall be found in the AIV Tests Specification to be issued in phase CD and in the Statement of Work issued by MMS towards its co-contractor DSS.

Suitcases requirements are addressed in the EGSE descriptive documents.

METOP SPACE TO GROUND IF SPECIFICATION

ANNEX 1

BIT CONVENTION

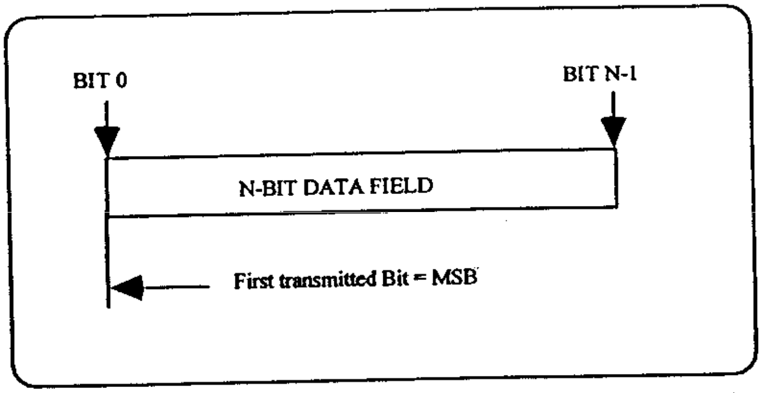
BIT NUMBERING CONVENTION AND NOMENCLATURE

The following convention should be observed when interpreting the bit numbering which is used throughout the Metop Space to Ground Interface Specification.

The first bit in the field to be transmitted (i.e the most left-justified bit when drawing a figure) is defined to be "Bit 0".

The following bit is called "Bit 1" and so on, up to " Bit N-1".

When the field is used to express a binary value (such as an integer), the Most significant Bit (MSB) shall be the first transmitted bit of the field, i.e "Bit 0".



Data fields grouped into 8-bit words, referred as octet, conform to the above convention which identifies each octet in a forward-ordered N-octet field.