Title:

MISSION AND OPERATION DEFINITION

CI - No: 000000

DRL Refs : D-MI1

	Name	Date	Signature
Prepared by:	P. Kolster	04.05.2016	
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Change Record

Issue	Date	Sheet / Chapter	Description of Change
1	02.12.20118	all	first issue
2	24.07.2009	All 174/1751 51	Updates reflecting updated concept and implementation JAXA-SRR-19; JAXA-SRR-20,
3	30.11.2011	all	Major updates to sections acc. program progress, the detailed change log is restricted to early changes already used in close-out references or changes based on formally recorded aspects
		2.2	Typo corrected in the table (repetition)
		3.2.1	In Table 3.2-2 SAT-PRE replaced by SAT-SBY
		3.2.1	Fig 3.2-1; text updated in order to clarify that the sequence is autonomously executed (No Ground intervention) Table updated to consider XBS-SBY and (XBS-OPR) for POM.
		3.3.1.2	Mode description updated.
		3.3.1.4	CPR Deployment move from SAT-NAM to SAT-POM
		3.3.1.5	(TBC) about 1.5° of fine Nadir Pointing deleted
		5.1.1.6	(TBC) removed
		5.1.2	Process ID Table updated (as per EC.STD.ASD.SY.00001- Issue 4)
		5.1.3	Update of Table 5.1-1 (as per EC.STD.ASD.SY.00001- Issue 4)
		5.2.1	(TBC) for GPS and STR removed
		5.2.2	(TBC) deleted in Figure 5.2-2
		5.2.3	Table 5.2-1 updated and corrected
		5.3.2.2.2	• "SKEL" replaced by "System Log" • Update acc. AI-14 - MoM EC-MOM-ESA-SY-00247 (EC PDR System RID-240)
		5.3.3	Obsolete Text deleted
		6.2	• Table 6.2-1 Electrical Block Diagram updated • PCS replaced by EPS
		6.4.1	Number of batteries increased from "two" to "three" Figure 6.4-1 EPS Architecture updated

Issue	Date	Sheet / Chapter	Description of Change
		6.4.1.2.2	Figure 6.4-3 PCDU – OBC interface diagram updated
		6.4.2.1.1	Figure 6.4-5 - RIU Functional Architecture updated
		6.4.3	Update acc. AI-18 - MoM EC-MOM-ESA-SY-00247(EC PDR System RID-306)
		6.4.3.1	Text edited.
		6.4.3.2	Figure 6.4-10 - Operational Interfaces between OBC, RIU and one of the S-Band Transponders updated
		6.4.3.3	Table 6.4-5 added
		6.4.3.4	Text added
		6.4.4.1	• AOCS Mode Transition Diagram update (as per SDS-6676, SDS-6875, SDS-7441 in EC.RS.ASD.SY.00005 – Issue 4) • Description of new submode AOC-NOM-DEP added • Tables 6.4-6 and 6.4-7updated
		6.4.4.2	AAD and FSS added to the list of AOCS SW blocks
		6.4.5.1.2	Figure 6.4-13 updated
		6.4.5.2.2	Figure 6.4-14 updated
		6.4.5.3.2	Figure 6.4-15 updated
		6.4.5.4.2	Figure 6.4-16 added
		6.4.5.5.2	Figure 6.4-17 added
		6.4.5.6.2	Figure 6.4-18 added
		6.4.5.7.2	Figure 6.4-19 updated
		6.4.5.8.2	Figure 6.4-20 updated
		6.4.5.9.2	Figure 6.4-21 added
		6.4.6.1	Update of RCS Propellant and Pressurisation Assembly components (as per EC.UM.ASU.BP.00001 – Issue 1)
		6.4.6.2	Figures 6.4-17 and 6.4-18 updated
		6.4.7	Update of Tables 6.4-4 and 6.4-5 (as per EC.STD.ASD.SY.00001 – Issue 4)

Issue	Date	Sheet / Chapter	Description of Change
		6.5.1.1	Figure 6.5-1 updated (RW's added)
		9.3.2	Paragraph updated as per EC.STD.ASD.SY.00001 – Issue 4
		10.4	Chapter 10.4 update as per. EC PDR AI 0247-15
		13.2.1	Update acc. AI-27 - MoM EC-MOM-ESA-SY-00247 (EC PDR System RID -238)
		Annex I	TC Uplink Budget justified and re-calculated in a more detailed way (as per AI-28 & AI-22 - MoM EC-MOM-ESA-SY-00247) (EC PDR System RID-271&379)
		Annex II	TM Data Rate Budget justified and re-calculated in a more detailed way (as per AI-28 - MoM EC-MOM-ESA-SY-00247) (EC PDR System RID-271)
		13.1	Autonomous SADM operation confirmed as per AI-23 - MoM EC-MOM-ESA-SY-00247
		5.3.2.3.4	SCHL Handling clarifications added as AI 17 of EC-MOM-ESA-SY-0247
		7.1.2 & 6.4.6	RCS redundancy clarified/corrected acc. AI 21 of EC-MOM-ESA-SY-0247
		9	Chapter updated based on EC.TN.ASD.SY.00110 and MMFU Delta PDR/Delta SW SRR including close-out of AI 24 of EC-MOM-ESA-SY-0247 requesting detailing of NRT and playback operations Revised to consider MMFU descoping acc. EC.TN.ASD.SY.00135
		6	Equipment Information and functional chain updates
		4	Instrument Commissioning Needs added and refined as discussed during EC PM#20 (EC.MN.ASD.SY.00537)
		11&12	FDIR mechanisms and principles detailed acc AI-30 of. EC-MOM-ESA-SY-0247
		2.2 & 5.2.4 & 5.2.5	Driving mission operation rqmt SDS-2063/OPS-CO-15/R on on-board SW image management and related chapters on Large Data Transfer & TC sequencer deleted acc. EC.TN.ASD.SY.00135
4	08.02.2013		
		2.3.1	Update of Operations Scenario according to OCIDR-PDS-106;

Issue	Date	Sheet / Chapter	Description of Change
			Action Item Reference: OCIDR-ALL-025/9.
		2.3.2	OCIDR-FOS-89; Action Item Reference: OCIDR-ALL-025/7. Document **not** updated since the definition of <ANOM_RESP_TIME> and <ANT_SWITCH_TIME> is exactly as defined in the ECSS-E-ST-70-11C.
		3.1.4	Update of MOP: Measurement and Operational Phase according to OCIDR-PDS-107; Action Item Reference: OCIDR-ALL-025/10.
			Definition of support mode added according to OCIDR-SAT-13; Action Item Reference: OCIDR-ALL-025/2.
			Solar Array Drive chapter updated.
		7.1.2	Table **7.1-1** Redundancy Architecture updated for MAG and STR. OCIDR-SAT-5; Action Item Reference: OCIDR-ALL-025/8.
		9.3	Table added in order to shows how the satellite ancillary data, S/C State Vector and other o/B data products are generated, routed to, stored where, retrieved from and transmitted via the down link terminal. According to OCIDR-SAT-6; Action Item Reference: OCIDR-ALL-025/6.
		Annex III	Spacecraft Configuration Vector updated; STR A & STR B (changed from STR-1 & STR-2; TCS/Heater HTRCtrlGroup_1_A/_B and TCS/Heater HTRCtrlGroup_9_A/_B; ATLID related units updated.
5	05.04.2016		EC System CDR Issue plus MOCDv4 Comments (ESA Excel)
		1.2.3	MOCD v4 Comments – Originator ID: MS-02 / Document Number for RD-103 corrected. EC_ESAJAXA_CPR_CDR SY - RID: SYS-32 / CPR Instrument Orbital Operation Handbook (CPR IOOH) added to RD list.
		2.2 3.3.2; 6.3.2; 15.2.3.1; 15.2.3.2; 15.2.4; 15.3.3.1; 15.3.3.2; 15.3.4; 15.4.3.1;	MOCD v4 Comments – Originator ID: PR-02 / Reference added.

Issue	Date	Sheet / Chapter	Description of Change
		15.4.4; 15.5.4; 15.5.3.1; 15.5.3.2;	
		2.1.3	Update of Table 2.1 1: EarthCARE Payload and Observable Parameters.
		2.1.4	Update of Figure 2.1 5: EarthCARE System Overview and Figure 2.1 6: EarthCARE Satellite in flight configuration.
		2.1.4.1	New chapter introduced 2.1.4.1 Launch System
		2.1.4.2	New chapter introduced 2.1.4.2 Ground Segment System GS-OCIDR-ALL OCIDR-PDS PDS-106 Text updated in accordance with panel disposition.
		2.1.4.3	New chapter introduced 2.1.4.3 Satellite Configuration
		2.3.2	MOCD v4 Comments – Originator ID: FOS-PR-01 / Text updated; HK TM for CPR added. GS-OCIDR-ALL OCIDR-FOS – RID FOS-88 / Text not change since the “Initiator recommended solution” is in contradiction to the definition of ECSS-E-70-11A [ND-152] GS-OCIDR-ESA-ASD SAT-4 / Update of <TIME_CORREL_ACCUR> definition. Update of <BATT_CHARGE_ACC>
		3.X	MOCD v4 Comments – Originator ID: FOS-TO-06 / Chapter 3.X reworked.
		3.1.1	MOCD v4 Comments – Originator ID: FOS-TO-04 / LEOP description updated; Orbit manoeuvres for orbit maintenance added.
		3.1.2	EARTHCARE SAT-PRE-CDR SYSTEM - RID: SYSTEM-55 LEOP configuration updated in accordance with 570-AI-54
		3.1.4	GS-OCIDR-ALL OCIDR-PDS RID PDS-107 PDGS responsibility added.
		3.2.2	MOCD v4 Comments – Originator ID: FOS-TO-07 / Status of EPS during SAT-SBY corrected.

Issue	Date	Sheet / Chapter	Description of Change
		3.3.1	Update of Satellite Status versus Mission Phases paragraph.
		3.2.7	GS-OCIDR-ALL OCIDR-PROJ RID PROJ-71 S-Band configuration for Satellite Safe Mode added.
		3.4	MOCD v4 Comments – Originator ID: FOS-TO-12 / Note (1) updated.
		3.4.2	GS-OCIDR-ALL OCIDR-SAT – RID SAT-13 Support mode definition added.
		3.4.2.X	Mode transition Subchapter updated.
		4.X	Update of chapter 4 “4. EARTHCARE MISSION TIMELINES” GS-OCIDR-ALL OCIDR-SAT RID SAT-14 & GS-OCIDR-ALL OCIDR-PDS RID PDS-110 ATLID calibration (Page 52, Par.4.2.2.1 of Issue 3) has now been moved to chapter 15.2 and the definition of S/C including instruments can be found in [RD-141].
		5	Update of chapter 5. Overall Operability Concept
		5.2.1	MOCD v4 Comments – Originator ID: FOS-PR-05 / Note added.
		6.3.1	MOCD v4 Comments – Originator ID: FOS-TO-19 / Definition of voltage range added.
		6.3.2	MOCD v4 Comments – Originator ID: FOS-JI-07 / Document reference added.
		6.5.1	MOCD v4 Comments – Originator ID: FOS-PR-08 / Phase B2 text removed. Figures for the minor frame allocation for the Platform and the Payload MIL Bus added. Reference to the MIL BUS Traffic Analysis added.
		7.1	Description of Redundancy Concept updated.
		7.1.1	Description of Redundancy Principles updated.
		7.1.2	MOCD v4 Comments – Originator ID: FOS-PR-09 / RIU redundancy concept in table 7-1 updated. MOCD v4 Comments – Originator ID: FOS-PR-07 / MAG & GS-OCIDR-ALL OCIDR-SAT / SAT-5

Issue	Date	Sheet / Chapter	Description of Change
			redundancy text and type of redundancy in table 7-1 updated and number of installed MAG units corrected in chapter 6.2 MOCD v4 Comments – Originator ID: FOS-TO-20 / P/L MIL redundancy text in table 7-1 updated. MOCD v4 Comments – Originator ID: FOS-PR-10 / Text "*After one failure both LPE supplies will be switched on for internal cross strapped configuration*" removed in table 7-1. MOCD v4 Comments – Originator ID: FOS-JI-08 / Text updated. EC_ESAJAXA_CPR_CDR SY - RID: SYS-33 Update of LPE type of redundancy.
		9.2.2	MOCD v4 Comments – Originator ID: FOS-PR-12 TBC removed for "Acquisition times" plus a reference to the document where the "acquisition times" are defined.
		9.2.3	MOCD v4 Comments – Originator ID: FOS-TO-21 Duplicated table 9.3-1 removed.
		9.3	Update of Table 9.3 1 On-board data product overview.
		9.3.1	MOCD v4 Comments – Originator ID: FOS-PR-13 & GS-OCIDR-ALL OCIDR-SAT SAT-6 TBC removed plus reference to the EarthCARE Ancillary Data ICD updated.
		9.3.3	MOCD v4 Comments – Originator ID: FOS-PR-14 / TBC removed.
		9.4.2	MOCD v4 Comments – Originator ID: FOS-PR-15 / Science Data Stream table updated.
		9.5.2	MOCD v4 Comments – Originator ID: FOS-PR-16 / document updated. Record pointer is replaced by write pointer. MOCD v4 Comments – Originator ID: FOS-PR-17 / text updated.
		9.5.2.2	GS-OCIDR-ALL OCIDR-SAT – SAT-4 Description of independence for PP1 and PP2 added.
		9.5.8	GS-OCIDR-ALL OCIDR-SAT – SAT-4

Issue	Date	Sheet / Chapter	Description of Change
			Time margin (value still TBD) is added to the text.
		9.5.3.3	MOCD v4 Comments – Originator ID: FOS-JI-11 / Reference added.
		9.6.2	Update of chapter 9.6.2
		10.1	MOCD v4 Comments – Originator ID: FOS-PR-18 / Text updated.
		10.4.2.1	EC_ESAJAXA_CPR_CDR SY - RID: SYS-39 Update in order to consider Interval for CPR Silent Mode Suspension.
		10.4.2.2	EC_ESAJAXA_CPR_CDR SY - RID: SYS-40 Note added: The CPR command reaction time has to be considered by Mission planning.
		13.1	EC_ESAJAXA_CPR_CDR SY - RID: SYS-41 Removal of TBD by description of RSA status to be monitored. Deployment sequence updated.
		13.4	EC_ESAJAXA_CPR_CDR SY - RID: SYS-6 Update of CPR mode / configuration during SAT OCM mode.
		15.1.4	MOCD v4 Comments – Originator ID: FOS-PR-21/ Text updated.
		15.1.5	MOCD v4 Comments – Originator ID: FOS-PR-22/ Text updated.
		15.2.X	Chapter updated
		15.3.X	Chapter updated
		15.4.X	Chapter updated
		15.5.6	GS-OCIDR-ALL OCIDR-SAT RID SAT-15 Chapter updated with respect to instruments mode during CPR sea/surface calibration.
		15.5.8	EC_ESAJAXA_CPR_CDR SY - RID: SYS-27 Update of CPR Operational Mode Select Command.
		15.5.9	EC_ESAJAXA_CPR_CDR SY - RID: SYS-42 TBD removed by CPR science date product content.

Issue	Date	Sheet / Chapter	Description of Change
		Annex I	Update of SCV

Change log for Pre-SAT CDR RIDs / Action Items not covered in this RP

Document	Doc. No.:	Sheet / Chapter	Description of Change
EartCARE Flight Operations Manual Volume 3 – Power System	EC.UM.ASD.SY.00014 Issue 2	3.3.2.3.5	EARTHCARE SAT-PRE-CDR SYSTEM - RID: ENGINEERING-121 Update of Thermal Knife/Pyro Interfaces in accordance with 570-AI-108
EARTHCARE SATELLITE SPACE SEGMENT – SATELLITE OPERATIONS CONSTRAINTS	EC.TN.ASD.SY.00158 Issue 2	2.1.2	EARTHCARE SAT-PRE-CDR SYSTEM - RID: ENGINEERING-121 Introduction of Constraints / Critical TCs in accordance with 570-AI-108
EARTHCARE SATELLITE SPACE SEGMENT – SATELLITE OPERATIONS CONSTRAINTS	EC.TN.ASD.SY.00158 Issue 2		EC_ESAJAXA_CPR_CDR SY RID: SY-31 Introduction of CPR Roll manoeuvre constraints in to referenced TN.

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TABLES

Data Rate Generation Budget			
ATLID			
Packet Type	Frequency	Size (byte)	Comment
Science Data	25.50 Hz	1 786	
CAS data	1.59 Hz	1 374	
AUX data	1.00 Hz	794	
ATLID Short TM	1.00 Hz	154	
ATLID Extended TM	0.05 Hz	187	
ATLID Thermistor TM	0.05 Hz	234	
ATLID TLE TM1-2	0.05 Hz	196	
ATLID TLE TM3-4	0.05 Hz	196	
ATLID IDE TM	0.05 Hz	163	
ATLID BSM TM	0.05 Hz	109	
ATLID Data Rate:		390 kbit/s	
BBR			
Packet Type	Frequency	Size (byte)	Comment
Science Data	4.39 Hz	3 530	
BBR Short TM	1.00 Hz	82	
BBR Long TM	0.05 Hz	224	
BBR Data Rate:		125 kbit/s	
CPR			
Packet Type	Frequency	Size (byte)	Comment
Science Data	14.00 Hz	2 370	
AUX data	1.00 Hz	238	
CPR TM	1.00 Hz	80	
CPR Data Rate:		268 kbit/s	
MSI			
Packet Type	Frequency	Size (byte)	Comment
Science Data (6 Channels on Average)	15.88 Hz	4 848	
AUX data	15.88 Hz	808	
MSI Short TM	1.00 Hz	66	
MSI "ICU" TM	0.05 Hz	171	
MSI "MSI" TM	0.05 Hz	179	
MSI Data Rate:		719 kbit/s	
S/C Equipment			
Packet Type	Frequency	Size (byte)	Comment
S/C Position & Attitude	1.00 Hz	120	
StarTracker Attitude	20.00 Hz	59	
GPS Navigation Solution	1.00 Hz	124	
S/C other TM (to be detailed, 12.8 kbit/s allocation, 64 Byte Average TM Size)	25.00 Hz	64	
S/C Data Rate:		24 kbit/s	
Specification Margins			
Packet Type	Frequency	Size (byte)	Comment
250 kbit/s ESA Growth Margin	25.00 Hz	1 250	
25% Margin on Operations	38.15 Hz	1 250	
Margin Data Rate:		631 kbit/s	
Sum Data Generation Rate			
Science Data		1498 kbit/s	
HKTM		28 kbit/s	
Specification Margins		631 kbit/s	
Overall Data Rate		2157 kbit/s	

FIGURES

1. INTRODUCTION

1.1 Scope of the Document

This document provides the mission and operational concept description of the EarthCARE satellite. The major objectives of the document are

- to give an overview of Mission Phases, associated System Modes and respective status of equipment and units
- to provide a breakdown of the S/C functions and subsystem functions
- to summarise the baseline architectures of the subsystems / units
- to give an overview of commandability and observability concepts,e.g. the overall TM/TC routing as well as equipment commandability and observability concepts
- to describe the onboard data handling (e.g. datation, synchronisation and measurement data management concept)
- to identify the role of On-Board Control Procedures (OBCP's)
- to provide an overview of the on-board Fault Detection, Isolation and Recovery (FDIR) Scheme

The document is intended to be a living document during the initial phase of the project and will be maintained until CDR. Although the document aims to provide all operations relevant information including the underlying HW architecture and HW / SW interfaces, in some areas reference is made to details provided in separate documents. After CDR, the information provided within this document will be transferred to specific documents, especially the individual volumes of the EarthCARE Flight Operations Manual..

1.2 References

1.2.1 Applicable Documents

Reference ID	Document Title	Document Number
[AD-13]	Mil Bus Protocol Specification	EC.RS.ASD.SY.00011
[AD-26]	Earth Explorer Mission CFI Software MISSION CONVENTIONS DOCUMENT	CS-MA-DMS-GS-0001 issue 1.3
[AD-99]	EarthCARE Satellite Design Specification	EC.RS.ASD.SY.00005
[AD-110]	EarthCARE Packet Utilization Standard	EC.STD.ASD.SY.00001
[AD-120]	Selective Downlink based on packet criteria	EC.RFW.ASD.SY.00028

1.2.2 Normative Documents

Reference ID	Document Title	Document Number
[ND-115]	Time Code Formats (ISO 11104)	CCSDS 301.0-B-3
[ND-150]	Ground systems and operations - Part 1: Principles and requirements	ECSS-E-70 Part 1A
[ND-151]	Ground systems and operations - Part 2: Document Requirements Definitions (DRD)	ECSS-E-70 Part 2A
[ND-152]	Space Engineering - Space Segment Operability	ECSS-E-70-11A
[ND-153]	Space Engineering: Test and operations Procedure language	ECSS-E-70-32A
[ND-154]	Ground systems and operations - Telemetry and telecommand packet utilisation (PUS)	ECSS-E-70-41A
[ND-264]	European Code of Conduct for Space Debris Mitigation, 28 June 2004, Issue 1.0	

1.2.3 Reference Documents

Reference ID	Document Title	Document Number
[RD-01]	Abbreviation List	EC.LI.ASD.SY.00001
[RD-02]	Satellite Technical Description	EC.TN.ASD.SY.00021
[RD 03]	EarthCARE Mission and Operation Definition Report	EC.RP.ASD.SY.00016
[RD-04]	Space-to-Ground ICD	EC.ICD.ASD.SY.00010
[RD-05]	EarthCARE FDIR Concept and Implementation Document	EC.RP.ASD.SY.00015
[RD-06]	System Budgets Dodument	EC.TN.ASD.SY.00007
[RD-07]	EarthCARE On Board Time Management	EC.TN.ASD.SY.00014
[RD-08]	EC Flight Procedure ICD	EC.ICD.ASD.SY.00008
[RD-09]	Ground Operation Constraints	EC.TN.ASD.SY.00045
[RD-40]	ATLID Technical Design Description	EC.TCN.ASF.ATL.00002
[RD-41]	ATLID Flight Operation Manual	EC.UM.ASF.ATL.00001
[RD-50]	BBR Technical Design Description	EC-TD-SEA-BBR-0001
[RD-51]	BBR Flight Operation Manual	EC-UM-SEA-BBR-0001
[RD-60]	MSI Technical Design Description	EC.RP.SSTL.MSI.00005
[RD-61]	MSI Flight Operation Manual	EC.UM.SSTL.MSI.00001
[RD-70]	CPR Technical Design Description	SEC-080001 NC
[RD-71]	CPR Instrument Orbital Operation Handbook (CPR IOOH)	EC-N-T-13108
[RD-100]	SATELLITE GROUND OPERATIONS CONSTRAINT	EC.TN.ASD.SY.00045
[RD-101]	EARTHCARE SPACE SEGMENT – SATELLITE OPERATIONAL TIMELINES	EC.TN.ASD.SY.00157
[RD-102]	EARTHCARE SPACE SEGMENT SATELLITE FLIGHT PROCEDURES	EC.SOP.ASD.SY.00001
[RD-103]	EARTHCARE SPACE SEGMENT – SATELLITE OPERATIONs CONSTRAINTS	EC.TN.ASD.SY.00158
[RD-104]	EARTHCARE SPACE SEGMENT – SATELLITE TM/TC DEFINITION	EC.LI.ASD.SY.00067
[RD-105]	EARTHCARE SPACE SEGMENT SATELLITE OPERABILITY REPORT	EC.RP.ASD.SY.00167
[RD-110]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 2 - DATA HANDLING SYSTEM	EC.UM.ASD.SY.00013
[RD-111]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 3 - ELECTRICAL POWER SYSTEM	EC.UM.ASD.SY.00014
[RD-112]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 4 - AOCS & RCS SYSTEM	EC.UM.ASD.SY.00015
[RD-113]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 5 - S - BAND SYSTEM	EC.UM.ASD.SY.00016

Reference ID	Document Title	Document Number
[RD-114]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 6 - THERMAL CONTROL SYSTEM	EC.UM.ASD.SY.00017
[RD-115]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 7 - PAYLOAD DATA HANDLING & TRANSMISSION SYSTEM	EC.UM.ASD.SY.00018
[RD-116]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 8 - ATLID USER MANUAL	EC.UM.ASD.SY.00019
[RD-117]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 9 - BBR USER MANUAL	EC.UM.ASD.SY.00020
[RD-118]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 10 - MSI USER MANUAL	EC.UM.ASD.SY.00021
[RD-119]	EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 11 - CPR USER MANUAL	EC.UM.ASD.SY.00022
[RD-130]	EARTHCARE OVERALL ASSEMBLY AND GEOMETRICAL DRAWINGS	EC.ICD.ASD.SY.00011
[RD-131]	EARTHCARE ELECTRICAL INTERFACE CONTROL DOCUMENT	EC.ICD.ASD.SY.00015
[RD-132]	EARTHCARE ELECTRICAL INTERFACE DIAGRAM (EID)	EC.DRW.ASD.SY.00002
[RD-133]	MIL BUS Traffic Analysis	EC.TN.ASD.SY.00075
[RD-134]	EarthCARE CSW Data Pool ICD	EC.ICD.ASD.SY.00024
[RD-135]	EarthCARE Ancillary Data ICD	EC.ICD.ASD.SY.00026
[RD-139]	Launcher IRD	EC.IRD.ASD.SY.00013
[RD-140]	Launcher Interface Control Document (DCI)	SOY-DCI-1/51180-B-AE
[RD-141]	EarthCARE Characterization/Calibration Plan	EC.PL.ASD.SY.00016
[RD-142]	EC Satellite Operability Report	EC.RP.ASD.SY.00167
[RD-143]	EC Software System Specification (SSS)	EC.RS.ASD.SY.00025

1.3 Definitions

1.3.1 General Terms

1.4 Abbreviations

General EarthCARE abbreviations are in .
Specific abbreviations used in this document are given below.

CEL	Critical Event Log
HPTM	High Priority TM
PBTM	Playback TM
RTTM	Real -Time TM
SKEL	Spacecraft Key Event History Log

2. EARTHCARE MISSION REQUIREMENTS AND OVERVIEW

2.1 EarthCARE Background

2.1.1 Earth Explorer Missions

Earth Explorer Core Missions are an element of the Earth Observation Envelope Programme. They are defined as major missions led by ESA to cover primary research objectives set out in the Living Planet Program (ESA, 1998). The Earth Clouds, Aerosols and Radiation Explorer Mission (EarthCARE) has been approved for implementation as the third Earth Explorer Core Mission.

EarthCARE is a cooperative mission between ESA and JAXA, where JAXA will provide a Cloud Profiling Radar. ESA is responsible for the entire system including the Spacecraft, three instruments, the Launcher and the Ground Segment.

The EarthCARE Mission will help in determining the Earth radiation budget by providing global observations of vertical cloud and aerosol profiles. The mission is centred on the synergetic use of the data provided by an instrument suite consisting of an ATmospheric LIDar (ATLID), a Cloud Profiling Radar (CPR), a Multi-Spectral Imager (MSI) and a BroadBand Radiometer (BBR).

2.1.2 Scientific Objectives

The difficulty of representing clouds and aerosols and their interactions with radiation, constitutes a major source of uncertainty in predictions of climate change using numerical models of atmospheric circulation. Accurate representation of cloud processes is also critical for the improvement of numerical weather predication. A first step in gaining confidence in such predictions is to check that these models are at least correctly representative of the clouds and aerosols in the present climate. Unfortunately there are no global datasets providing simultaneously the vertical profiles of clouds and aerosol characteristics together with vertical temperature and humidity profiles and the top-of-the-atmosphere (TOA) radiance. Such datasets are crucial to validate the model parameterisations of cloud processes regarding both water and energy fluxes. The vertical profiles are important in controlling the radiative transfer processes in the atmosphere, and so affect the heating profiles, which then influence the dynamics.

Indirect aerosol effects on cloud radiative forcing as well as cloud parameterisation are today the biggest sources of uncertainty in climate prediction. The critical cloud radiation feedback can not be modelled without accurate cloud and aerosol parameterisations.

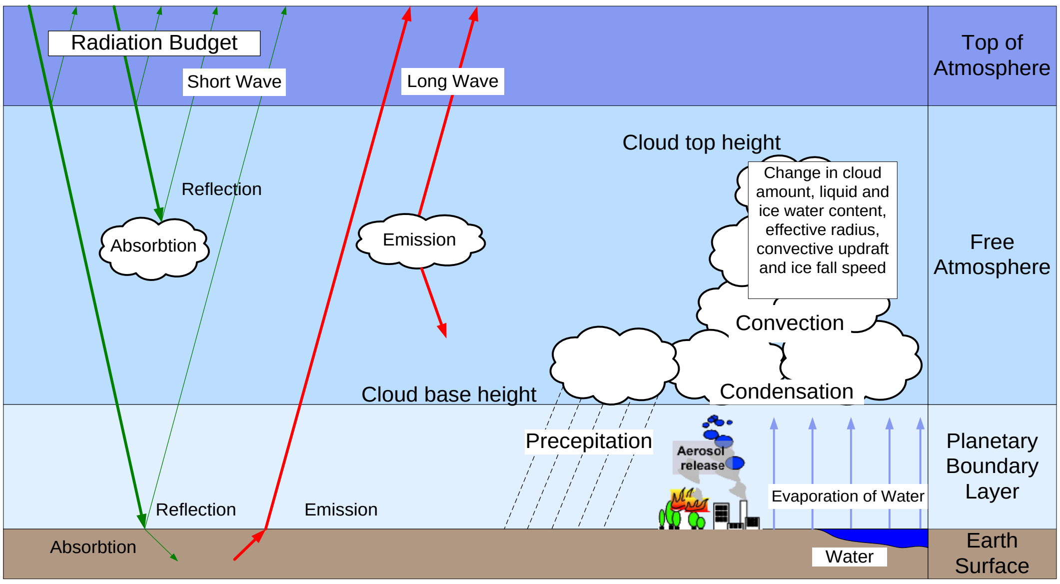


Figure 2.1-1: The scope of the EarthCARE mission.

The objective is to retrieve vertical profiles of cloud and aerosol, and characteristics of the radiative and microphysical properties so as to determine flux gradients within the atmosphere and fluxes at the Earth's surface, as well as to measure directly the fluxes at the top of the atmosphere and also to clarify the processes involved in aerosol / cloud and cloud / precipitation / convection interactions.

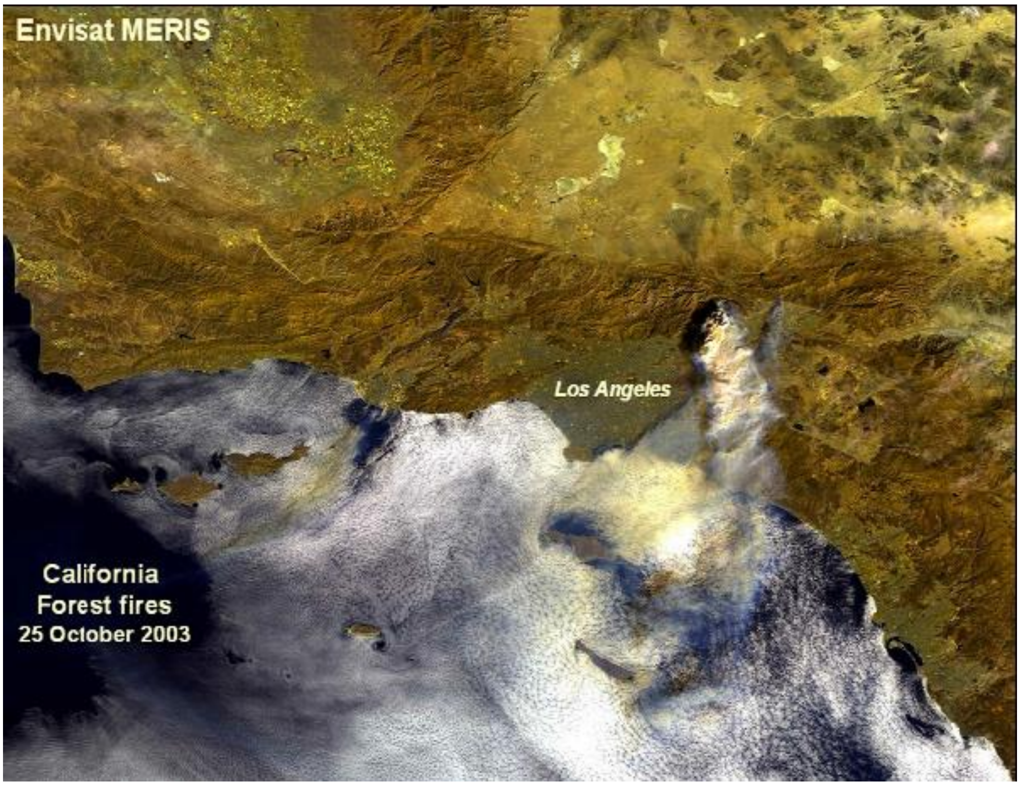


Figure 2.1-2: Wild fires in California (25 October, 2003, ESA, MERIS).

The aerosols are transported SSW and interact with low level cloud off the Californian coast. Aerosols above the stratocumulus cloud layer reduce their reflectivity (positive forcing), while aerosols within the cloud lead to brighter clouds (negative forcing). The same is true for the ship tracks visible in the left part of the image

For these reasons, EarthCARE has been specifically defined with the specific scientific objectives of quantifying aerosol-cloud-radiation interactions so they may be included correctly in climate and numerical weather forecasting models to provide:

- Vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds
- Vertical distribution of atmospheric liquid water and ice on a global scale, their transport by clouds and radiative impact
- Cloud overlap in the vertical, cloud-precipitation interactions and the characteristics of vertical motion within clouds
- The profiles of atmospheric radiative heating and cooling through a combination of retrieved aerosol and cloud properties

2.1.3 Instrument Complement

The observational requirements discussed above indicate the need for measurements from a single satellite platform of the vertical structure of aerosols and clouds, plus complementary information on cloud-scale vertical velocities and precipitation, and of the corresponding broad-band and narrow-band radiances at the top of the atmosphere. The profile information can only be provided by active instruments, a lidar for aerosols and thin clouds and a high frequency (94 GHz) doppler radar for clouds. These instruments can also provide the additional required information on discriminating absorbing from non-absorbing aerosols, on cloud-scale vertical velocities and precipitation (mainly drizzle) rates.

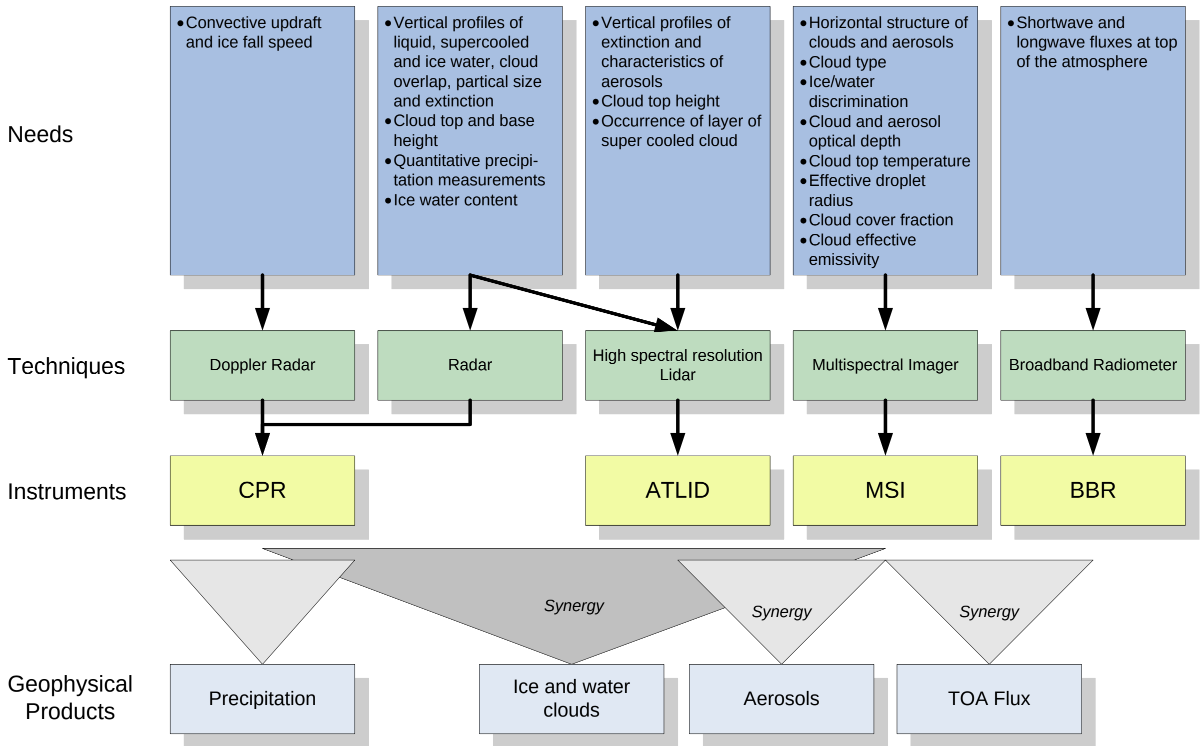


Figure 2.1-3: Summary of measurement needsand techniques and the related EarthCARE instruments.

The EarthCARE sensors as a complement will produce a set geophysical product for which again synergy is needed to perform the process studies of interest

A multi-spectral imager is required to provide additional geographical coverage of aerosol and cloud optical property retrievals, and a broad-band radiometer is required to measure radiances and to derive fluxes.

These measurements need to be made for the whole globe and for a period long enough to ensure that all of the important climatic regimes are represented with the necessary statistical significance. This leads to the requirement for a single satellite mission with a lifetime of several years, in a Sun-synchronous polar orbit with an altitude as low as possible to optimise the performance of the two active instruments (lidar and cloud radar), which are supplemented by a multi-spectral imager providing cross-track observations and a broad-band radiometer for determining incoming and outgoing radiation simultaneously. Additional information on atmospheric temperatures and humidity can be obtained from other sources. The four EarthCARE instruments are listed with the corresponding observable parameters in the following table. The combination of passive and active instruments provides a unique set of vertical distributions of cloud and aerosol parameters.

Instrument	**Observable Parameters Single Instruments**	**Observable Parameters Instrument Combination**
CPR Cloud Profiling Radar	• Vertical profiles of cloud structure (water / ice content) • Cloud top height • Cloud base height • Quantitative precipitation measurements • Ice Water Content to a factor of 2	CPR / Lidar • Vertical profiles of the physical parameters of the cloud • Provide estimates of cloud particle size • Ice Water Content can be estimated to about 30-40% • Occurrence of layers of super cooled cloud
ATLID Atmospheric Lidar	• Vertical profiles of the physical parameters of aerosols • Cloud top height • Occurrence of layers of super cooled cloud	
MSI Multi-Spectral Imager	• Cloud horizontal structure / variability • Cloud type • Ice / water discrimination • Cloud optical depth • Effective droplet radius • Cloud top temperature • Aerosol optical depth • Cloud cover fraction • Cloud effective emissivity • LWP • All the above MSI measurements at cloud top only for thick cloud	MSI / CPR / Lidar • More accurate estimates of MSI observables MSI / BBR • Quantify variability within footprint of BBR
BBR Broad-Band Radiometer	• Short–wave and long-wave fluxes at the top of the atmosphere	BBR / Lidar / CPR • Constraint on the radiative flux derived from the cloud and aerosol profiles measured by the active instruments

Table 2.1-1: EarthCARE Payload and Observable Parameters

The combined Radar and Lidar retrieval is potentially extremely powerful. These two instruments have the unique property of penetrating clouds and providing vertical profiles of cloud and aerosol characteristics. The combination of the different instruments on board one spacecraft leads to additional observable parameters as the single instruments itself could provide, but leading to co-registration requirements between the different instruments.

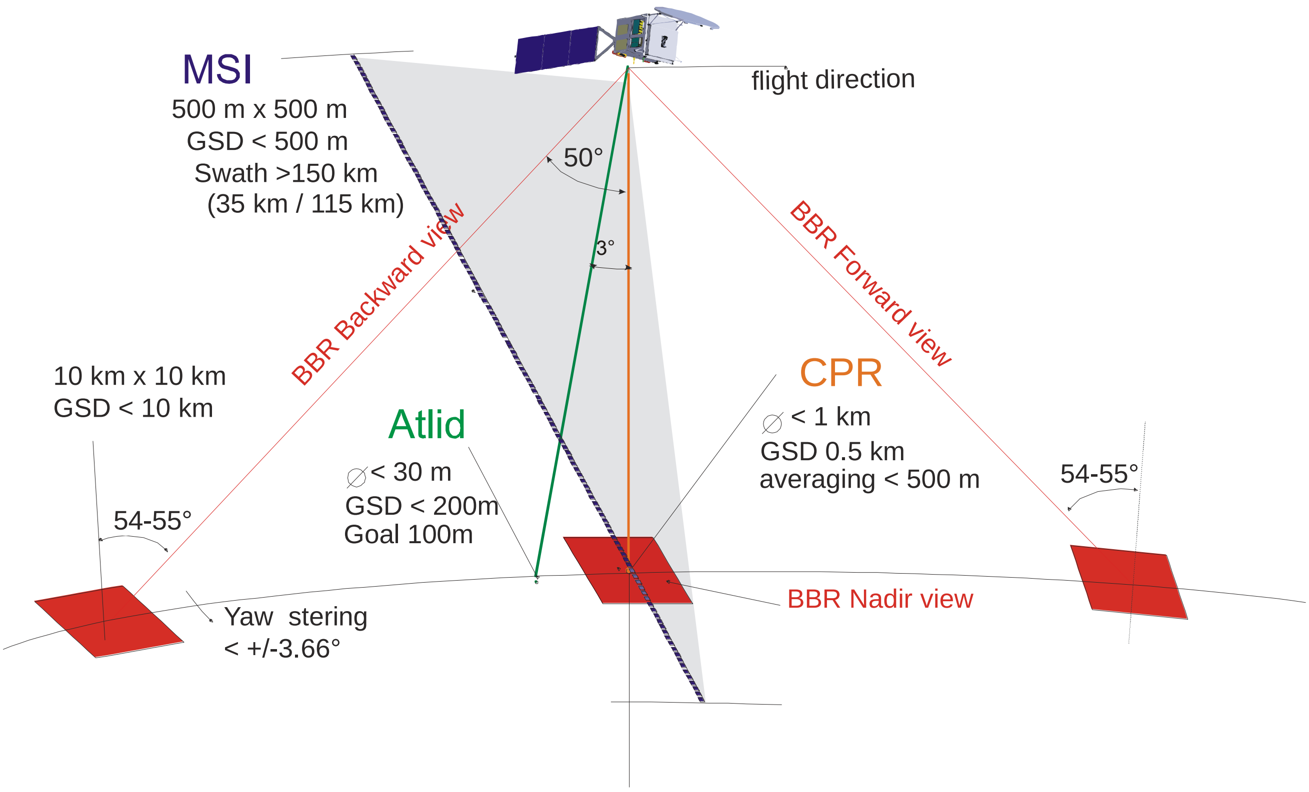


Figure 2.1-4: EarthCARE observation concept.

The footprints of the nadir-pointing CPR and MSI, the 3° backward-looking ATLID, and the three BBR views The EarthCARE mission is centred on the synergetic use of the data provided by an instrument suite consisting of active and passive sensors. This observation principle is depicted in Figure 2.1-4. All instruments observe the same volume of atmosphere, although at slightly different times, with the imager providing in addition across-track information. This principle allows not for only micro- and macro-level cloud and aerosol measurements to be taken as vertical profiles along the flight track, but also for acquiring horizontal bi-dimensional information by means of the across-track observations of the multi-spectral imager. The payload is accommodated on the satellite in a way that meets the viewing and alignment requirements, while the platform provides service functions like electrical power supply, data interfaces, attitude control and thermal control.

2.1.4 EarthCARE System Description

The EarthCARE system comprises a satellite carrying an Atmospheric Lidar (ATLID), a Cloud Profiling Radar (CPR), a Broad Band Radiometer (BBR) and a Multispectral Imager (MSI) and a ground segment providing the operational facilities required to operate the mission and to exploit the mission products of Level 0, Level 1B and higher level products. Additionally there is an EarthCARE End to End Simulator established to allow the user community to early assess the system performance and to perform sensitivity studies.

Figure 2.1-5: EarthCARE System Overview

2.1.4.1 Launch System

The EarthCARE satellite design is compatible to the current baseline launcher Soyuz (from Kourou), which is outlined in Figure 2.1-6.

Launcher back up initially foreseen (Zenit) is no longer pursued due to the consolidation achieved on the Soyuz baseline and the fact that the Zenit commercialisation is no longer sustainable.

The technical interface agreements between launch provider Arianespace, ESA and Airbus DS are summarized in the Launch System/Spacecraft Interface Control File [RD-140] and the Launcher IRD [RD-139]

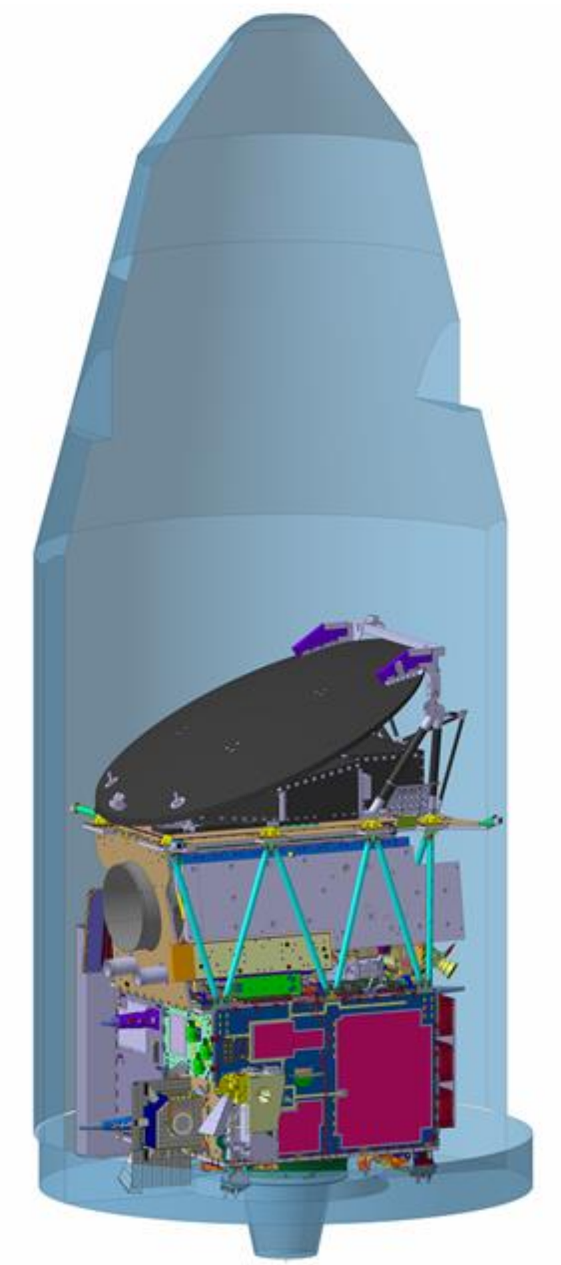


Figure 2.1-6: EarthCARE baseline launcher Soyuz from Kourou

2.1.4.2 Ground Segment System

The Ground Segment of the EarthCARE system is composed of two elements:

- The Flight Operation Segment (FOS) is responsible for spacecraft commanding, spacecraft health monitoring, orbit control and on-board software configuration and maintenance. The FOS will be provided by the Agency according to interface requirements and operations manuals provided by the Contractor.
- The Payload Data Ground Segment (PDGS) is responsible for quality control resulting in science data acquisition, processing, archiving and distribution, as well as mission planning. The PDGS will be provided and operated by the Agency and will include interfaces to the JAXA data-segment. The PDGS will include an operational version of the L1 processors defined and prototyped by the Contractor and a version of the CPR prototype processor delivered by JAXA.

The spacecraft design support all Measurement/Operational Phase operations via a single, dedicated Master ground station located at Kiruna, Sweden. A dedicated S.-band antenna for command and control and a dedicated X-Band antenna for data dump are considered.

The spacecraft design provide the necessary features in order to support instrument data dissemination (multi-dumps) to other secondary ground stations as long as the secondary X-Band station is compatible to the X-band design implemented to support the data dissemination towards the X.band station in Kiruna.

The sizing of the S- and X-band system on board EarthCARE considers the 13 m and 15 m antenna in Kiruna for nominal operation. The ground station characteristics are provided by ESA in [RD-05].

For LEOP additionally the characteristics of the ground stations in Svalbard (13 m) and Troll (7.3 m) are considered. Vilspa (Villafranca / Spain) is TBC.

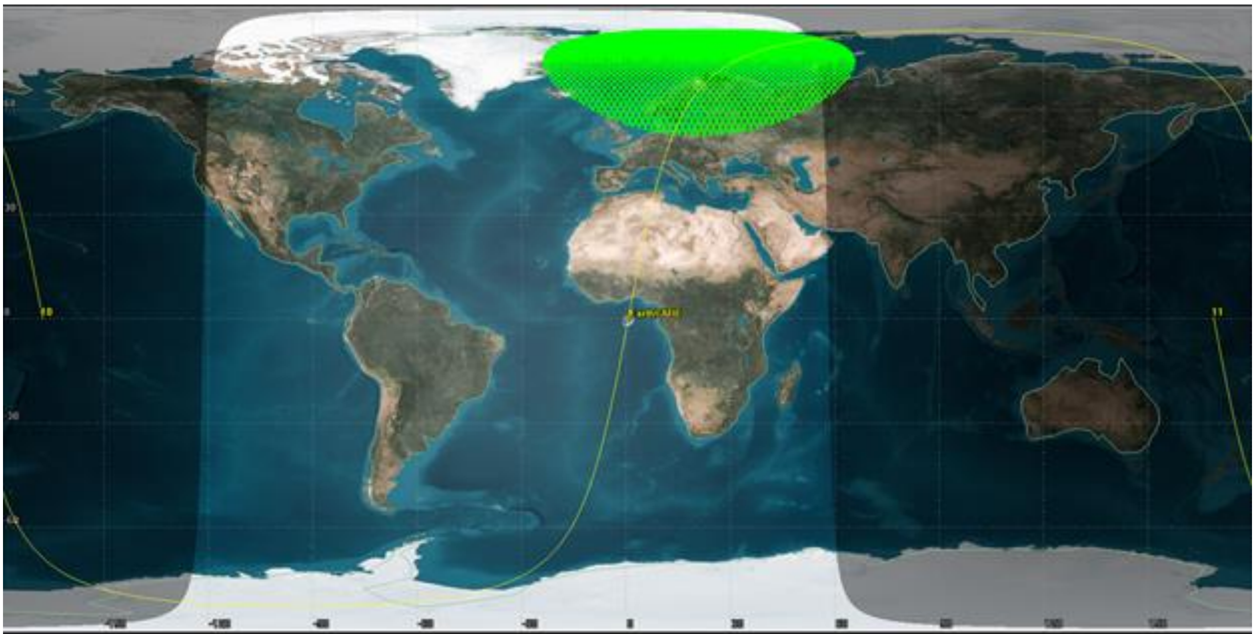


Figure 2.1-7: Ground track for the nominal orbit together with the visibility of the G/S in Kiruna (>5° elevation assumed).

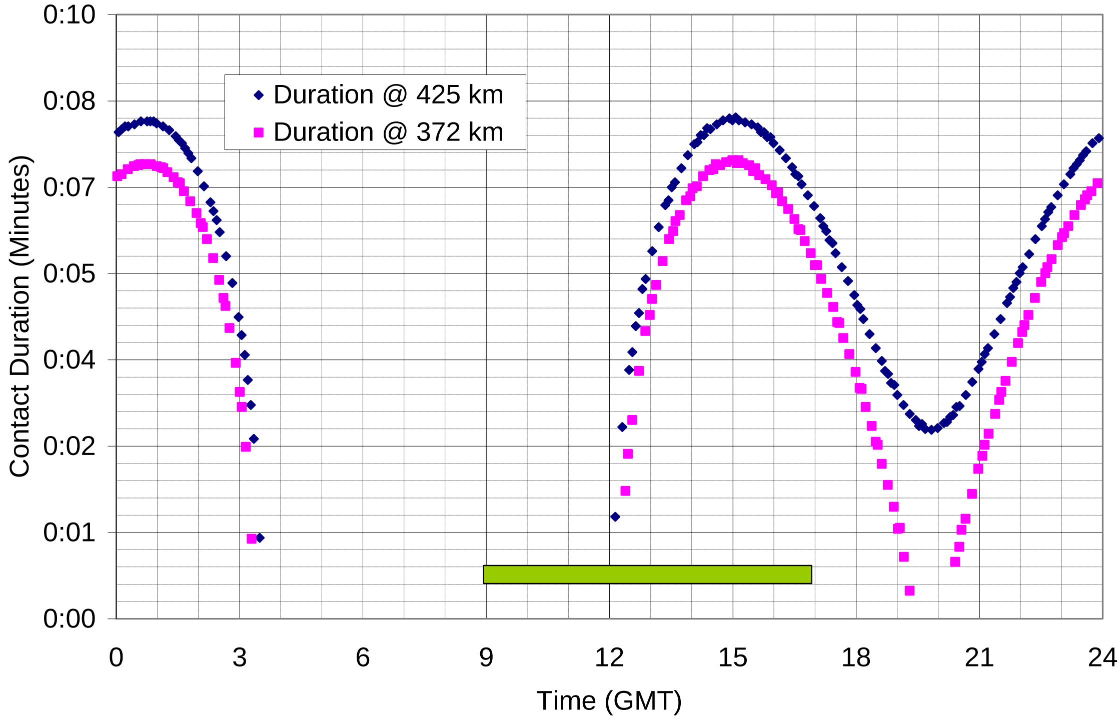


Figure 2.1-8: Typical duration of G/S contacts versus local time at the ground station for the lowest and highest altitudes considering a limit of 5° elevation.

As seen from the figure above there will be no contact to the nominal ground station between 3:00 and 12:00 (GMT). During the rest of the day there are every 1.5 hours ground contacts possible.

Finally, it is highlighted that the Agency will develop an EarthCARE End-to-End mission Simulator (ECEESIM). The ECEESIM will be composed of separate modules representing individual elements in the overall EarthCARE 'observations to science products' chain. The Contractor is responsible for the elements of the ECEESIM representing the Flight Segment as well as the Level 0 to 1 processing and the Contractor shall support the Agency in defining the relevant data interface.
The main elements of the ECEESIM are:

- (a) An EarthCARE scenery simulator
- (b) An EarthCARE Satellite System Simulator (ESSS) including Instruments Models and auxiliary modules such as AOCS, orbit propagator, datation etc
- (c) An EarthCARE Ground Processor (ECGP): raw/Level 0 to Level 1 data products
- (d) A higher level products processor

The EarthCARE scenery simulator (a) and the higher level products processor (d) are not under the responsibility of the Contractor but interfaces from/to these modules will need to be agreed. The ESSS (b) is under the responsibility of the Contractor. It is composed of a series of individual modules (ATLID, BBR, CPR, MSI models and auxiliary modules such as AOCS, orbit propagator, datation etc). For the CPR, the Contractor responsibility covers integration and final testing of the CFI CPR instrument model. The ESSS output shall be compatible with the input of the ECGP (c) which is as well under the responsibility of the Contractor. For the CPR, the Contractor responsibility covers integration and final testing of the CFI CPR processor

2.1.4.3 Satellite Configuration

Figure 2.1-9: EarthCARE Satellite in flight configuration

Detailed description of the EC Satellite design can be found in the Satellite Technical Description [RD 02].

2.2 Mission Operation Requirements

For EarthCARE the following key operation requirements have been identified in [AD-99] with key adaptations agreed in EC.TN.ASD.SY.00135 (EC.RFW.ASD.SY.00047)

SDS Ref.	SRD-Ref	Requirements Text	Design Impact
SDS-1995	OPS-NO-5; OPS-EO-3	After launch without ground contacts in nominal and one-failure situations, the satellite shall survive, without subsequent loss of mission, for a duration of at least : • 5 [TBC] orbits prior solar array deployment • 5 days after solar array deployment in LEOP • 8 days in COP and MOP	Driving the design of the on-board failure detection, isolation and recovery system, of the Satellite Safe Mode as well as the nominal operation resources.
SDS-5941	OPS-CO-7	It shall be possible to program the Satellite for fully autonomous operations not requiring commanding by the Ground Segment for at least a period of 5 days.	All driving the nominal operation resources and capabilities in terms of on-board resources, autonomy (master timeline and orbit position scheduling capabilities) and high level

SDS Ref.	SRD-Ref	Requirements Text	Design Impact
SDS-5922		Calibration and orbit control manoeuvres shall be specified and designed so as to minimise nominal mission interruption.	operation
SDS-2014	OPS-NO-14	Because the operations performed during the External Calibration Sequences may disrupt measurements by other Instruments, the design of the EarthCARE satellite and of its operation timeline shall be made towards minimizing the External Calibration Sequence duration. Via this requirement, the External Calibration operations should also avoid to affect other instruments which have been already calibrated.	
SDS-2019	OPS-NO-16	Orbit maintenance shall be commanded by ground. The orbit maintenance sequences shall be designed to support continuation of instrument operation as long as possible either in normal operation at temporarily degraded performance or in an operational mode minimizing the unavailability duration (due to minimization of instrument deactivation/activation transitions).	
SDS-2140	OPS-IC-3; OPS-NO-7	The spacecraft design shall allow to be fully operated during MOP via a single Master Ground Station (Kiruna, TBC) for nominal command and control (via S-band).	
SDS-2009	OPS-NO-12	Although few satellite routine maintenances may lead to the disruption of L1B production, EarthCARE shall be designed towards maximizing measurement operation time. This requirement implies the possibility to operate all the EarthCARE instruments simultaneously in parallel. During the nominal lifetime of the mission, it shall be possible to change three times between the nominal orbit for routine phase and the CAL/VAL orbit. Note: This means that 3 cycles (routine orbit -> CAL/VAL orbit; CAL/VAL orbit --> routine orbit) will be possible. The possibility of lowering the orbit (CAL/VAL --> routine orbit) by atmospheric drag (without a dedicated additional manoeuvre)	

SDS Ref.	SRD-Ref	Requirements Text	Design Impact
		is not excluded.	
SDS-5705	DHS-TC-7	The software shall allow spacing of time-tagged telecommands as close as 100 ms (TBC) while the release time instant of these time-tagged telecommands will be in line with the accuracy specified under SDS-2123.	Driving the design to support TC execution at least a 10 Hz.
SDS-2123	OPS-TI-4	The release time accuracy for time-tagged telecommands, under on-board software control, shall be better than 50 ms (TBC).	
SDS-6434	OPS-GE-3; OPS-SC-1; OIRD TM-25; OPS IC-5; DHS-MM-23; OPS-OB-1	In SAT-NOM mode a copy of all HK and satellite ancillary data shall be accumulated and stored on the MMFU mass memory.	Driving the on-board design to provide a complete on-board data flow to the payload data ground system, which is independent from the monitoring and control data flow to the flight operation segment

2.3 Operations Architecture Overview

2.3.1 Operations Scenario

The EarthCARE satellite will be operated by ESA in coordination with other Earth Explorer missions via a single ground station in its operational phases.

The operation concept for the EarthCARE satellite aims to support a simple and robust mission operation concept focusing on simplified mission operation execution, thus supporting an efficient and cost effective S/C operation. The “Offline” characteristics of the spacecraft and instrument operations are completely scheduled by ground control, but are efficiently supported by on-board autonomy capabilities like potential master timeline and orbit position schedulers as well as simple but efficient on-board control procedures.

For nominal operations, the autonomous capabilities are employed to facilitate operations in the frame of the overall mission plan and to take care of the numerous back-ground tasks for management and surveillance of spacecraft equipment and payload, e.g. time distribution, data collection and downlink, parameter monitoring, thermal control, battery management, attitude control etc..

Complete monitoring and control of the satellite, including replay of recorded data will be conducted via the S-band up- and downlink channels of the satellite. Real time operations will be reduced to a minimum. The contacts between the Mission Operations Control Centre and the satellite will primarily be used for pre-programming of the on-board schedulers and for replay of recorded monitoring and control data for off-line status assessment and anomalies detection.

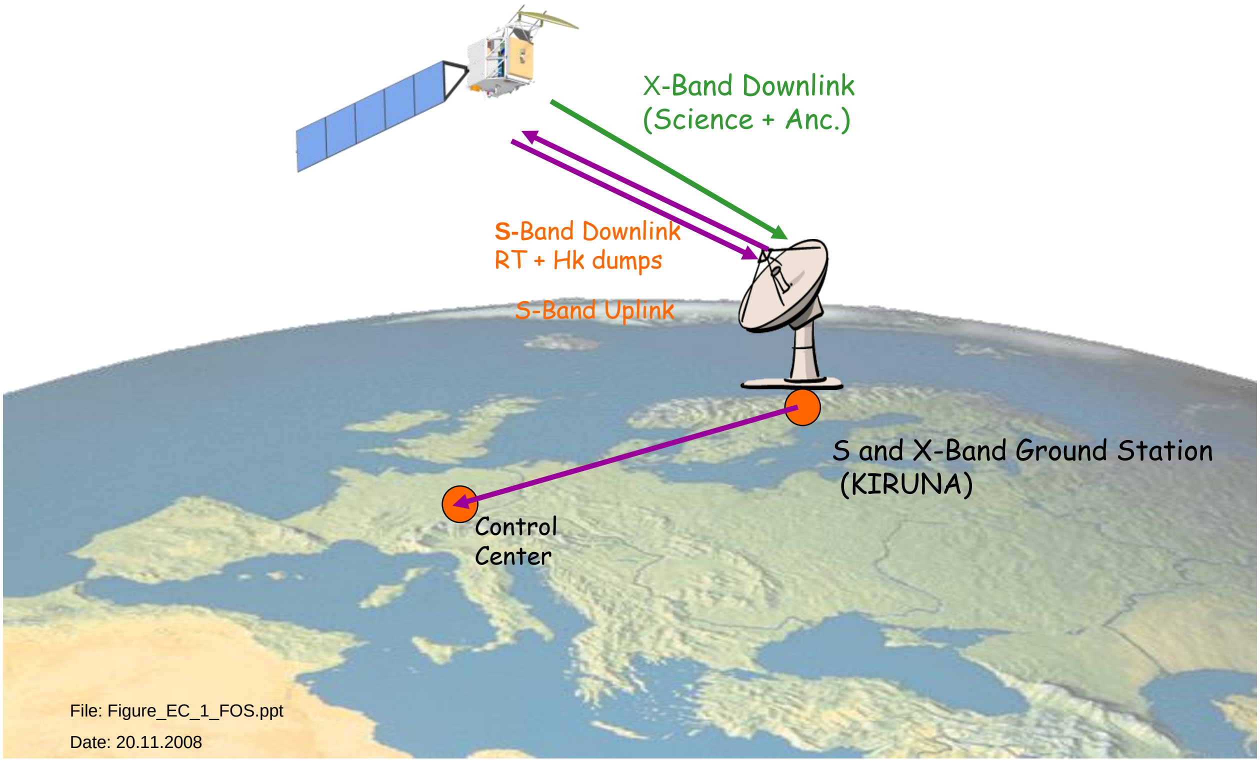


Figure 2.3-1 EarthCARE Operation Scenario

Four instruments are located on one platform: the CPR (Cloud Profiling Radar), the ATLID (atmospheric light radar), the MSI (multi spectral imager) and the BBR (broadband radiometer). Each instrument contains its own ICU (instrument control unit) which acts as a PUS packet terminal. The four instruments are operated along a generic mode and mode transitions concept, supporting operation by standardized instrument operational procedures. All instruments are synchronized to the central on-board time and are using this synchronized time also for time stamping of all TM packets and science data. Thus all data can be precisely correlated.

The instrument measurement data dissemination is via X-Band downlink. During the operational phase, one dedicated ground station will be used to acquire the instrument science data stream. The operational scenario baseline relies on the use of all the passes over the ground station in order to be able to replay all the science data generated on-board the satellite while minimizing the time between sensing the data on-board and their availability at the ground segment level. The X-band downlink data stream embeds a copy of the monitoring and control data, satellite ancillary, instrument measurement and instrument ancillary data basically supporting a complete independent data processing within the PDGS.

In addition to this baseline operation scenario the EarthCARE operations design support

- multi-dump (i.e. dump of same data to several ground stations) for all data types and
- near real time downlink of data, stored latest on the MMFU, by keeping the packet stores open for downlink when emptied instead of terminating downlink sequence . The near real-time downlink capability allows data dissemination with minimum latency and without obvious on-board storage while they are generated.

The Mission operations conducted by ESA starts at switch-over to internally provided power on the launch pad and commence on the separation of the satellite from the launcher and continue until disposal at the end of the mission. Mission operations include the following tasks:

Mission Planning generating the operation sequences to be uploaded to the satellite based on inputs provided by the payload data ground segment for the instrument schedules and the X-band station schedules, the flight dynamics for orbit control sequences and by the flight operations segment for satellite monitoring and control operations via S-Band station taking into account the ground station availability for the EarthCARE mission.

Satellite Monitoring and Control by means of processing the housekeeping telemetry such that the status and behaviour of all satellite sub-systems are monitored. Satellite control taking care for upload of the time-/orbit position- tagged telecommands and additional control actions as required by means of immediate commands i.e. in responds to planned maintenance activities e.g. for on-board SW or monitoring anomalies.

Attitude and Orbit determination: Orbit determination and control using tracking data both provided by the sensors of the attitude and orbit control system and by ground tracking and implementing orbit manoeuvres to change the satellite velocity such that required orbital conditions are achieved. Attitude determination based on the processed attitude sensor data is provided for satellite monitoring. Having all related data contained in both data streams (S- and X-band) supports an operationally optimized implementation in the ground segment.

Quality Control(1) resulting in acquisition, processing, archiving and distribution of scientific data products is the essential operational service of the EarthCARE mission to provide an optimum access of the user group to data generated by the EarthCARE satellite and its multi-instrument payload.

(1) Quality control task is performed on Ground.

2.3.2 EarthCARE S/C Operability Mission Constants

Various operation and operational design related mission constants are identified in [AD-99], which can be summarized in the following table extracted from [ND-152].

Mission Parameter	Parameter Description	Appl.	value
<ANOM_RESP_TIME>	Minimum response time for the ground segment to react to anomalies detected from the telemetry with the generation of a telecommand NOTE: This is applicable for short, well-defined intervals during critical mission phases and for pre-agreed contingencies and anomaly conditions.	Y	LEOP: 2 orbits
<ANT_SWITCH_TIME>	minimum time interval that is available for switching between on-board antennas	N	
<AUT_DUR_EXEC>	interval of time for which the space segment can execute nominal mission operations autonomously	Y	> 5 days
<AUT_DUR_DATA>	interval of time for which the space segment can store mission data on-board	Y	> 72 hours
<AUT_DUR_FAIL>	interval of time for which the space segment safety is ensured (without ground segment intervention) in the event of a single failure	Y	5 hours before SA deployment 5 days in LEOP 8 days in COP/MOP
<BATT_CHARGE_ACC>	accuracy to which the charge status of an on-board battery can be determined	Y	0.1 Note: The Ground processing tool (BEAST) using EC TM (Battery temp, Battery Voltage and current) in order to determine / plot battery charge state.
<DIAG_MIN_INTERV>	minimum sampling interval for sampling an on-board parameter in diagnostic Mode	Y	0.1 sec

Mission Parameter	Parameter Description	Appl.	value
<GRND_RESP_TIME>	Response time for control functions involving the ground segment NOTE There can be several such parameters for a given mission.	Y	- 2 orbits LEOP before SA deployment - 72 hours
<PARAM_ABS_SAMPL_TIME>	accuracy of determination of the absolute (on-board) sampling time of a telemetry Parameter	Y	Science data: 1 ms HK TM data: 100 msec Note: HK TM for CPR data: 1 sec
<PARAM_REL_SAMPL_TIME>	accuracy of determination of the relative sampling time of any two telemetry parameters	Y	0.2 sec (TBC)
<PAYLOAD_INT>	interval of time following separation from the launcher during which there is no requirement for the ground segment to perform extensive payload operations	Y	5 days
<PKT_RETR_DELAY>	Maximum time delay for the ground segment to retrieve data generated at an earlier time and stored on-board. NOTE: There can be several such mission parameters relating to data of different operational priority.	Y	72 hours
<PKTS_NUM_STORED>	Number of packets stored in short-term storage on-board NOTE: This is applicable for missions with continuous ground coverage.	N	
<POW_CONS_THRESH>	threshold of electrical power consumption beyond which specific requirements exist for the provision of telemetry data	Y	20 W
<RESOURCE_MARGIN>	minimum resource margin for on-board subsystems and payloads that is available at all times during the mission EXAMPLE: on-board memory, CPU load, bus traffic and registers	Y	0.25
<TC_VERIF_DELAY>	maximum delay between the execution of a telecommand and its verification within the telemetry	Y	10 sec
<TIME_CORREL_ACCUR>	correlation accuracy between on-board time and ground time OBT to UTC correlation (nominal mission) OBT to UTC correlation (o/B drift {GPS reboot})	Y	 0.1 msec 0.9 msec

3. EARTHCARE MISSION PHASES AND MODES

3.1 Mission Phases

There are 5 phases within the spacecraft's lifecycle:

- Pre-Launch
- Launch & LEOP Autosequence
- In Orbit Verification (IOV) & Commissioning (COP)
- Operational Phase (MOP) including Mission Extension
- De-orbit

The EARTHCARE mission phases are defined in accordance with [AD-99].

3.1.1 Pre-Launch

The Pre-Launch phase consists of the following main operations.

Pre-Launch Main operations
Satellite OFF: • The satellite is completely switched off and un-powered in this mode. • During AIT and other ground handling (e.g. transportation), the satellite is maintained within non-operational temperature range by external environment control.
Satellite Standby: • SAT-SBY is used during all ground operations as starting point for system testing. • In SAT-SBY the AOCS is in AOCS Standby Mode and tolerates inhibition of its actuators and any sensor reading. • It serves for preparation of the spacecraft for the launch phase. • In the transition to SAT-LAU the Latch valves will be opened.
Under ground control / during ground test phase: • Controlled via EGSE Check-out system

Table 3.1-1: Main Operations of Pre-launch Phase

3.1.2 Launch & Early Operation Phase (LEOP)

The LEOP phase consists of the following main operations.

LEOP Main operations
Launch and Ascent: • Internally powered pre-launch phase, during the count-down. • Launch phase, from the launch until separation of the satellite from the launcher • Survival heaters (temperature is controlled via thermostats) are switched on
Separation Sequence triggers at separation the autonomous initialization sequence comprising: • Passive drift (min. 20 sec) with no thruster actuation to protect the upper stage of the launcher from excessive plume impingement • Separation Delay (min. 60 sec including the passive drift phase) for EMC compatibility of EarthCARE equipments (e.g. RMU (MIMU)) • TTC Terminal S-band link acquisition of the satellite • activation of all on-board functions to achieve a thermally and power safe attitude allowing full communication exchange with the ground

LEOP Main operations
• Rate Damping • Deployment of solar array (incl. SA rotation) and delivery of power. • Attitude rate reduction and coarse earth oriented attitude acquisition • Coarse yaw attitude acquisition
Under ground control / during ground contact phases: • Nominal platform conditioning (power & thermal) • Initial spacecraft check-out (incl. GPS activation) • Nominal attitude acquisition • CPR antenna deployment • Transition to satellite pre-operational mode • Orbit manoeuvres for injection error correction, if required • RCS pressurization valve release • Orbit manoeuvres for orbit maintenance

Table 3.1-2: Main Operations of Launch and Early Operations Phase

3.1.3 In Orbit Verification (IOV) & Commissioning (COP)

In Commissioning Phase the following main platform, data handling and instrument operations are to be conducted:

COP Main operations
In-orbit Check-out: • Switch-on and check-out of all Platform equipment • Switch-on and check-out of payload data handling and X-band transmission • Switch-on and check-out of nominal instruments • Nominal Operations check-out
In-orbit Calibration, Characterization and validation activities • Instrument calibrations • Performance characterization of instruments • Data acquisition and L1B processor check-out
Orbit acquisition • Orbit manoeuvre sequences to transition to operational orbit. • Orbit manoeuvres for orbit maintenance

Table 3.1-3: Main Operations of In Orbit Verification and Commissioning Phase

3.1.4 Operational Phase (MOP) including Mission Extension

The main operations of the Measurement and Operation phase are:

MOP Main operations
Nominal operations • Monitoring and control data replay and downlink via S-Band • Science data generation • Intermittent external and internal calibrations on different repeat periods (orbital, weekly, monthly) • HK and science data replay and downlink via X-band • Orbit manoeuvres for orbit maintenance • science data generation and quality control • science processor maintenance and evolution

Table 3.1-4: Main Operations of Measurement and Operation Phase

PDGS is responsible during MOP for the following:

- science data generation and quality control
- science processor maintenance and evolution
-

3.1.5 De-orbit

Satellite operations in the End-of-Life Phase are pretty limited. The satellite design approach aims on being compatible to the European Code of Conduct for Space Debris Mitigation [ND-264] by generating no harmful debris when entering uncontrolled the atmosphere.
Even in case of a controlled de-orbiting avoiding generation of harmful debris is essential as an uncontrolled re-entry can never be totally excluded in reality due to e.g. a major satellite malfunctioning. Remaining fuel, if not spent for mission extension, could be used for improved atmospheric re-entry. The OPS schedule would help considerably in achieving the necessary manoeuvre precision.

3.2 Mode Definition

The EarthCARE system configurations are to be considered in context with the overall EarthCARE mode diagram shown in Figure 3.4-1.

3.2.1 Satellite OFF Mode (SAT-OFF)

In SAT-OFF the satellite is completely switched off and un-powered in this mode. During AIT and other ground handling (e.g. transportation), the satellite is maintained within non-operational temperature range by external environment control.

Within credible failure scenarios the satellite will never experience this mode after launch; only in case of multiple failures beyond those credible failure scenarios. Therefore it is handled as ground operation mode only.

3.2.2 Satellite Standby Mode (SAT-SBY)

SAT-SBY is used during all ground operations as starting point for system testing. It serves for preparation of the spacecraft for the launch phase. In SAT-SBY the AOCS is in AOCS Standby Mode and tolerates inhibition of its actuators and any sensor reading. It will also be used during all ground operations as starting point for system testing. In the transition to SAT-LAU the Latch valves will be opened.

3.2.3 Satellite Launch Mode (SAT-LAU) [L-12 hours]

The satellite will be in SAT-LAU from the switch-over from ground-supplied power to the Satellite internal batteries until satellite separation. The battery is connected to the central PCDU DC/DC converters and delivers power to the OBC and the S-band receivers which are operational. The duration of the Launch Mode is limited by the capacity of the battery.

3.2.4 Satellite Nominal Acquisition Mode (SAT-NAM)

The Nominal Acquisition Mode will start with identification of satellite separation from the launcher. In this Mode the AOCS will reduce the satellite rates and subsequently will acquire and maintain safe 3-axes stabilised nadir earth pointing attitude. This Mode will be used after separation but also after certain failure situations occurring in Nominal Mode.
With detection of separation the acquisition sequence will autonomously start and run a predefined LEOP auto-sequence comprising mainly the following activities:

- Initial unit incl. S-band transmitter and RT downlink switch on
- Survival level thermal control
- Rate reduction
- Solar Array deployment
- Rate reduction and coarse nadir pointing attitude acquisition

The generation of power is autonomously started as soon as solar input is available on the solar arrays. The release of the SA deployment is triggered autonomously as part of the autonomous LEOP initialization function. The LEOP auto-sequence is designed to autonomously handle all credible single failures of individual elements in the functional chain. In case of problems the LEOP autosequence function can be triggered by telecommand to force the SA deployment. Solar array rotation is only started after successful SA deployment.
In case of system reconfigurations after successful completion of SA deployment the LEOP auto-sequence is no longer executed but the nominal system software initialisation, comprising initial unit switch on and attitude acquisition, is performed.
The end of the acquisition sequence is characterised by a stable S/C configuration in terms of attitude, power and thermal. The platform thermal control system will keep the used units within operational temperatures

and all other units within their non-operational limits. Immediately after switch on of the S-Band system the ground can establish the link for TM acquisition and telecommanding. Ranging will be performed to identify the initial orbit parameters.

3.2.5 Satellite Pre-Operational Mode (SAT-POM)

The Satellite Pre-Operational Mode is the spacecraft mode where nominal platform operation is ensured while the instruments are in protected configurations. SAT-POM is characterized by the following conditions:

- All equipments required for nominal platform operation are switched on
- Nominal platform thermal control is provided. The Thermal Control System keeps all platform and internal instrument equipments within their nominal temperature range. Externally mounted instruments are thermally controlled by instrument thermal HW supplied via survival power lines.
- The AOCS provides and maintains a stable 3-axis controlled fine pointing attitude. If commanded attitude and orbit control manoeuvres are possible. Orbit manoeuvres requiring significant attitude re-orientations e.g. for inclination and node control are executed in this mode
- The CDHS records monitoring and control data e.g. HK and satellite ancillary data in the OBC mass memory and transmit RT TM data via TT&C (at least during the planned S-Band Ground Station contacts). OBC mass memory data are replayed over S-band, if commanded. Transmission of monitoring & control data and satellite ancillary data to the PDHT can be enabled by command
- The instruments are switched off in protected configuration and power is provided in hot redundancy to the instrument survival heater system. Some few essential decontamination heaters are operated under S/C control. Upon command individual Instrument switch-on for check-out and maintenance activities are possible.
- The PDHT is maintaining recorded data, if switched on before. Data retrieval and downlinked over the X-Band Ground Station is possible on command.

The CPR deployment will be done under ground control in this mode (in AOC-NOM)

3.2.6 Satellite Nominal Operational Mode (SAT-NOM)

The Satellite Normal Operation (SAT-NOM) mode is the spacecraft mode where science data are collected and delivered to ground. SAT-NOM is characterized by the following conditions:

- All equipments and instruments required for nominal operation are switched on
- The platform Thermal Control System performs nominal thermal control to keep all platform and internal instrument equipments within their nominal temperature range. Instruments with externally mounted equipments are performing individual nominal thermal control.
- The AOCS provides a stable 3-axis controlled attitude as required for scientific instrument operations. Attitude manoeuvres and orbit control manoeuvres are possible on command, but may constrain scientific operation of individual instruments
- The CDHS records monitoring and control data e.g. HK and satellite ancillary data in the OBC mass memory and transmits RT TM data via TT&C (at least during the planned S-Band Ground Station contacts). OBC mass memory data are replayed over S-band, if commanded. Transmission of monitoring & control data and satellite ancillary data to the PDHT is active.
- The S/C state vector command is provided to the instruments for instrument nominal operation support. In SAT-NOM the satellite indicates in the S/C State vector quality field at least the following information
    - validity identifier for each element of the S/C state vector
    - AOCS Detailed Mode identifier
    - Nadir pointing performance identifier, which is set if the AOCS is in its full performance fine pointing mode and S/C nadir is within less then 1.5° from its nominal orientation. This information will be used by ATLID to identify critical backscatter situations.
- Nominally all instrument are commanded ON and operate in their commanded mode
- Science data acquisitions are executed according to the on-board schedules and constraints and the mission data are recorded by the PDHT on the MMFU. MMFU Data retrieval and downlinked over the X-Band Ground Station is possible on command

3.2.7 Satellite Safe Mode (SAT-SAF)

The Satellite Safe Mode (SAT-SAF) is the final back-up mode during all mission phases, which is only entered in case of a critical on-board failure that cannot be recovered at a lower level. A safe coarse earth pointing attitude is maintained with magnetic torquer and RCS based on coarse earth sun sensor and rate measurements within the constraints allowing a continuous supply of power to essential loads and maintaining a stable (thermal, sun blinding, ATOX) environment compatible with the satellite survival. A two-way communication link via COM TTC S-band link with the ground station is established when coverage is available for housekeeping telemetry data and commanding (i.e. providing suitable link margins with omni-directional coverage). The Satellite Safe Mode (SAT-SAF) configuration is equivalent to SAT-NAM except that redundant units are selected according to the setting in the Spacecraft Configuration Vector (SCV)
In case of a system reconfiguration to Safe Mode during execution of the LEOP auto-sequence the LEOP auto-sequence is executed in Safe Mode configuration. In case of system reconfigurations after successful completion of SA deployment the LEOP auto-sequence is no longer executed but the Safe Mode system software initialisation is performed.
In case of system reconfiguration during CPR antenna deployment, which nominally is performed in SAT-POM triggered under ground control, the CPR antenna deployment is completed during Safe Mode system initialisation. In case of system reconfigurations before the CPR antenna deployment is started by ground or after successful completion of CPR antenna deployment this system function is not executed but the regular Safe Mode system software initialisation is performed.
In Safe Mode the telemetry and data acquisition (TDA) configuration allow unambiguous and immediate identification of Safe Mode and its correct operation by an appropriate set of telemetry packets. On-board event and TC acknowledgement history and data required to unambiguously determine the reason for triggering safe mode are available for real-time TM access and stored in OBC mass memory areas or safeguarded memory which can be dumped and reset by ground. The proposed EarthCARE design provides the complete HK history prior to entering the safe mode for ground analysis.
The basic configuration for the Satellite Safe Mode will be based on the following subsystem configuration:

- All equipments are switched on based on the Safe Mode configuration of the S/C configuration vector.
- The solar array will be positioned in its fixed safe mode orientation
- The AOCS will be in its Safe Mode configuration, i.e. in AOC-ASM using redundant equipment. In the transition to AOCS-ASM all equipments are switched off and the redundant equipment is on
- The RCS will be used on the redundant side
- The CDHS i.e. the OBC/RIU will be operating on the redundant side to exclude avionics related failure
- The OBC MM will continue recording HK data with a predefined TM set for Safe Mode on unchanged OBC MM. The stored mass memory content before Safe Mode occurred is preserved by MM configuration information maintained within the OBC MM controller and complemented by SGM RAM stored information.
- MIL-Bus communication will be executed on the redundant side
- PCDU TM/TC Interface will be switched to redundant side
- The PDHT subsystem (XBS, MMFU) and the Payload (ATLID, BBR, MSI and CPR) will be switched down to safe configurations.
- S-band Transmitter will be permanently powered, but remain on the nominal side on the default data rate configured for the mission phase

The Safe Mode is considered to be the ultimate FDIR reaction upon S/C anomalies to ensure the safety of the satellite. Safe Mode requires recovery by the Ground.

3.3 Mission Phases versus Satellite Modes versus Equipment Status

3.3.1 Satellite Status versus Mission Phases

The relation of S/C Operation Phases to satellite modes is given in the following table.

S/C Mode	Mission Phase	Pre-Launch	LEOP	COP	MOP	End of Life
		launch configuration setup: - OBC switched-on - SBS RX on, TX off - AOCS Standby - Thermal Control active - CatBed heater on - DHS off - Instruments off	- launch, auton. Separation - attitude acquisition - S-Band TX switch –on - TCS & EPS configuration - SA deployment - manoeuvre (if needed) - platform initial check-out	- COP orbit acquisition manoeuvres - orbit maintenance - platform commissioning - instrument switch-on - instr. char/calib - G/S data acq./comm. - L1B product verification	- MOP orbit acquisition - nominal satellite ops - nominal instrument ops - orbit maintenance - inst. Calibrations - nominal observation	
OFF	SAT-OFF					
Nom.	SAT-SBY	x				
	SAT-LAU	x	x			
	SAT-NAM		x			x
	SAT-POM		x	(x)	(x)	x
	SAT-NOM			X	x	
Cont.		Launch cont. ID				
	SAT-SAF		x	X	x	x
	SAT-NAM		x	X	x	x
	SAT-POM			X	x	x

Table 3.3-1 Satellite Mode to Mission Phase Relation

Note: The Satellite Modes can be nominally commanded as part of the activities planned for the phase, however are typically activated only temporarily.
Satellite Modes are virtually established by the individual modes/states of functional chains:

- EPS
- CDHS
- TT&C
- AOCS
- RCS
- TCS
- PDHT
- Instruments

Please Note:

There are no single TCs which will establish satellite mode(s) in an automated manner, i.e. satellite modes / configuration have to be established by Ground Commanding using dedicated EarthCARE Flight Procedures.

3.3.2 Equipment Status versus Mission Phases and System Modes

This section gives an overview of the status of the equipment for the various mission phases and system modes as defined above.

S/C Mode / Configuration		SAT-SBY		SAT-SBY		SAT-LAU		SAT-NAM		SAT-NAM	
		AIT-Coldstart		PRE LAUNCH		Launch		post Separation		post SA-Deployment	
Red		A	B	A	B	A	B	A	B	A	B
S/W Platform / Functions											
OBC	CDHS S/W	RUNNING		RUNNING		RUNNING		RUNNING		RUNNING	
	FDIR settings	Flight (PM-EEPROM		ADAPTED		FULL		FULL		FULL	
	TM Mode	LEOP		LEOP + specific AIT set		TDA_LEOP		TDA_LEOP		TDA-SFM	
	TM Rate	LOW (CSW default)		HIGH		LOW (SGM-RAM)		LOW (SGM-RAM)		LOW -> HIGH	
	RT HK Downlink	via UMB		via UMB		NO		NO -> YES		YES[1)]	
	TC/Commanding	via UMB		via UMB		NO		YES		YES	
	HK Recording on MM	YES		YES		YES		YES		YES	
	AOCS Mode	AOC-SBM		AOC-SBM		AOC-SBM		AOC_ASM->RD->DEP		AOC-ASM	
	AOCS Attitude / Pointing	N/A		N/A		N/A		->Rate Damping		Coarse Earth Pointing	
	TCS Settings	DISABLED		TCS-LAU		TCS-LAU		TCS-LAU		TCS-SUR	
	MTL	DISABLED, empty		DISABLED, empty		DISABLED, empty		DISABLED, empty		DISABLE->ENABLED	
	OPS	DISABLED, empty		DISABLED, empty		DISABLED, empty		DISABLED, empty		DISABLE->ENABLED	
	OBRT PPS	OBC OBRT		OBC OBRT		OBC OBRT		OBC OBRT		OBC OBRT	
	Ancillary Data Generation	NO		NO		NO		NO		NO	
	SGM-RAM defaults	EMPTY	EMPTY	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT
	SGM-EEPROM defaults	ADAPTED	ADAPTED	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT
	PayloadCtrl	**PLM-LAU**		**PLM-LAU**		**PLM-LAU**		**PLM-LAU**		**PLM-SAF**	
H/W Platform											
	PF MILBUS	USED	HSBY	USED	HSBY	USED	HSBY	USED	HSBY	USED	HSBY
CDHS	OBC										
	TC Decoder	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	OBT/TM Encoder	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
	PM	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
	RM	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	OBC-MM	ON	INACTIVE	ACTIVE	HSBY	ACTIVE	HSBY	ACTIVE	HSBY	ACTIVE	HSBY
	HK Data Recording	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
RIU	CTRL	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
	AOCS I/F	OFF	OFF	ON	OFF	OFF	OFF	OFF->ON	OFF	ON	OFF
	RCS I/F	OFF	OFF	ON	OFF	OFF	OFF	OFF->ON	OFF	ON	OFF
	SADE I/F	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF->ON	OFF
EPS	PCDU-AUX	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	PCDU-TM	ACTIVE	INACTIVE	ACTIVE	INACTIVE	ACTIVE	INACTIVE	ACTIVE	INACTIVE	ACTIVE	INACTIVE
	Bat Relays	ANY		CLOSED		CLOSED		CLOSED		CLOSED	
	Solar Array	STOWED		STOWED		STOWED		STOWED->DEPL		DEPL	
	SA Rotation	DISABLED		DISABLED		DISABLED		DIS->ENA		ENABLED - FIXED	
	SA Rotation Control	DISABLED		DISABLED		DISABLED		DIS->CESS based		CESS Based	
TT&C	SBS-RX	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
	TC Mode	via TM/TC-FE		via TM/TC-FE		NO TC		64 kbps	64 kbps	64 kbps	64 kbps
	SBS-TX	OFF	OFF	OFF	OFF	OFF	OFF	OFF->ON	OFF	ON (1)	OFF
	TM Mode	LOW		LOW		LOW (SGM)		LOW (SGM)		LOW/HIGH (SGM)	
	COH	ANY ??		OFF		OFF		OFF		OFF (ON by cmd)	
	RNG	ANY ??		OFF		OFF		OFF		ON/OFF 4)	
PDHT	MMFU	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	Data Recording	OFF		OFF		OFF		OFF		OFF	
	XBS	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
AOCS	AOCS Mode	AOC-SBM		AOC-SBM		AOC-SBM		AOC-ASM_RD->EP		AOC-ASM	
	CESS	ON - UNUSED		ON - UNUSED		ON - UNUSED		ON - USED		ON - USED	
	MTQ MTQ 1	OFF	OFF	OFF	OFF	OFF	OFF	ON-unused	OFF	ON	OFF
	MTQ 2	OFF	OFF	OFF	OFF	OFF	OFF	ON-unused	OFF	ON	OFF
	MTQ 3	OFF	OFF	OFF	OFF	OFF	OFF	ON-unused	OFF	ON	OFF
	MAG	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF
	RMU	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	OFF
	DSS DSS 1	OFF		OFF		OFF		OFF->ON		ON - USED	
	DSS 2	OFF		OFF		OFF		OFF->ON		ON - USED	
	DSS 3	OFF		OFF		OFF		OFF->ON		ON - USED	
	STR	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF->ON	OFF->ON
	GPS	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF->ON	OFF
	RWU RWU 1	OFF		OFF		OFF		OFF		OFF->ON (unused)	
	RWU 2	OFF		OFF		OFF		OFF		OFF->ON (unused)	
	RWU 3	OFF		OFF		OFF		OFF		OFF->ON (unused)	
	RWU 4	OFF		OFF		OFF		OFF		OFF->ON (unused)	
RCS	Mode	INACTIVE		INACTIVE		INACTIVE		RCS-LAU		RCS-OPR	
	THR Branch	INACTIVE	INACTIVE	INACTIVE	INACTIVE	INACTIVE	INACTIVE	INACTIVE	INACTIVE	ACTIVE	INACTIVE
	Catbed Heaters SBY	OFF	OFF	OFF->ON	OFF->ON	ON	ON	ON	ON	ON	ON
	Catbed Heaters HUP	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF->ON	OFF
TCS	Htr Groups	AIT	OFF	AIT	OFF	LAU	LAU	LAU	LAU	SUR	SUR
	SW ctrl Htr	AIT	OFF	AIT	OFF	ACTIVE		ACTIVE		ACTIVE	
H/W Payload											
	PL MILBUS	USED	HSBY	USED	HSBY	USED	HSBY	USED	HSBY	USED	HSBY
ATLID	Mode	ATLID-OFF		ATLID-OFF		ATLID-OFF		ATLID-OFF		ATLID-OFF	
	Survival HTR	OFF	OFF	OFF	OFF	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)
	ACDM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	LPE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	HPE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
BBR	Mode	BBR-LAU		BBR-LAU		BBR-LAU		BBR-LAU		BBR-OFF	
	Survival HTR	OFF	OFF	OFF	OFF	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)
	ICU	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	LPE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
MSI	Mode	MSI-OFF		MSI-OFF		MSI-OFF		MSI-OFF		MSI-SAF	
	Survival HTR	OFF	OFF	OFF	OFF	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)
	ICU	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	LPE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
CPR	Mode	CPR-LAU		CPR-LAU		CPR-LAU		CPR-LAU		CPR-LAU	
	Antenna	STOWED		STOWED		STOWED		STOWED		STOWED	
	Survival HTR	OFF	OFF	OFF	OFF	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)
	ICU	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	LPE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
	HPE	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

Table 3.3-2 Satellite configurations until LEOP

S/C Mode / Configuration (Red)			SAT-POM		SAT-NOM AOC-NOM		SAT-NOM AOC-OCM		SAT-SAF post Separation		SAT-NAM	
			A	B	A	B	A	B	A	B	A	B
S/W Platform / Functions												
OBC	CDHS S/W		RUNNING		RUNNING		RUNNING		RUNNING		RUNNING	
		FDIR settings	FULL		FULL		FULL		REDUCED		FULL	
		TM Mode	TDA_NOM1		TDA_NOM2		TDA_NOM1		TDA-SFM		TDA-SFM	
		TM Rate	HIGH (SGM-RAM)		HIGH (SGM-RAM)		HIGH (SGM-RAM)		HIGH (SGM-RAM)		HIGH (SGM-RAM)	
		RT HK Downlink	YES[1)]		YES[1)]		YES[1)]		YES[1)]		YES[1)]	
		TC/Commanding	YES		YES		YES		YES		YES	
		HK Recording on MM	YES		YES		YES		YES		YES	
		AOCS Mode	AOC-NOM		AOC-NOM		AOC-OCM		AOC-ASM		AOC-ASM	
		AOCS Attitude / Pointing	Nom. Earth Pointing		Fine. Earth Pointing		Fine Earth Pointing		Coarse Earth Pointing		Coarse Earth Pointing	
		TCS Settings	TCS-NOM		TCS-NOM		TCS-NOM		TCS-SAF		TCS-SUR	
		MTL	ENABLED		ENABLED		ENABLED		DISABLED, empty		ENABLED	
		OPS	ENABLED		ENABLED		ENABLED		DISABLED, empty		DISABLED	
		OBRT PPS	GPS		GPS		GPS		OBC OBRT		OBC OBRT	
		Ancillary Data Generation	ENABLED		ENABLED		ENABLED		NO		NO	
		SGM-RAM defaults	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT(7)	FLIGHT(7)	FLIGHT	FLIGHT
		SGM-EEPROM defaults	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT	FLIGHT(7)	FLIGHT(7)	FLIGHT	FLIGHT
		PayloadCtrl	PLM-SBY		PLM-NOM		PLM-IDLE		PLM-SAF		PLM-SAF	
H/W Platform												
		PF MILBUS	USED	HSBY	USED	HSBY	USED	HSBY	HSBY	USED	USED	HSBY
CDHS	OBC											
		TC Decoder	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
		OBT/TM Encoder	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
		PM	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
		RM	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
		OBC-MM	ACTIVE	INACTIVE	ACTIVE	INACTIVE	ACTIVE	INACTIVE	ACTIVE	INACTIVE	ACTIVE	ACTIVE
		HK Data Recording	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
RIU		CTRL	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
		AOCS I/F	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
		RCS I/F	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
		SADE I/F	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
EPS		PCDU-AUX	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
		PCDU-TM	ACTIVE	INACTIVE	ACTIVE	INACTIVE	ACTIVE	INACTIVE	INACTIVE	ACTIVE	ACTIVE	INACTIVE
		Bat Relays	CLOSED		CLOSED		CLOSED		CLOSED		CLOSED	
		Solar Array	DEPL		DEPL		DEPL		DEPL		DEPL	
		SA Rotation	ENABLED - VARYING		ENABLED - VARYING		ENABLED - FIXED		FIXED		ENABLED - FIXED	
		SA Rotation Control	GPS based		GPS based		GPS based		CESS Based		CESS Based	
TT&C		SBS-RX	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
		TC Mode	64 kbps	64 kbps	64 kbps	64 kbps	64 kbps	64 kbps	64 kbps	64 kbps	64 kbps	64 kbps
		SBS-TX	ON (1)	OFF	ON (1)	OFF	ON (1)	OFF	ON (1)	OFF	ON (1)	OFF
		TM Mode	LOW/HIGH (SGM)		LOW/HIGH (SGM)		LOW/HIGH (SGM)		LOW/HIGH (SGM)		LOW/HIGH (SGM)	
		COH	OFF (ON by cmd)		OFF (ON by cmd)		OFF (ON by cmd)		OFF (ON by cmd)		OFF (ON by cmd)	
		RNG	OFF		OFF		OFF		ON 4)		ON/OFF 4)	
PDHT	MMFU		OFF->ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF
		Data Recording	Enabled if USABLE		Full		Full		OFF		OFF	
		XBS	OFF->STB	OFF	STB<->OP(6)	OFF	ON (6)	OFF	OFF	OFF	OFF	OFF
AOCS		AOCS Mode	AOC-NOM		AOC-NOM		AOC-OCM		AOC-ASM		AOC-ASM	
	CESS		ON - USED		ON - USED		ON - USED		ON - USED		ON - USED	
	MTQ	MTQ 1	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
		MTQ 2	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
		MTQ 3	ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
	MAG		ON	OFF	ON	OFF	ON	OFF	OFF	ON	ON	OFF
	RMU		OFF	OFF	OFF	OFF	ON	OFF	OFF	ON	ON	OFF
	DSS	DSS 1	ON - FDIR		ON - FDIR		ON - FDIR		ON - USED		ON - USED	
		DSS 2	ON - FDIR		ON - FDIR		ON - FDIR		ON - USED		ON - USED	
		DSS 3	ON - FDIR		ON - FDIR		ON - FDIR		ON - USED		ON - USED	
	STR		ON	ON	ON	ON	ON	ON	OFF	OFF	OFF->ON	OFF
	GPS		ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF->ON	OFF
	RWU	RWU 1	ON-used		ON-used		ON-used		OFF		OFF->ON (unused)	
		RWU 2	ON-used		ON-used		ON-used		OFF		OFF->ON (unused)	
		RWU 3	ON-used		ON-used		ON-used		OFF		OFF->ON (unused)	
		RWU 4	ON-used		ON-used		ON-used		OFF		OFF->ON (unused)	
RCS	Mode		RCS-SBY		RCS-SBY		RCS-OPR		RCS-OPR		RCS-HUP	
	THR Branch		INACTIVE	INACTIVE	INACTIVE	INACTIVE	ACTIVE	INACTIVE	INACTIVE	ACTIVE	ACTIVE	INACTIVE
	Catbed Heaters	SBY	OFF	ON	OFF	ON	ON	ON	OFF	ON	ON	ON
	Catbed Heaters	HUP	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF->ON	ON	OFF
TCS	Htr Groups		NOM	NOM	NOM	NOM	NOM	NOM	SAF	SAF	SUR	SUR
	SW ctrl Htr		ACTIVE		ACTIVE		ACTIVE		ACTIVE		ACTIVE	
H/W Payload												
		PL MILBUS	USED	HSBY	USED	HSBY	USED	HSBY	HSBY	USED	USED	HSBY
ATLID	Mode		ATLID-Support		ATLID-NOM		ATLID-Support		ATLID-OFF		ATLID-OFF	
	Survival HTR		ON (ACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)
	ACDM		OFF->ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF
	LPE		OFF->ON	OFF	ON(RDY)	OFF	ON(RDY)	OFF	OFF	OFF	OFF	OFF
	HPE		OFF->ON	OFF	ON(RDY)	OFF	ON(RDY)	OFF	OFF	OFF	OFF	OFF
BBR	Mode		BBR-Support*[TBC PK]		BBR-NOM		BBR-Support		BBR-OFF		BBR-OFF	
	Survival HTR		ON (ACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)
	ICU		OFF->ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF
	LPE		OFF->ON	OFF	ON(RDY)	OFF	ON(RDY)	OFF	OFF	OFF	OFF	OFF
			OFF->ON	OFF	ON(RDY)	OFF	ON(RDY)	OFF	OFF	OFF	OFF	OFF
MSI	Mode		MSI-Support[TBC PK]		MSI-NOM		MSI-Support		MSI-OFF		MSI-SAF	
	Survival HTR		ON (ACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)
	ICU		OFF->ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF
	LPE		OFF->ON	OFF	ON(RDY)	OFF	ON(RDY)	OFF	OFF	OFF	OFF	OFF
			OFF->ON	OFF	ON(RDY)	OFF	ON(RDY)	OFF	OFF	OFF	OFF	OFF
CPR	Mode		CPR-Support		CPR-NOM		CPR-Support		CPR-OFF		CPR-LAU	
	Antenna		STOWED->DEPL		DEPL		DEPL		DEPL		DEPL	
	Survival HTR		ON (ACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON(INACT)	ON (ACT)	ON(INACT)	ON (ACT)	ON(INACT)
	ICU		OFF->ON	OFF	ON	OFF	ON	OFF	OFF	OFF	OFF	OFF
	LPE		OFF->ON	OFF	ON(RDY)	OFF	ON(RDY)	OFF	OFF	OFF	OFF	OFF
	HPE		OFF->ON	OFF	ON(RDY)	OFF	ON(RDY)	OFF	OFF	OFF	OFF	OFF

[PK4]

Table 3.3-3 Satellite configurations during COP / MOP (post LEOP)

Notes:

(1) TX switched off-on-off for each ground pass (from Separation mode onward), except for safe mode in which it is permanently switched-on
(2) if transition to safe mode occurs between separation and boom deployment
(3) the same telemetry mode (high/low) as used before the transition to safe mode shall be established (to be set SGM entry to be used)
(4) Ranging may be switched on by HPC-1 or SW upon PM re-boot (i.e. in any transition to SAT-SAF). Coherency will be selectively activated by ground command during ground contacts in the transition from Separation Mode to Early orbit Mode, and during the recovery following an autonomous transition to SAT-SAF.
(5) Initial SA configuration is stowed, transition to deployed configuration is triggered after rate damping condition are reached upon time-out conditions
(6) XBS TX HF are switched STB<->OPERATION according to onboard schedules
(7) Only essential groups are leaded into SW at Safe Mode System Initialisation
(8) Instrument support mode means that limited instrument operation (Instrument ICU is powered) is possible. Any further instrument configuration / operation inside the support mode have to be initiated and controlled under Ground responsibility this includes also the setting of the CSW instrument unit manager; SCV and FDIR related PUS Services. For example the CPR QOF switching has to be performed in a special CPR configuration (SPU running; LPE outlet powered) which can be performed in SAT-POM with CPR-Support Submode.

3.4 Satellite Modes and Mode Transition

3.4.1 Satellite Mode Transition Overview

The Satellite Modes and transitions are shown in .

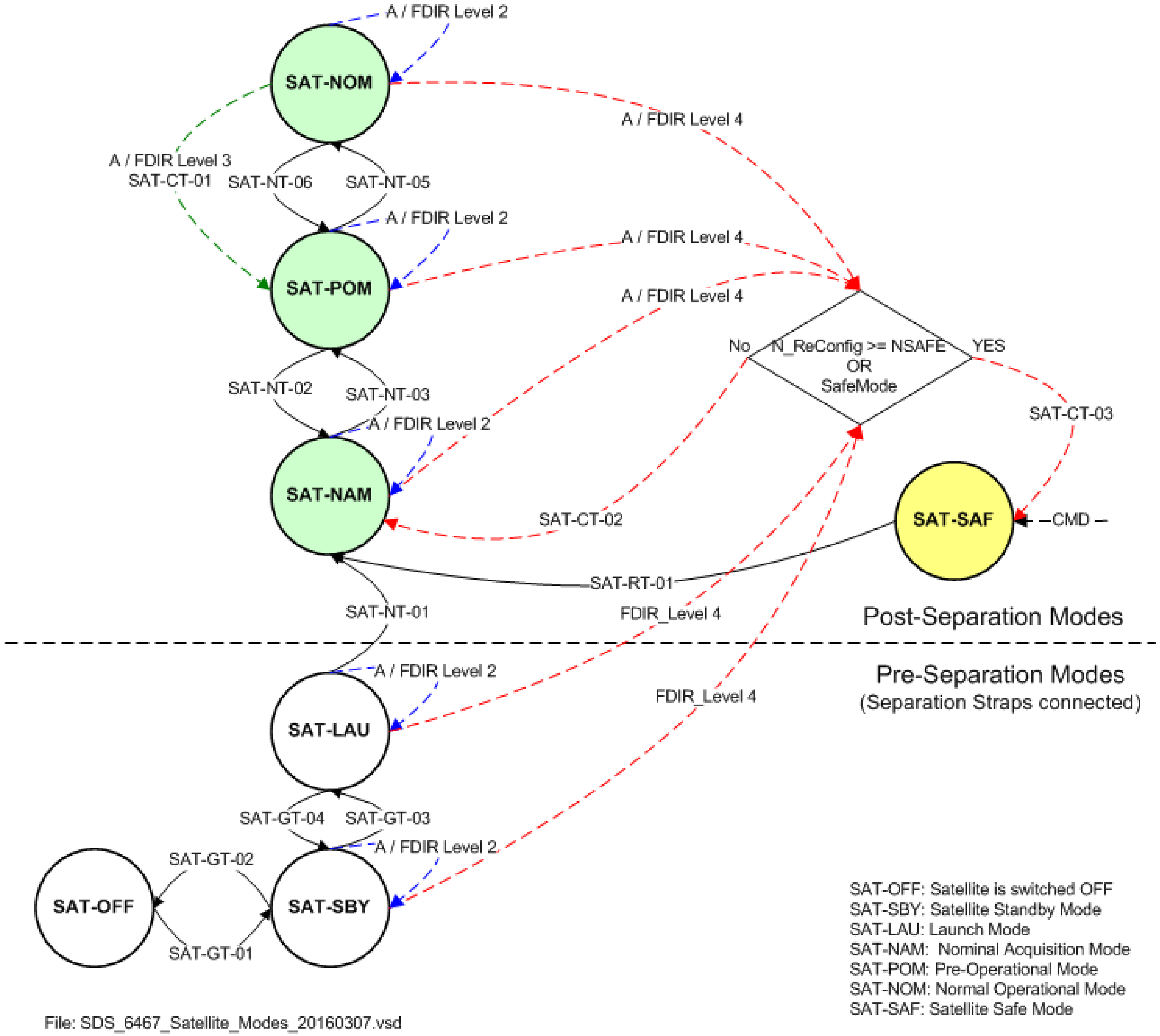


Figure 3.4-1 Satellite Mode Transitions

Notes:

- In case of major system problems in SAT-LAU the system is autonomously reconfigured to safe mode configuration awaiting start of the initialization sequence by separation identification
- The FDIR activity will be reported to ground.
- The satellite and instrument modes are subject of further detailed description in the sub-sequent chapters. Especially the definition of a generic instrument mode and mode transition concept is seen mandatory to support an efficient instrument operation on a multi-payload satellite mission.

3.4.2 Satellite Mode Transition Description

3.4.2.1 Satellite Pre Separation Modes Transitions

3.4.2.1.1 SAT-OFF to SAT-SBY (SAT-GT-01)

This Satellite mode transition is used during ground operation and the Satellite will be in the Basic Test Mode (BTM). Mode transition is performed under ground (AIT) control.

3.4.2.1.2 SAT-SBY to SAT-OFF (SAT-GT-02)

This Satellite mode transition is used during ground operation and the Satellite will be switched OFF. Mode transition is performed under ground (AIT) control.

3.4.2.1.3 SAT-SBY to SAT-LAU (SAT-GT-03)

This Satellite mode transition is used during ground operation and the Satellite will be in the Launch configuration. Mode transition is performed under ground (AIT@CSG) control.

3.4.2.1.4 SAT-LAU to SAT-SBY (SAT-GT-04)

This Satellite mode transition is used during ground operation and the Satellite will be in the Basic Test Mode (BTM). Mode transition is performed under ground (AIT@CSG) control.

3.4.2.2 Satellite Post Separation Modes Transitions – Nominal Operation

3.4.2.2.1 SAT-LAU to SAT-NAM (SAT-NT-01)

The transition from Satellite Launch Mode to the Satellite Nominal Acquisition Mode is triggered by the separation of the satellite from the fregat stage by the release of the separation strap.
This transition is executed and controlled by the LEOP Autosequence which is part of the OBC CSW.
Further details of the LEOP Autosequence itself can be found in [RD-101].

3.4.2.2.2 SAT-NAM to SAT-POM (SAT-NT-03)

The transition from SAT-NAM to the SAT-POM is initiated via dedicated Ground Procedures.

3.4.2.2.3 SAT-POM to SAT-NAM (SAT-NT-02)

The transition from SAT-POM to the SAT-NAM is initiated via dedicated Ground Procedures or via EC o/B FDIR. For more details please refer to [RD-05].

3.4.2.2.4 SAT-POM to SAT-NOM (SAT-NT-05)

The transition from SAT-POM to the SAT-NOM is initiated via dedicated Ground Procedures.

3.4.2.2.5 SAT-NOM to SAT-POM (SAT-NT-06)

The transition from SAT-NOM to the SAT-POM is initiated via dedicated Ground Procedures.

3.4.2.3 Satellite Post Separation Modes Transitions – Contingency Operation

3.4.2.3.1 SAT-SAF to SAT-NAM (SAT-RT-01)

The transition from SAT-SAF to the SAT-NAM is initiated via dedicated Ground Procedures.

3.4.2.3.2 SAT-XYM to SAT-NAM (SAT-CT-02)

Recovery from Safe Mode to Nominal operations will be performed by Ground according to a predefined procedure. The following principal activities are foreseen:

- Post-reconfiguration activities needed by CDHS
- Select whether Image to be loaded is Image 1 or Image 2
- Modify satellite configuration vector for Nominal operations (as result of any failure analysis)
- Re-boot OBC with a Reset command to load nominal S/C configuration
- Perform Mode transitions SAT-SAF to SAT-NAM
- Continue nominal mode transition sequence to normal operation mode and prepare for Nominal operations.

3.4.2.3.3 SAT-ANY to SAT-SAF (SAT-CT-03)

EarthCARE will use an incremental safeguarding approach, where in the first instance use is made of the redundant resources when the primary resource is suspected to have caused the failure. This is to avoid unnecessary safe mode switching. However, in case the redundancy switching has not led to resolving the problem, the Satellite Safe Mode is entered.

Autonomous transitions to Safe Mode will be established by

- Failures detected by the AOCS anomaly detectors – via AOCS Safe Mode alarm and OBC reconfiguration
- System Under voltage detection
- Failures during repeated OBC reconfiguration sequences of the S/C (i.e. Alarm Pattern remains on the RM, leading to further reconfiguration attempts)

Ground based transitions to Safe Mode can be initiated by the following two mechanisms via Flight Operation Procedures

- By execution of a dedicated High Priority Command Sequence for Safe Mode
- By execution of a dedicated Safe Mode TC function (to be treated as critical command and requiring explicit arming beforehand), which triggers an AOCS alarm input to the reconfiguration module.

Further details on the EarthCARE FDIR are given in [RD-05].

3.4.2.3.4 Recovery from Safe mode

Recovery from Safe Mode to Nominal operations will be performed by commands from ground according to a predefined flight control procedure. The following principal activities are foreseen:

- Post-reconfiguration activities needed by CDHS
- Select whether Image to be loaded is Image 1 or Image 2
- Modify SCV for Nominal operations (as result of any failure analysis)
- Re-boot OBC with a Reset command to load nominal S/C configuration and to perform the recovery mode transitions SAT-SAF to SAT-NAM
- Continue nominal mode transition sequence to normal operation mode and prepare for nominal operations.

4. EARTHCARE MISSION TIMELINES

4.1 LEOP Phase Timeline

The Satellite LEOP Phase Timeline is described in chapter 3 of [RD-101].

4.2 Commissioning Phase Timeline

The Satellite Commissioning Phase Timeline Operational Timelines is described in chapter 4 of [RD-101].

4.3 Satellite MOP Timeline

The Satellite MOP Timeline is described in chapter 5 of [RD-101].

5. OVERALL OPERABILITY CONCEPT

The key features of the EarthCARE operations concept comprise the following items:

- Commandability; identifying how the EarthCARE satellite and its individual elements/units are commanded, either from the Ground or from onboard schedules
- Observability; identifying how the operationally relevant information onboard the EarthCARE satellite is observed and routed to Ground
- Satellite configuration handling; identifying how the configuration of satellite elements is managed onboard
- Operations scheduling; identifying how onboard activities are scheduled.
- Mission data handling; identifying how the payload measurement data is collected and routed to Ground
- Failure handling; identifying how onboard failures are detected, reported and managed.

Compliance to the ECSS Space and Ground Operation Standards is a central requirement to facilitate and organize the satellite operation efficiently and in an optimum context with the ESA multi-mission ground segment.

In line with these ECSS operation standards the EarthCARE spacecraft operation is based on strong hierarchical application process architecture outlined in the next sections.

5.1 Application Architecture

5.1.1 Basic Architecture Definition

The application process hierarchy is a central element of S/C operation in line with the ECSS operation standards. This hierarchy defines effective TC and TM routing paths as well as responsibilities upon lower and higher level failure handling.

One central element is a common capability set which is supported for all on-board applications and which offer an essential and effective interaction between the on-board applications and the FOS application, designed in line with the ECSS operation standards.

The following services of [AD-110] are commonly supported by all on-board application processes:

- TC acknowledgement service
- HK & Diagnostic services
- Function service providing application dedicated capabilities
- Connection Test
- Event Generation service
- Monitoring service
- Event action service
- Parameter Management

For each on-board PUS packet terminal equipment and instrument one application provides additional common application characteristics dedicated [AD-110] services:

- Direct Commanding
- Memory Management (in one application per equipment)

For the EarthCARE satellite these are

- Data management system (DMS) application for the OBC
- each instrument application
- each STR application
- each GPSR application
- each MMFU application

The highest level operational application layer is the Flight Operation Segment (FOS). It is the central command and control authority as well as the highest level failure detection, isolation and recovery for the EARTHCARE satellite.

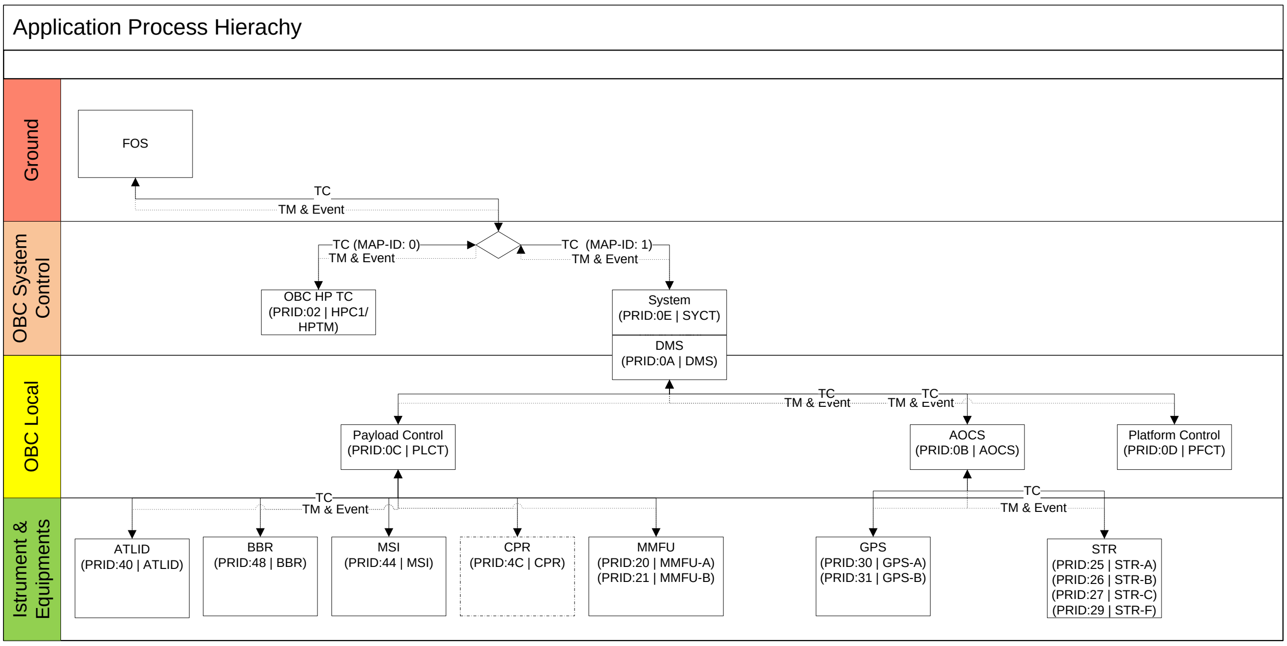


Figure 5.1-1 EC Application Process Hierarchy Specific Application Process Capability Definition

5.1.1.1 Flight Operation System Application

The Flight Operation system application is provided by a SCOS based monitoring control system embedding ECSS ground operation standard and rules compatible telecommand packet encoding and telemetry packet decoding as well as monitoring and event detection capabilities.

5.1.1.2 System Control Application

The system control application establishes the highest level on-board SW application process and provides.

- the system initialization sequence
- the highest level SW FDIR instance resolving those issues which can not be completely solved on lower level

5.1.1.3 Data Management System Application

The data management system application links the various on-board applications with ground by routing the TC and TM packets through the on-board system and providing access to the core data handling units of the spacecraft. Thus the DMS application is responsible for.

- the central TC & TM routing services including the command and control of the S-band TMTC equipment
- Master schedule and orbit position schedule operations
- On-board Computer (OBC) HW & SW management
- Remote Interface Unit (RIU) equipment and module management
- OBC HW configuration & Device commanding
- Memory patch and dump
- Providing the data management and central on-board communication interfaces related FDIR

5.1.1.4 Platform Control Application

The platform control application is responsible for:

- Thermal Control for the platform as well as the payload and instrument interfaces
- Power Management
- PCDU equipment data acquisition, processing and control
- Thermal SW FDIR instance resolving those issues which can not be completely solved on lower level

5.1.1.5 Attitude and Orbit Control Application

The AOCS application is responsible for

- AOCS TC & TM processing
- AOCS equipment data acquisition, processing and control incl. propulsion
- AOCS functions & algorithms
- AOCS dedicated FDIR

The AOCS application is embedded in the central software of the OBC, therefore no specific memory management sub-service is required for the AOCS application

5.1.1.6 Payload Control Application

The Payload Control application, which is part of OBC central software, is responsible

- TC routing to instruments
- TM collection from instruments
- Instrument and PDHT dedicated FDIR which can not be resolved on lower level
- Provision of instrument operation support functions e.g. by provision of the S/C State Vector information to the instruments
- Monitoring of high level instrument interfaces and supervisor for actions requiring control of S/C level interfaces based on instrument events

5.1.1.7 Instrument Applications

The instrument ICU SW Applications and equipments acting as EC PUS packet terminals provide in addition to the common application capability set

- Instrument specific functional mode and state handling
- Science data management service
- Nominal Instrument Thermal Control
- Instrument device commanding
- Instrument internal FDIR based on the common services set and extended by special HW and SW functions within the instrument
-

5.1.1.8 Equipment Applications

The equipments acting as EC PUS packet terminals provide in addition to the common application capability set

- Equipment specific functional mode and state handling
- Specific functional data management service e.g. MMFU data storage and retrieval service
- Equipment device commanding
- Equipment memory management service

The treatment of equipments as full EC application strongly depends on compatibility with the EarthCARE PUS. For COTS equipment this might not be achievable. In this case those equipments are treated equivalent to other non-intelligent equipments, which means:

- The equipment TM provided as part of the telemetry of the controlling application.
- TC's destined to the equipment are acknowledged by the controlling application, considering the communication as well as the equipment command acknowledgement

- For packet terminals private services for TC as well as TM packet forwarding

5.1.2 Definition of Application Process ID's

The definition of Application Process ID's (APID) is given by an 11-bit field, where the Process ID (PRID) is used to assign and identify the onboard processes, while the definition of the packet category (CAT) is used to define specific packet grouping principles. The EarthCARE definition for the Process ID's is as follows [AD-110]:

PRID(hex)	Unit	MN	Application	Functions
00			TIME (TM only)	- Time Management
01			Spare	
02	OBC HW	HPC1	OBC High Priority TC Functions	- High Priority Commanding to CPDU (MAP-0)
02	OBC HW	HPTM	OBC High Priority TM Functions	- for Prime HPTM Packet - for Redundant HPTM Packet
CSW internal PRID's				
0A	CSW	DMS	Data Management Application	- Boot - Packet routing - Packet organization - System logging functions - MTL/OPS functions - OBC functions - RIU equipment management - Event/action functions - Patch/dump functions - Time Management Functions - OBC MM handling functions - S-band RF Functions - FMS - TC sequencer (Service 152)
0E	CSW	SYCT	System Control Application	- S/C modes - S/C Init - FDIR/S - S/C Conf Management (SCV)
0B	CSW	AOCS	AOCS Application	- AOCS Command and Control - AOCS equipments
0C	CSW	PLCT	Payload Control Application	- Payload Command and Control
0D	CSW	PFCT	Platform Control Application	- TCS Command and Control - Power Command and Control
OBC CSW CSW external PRID's				
20	MMFU-A		MMFU-A Application	
21	MMFU-B		MMFU-B Application	
30	GPS-A		GPS-A Application	
31	GPS-B		GPS-B Application	
25	STR-A		STR-A Application	
26	STR-B		STR-B Application	
27			reserved	
29	STR-F		Fall back PRID for STR with invalid RT address	
Instrument PRID's				

PRID(hex)	Unit	MN	Application	Functions
40	ATLID		ATLID Application	
44	MSI		MSI ICU Application	
48	BBR		BBR ICU Application	
4C	CPR		CPR ICU Application	
Others				
60-77	EGSE		reserved	
78-7C	ESOC			
7D-7E			Reserved w/o assignment	
7F			IDLE PACKET	

5.1.3 EarthCARE Packet Utilization Standard

The service concept of the EarthCARE applications is based on the ECSS Packet Utilization Standard tailored based on the project specific operation interface requirements document and the Astrium internal standard tailoring.

The following table lists the major services that are provided for EarthCARE. Further details on the sub-services are contained in the EC-PUS Standard [AD-110].

Service Type	**Name**	**Use**
1	Service 1: Telecommand Verification	Provides TC feedback to the Ground
2	Service 2: Device Command Distribution	Provides direct commanding capability
3	Service 3: Housekeeping and Diagnostic Data Reporting	Provides HK reporting capability for nominal and contingency operations
4	Service 4: Parameter Statistics Reporting	N/A
5	Service 5: Event Reporting	Provides event driven reporting capability
6	Service 6: Memory Management	Provides functions to patch, dump and check onboard memories
7	Not used	-
8	Service 8: Function Management	Provides additional onboard functionality as required by specific applications/payload
9	Service 9: Time Management	Provides Time handling related functionality
10	Not used	---
11	Service 11: On Board Operations Scheduling	Provides management of MTL functionality / scheduling
12	Service 12: On Board Parameter Monitoring	Provides onboard parameters monitoring
13	Service 13: Large Data Transfer Service	N/A
14	Service 14: Packet Forwarding Control	Provides the handling of packet forwarding to the S-band
15	Service 15: On Board Storage and Retrieval	Provides the management of HK packets onto

Service Type	Name	Use
		the OBC HK MM
16	Not used	---
17	Service 17: Test	Provides a test capability for onboard applications
18	Service 18: On Board Operations Procedures	Provides the capability for onboard procedure implementation (in EC replaced by Service 148)
19	Service 19: Event/Action	Provides the handling of onboard actions related to onboard events
140	Service 140: Parameter Management	Provides the generic management of onboard parameters - Provides the Update S/C State Vector Data TC as private sub-type
142	Service 142: Functional Monitoring	Provides capability to monitor on-board functions
145	Service 145: S/C State Vector Management	Provides the management and update service for S/C state vector data to on-board users
148	Service 148: On-board Macro Procedures	This Service replace the Service 18
149	Service 149: Thermal Control	Provides configuration and management capability for SW based thermal control loops
151	Service 151: Orbit Position Schedule (OPS)	Provides management of orbit position scheduling functionality / scheduling
199	Instrument Reporting Service	Provides common instrument report capability
200-209	MMFU Private Service	Reserved for private MMFU services
210-219	GPS private services	Reserved for private GPS services
220-224	STR private services	Reserved for private STR services
225	ATLID Science Service	Provides the ATLID science and instrument ancillary data
226	ATLID Science Investigation service	Provides high rate science investigation data
227-229	ATLID Private Service	Reserved for private ATLID services
230	BBR Science Service	Provides the BBR science and instrument ancillary data
231-234	BBR Private Service	Reserved for private BBR services
235	MSI Science Service	Provides the MSI science and instrument ancillary data
236-239	MSI Private Service	Reserved for private MSI services
240	CPR Science Service	Provides the CPR science and instrument

Service Type	Name	Use
		ancillary data
241-245	CPR Private Service	Reserved for private CPR services

Table 5.1-1 Major EarthCARE PUS services

A detailed list of private service definitions is given in, a summary is given in the instrument command and control sub-chapters of chapter 15
The detailed applicability of the PUS services for the individual applications is defined in [AD-110]

5.2 Commandability Concept

5.2.1 On-Board TC Routing

Telecommands uplinked from the EARTHCARE Flight Operations Segment (FOS) can be categorised as follows:

- High Priority Commands being directly routed to HW
- Application Commands being routed to the TC Packet Handler within the System Control SW

The routing is performed according to the MAP (multiple access points) identifier in the TC Segment Header and is conceptually shown in the picture below. Telecommands routed to the CSW are then further routed to the individual application processes (identified by a Process Identifier - PRID) within the CSW, e.g. System control, AOCS, payload control) as well as of those of external PUS packet terminals (e.g. each instrument, MMFU, STR, GPS). In case that two latter equipments are COTS equipments, thus pure (i.e. non-PUS) packet terminals private telecommand and telemetry transfer services will be used to communicate with those equipments.
The TC routing rules follow the application hierarchy defined in chapter 5.1.

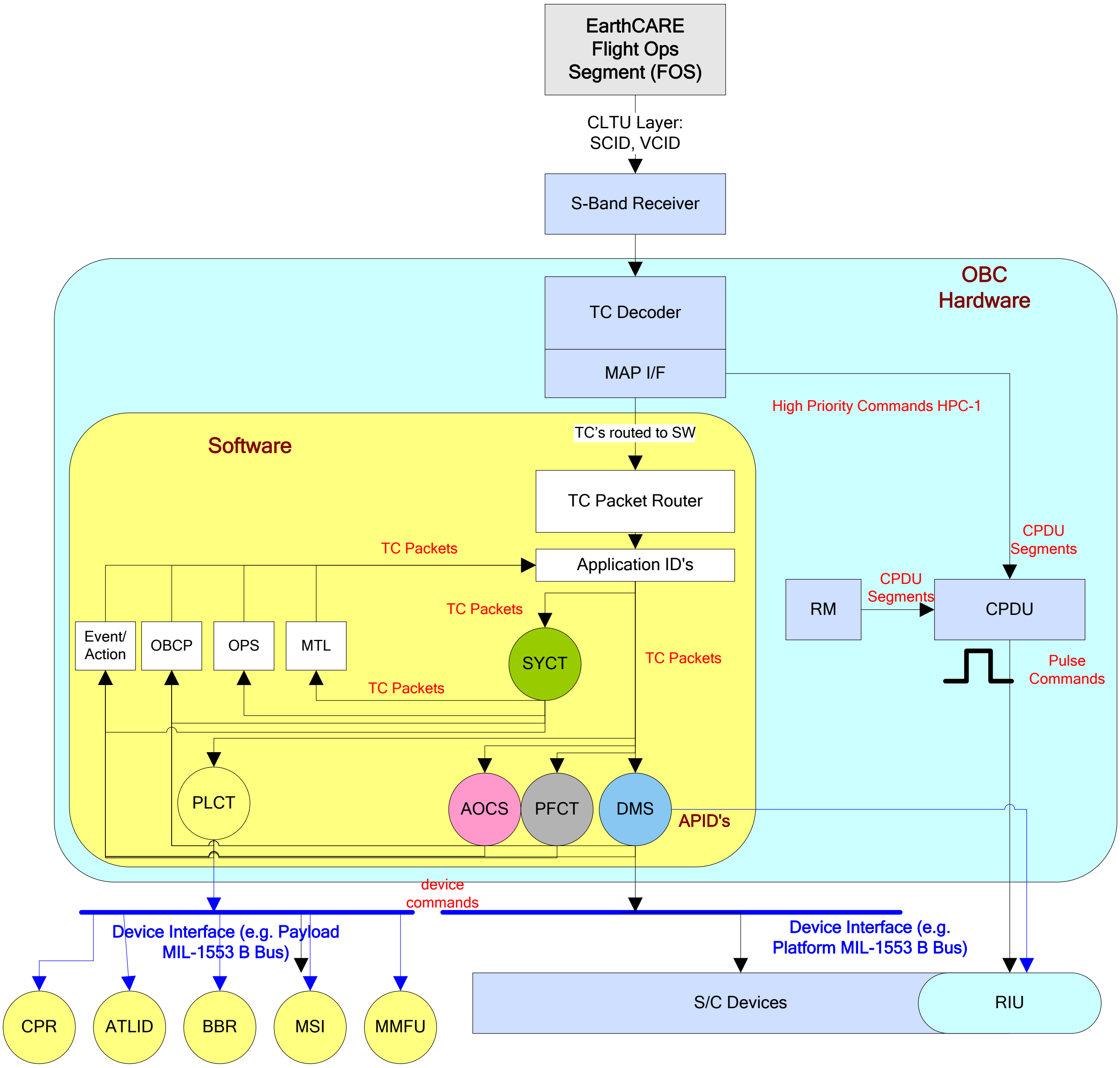


Figure 5.2-1 EARTHCARE TC Routing Scheme

Note: Detailed description is given in EC FOM Volume 2 - Data Handling Subystem. [RD-110]

5.2.2 Routing of Telecommands within CSW

The routing of TC's within the CSW is performed according to the following scheme of Figure 5.2-2:

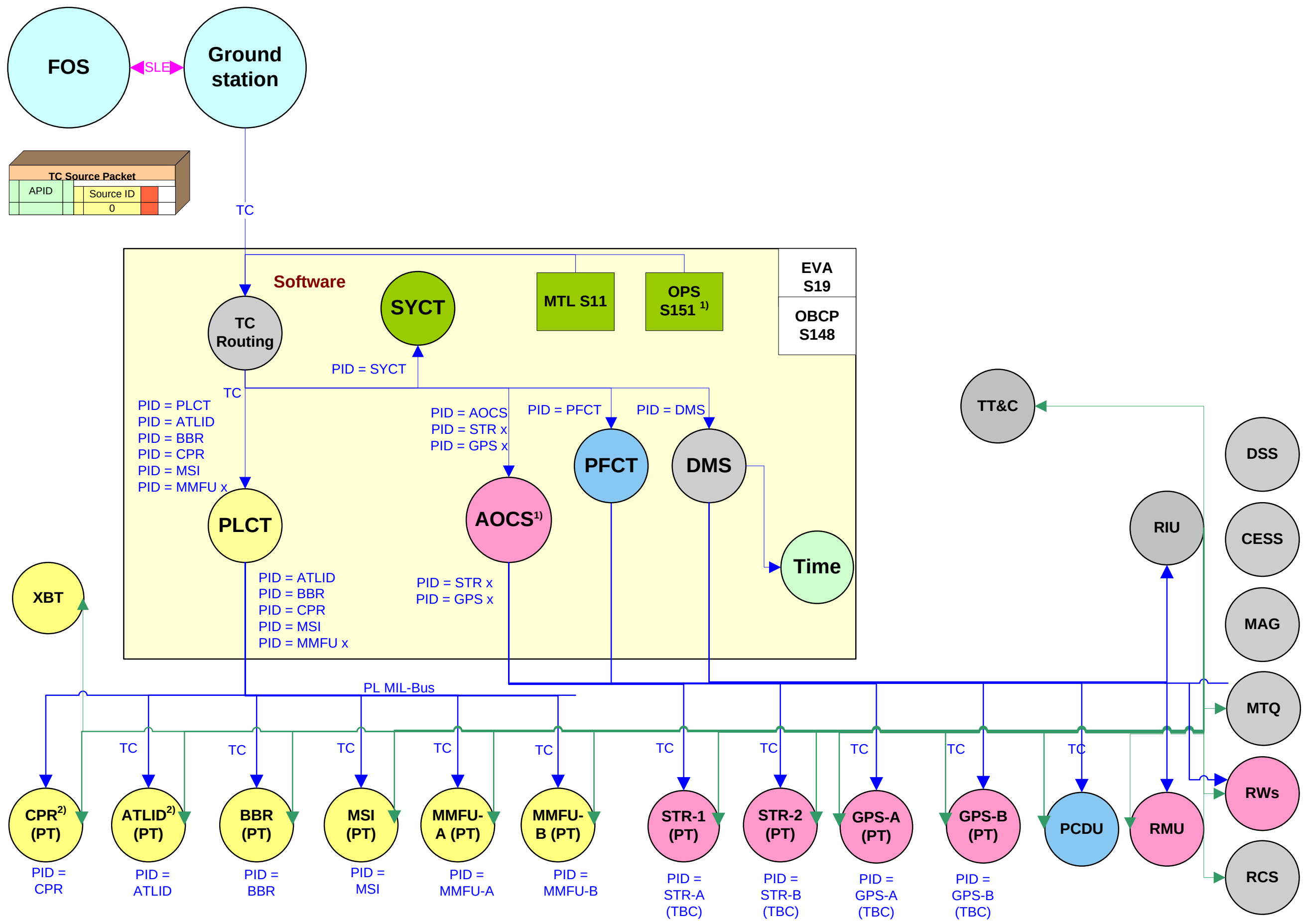


Figure 5.2-2 TC routing within CSW

Command Sources

As given in the above figure, the following command sources exist:

- Flight Operations Centre (FOS)
- On-board schedules (MTL, OPS)
- On-Board Control Procedures (OBCP - service 148) per applicable application process
- Event/Action Service (EVA - service 19) per applicable application process

The command sources are clearly identified in the SOURCE ID field of the TC packet header and reflected in the DESTINATION ID field of the TM(1,x) packet header generated in response to the received TC (see [AD-110] for details).

This allows distinction of TC's originating from different sources as required by OIRD TCV-7.

5.2.3 Command Categories

High Priority Commands (HPC) are used to command vital functions and are implemented as Command Pulse Distribution Unit (CPDU) commands defined by CPDU packets. High priority TC's can be distinguished as follows:

- HPC 1 commands: CPDU commands without involvement of SW (MAP 0)
- HPC 2 commands: CPDU commands initiated by the RM
- HPC 3 commands: CPDU or RIU Pulse commands with involvement of OBC SW

<u>Critical Commands</u> are those which could cause permanent mission degradation when not executed at the correct time. Therefore, critical commands will have to be identified and to be enabled before hand by a dedicated enabling mechanism.

Critical commands are defined basically on two levels:

- On database level, where critical commands are marked by a dedicated criticality flag
- On operational level, where critical commands are handled via an arm and fire mechanism.
- On design level, where critical functions are protected by separated functionality that needs to be active both before taking effect.
- On procedural level, where critical operations are either only given as contingency procedures or not provided at all.

In the first case the command is sent to the satellite only upon explicit and formal confirmation of the command authority in the mission control centre. In the second case two commands need to be sent to the satellite to execute the intended operation.

The following onboard protection mechanisms are in place:

(1) For TC(8,1) functions, an arming/enabling logic is put in place that is described in the EC-PUS. Only enabled TC's can be executed.

(2) For critical sub-services, a functional protection is provided. The following table gives an over of the critical subservices and the respective protection scheme:

Critical sub-services	Protection	1st step TC
TC (11,3) Reset Command Schedule	MTL needs to be globally disabled	TC(11,2)
TC (12,4) Clear Monitoring List	Monitoring Function needs to be globally disabled	TC(12,2) [N=0]
TC (151,3) Reset OPS	OPS needs to be globally disabled	TC(151,2)
TC(148,2) Delete Procedure	Affected OBCP needs to be locked	TC(148,132) Locked
TC(148,128) Add TC to OBCP	Affected OBCP needs to be locked	TC(148,132) Locked
TC(148,129) Delete TC from OBCP	Affected OBCP needs to be locked	TC(148,132) Locked

Table 5.2-1 List of critical sub-services

5.2.3.1 High Priority Commands

Vital equipment will be commanded by High Priority Commands / CPDU Commands in order to be able to command vital S/C functions in case of loss of SW functionality or major mission problems. The following table gives an overview of the actual HPC-1/2/3 command allocation in EarthCARE. The green shaded rows are HPCs which are used OBC external (i.e. available on an OBC connector), the yellow shaded are OBC internal. The blue shaded are unused command numbers.

Note 1) the allocation of the external HPC commands (channel designation SHP Extn) is not yet final, but provided to give the overview on the HPC commands The allocation of OBC SHP channels will be revised to account for

- the SW access limit to be set in the OBC TTR PROM
- the failure groups of the SHP outlets

Note 2) These SHP outputs primarily account for a cold redundant OBC SHP output section. In case of hot redundant OBC SHP output section these commands need not be used

The list of CPDU commands is given in [RD-142]

Device Commanding

For device commanding and register loading direct access to the API SW interface is provided via service 2.

The device command distribution service provides the capability

- To distribute Command Pulse Distribution Unit (CPDU) commands for unconditional switching of unit functions.

- To distribute directly 1553 bus command messages
- To access via a simple normative interface directly the API software for debug and checkout purposes

These commands are executed as soon as possible after acceptance of the telecommand. The granularity id defined by the highest frequency time slot of the application sampling cycles.

5.3 Observability Concept

The observability of a system is characterised by the set of housekeeping information that is provided on system, subsystem or unit level, which allows unique identification of its overall status. The correct level of observability allows the operational Ground Segment to get the appropriate data for the satellite, instrument, subsystem or unit for taking any action if required.

The EARTHCARE observability architecture is based on the following functionality:

- Provision of High Priority HW Telemetry (HPTM) function for selected items without SW involvement
- Cyclic HK data acquisition by the CSW or the packet terminals and onboard storage by the OBC SW applications into a System Data Pool (SDP) or in local data pools
- Provision of HK telemetry via definitions of HK parameter lists (Structure – ID's – SID's)
- Provision of SW provided monitoring function via PUS services
- System logging function: critical events are logged into SGM; extended information is provided in the MM Information Log and downlinked in X-Band.
- Dump of memory cell content

The PUS services allow the ground full control over the spacecraft observability. A standard set of HK and diagnostic packets can be defined pre-launch, and enabled/ disabled as necessary; new packets or monitoring can be enabled, disabled or created by the ground for use at a later time using Service 3.

○ Telecommand verification	- Service 1:	execution success and failure are reported
○ Telemetry packets	- Service 3:	House Keeping reporting and Diagnostic
○ Event reporting	- Service 5:	All events and data exchanges between individual on-board software application processes, the ground segment and external hardware functions will be logged as events or with regard to the success of the transfers or the completion of a process.
○ Memory dump	- Service 6:	Memory dump and check memory.
○ On-Board Parameter Monitoring	- Service 12:	This service monitors the user selected parameters against uplinked limits or expected status. In the event of a transgression a report is generated and if desired an event action (service 19) can be performed.

5.3.1 HW Provided Observability Functions - High Priority Telemetry (HPTM)

The OBC provides High-Priority TM (HPTM) packets that are part of the S-band downlink. The HPTM packets contain vital information about the system like the following information

- Status of Internal OBC functions (PM Status RM Statues etc.)
- Status of equipment external to the OBC which can be commanded by HPC-1 commands (RIU, S-band receiver etc.)
- The HPTM packets will be generated and sent to the ground even if the SW is not operational, e.g. in case of system reconfigurations.

The content of the EarthCARE HPTM packet is defined in [AD-110].

5.3.2 SW Provided Observability Functions

5.3.2.1 Cyclic HK

Cyclic HK is provided by the individual packet terminals (OBC applications, STR, GPS, MMFU, ATLID, BBR, MSI, and CPR) in predefined structures (SID's) according to general observability needs. The SID numbering scheme will follow the recommendations given below.

(1) The SID numbering range will be categorised for each PRID in accordance to functional usage. The combination of PRID + SID allows unique identification of the structure.
(2) For nominal operations the first three categories (SID ranges 1 to 60) of the following table are intended; the category "SpecificDataRequest HK SID's" may be used to downlink special HK packets after occurrence of an onboard anomaly (data pool snapshot).
(3) Exceptions to the allocation may exist for recurring units (e.g. GPS).
(4) In order to support continues source sequence counts for all HK TM report packets in the realtime downlink two different packet categories can be assigned for service 3 HK as well as diagnostic TM report packets. The PCAT values are assigned based on SID ranges. However the packet forwarding into RT and to the on-board storage devices is completely controlled via service 14 and service 15. It is the user responsibility to properly configure these services to ensure that the packets with SID values assigned to PCAT-HK and PCAT-Diag are forwarded to VC-0, packets with SID values assigned to PCAT-no-RT are not forwarded to VC-0.

Housekeeping SID's				
Structure ID			**Assignment**	**PCAT**
1	-	10	General Status & Summary Information HK SID's	PCAT-HK
11	-	30	Mode related HK SID's	PCAT-HK
31	-	60	Equipment related HK SID's	PCAT-HK
61	-	90	SpecificDataRequest HK SID's	PCAT-HK
91	-	100	Spare 1	PCAT-HK
101	-	110	ESOC	PCAT-HK
111	-	127	HK TM reports excluded from RT	PCAT-no-RT
Diagnostic SID's				
Structure ID			**Assignment**	**PCAT**
128	-	137	General Status & Summary Information Diagnostic SID's	PCAT-Diag
138	-	157	Mode related Diagnostic SID's	PCAT-Diag
158	-	187	Equipment Diagnostic HK SID's	PCAT-Diag
188	-	217	Specific Diagnostic SID's	PCAT-Diag
218	-	228	Spare 1	PCAT-Diag
229	-	238	ESOC	PCAT-Diag
238	-	254	DIAG TM reports excluded from RT	PCAT-no-RT

Table 5.3-1: SID numbering scheme

5.3.2.2 On-request (Non-Cyclic) HK Reporting

There are two dedicated service 3 capabilities which allow generation of non-cyclic TM reports containg HK information:

(5) The on-board software applications support to request at any time as a snaphot of the current status the provision of an additional TM(3,25) or TM/3,26)HK TM report for any defined SID independent from the current cyclic provision state of the service 3 TM report. Operationally this capability is used to provide a status overview for quasi static HK TM parameters which however should be available as up to date information at begin of the contact. It also is used to generate snapshot status information in case of event driven activities, where a time correlated status information is important
(6) In addition there exists the capability to generate upon reception of service 3 private sub-type TC, one TM(5,x) event report with a severity corresponding to the given EID and the SID and all

parameters of the HK resp. FDIR SID definition in the parameter field of the event report. This feature is exclusively used in context of FDIR actions to provide detailed information also via system log capabilities upon major system and functional chain FDIR activities.

5.3.2.3 Event reporting and recording

5.3.2.3.1 I Event Reporting Functions

Information of operational significance like:

- failures or anomalies detected on-board;
- start and/or end of autonomous on-board actions and processes;
- progress of operations and activities, e.g. detection of events which are not anomalous (such as payload events), reaching of predefined steps in an operation.event re

are reported by events. All event related information generated by on-board SW or services provided by on-board SW are reported by service 5 event report TM packets of [AD-110].

There are various instances which can trigger generation of service 5 event report packets

In EarthCARE the service 5 event ID’s are unique within one application. The combination of application process ID and event ID is unique over the complete system. The severity is directly related to the event ID as defined in following table:

EID 5,1	Event	EID 5,2	Event	EID 5,3	Event	EID 5,4	Event	Group
0x0000		0x4000		0x8000		0xC000		reserved
0x0001		0x4001		0x8001		0xC001		Boot S/W Events (fix allocation)
0x0002		0x4002		0x8002		0xC002		
…..		…..		…..		…..		
0x001E		0x401E		0x801E		0xC01E		
0x001F		0x401F		0x801F		0xC01F		
0x0020		0x4020		0x8020		0xC020		General Application S/W Events
0x0021		0x4021		0x8021		0xC021		
…..		…..		…..		…..		
0x041E		0x441E		0x841E		0xC41E		
0x041F		0x441F		0x841F		0xC41F		
0x0420		0x4420		0x8420		0xC420		Specific Application SW Events
0x0421		0x4421		0x8421		0xC421		
…..		…..		…..		…..		
0x141E		0x541E		0x941E		0xD41E		
0x141F		0x541F		0x941F		0xD41F		
0x1420		0x5420		0x9420		0xD420		Events from unexpected S/W and H/W Errors
0x1421		0x5421		0x9421		0xD421		
…..		…..		…..		…..		
0x149E		0x549E		0x949E		0xD49E		
0x149F		0x549F		0x949F		0xD49F		
0x14A0	Normal Monitoring Events	0x54A0	Low Severity Monitoring Events	0x94A0	Medium Severity Monitoring Events	0xD4A0	High Severity Monitoring Events	S12 Parameter Monitoring Events

EID 5,1	Event	EID 5,2	Event	EID 5,3	Event	EID 5,4	Event	Group
0x14A1		0x54A1		0x94A1		0xD4A1		
…..		…..		…..		…..		
0x26FF		0x66FF		0xA6FF		0xE6FF		
0x2700	CHDS	0x6700		0xA700		0xE700		
…..		…..		…..		…..		
0x27FF		0x67FF		0xA7FF		0xE7FF		
0x2800	Normal Monitoring Events	0x6800		0xA800		0xE800		S142 Parameter Monitoring Events
…..								
0x349E		0x749E		0xB49E		0xF49E		
0x349F		0x749F		0xB49F		0xF49F		
0x34A0		0x74A0		0xB4A0		0xF4A0		OBCP Events
0x34A1		0x74A1		0xB4A1		0xF4A1		
…..		…..		…..		…..		
0x3EFE		0x7EFE		0xBEFE		0xFEFE		
0x3EFF		0x7EFF		0xBEFF		0xFEFF		
0x3F00		0x7F00		0xBF00		0xFF00		ESOC
0x3F01		0x7F01		0xBF01		0xFF01		
…..		…..		…..		…..		
0x3FFD		0x7FFD		0xBFFD		0xFFFD		
0x3FFE		0x7FFE		0xBFFE		0xFFFE		
0x3FFF		0x7FFF		0xBFFF		0xFFFF		reserved

Table 5.3-2 Event ID Range Definition Table

Gravity	TM	Description
Normal	TM(5,1)	Normal progress report
Low	TM(5,2)	Low sverity anomaly report
Medium	TM(5,3)	Medium severity anomaly report
High	TM(5,4)	High severityr anomaly report

Table 5.3-3: Report garvity assignment

Onboard events will be provided basically in the following areas:

(7) system log / critical event log in the SGM
(8) Packet Store located on the OBC MM, denoted as Spacecraft History Log (SCHL), containing all TC acknowledge report packets as well as all event report packets.
(9) reconfiguration log located in the OBC TTR board to retrieve information in case one or multiple system reconfigurations (OBC re-boot has occurred)

5.3.2.3.2 System Logging Functions

The System Log will comprise TM (1,2), TM (1,8), TM (5,3) and TM(5,4) events and will be stored in the SGM RAM A and B equally.

Due to the fact that the system initialisation sequence and the LEOP auto sequence coded in SW will produce TM (5,3)/TM(5,4) events, the complete boot sequence and the complete LEOP auto sequence will be visible in the System Log. In this exceptional case TM(5,3) will be used to report positive progress to be noticed and considered by ground operations, while TM(5,4) will report problems identified in the autonomous LEOP sequence.

The key requirement for the system log sizing is that the satellite system log shall be able to cover 8 days. This value coincides with a nominal autonomy period of 5 days and accompanied by 3 days (72 hour) outage period of the ground segment before or after the autonomy period and thus the corresponding system requirement that the satellite shall survive without commanding for 8 days. Based on this understanding the EarthCARE system log sizing requirement is no longer very different from the typical system requirement to size the system log at least for the maximum specified period of G/S outage plus one day, and in any case not less than 72 hours. Effectively:

During the nominal autonomy period (5 days) nominally no or only few system log entries are occurring. Exceptional cases where nominal operation might yield a system log entry are completion and return from special operation sequences namely the orbit control manoeuvre sequence and the external calibration sequence. These are occurring far below the autonomy period repetition rate hence it is sufficient to account 2 entries per sequence type in the budget.

The event reports for execution of MTL/OPS commands with disabled status are defined to be TM(5,2) which are not recorded in the system log. This situation can anyhow only occur after an on-board failure yielding a partial or complete disabling of MTL/OPS or by ground operation error.

Thus the system log size is determined by the event generation capacity in case of a series of failures. The event reporting functions are requested to be designed to avoid repeated events in case of subsequent occurrences of an error. The system design is consequently oriented towards avoidance of repeated event reports or event report series. For all monitoring events at least the number of positive checks are needed to get back into limits which is a precondition to retrigger an event report after the re-occurrence of an out-of-limit condition. In addition the EarthCARE FDIR is designed in a hierarchical way based on time and impact of the FDIR reaction embedding autonomous disabling of already triggered typically lower level FDIR reactions. Higher level surveillances with more stringent FDIR reactions ensure that in case of non-successful lower level reactions the system is finally commanded in satellite safe mode. In Satellite Safe Mode only a minimum set of surveillances remain active as the system operates with the set of utmost redundant i.e. by definition healthy resources, hence a configuration ensuring generation of utmost minimum number of further failures reports i.e. event report packets.

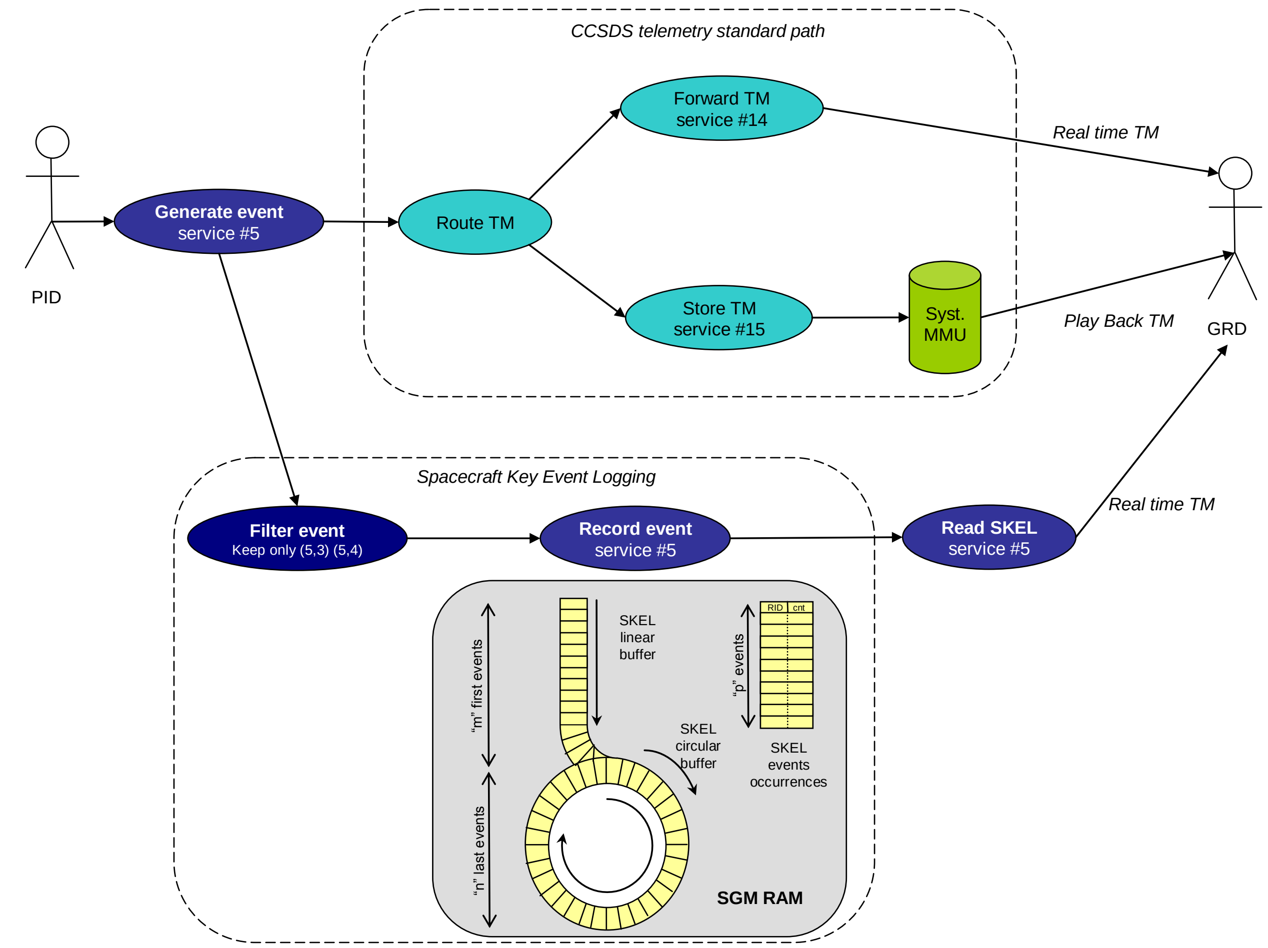
In the sense of an overall robust system design this effort on a systematic control of the event generation mechanisms is accomplished by a system log implementation designed to cope with extreme requirements on non-visibility and autonomy periods. The system log concept in the SGM allows to record anomaly or error reporting in a combination of a linear and a circular buffer. The Linear buffer contains the n first events generated (the oldest ones) and the circular buffer the last m events generated (the newest ones).

In an ordinary case, the full size of the System Log allows to record up to ‘m + n’ events. In case of burst of events, the ‘m’ first events and the ‘n’ last events are recorded in the System Log and a counter of occurrences for ‘p’ events is available in order to keep the trace of the first ‘p‘ events, which may get overwritten, even in the case the buffers are not large enough to record the whole sequence of events.

Overall the concept allows to store major system events over an arbitrary long period.

The following packets will be stored into the *System Log:*

- TM(1,2); TM(1,8)
- TM(5,3); TM(5,4)



Service 5 provides the telecommand to:

- Read the Logs and the table. This telecommand may produces several TM as result (TM for the circular buffer, TM for linear buffer and TM for event occurrence table)
- Clear the Logs and the table (1 single TC as this insures the coherency between the three entities).

When downlinking the system log, only the entries within the system log are downlinked, i.e. there is no extra data structure where the system log events are embedded. Therefore the source sequence counter may be out of order when compared with the RT downlink that is coming in parallel. It is assumed that the FOS is able to handle this case.

For determination of the required SGM RAM size the following boundary conditions are considered:

- failed execution of a complete MTL/OPS yielding a corresponding number of either TM(1,2) or TM(1,8)
- up to 1024 TM(5,3) or TM(5,4) entries:

This sums up to about 4000 entries. Considering an approximate average anomaly report size of 32 bytes this yields 128 kbyte.

Based on these boundary conditions an SGM size of 128 kByte and the possibility to manage up to 6000 system log entries are settled as requirement for the EarthCARE CSW. The EarthCARE OBC HW provides 512 kByte SGM RAM size. The available OBC SGM RAM size is subdivided in

OBC HW SGM RAM	512	kByte
System Context	256	kByte
System Log	128	kbyte
Margin	128	kbyte
	25	%

Considering in addition that the required safe guard recorder function routes all event and acknowledgement packets in addition to the OBC mass memory which remains powered and operated also in Satellite Safe Mode (SAT-SAF) this storage capacity is seen sufficient to cover the EarthCARE mission needs.

5.3.2.3.3 Reconfiguration Log

A reconfiguration log will be stored in the OBC for retrieval of information after an OBC reboot. The latter one is not in the form of service 5 event report TM packets but in a HW driven proprietor format of the OBC (see [RD-16]), which can be retrieved by ground via CSW provided services.

5.3.2.3.4 Spacecraft History Log (SCHL)

The spacecraft history log is provided in case the service 15 storage selection is setup to distribute the overall TM packet data stream over several packet stores. In this case one packet store of the OBC Mass Memory provides the on-board event and command history, called the spacecraft history log. The SCHL is configured via service 15 packet routing tables and collects all (positive (TM(1,1) & TM(1,7) as well as negative TM(1,2) & TM(1,8)) command acknowledgement report packets as well as all event report packets (TM(5,1), TM(5,2), TM(5,3) and TM(5,4)). As such it contains the full trace of the operation history. The sizing will be adequate to support the mission operation autonomy period of 8 days. In case of system log limitations due to SGM size restrictions this on-board store will contain the required information to restore the spacecraft operation history. In case of constraint storage volume the packet store type of the spacecraft history log would be bounded with overwrite disabled, but due to the oversized available on-board storage volume the SCHL can be setup large enough that the storage type unbounded with overwrite can be selected. The retrieval of the TM packets stored in the spacecraft history log will be provided via standard downlink capabilities of service 15. The spacecraft history log is provided in the playback virtual channel used for downlink of periodic HK and other TM report packets. Successful reception of all contained packets can be verified on ground by continuous source sequence count checks. Upon complete reception and reaching a minimum fill level of the packet store, the Read Marker of the bounded packet store is adjusted by deleting the packet store content up to the time of the last received packet. The Read Marker can be adjusted with the segment based granularity of the packet stores on the OBC mass memory.
In case one overall S/C monitoring and control TM packets store is configured the Spacecraft History Log is part of this overall store, but not retrievable exlusively and independent from the other TM packets.

5.3.3 Observability during the various Mission Phases

This section is to provide an overview over the S/C observability in the various EarthCARE Mission Phases. During the various mission phases, the onboard events and TM will be visible by the following means:

Mission Phase	Recording Capability	Redundant recording	Comment
LEOP	OBC MMU : All TM packets / SIDs are recorded Dedicated LEOP SIDs are defined to cover the LEOP needs	SGM A + SGM B (hot redundant)	LEOP auto sequence is recorded on both stores, i.e. SGM's and MMU. In case of MMU failure, the LEOP auto sequence related events are still recorded on the SGM
Nominal Mission incl. Commissioning	All TM packets / SIDs are recorded onto the OBC MMU Dedicated SIDs are defined	SGMA+B for essential events; MMFU contains copy of all HK data	As soon as PDHT/XBS is switched on and operational, TM data canbe forwarded for storage on MMFU.
Satellite Safe Mode SAT-SAF	All TM packets / SID' are recorded onto the OBC MMU	SGM A + SGM B (hot redundant)	

It can be seen that with this allocation, redundant recording capabilities exist for all of the mission phases. In addition, during the critical Mission phases as LEOP and Safe Mode, the complete HK data is recorded onto the OBC HK mass memory. Since the HK data recorded out of coverage is downlinked via the S-Band (and not via the X-band as in other EO missions), the onboard resources for data recording are permanently available. In case that the nominal Safe Mode recording capability is lost due to an additional OBC HK MM related failure (being a second failure) an on ground procedure will be available to configure the redundant OBC HK MM for HK recording.
This nominal recording capability is even extended when failures need to be tracked. This is implemented as follows: within the PUS service 3, the functionality exists to perform a data pool snapshot in case of an out-of-limit condition by requesting a HK report package via TC (3,136) which generates a specific TM (3,25) packet only once. This functionality may be used to get the most recent data pool information in case of an anomaly and will therefore be collected when an Out-of-limit condition is triggered.
This packet is not only routed to the OBC HK MM, but also into the SGM located system logs to safeguard the information, so that all data are available to the Ground for analysis of a specific error using the failure isolation procedures given in the FOM.

6. EARTHCARE FUNCTIONAL CHARACTERISTICS

6.1 Definitions of functional categories

In the following, a categorisation of functions is provided for operational purposes. From an operational point of view, the EARTHCARE functions are distinguished into *vital functions*, *mission critical functions* and *hazardous functions* as follows:

a) Vital functions*:* functions that, if not executed, or wrongly executed, could cause *permanent mission degradation*.

In this sense, vital functions can be commanded from ground using high-priority telecommands via the hot redundant TC decoders (thus via the hot redundant CPDU's) or via redundant command implementation (e.g. for the PCDU-SA interface)

Permanent mission degradation means that nominal S/C functions or performance can neither be achieved on the nominal nor on any redundant chain for the remainder of the mission lifetime.

b) Mission critical functions*:* functions that in case of function loss or unwanted function execution could lead to permanent mission degradation.

c) Hazardous functions: functions that when executed at the incorrect time could cause mission degradation or damage to equipment, facilities or personnel.

In EARTHCARE, *vital functions* either are implemented in hot redundancy (e.g. the reconfiguration function, the OBT function, the TC decoding function) or they can be commanded from ground using high-priority (CPDU) commands. These commands allow the ground, to set up the S/C up to the start of the processor module and to load at least a safe configuration of the S/C and to start the OBC SW. It is clear that the loss of those vital functions will lead to mission degradation.

For SW, the complete CSW as well as all SW functions that cannot be patched and dumped have to be considered *mission critical*. The CSW is rated as mission critical in total as it contains the Safe Mode as well as the Nominal Mode functions in one image.

6.2 Overall Functional Electrical Architecture

Figure 6.2-1 depicts the functional electrical architecture of the EARTHCARE electrical system. It shows also hot redundant elements, e.g. Reaction Wheels are ON at the same time.

The following on-board systems are considered:

- Electrical Power System (EPS)
- Core Data Handling System (CDHS) including SW
- Tracking, Telemetry and Command System (TT&C)
- Attitude and Orbit Control System (AOCS)
- Reaction Control System (RCS)
- Platform Thermal Control System (TCS)
- Payload Data Handling and Transmission System (PDHT)
- Instruments (INS)

The electrical architecture is based on a compact design, which uses a minimum number of units. By this way, the complexity of the system is decreased while the reliability is increased. Further advantage of the baseline design is the significant reduction of risk by

- Proven and qualified unit design which require limited modifications and low number of interfaces
- Functions which are related to each other are combined in one unit and tested on equipment level
- The number of interfaces and functions, which can only be tested on satellite level, is minimised

The system design includes a robust **PCDU** design making maximum use of the solar array and safe battery management techniques. The **CDHS** manages all onboard command & control functions as well as the data handling by means of a high performance processor system. Furthermore, this processor system is in charge of handling the attitude and orbit control. Essential functions can be commanded from ground without software interaction (HPC-1 commands). The start-up and FDIR concept provides a safe operation of the satellite in case of any credible anomaly without the need for a ground interaction. An S-Band based **TT&C** with permanently hot redundant receivers and antenna coverage of 360° supports a fully reliable command access to the satellite in any spacecraft attitude. By combined operation of the CDHS and the TT&C system real-time data as well as playback of recorded monitoring and control data is possible. For mission data storage and formatting, a mass memory sized to the mission needs and an appropriate formatter is implemented, which will provide the recorded data to a high speed X-Band based down-link. An AOCS using as sensors star trackers, GPS, a combined earth/sun sensor, coarse rate sensor, triple redundant Digital Sun Sensor and magnetometers and as actuators reaction wheels, magnetorquers and a mono propellant based reaction control system. The proposed architecture provides full spacecraft and payload redundancy, so that in case of a single (credible) failure within the spacecraft platform the mission can be continued nominally.

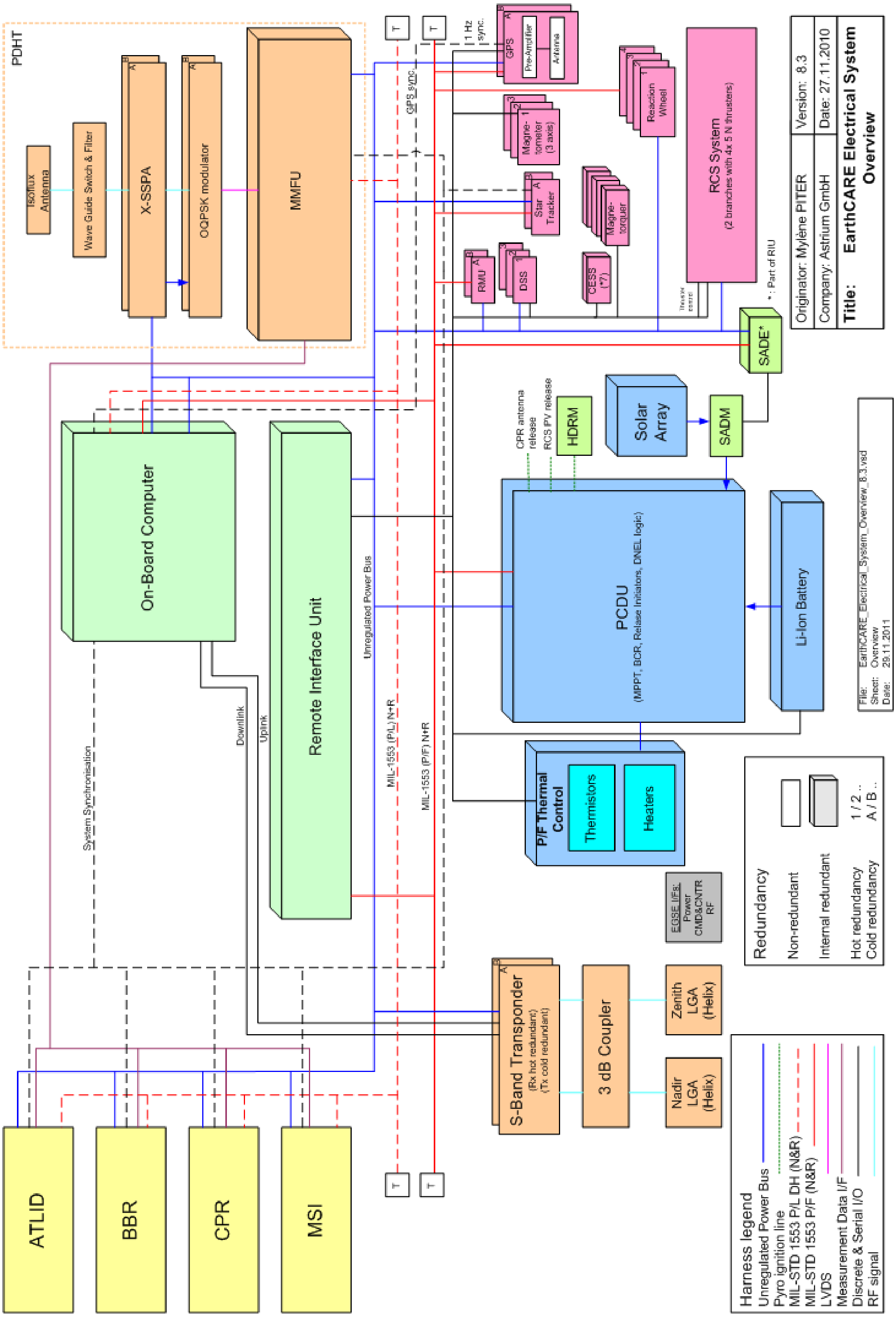


Figure 6.2-1 Electrical Block Diagram

The main elements of the EARTHCARE system architecture are the following:

Electrical Power Control and Storage System (EPS) comprising:

- Power Control and Distribution Unit (PCDU)
- Deployable Solar Array (SA) including SA Drive Mechanism (SADM) and SA Drive Electronics (SADE)
- Li-Ion Battery

The key functions of the EPS are:

- Distribution of unregulated primary power to the platform units and instruments
- control of the power provided by the solar generator and the battery
- provision of power and switching functions for thermal control heaters of the satellite

For details on the EPS see section 6.4.1.

Data Handling System (DHS) comprising:

- ERC32 based On-Board Computer (OBC)
- Remote Interface Unit (RIU) providing the standard and mission dedicated I/O interfaces (e.g. AOCS, propulsion, instrument, etc.) and embarking the SA Drive Electronics (SADE)
- On-Board Software (OBSW) with Central Mission SW (CSW)

The key functions of the DHS are:

- command reception, decoding, forwarding and execution according to PUS standard in real time (direct), time delayed (MTL) or orbit dependent (OPS).
- platform avionics, PCS, TCS, TT&C, XBS HK data acquisition and packaging
- instrument and instrument relevant monitoring and control telemetry packet acquisition and routing
- forwarding and formatting of all monitoring and control real-time telemetry
- routing and storage of all monitoring and control data as well as replay and formatting for transmission to ground
- payload control
- system operation
- system resource management
- system survey, failure detection and system reconfiguration

Two MIL-Buses 1553B will be implemented for the command and control interface. The Platform MIL-Bus provides for the communication interface between OBC and Platform equipment (RIU, PCDU, GPS Receiver and Star Trackers). The Payload MIL-Bus provides for the communication between the OBC and Payload equipment (MMFU, ATLID, BBR, CPR, and MSI). For more details see section 6.5.1.
Additional dedicated interfaces will be used as dictated by the various units to be controlled by the OBC and RIU. This will allow the usage of standard components, like AOCS actuators and sensors.

Tracking, Telemetry and Command System (TT&C) comprising:

S-Band Transponder The key functions of the TT&C are:

- reception and demodulation of S-band up-link command and control signals
- modulation and transmission of S-band downlink HK signals
- provision of ranging and coherent mode capabilities

For details on the TT&C see section 6.4.2.

Attitude and Orbit Control System (AOCS) comprising:

- 7 Coarse Earth / Sun Sensor (CESS)
- 2 Star Trackers (STR)
- 2 GPS receivers
- 2 three-axis Magnetometers (MAG)
- 2 Rate Measurement Units (RMU)
- 3 redundant Magnetorquers (MTQ)

- 4 Reaction Wheels (RW)
- 3 Digital Sun Sensors (DSS)
- 1 Reaction Control System (RCS)

For details on the AOCS see sections 6.4.3

Thermal Control System (TCS) comprising:

- set of heaters
- set of thermistors
- thermal control software (part of the central software)

For details on the TCS see section 6.4.4

Payload Datahandling and Transmission System (PDHT) comprising:

- MMFU
- X-Band System (XBS)

The key functions of the PDHT are:

- MMFU command reception, decoding and execution according to PUS standard
- Recording of instrument science and ancillary data
- MMFU HK data acquisition and packaging according to PUS standard
- routing and storage of a copy of the monitoring and control data onto a Monitoring and control packet store
- replay and formatting for transmission to ground
- MMFU resource management
- MMFU survey, failure detection and system reconfiguration
- Formatting and encoding of all data transmitted to XBS
- modulation and transmission of X-band downlink signals

For details on the PDHT see section 6.4.5.

Instruments Segment comprising:

- ATLID
- BBR
- MSI
- CPR

For details on the Instrument operational aspects see section 15.

For the measurement data transfer, a Packet Wire Interface (PWR) between Instrument and MMFU will be used. Monitoring and control between CDHS and instruments is handled via a MIL-Bus 1553B interface.

6.3 Main Interfaces of the Electrical System

6.3.1 Instrument Interfaces

The following electrical interfaces exist between the platform and the instrument for operation:

- 28 V unregulated power bus (EarthCARE units are operated at a bus voltage range of between 19 V and 34 V. The nominal mainbus voltage range in all operational modes is 29.5 V to 33.6 V)
- Command & Control via MIL-BUS
- Health, Status & HK Signals
- Science Data via serial, packet based Interfaces, often denoted as Packet Wire Interface

For simplified AIT activities the electrical I/F harness is separated via a connector bracket at the mechanical I/F between the main structure and the instrument.

6.3.2 Test Interfaces

The Skin connectors for test interfaces comprise the following items:

- Platform MIL-Bus test interface prime/redundant
- Payload MIL-Bus test interface prime/redundant
- FCV test interfaces (for arming only)
- Safe/arm plugs for pyro connections
- Safe/arm plugs for battery power line
- PPS and GPS synchronisation pulse
- Fast load interface to OBC (tbc)
- TC bypass to OBC TC decoder
- TM bypass to OBC TFG
- TM bypass to MMFU TFG

Further details are provided [RD-131].

6.3.3 Umbilical Interfaces

Electrical umbilical interface usage is foreseen during AIT, maintenance activities and activities when the S/C is integrated onto the launcher. TM/TC is provided by Video I/F, connection to battery relays allows battery maintenance.

The umbilical interfaces comprise following:

- Main Bus voltage monitor
- Main Bus conditioning line
- Battery charge/discharge current monitor
- Battery Relay Commands
- Battery Relay Status Signals
- Battery Charge line
- Battery voltage monitor
- Separation straps
- TMTC interface

6.4 Individual System Operations

6.4.1 Electrical Power Subsystem (EPS)

Detailed descriptions, also relating to operational aspects, are also covered by:

[RD 111] EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 3 - ELECTRICAL POWER SYSTEM EC.UM.ASD.SY.00014

6.4.2 S-Band Telemetry, Tracking and Command Subsystem

Detailed descriptions, also relating to operational aspects, are covered by:

[RD 113] EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 5 - S - BAND SYSTEM EC.UM.ASD.SY.00016

6.4.3 Attitude and Orbit Control Subsystem (AOCS)

Detailed descriptions, also relating to operational aspects, are covered by:.

[RD 112] EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 4 - AOCS & RCS SYSTEM EC.UM.ASD.SY.00015

6.4.4 Thermal Control System (TCS)

Detailed descriptions, also relating to operational aspects, are covered by:.

[RD 114] EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 6 - THERMAL CONTROL SYSTEM EC.UM.ASD.SY.00017

6.4.5 Payload Data Handling Transmission Subsystem (PDHT)

Detailed descriptions, also relating to operational aspects, are covered by:.

[RD 115] EARTHCARE SPACE SEGMENT USER MANUAL (EC-SSUM) VOLUME 7 - PAYLOAD DATA HANDLING & TRANSMISSION SYSTEM EC.UM.ASD.SY.00018

6.5 On-board communication interfaces

6.5.1 MIL-BUS

6.5.1.1 MIL-BUS Topology

EarthCARE will feature the following MIL-Bus topology:

Platform MIL-Bus (see
Figure 6.5-1): one dual standby redundant will be used to communicate with PCDU, RIU and AOCS elements that have a MIL-Bus interface

Payload MIL-Bus (see
Figure 6.5-2): one dual standby redundant will be used to communicate with the MMFU and the Instruments

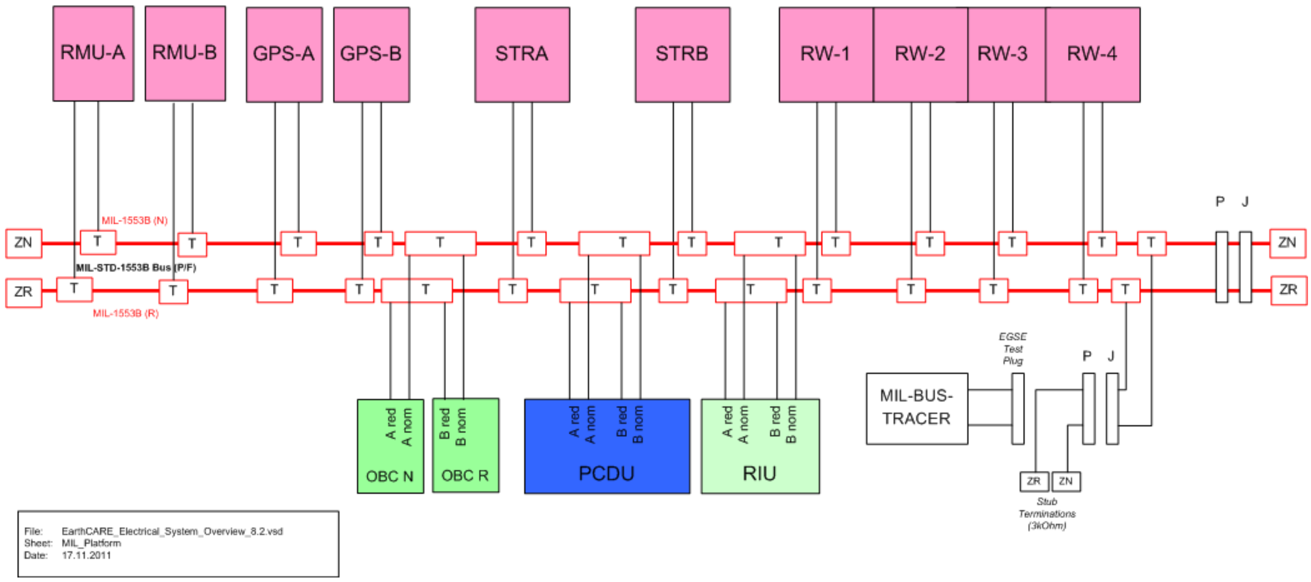


Figure 6.5-1: Platform MIL-Bus Topology

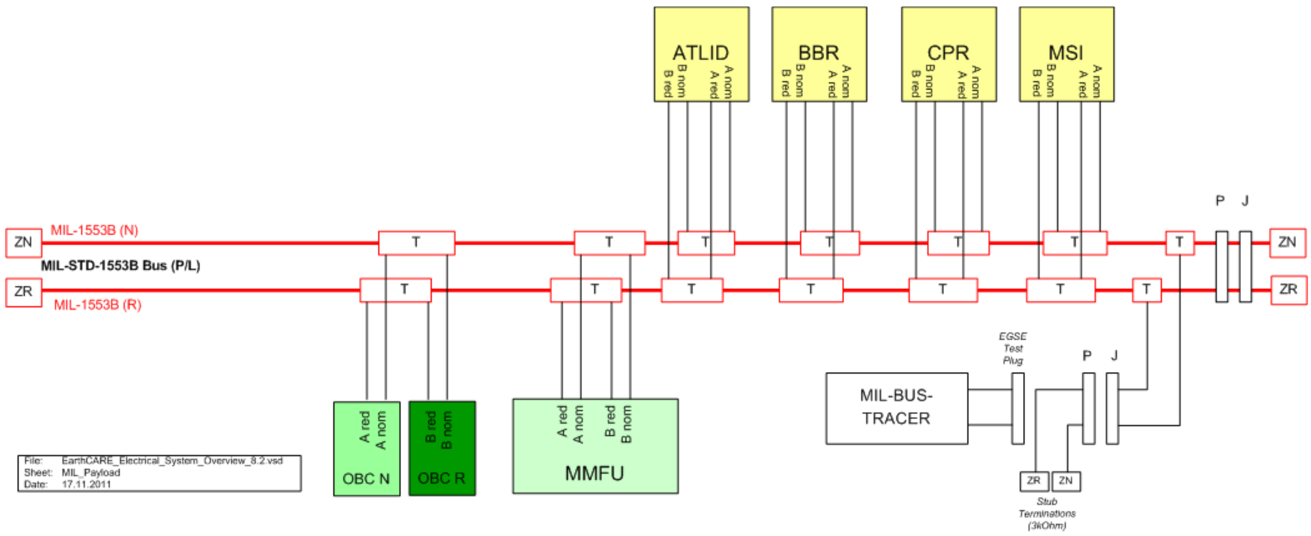


Figure 6.5-2: Payload MIL-Bus Topology

This architecture has the advantage to separate clearly platform and payload related functions, which provides thus a clear functional segregation and eases the overall error handling scheme. Further, platform functions can continue in the case of a failure on the payload bus.

6.5.1.2 MIL-BUS Functional Architecture

The general functional architecture of one MIL-Bus based communication network is depicted in Figure 6.5-3.

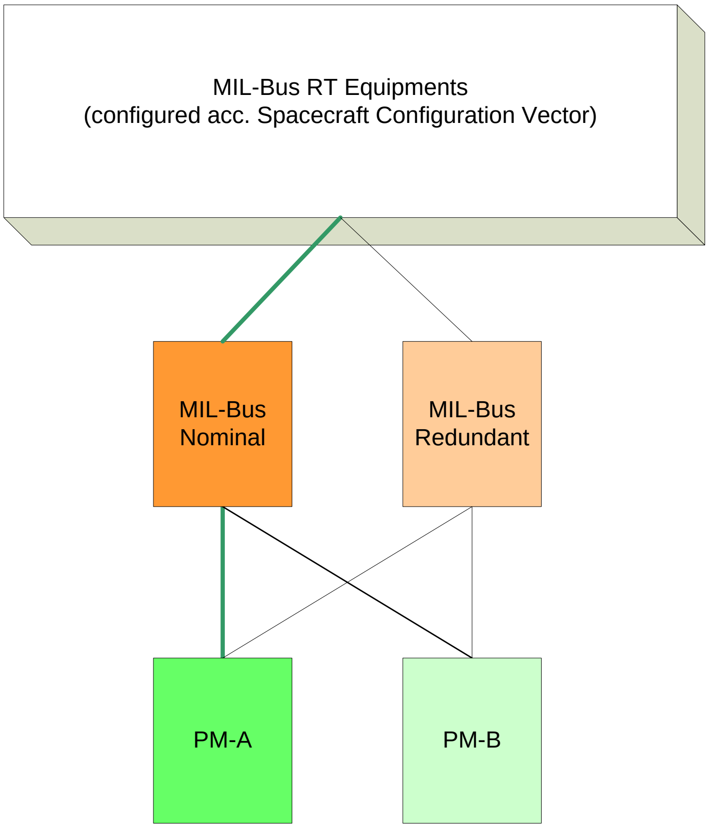


Figure 6.5-3 Mil-Bus Functional Architecture

The dual standby redundant MIL-Bus is functionally treated as a cold redundant communication unit, providing access to all equipments connected to this Mil-Bus. One Mil-Bus communication unit represents one MIL-Bus bus controller including the related interfaces towards the on-board SW as well as to the electrical output and the associated harness. The Mil-Bus remote terminal communication I/F including its input circuitry and internal interface to the equipment is allocated to the equipment. This functional breakdown is based on the failures rates of the MIL Bus communication interfaces, which are significantly smaller than the failure rates of the equipment, combined with the operational and functional requirements upon availability, observability, commandability as well as failure handling and investigation capability. Nominally, the communication is via Processor Module A (PM-A) on all nominal MIL-Bus interfaces. It needs to be noted in this context that the MIL-Bus serves also to distribute the on-board time to the equipment on the MIL-BUS via a mode code command SYNCHRONIZE with data words (CUC time). For equipments not connected to the MIL Bus the start of the major frame can be taken as synchronization reference, aiming on a synchronization accuracy of 1 msec.

6.5.1.3 MIL-BUS Communication

The communication is established by a MIL-Bus protocol in accordance with the EarthCARE Mil-Bus protocol specification [AD-13].

The MIL-Bus operation will be executed according to the following principles:

- The Mil-Bus scheduler will implement major and minor frames synchronized to the OBT.
- The major frames will have a period of 1 second, divided into minor frames of 50 ms (The value is derived from SRD DHS-TC-7). 20 minor frames / slots are available within 1 second.
- Each minor frame will provide a polling list of Mil-Bus messages. The polling list allows specification of delays between the different messages to support the implementation of low level protocols with non-intelligent remote terminals.
- The OBC SW will maintain a polling sequence table, configurable by ground TC (service 6) depending on default data transfers assigned to minor-frames, transfers triggered by telecommands and transfers initiated by RT requests ™. (periodic / aperiodic messages)

This is visualised in the following Figure 6.5-4.

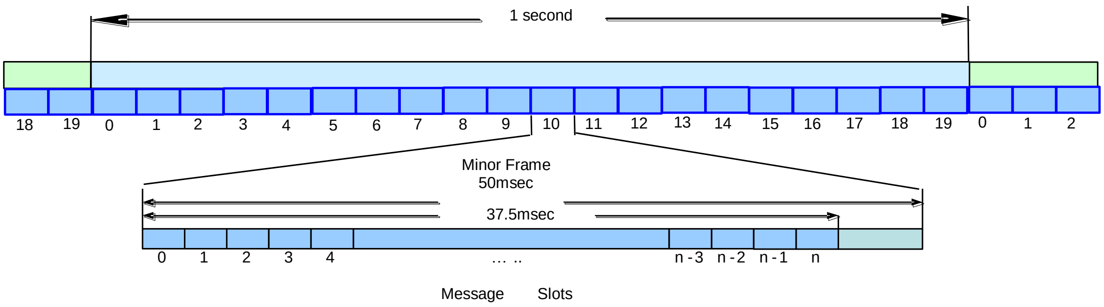


Figure 6.5-4: Definition of major frames and minor frames in the MIL-Bus protocol

The allocation of minor frames for the Platform- and Paylod MIL bus is shown in the figures 6.5-5 and 6.5-6.

Minor Frame Allocation for Platform MIL-Bus

Minor Frame	**0/10**	**1/11**	**2/12**	**3/13**	**4/14**	**5/15**	**6/16**	**7/17**	**8/18**	**9/19**
AOCS ALGO processing at 2Hz (no processing on the MIL-Bus)								Input pre-processing **ALGO**	AOCS TC's to RIU	-
Health status (STR-1, STR-2)	TM									-
RIU	TM1/TC	TM2/TC	TM3/TC	TM4/TC	TC	TC	TC	TC	AOCS TC	TC
DSS (via RIU)				TC	TM5					-
PCDU	TM/TC	TC	TM/TC	TC	TM/TC	TC	TM/TC	TC	TM/TC	TC
MIMU	TM DP1		TM DP2		TM DP3	TM 1 Hz	TM DP4		TM DP5	-
RW 1+2+3+4							TM		TC	-
GPSR-A		256	256	256		256		256	256	-
GPSR-B		256	256	256		256		256	256	-
STR-A	640	256	640	256	640	256	640	256	640	-
STR-B	640	256	640	256	640	256	640	256	640	-
Time Sync Broadcast minor frame15 only						TimeSync				-
Reset RT Health commands (STR-1, STR-2) with 2 bytes per command						Command				
PUS Service 2 message (with max. 64 bytes)		64		64		64		64		-

Figure 6.5-5: Allocation of minor frames for the Platform MIL-Bus protocol

Minor Frame Allocation for Payload MIL-Bus

Minor Frame	**0/10**	**1/11**	**2/12**	**3/13**	**4/14**	**5/15**	**6/16**	**7/17**	**8/18**	**9/19**
Health status (MMFU-A, MMFU-B, ATLID, BBR, MSI, CPR)	TM									-
MMFU-A (TC/TM) - nominal unit	1024		1024		1024		1024	1024	1024	-
MMFU-B (TC/TM) - standby unit	256		256		256		256	1024	256	-
ATLID (TC/TM)			1024		1024					-
BBR (TC/TM)				1024		1024				-
CPR (TC/TM)		1024				1024				-
MSI (TC/TM)		1024					1024			-
Time Sync Broadcast minor frame15 only						TimeSync				-
Reset RT Health commands (MMFU-A, MMFU-B, ATLID, BBR, CPR, MSI) with 2 bytes per command						Command				
PUS Service 2 message (with max. 64 bytes)		64		64		64		64		-

Legend:

TC	Telecommand
TM	Telemetry
TM/TC	Telemetry & Telecommand
TimeSync	Time synchronization message

Figure 6.5-6: Allocation of minor frames for the Payload MIL-Bus protocol

Minor Frame Allocation for Payload MIL-Bus

For a detailed description please refer to the MIL Bus Traffic Analysis document [RD-133]

Minor Frame

0/10
1/11
2/12
3/13

Consequently the EarthCARE MIL-Bus protocol supports the following different types of MIL-Bus subscribers:

- simple subscribers:
  The simple subscribers correspond to subscribers with no built in processor function (non intelligent RT). The simple subscribers correspond to a RT requiring less than 29 TC and 29 TM so that direct sub-addressing may be used. All data exchange is handled either by single Mil-Bus messages (max. 32 16-bit words) or in a two step approach by sending a command to the RT to select the required channel on the RT followed by a transfer to read or write the data word. Between the channel selection and the data transfer a RT specific delay may be necessary The protocol is driven by the HW design of the unit and dedicated for each unit. Simple subscribers are RIU, PCDU and RMU.
- complex subscribers:
  The complex subscribers require exchange of data blocks larger than one Mil-Bus message, therefore a higher level protocol layer is implemented. This data block transfer layer is used to exchange TM and TC packets between BC and remote terminals. Complex subscribers are GPS, STR, MMFU, and the instruments.

6.5.2 OBC Spacewire Interface

The OBC is equipped with a spacewire interface. EarthCARE does not make use of this interface in the flight configuration.

7. SPACECRAFT CONFIGURATION HANDLING CONCEPT

7.1 Redundancy Concept

In order to avoid the loss of platform functions mandatory for the mission, a tailored redundancy concept is required. Thus, the redundancy concept of the platform has to be such that a single (credible) failure does not cause a failure of essential platform functions. Accordingly all units have to be independent of their redundant alternatives.

7.1.1 Redundancy Principles

The redundancy principles can be characterised as follows:
Hot redundancy is provided for **vital S/C functions** (OBT, TC decoding, S-Band TC reception function, high priority commanding function (CPDU), reconfiguration function (RM), instrument survival heating, PCDU auxiliary power, STR, MAG, DSS, RW) in order to provide redundant resources without the need for specific configuration commands.

Hot standby is provided for the P/F and P/L MIL Busses.
Note: The BC and RT are operated in cold redundant configuration.

Cold redundancy operation of one unit means that only one unit out of two is declared as operational in-use.

Strict Cold redundancy identifies that the equipment / instrument is operated exclusively in cold redundancy (only one unit out of two / more is switched-on.

Functional redundancy is provided for functions, which do not cause a significant degradation of the mission in case of their loss, e.g. the number of CESS heads or thermal heaters. The heater design is such, that even in case of loss of a heater branch the remaining heater power is sufficient to establish minimum temperature. By this way, the hardware heaters are operated in hot/functional redundancy.
Redundant operation of some items may be required only in specific mission phases, e.g. usage of the PCDU TM/TC interface may be differently in LEOP than in the nominal mission.

7.1.2 Redundancy Architecture

The following table gives an initial summary of the redundancy provided in EARTHCARE:

Module / Subsystem	Module Elements	Type of redundancy	Comment
CDHS			
OBC	PM	Cold	Redundant Processor is allowed to be used in Service Mode with reduced functionality
	TC Decoder/CPDU	Hot	The TC decoder is selected by the VCID
	RM	Hot	Master/Slave principle; fail silent
	SGM	Hot	SGM-A and SGM-B provide essential context information
	OBC MMU	Cold	Note: second MMU is in STDBY (powered but not operationally used) in case of FDIR action only the rerouting into a different store (MMU-B) is needed
	OBRT clock	Hot	Master/slave principle
	S-band TFG	Hot	Hot Standby
RIU	CRTL+STD I/F	Cold	

Module / Subsystem	Module Elements	Type of redundancy	Comment
	IF boards (AOC, RCS, SAD)	Cold	
SBS			
	S-Rx (Receiver)	Hot	
	S-Tx (Transmitter)	Strict Cold	
PDHT			
XBS		Strict Cold	
MMFU	MSS	Strict Cold	
EPS			
PCDU	AUX Supplies	Hot	Completely powered and internal functional redundant
	TM/TC Interface	Cold	Only one is used for communication, but In order to achieve full internal redundancy of PCDU internal monitoring capabilities both be AUX supplies are powered hot redundant.
Battery		Hot	internal functional redundant
Solar Arravy		Hot	internal functional redundant
TCS			
Thermistors		Hot	Triple voted use, middle sensor reading (value in-between the others) is taken per axis
Heaters		Cold	
AOCS/RCS			
	CESS	Functional	The CESS head is triple majority voted
	DSS	Hot (2/3)	Triple voted use, middle sensor reading (value in-between the others) is taken per axis
	RMU	Cold (1/2)	
	STR	Hot	STR navigation solution available 5 sec. after power on
	GPS Receiver	Cold	GPS-A and GPS-B feature different APID's to allow for the redundant GPS being switched on for investigation purposes
	MAG	Hot	2 (3-axis units, Functionally paired with MTQ)
	MTQ	Strict Cold	3 units; redundant coils
	RW	Hot (3/4)	4 nom , but 3 channels after one failure
	RCS	Cold	2 separate RCS branches, TM from both RCS chains is available from both chains
	CBH	Cold	CBH-SBY heater active on both branches but CBH HUP heaters only active on one branch
ATLID			
	ACDM	Strict Cold	ICU of ATLID
	LPE	Cold	
	HPE	Strict Cold	Consist PLH & TXA
	Nominal HTR	Cold	
	Survival HTR	Hot	
BBR			
	ICU	Strict Cold	
	Survival HTR	Hot	
MSI			
	ICU	Strict Cold	
	Survival HTR	Hot	

Module / Subsystem	Module Elements	Type of redundancy	Comment
CPR			
	SPU	Strict Cold	ICU of CPR
	LPE	Strict Cold	
	HPE	Strict Cold	
	Nominal HTR	Cold	
	Survival HTR	Hot	3 individual LCL's
Other			
P/F Bus	MIL 1553 B	Cold	BC + RT are operated in cold redundant configuration
P/L Bus	MIL 1553 B	Cold	BC + RT are operated nominally in cold redundant configuration. Note: For the Instrument support mode the RT's of one instrument could be operated in "hot-redundant" via the service 2 on one P/L Mil Bus. Instrument RT hot redundant operation is not implementated as such in the CSW high level MIL-Bus protocol functionality therefore it has to be run manually.

Table 7.1-1 Redundancy Architecture

7.2 S/C Configuration Handling

The configuration of the satellite will be determined by the following elements:

- the configuration that is set up by the OBC/Reconfiguration Module by means of CPDU commands
- the configuration of other onboard equipment that is switched on by the system initialisation function or equipment setup routines by using of the Spacecraft Configuration Vector (SCV)
- the usage of onboard parameters that are read from the SGM (SW settings)

7.2.1 OBC/RM Related Configuration Handling

When a system reconfiguration is performed, the vital S/C equipment will be configured by the reconfiguration sequences that are executed by the OBC RM. These sequences will ensure that the desired principal S/C equipment is switched on. The sequences will be a series of CPDU commands (CPDU packets).

7.2.2 Configuration handling using the Spacecraft Configuration Vector (SCV)

The configuration of further non-vital onboard equipment is handled by the system initialisation function by using the Spacecraft Configuration Vector (SCV). The SCV will also be used when equipment needs to be switched on by a Flight Control Procedure. In this case high level setup functions are called up that use the SCV entries to determine which unit is to be used. The SCV will be composed of two elements:

- SCV_CONFIG (unit/component)

SCV_STATUS (unit/component)

SCV_CONFIG will be used to define the system configuration during the system initialisation process (e.g. after OBC boot) for the Nominal and the Safe Mode spacecraft configuration and to derive the required unit configuration during switch-on or autonomous switch-over.

SCV_CONFIG shall comprise the following subvectors:

- SCV_NOM
- SCV_SAFE
- SCV_HEALTH

SCV_NOM will define the configuration that is used in the S/C initialisation process when the Satellite Nominal Configuration is to be loaded or during a unit setup function.
SCV_SAFE shall define the configuration to be used for Satellite Safe Mode (SAT-SAF).
SCV_HEALTH shall indicate the health status of the unit.
SCV_STATUS represents the actual status of the components. This vector will be managed by the CSW during the initialisation and switching sequences. This vector is stored in the System Data Pool (SDP) only, i.e. no instance in the SGM shall exist. SCV_STATUS comprises following subvectors:

- SCV_PWR, indicating the power status of the individual equipments
- SCV_TM, indicating whether or not TM is acquired for the individual equipment
- SCV_OP, indicating whether an equipment is used/not used in an onboard process

The Spacecraft Configuration Vector with the default configuration for the system initialisation is given in ANNEX I
The SCV is used by various onboard functions as follows:

- During system initialisation, SCV information is used to setup the related equipment by means of TCs Unit_Setup
- Upon issuing of a setup command (e.g. when preparing STR and GPS for Nominal Operations), the equipment is switched on using the SCV information
- When an onboard reconfiguration is triggered, e.g. HTRCrtlGroup_2_A to HTRCrtlGroup_2_B, the SCV information is used.

8. SYNCHRONISATION AND DATATION CONCEPT

8.1 Timing and Datation Concept Definition

The timing and datation concept should be robust and simple while fulfilling all science data needs. It can simplify or complicate the operation of a satellite to a great extent so it is treated separately in this section.

The EarthCARE on-board time (OBT) system consists of

- An Absolute Time Provider, the GPS receiver issuing a synchronization signal identifying the GPS time system 1 second roll-over and a GPS time message either as dedicated TM packet or as part of the PVT solution
- A Central On-board Time (COBT) master as part of the OBC, also call On-board Time Reference (OBTR), mastering that one and only one time is used across the satellite by distribution on-board time synchronization messages and signals and that this time is known to ground for time correlation to UTC
- The time report packet, identifying the on-board transmission time of a repetitive unique bit in the downlink data stream to ground, which is transmitted to Ground allowing correlation of the OBT to Ground UTC
- A number of datation users, each comprising a Local On-board Time (LOBT) function for standalone operation, which is to be synchronized to the COBT to ensure consistent and full performance operation.
- There are two classes of datation users defined depending on the accuracy of the synchronized operation:
  - Class A datation users will be synchronized by dedicated HW line, the 1 PPS signal
  - Class B datation users will be synchronized by communication protocol embedded synchronization reference, which is the start of the major frame of the MIL-Bus Protocol.

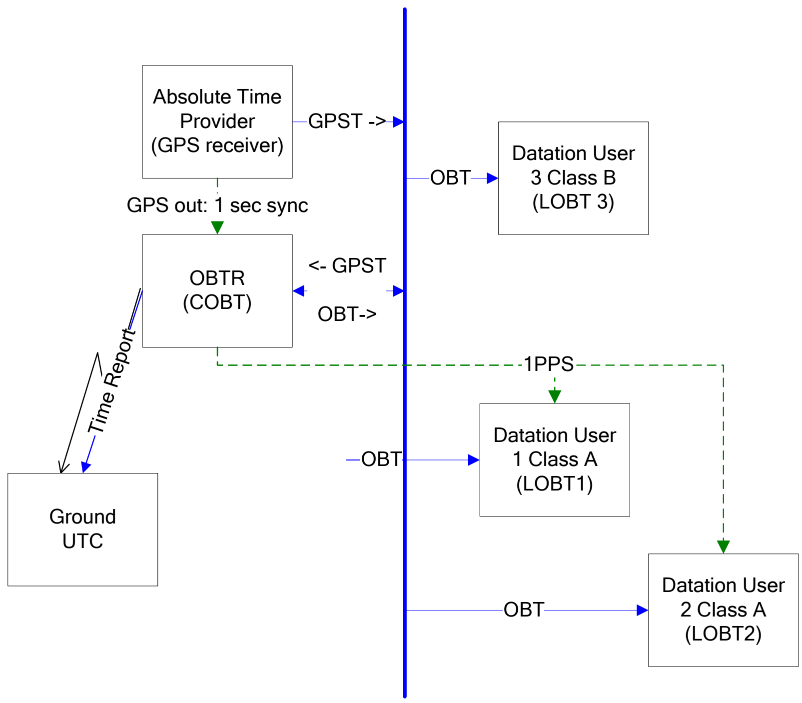


Figure 8.1-1 On-board Time System

The COBT is distributed as part of the communication via the on-board time synchronization message, which is provided well before the next synchronization reference signal and which contains the OBT of the next synchronization reference. For Class A users this is the 1 PPS signal from the OBC, for Class B users this is the major frame start of the MIL-Bus Protocol as depicted in Figure 8.1-2

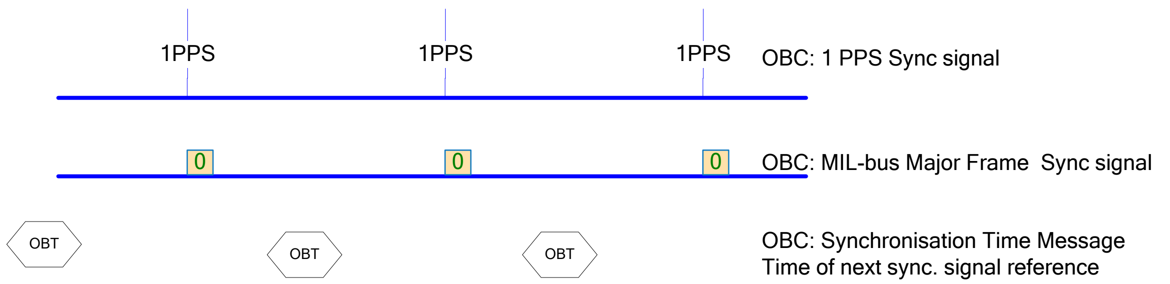


Figure 8.1-2 COBT message and synchronisation signal relation

8.2 LOBT Synchronisation

The datation users reset their LOBT synchronisation logic at switch-on or after interruption of the nominal synchronisation upon reception of a synchronisation reference signals and shall than resynchronise to the next received synchronisation reference signal. It shall be able to resynchronize upon an arbitrary received initial synchronisation signal provided that the subsequent synchronisation reference signals are received within the boundaries

The initial LOBT synchronisation process as well as reach LOBT re-synchronisation process commences according to the following scheme:

- Reset the LOBT sync logic with reception of the applicable synchronisation signal
- Commences with reception of the COBT information for the next synchronisation reference via communication protocol message and latch the received COBT into the LOBT pre-set register
- Synchronise at reception of the next synchronisation reference signal the LOBT and set the active LOBT register equal to the LOBT pre-set register containing the COBT of this sync signal.

The synchronized operation of any datation user shall be compatible with a variation of the synchronisation reference signal period of 10 msec of the expected arrival of the synchronisation reference. In case that the applicable synchronisation reference is not received within these conditions or the synchronisation time message in-between two synchronisation reference signals is not received the datation users maintain their local on-board time reference in free wheeling mode.

The datation users indicate at any time within the time field of its telemetry packets their LOBT synchronisation status. It should be possible to derive at any time the validity of the supplied time information.

8.3 In Flight Time Correlation

The spacecraft generates a continuous TM real-time data downlink stream and provides these data via virtual Channel 0 to the receiving ground station. The data stream is generated by the Frame Generator, merging the packets from the various Virtual Channels, adding the Reed-Solomon encoding blocks and the CADU headers (i.e. the Attached Synchronisation Marker). To allow the ground to correlate on board time to UTC the Frame Generator produces a TM Strobe on transmission of the leading edge of the first bit of the Attached Synchronisation Marker of every 32nd VC0 TM frame (Virtual Channel Frame count = 0, 32, 64, 96, 128, 160, 192, 224). The OBTR of this TM Strobe is latched to a dedicated register of the OBC. The CSW is then required to produce a Spacecraft Time Source Packet containing this sampled time for transmission before the next VC0 TM frame that will generate the next Time Strobe.

When the GPS Receiver is active the EarthCARE OBT is kept synchronised to GPST. When the GPS receiver is off the EarthCARE OBT is free running and will gradually diverge from GPST.
In order to command and control EarthCARE the ground will need to be able to convert from UTC to OBT and vice versa. While OBT is synchronised to GPST this conversion is simply a matter of adding the appropriate number of leap seconds.
However, while the OBT is free running the FOS will need to determine the correlation between OBT and UTC using the regularly S/C Time Report as follows;

- During each ground station pass, record the UTC of reception of the rising edge of each VC0 TM frame with Virtual Channel Frame count equal to 0, 32, 64, 96, 128, 160, 192, and 224.
- Extract the OBT at which the transmission of each of these frames started from the Spacecraft Time Source Packets. There should be one Spacecraft Time Source Packet between each 32nd VC0 TM frames giving the transmission time of the previous relevant VC0 TM frame.
- Using the spacecraft predicted orbit, correct the VC0 TM frame reception UTC for the spacecraft to ground station propagation delay. Thus for each 32nd VC0 TM frame both the OBT and UTC of the instant of transmission are known.
- Perform a least squares fit over the whole ground station pass to achieve a simple correlation of UTC to OBT of the form; OBT= (UTC-UTCref)*m+OBTref where UTCref, OBTref and m are the outputs of the linear correlation.

It should be noted that nominally the GPS Receiver will always be on, so OBT should be synchronised to GPST except in LEOP before the GPS receiver is first switched on, in Safe Mode and in SAT-NAM when returning from Safe Mode or following an OBC reset or reconfiguration.

8.4 COBT Synchronisation Verification

The onboard system will detect and recover from failures of the on-board time management system. However, the onboard system is dependent on the GPS Receiver giving a correct GPST and continuing to provide its sync signal on increment of the GPST seconds. In particular the on-board system will be unable to detect an initial error on GPST and will be unable to detect a slow drift of OBC 1PPS with respect to the GPST until the difference between GPST and OBT is greater than 1 second. However, these failures can be detected very easily by the ground regularly performing the time correlation function. Therefore the ground should perform the following monitoring activities;

- Following in flight OBT synchronisation to GPST perform a time correlation to confirm that OBT is set to GPST (i.e. UTC plus the appropriate number of leap seconds);
- During all S-band passes perform a time correlation and compute the delta between OBT and GPST. An alarm should be raised if this exceeds 10 milliseconds.

This monitoring function is expected to be an autonomous on-ground function

9. ON-BOARD DATA HANDLING AND DOWNLINK CONCEPT

9.1 Overview

The EarthCARE satellite comprises of 2 elementary downlink chains, an S-band and an X-band downlink channel. The interfaces between the Space Segment and the Ground Segment are shown in Figure 9.1-1 and basically constituted by the following elements:

S-Band Uplink for the transmission of

- Telecommands

S-Band Downlink for the transmission of

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

X-Band Mission Data Downlink for the transmission of

- Specifically configured selective near real-time instrument data
- ATLID Mission data (science and instrument ancillary data)
- BBR Mission data (science and instrument ancillary data)
- MSI Mission data (science and instrument ancillary data)
- CPR Mission data (science and instrument ancillary data)

X-Band Satellite Housekeeping Data Downlink for the transmission of

- Satellite housekeeping data including Satellite Ancillary Data

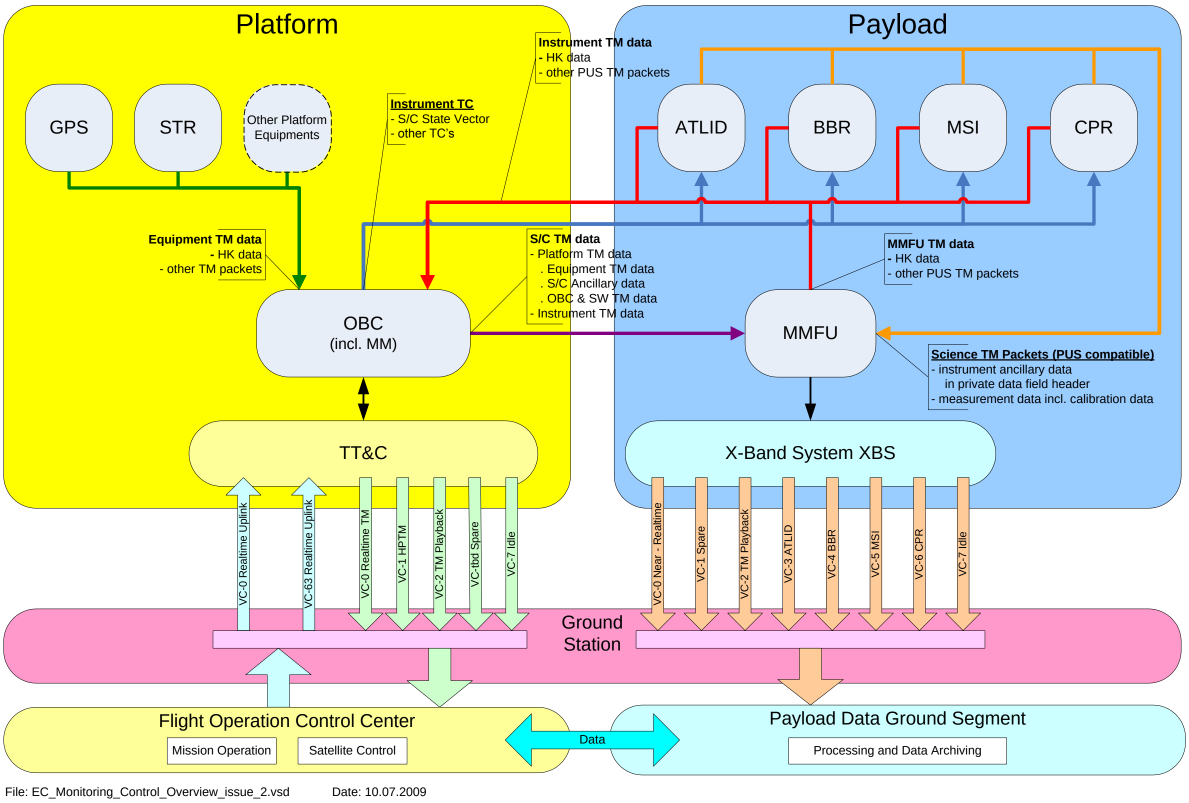


Figure 9.1-1: Satellite to Ground Segment Interfaces

The subsequent on-ground data flow is depicted including the embedding of the EarthCARE Ground Processors (ECGP) inFigure 9.1-2.

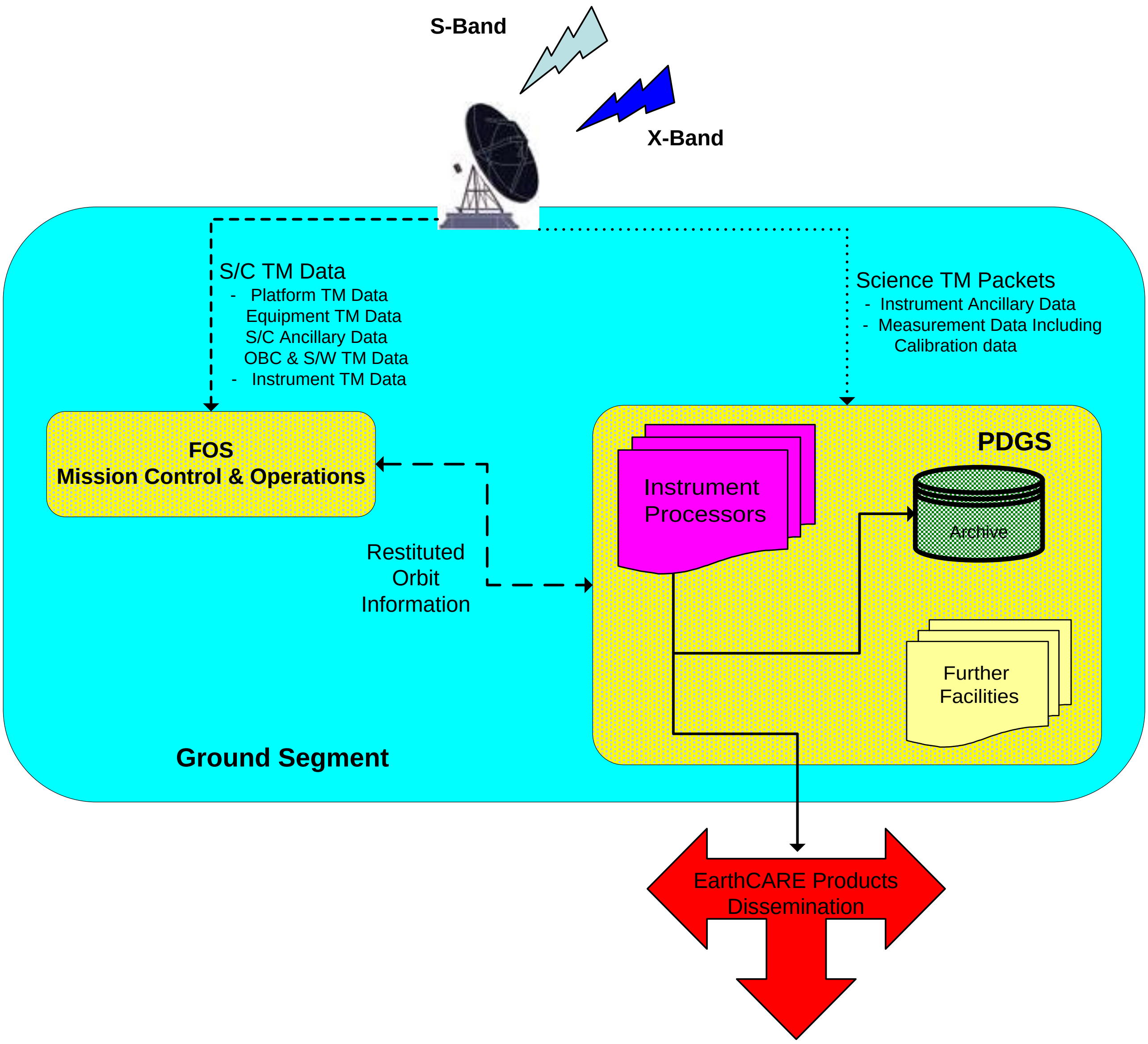


Figure 9.1-2 EarthCARE On-Ground Data Flow

The on-board data flow is depicted in Figure 9.1-3. The on-board applications are generating periodically HK, diagnostic and parameter report packets as well as other on-request TM packets. These packets are forwarded according to the settings of the real-time forwarding service of the data management system (DMS) application into the real-time S-band downlink data stream as well as according to the configuration of the data storage service onto the OBC mass memory for playback via S-band downlink. In addition in higher satellite modes when the MMFU is setup operationally all S/C monitoring and control data are forwarded to the MMFU. Upon activation of this packet routing to the MMFU the monitoring and control data of all applications including the satellite ancillary data are regularly stored to MMFU packet stores for playback via the X-Band downlink.

The science data are routed to the MMFU into one separate packet store per instrument. Each instrument packet store contains all science and instrument ancillary data needed for the level 1b processing. The satellite ancillary data are part of the satellite housekeeping data replay provided via separate virtual channel. One dedicated X-band virtual channel is assigned for each instrument (see chapter 9.5.7.1).

Each downlink chain is controlled and fed by a dedicated unit. The S-band downlink is controlled from the OBC and fed by real-time data from the OBC processing system as well as by playback of stored monitoring and control data from the OBC mass memory. The X-band downlink is controlled from the MMFU and is fed by a real-time channel allowing transfer of data with minimum delay for quasi on-line data access as well as by playback of stored mission data from the MMFU mass memory sections. The mission data provided via X-band downlink comprises the SW generated monitoring and control data contained in the S-band, the satellite ancillary data as well as all instrument science and ancillary data.

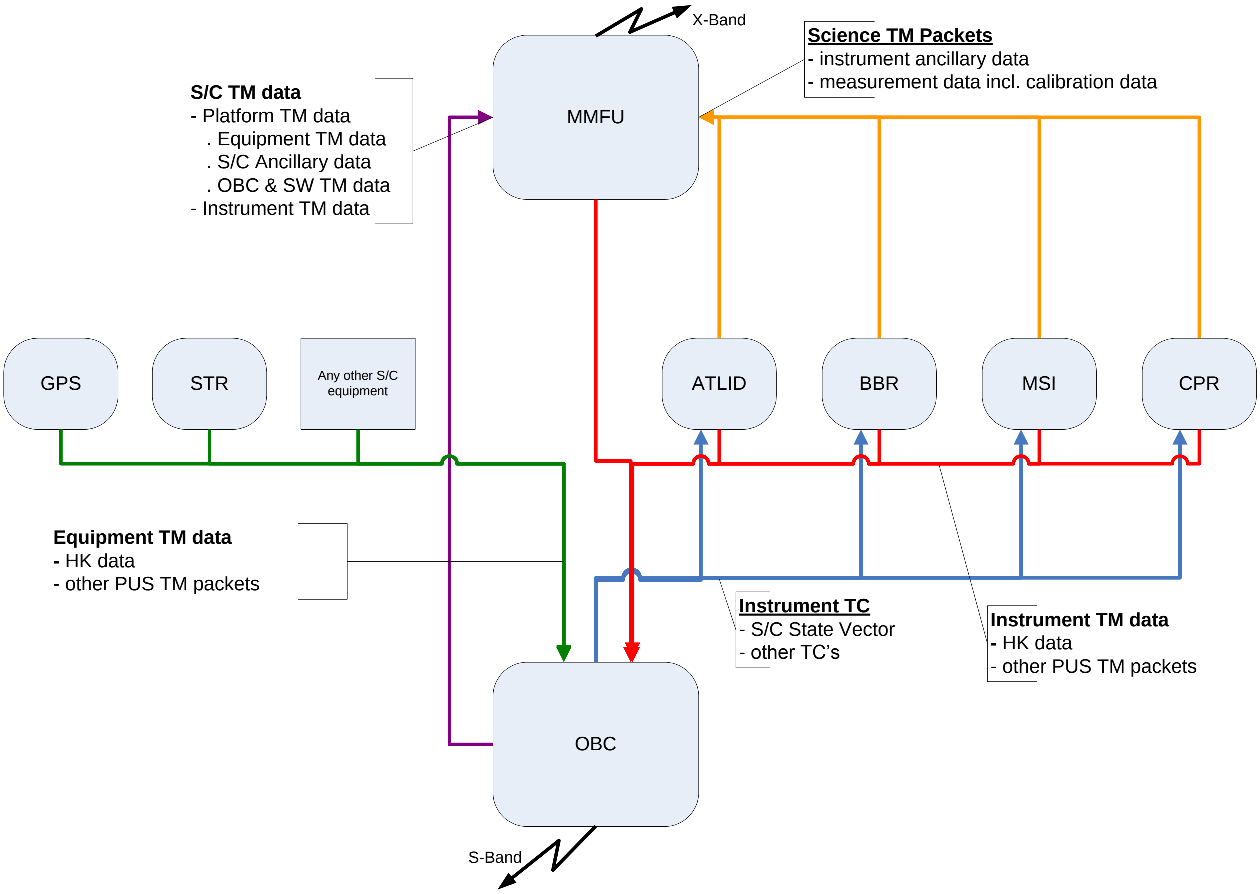


Figure 9.1-3 EC on-board data flow

From S/C side the data downlink concept of EarthCARE is based on the following downlink scheme:

- All TM related to command, monitoring and control will be downlinked via the S-Band. This means that all HKTM acquired during non-coverage periods of the satellite will be made available to the FOS via the S-Band link.
- The science data stream is constituted by the X-Band downlink and comprises:
  - All instrument science and instrument ancillary data TM will be downlinked via the X-Band link.
  - The recorded satellite housekeeping TM including the satellite ancillary data as part of the X-band downlink data stream accomplish the measurement and science in line with the system requirements for independent use and processing within the PDGS as well as for backup purposes.
  - The sum of instrument science and instrument ancillary data are denoted as mission data

Note: The recorded satellite housekeeping does not contain the packets exclusively provided in the S-band real-time virtual channel, i.e. the High Priority Telemetry Packet generated by OBC HW and the system log.

However the recorded satellite housekeeping data contain all stored event report packets as well as a service 3 HK report packet with extracted HPTM parameter information.
The X-band ground stations used for nominal operation can simultaneously be used for reception of S-band telemetry therefore no additional ground stations are required by this concept, but nevertheless can be supported. From S/C operation point of view a downlink strategy relying on S-band is much more robust as one relying on X-band since it is independent from S/C modes. S-band telemetry is provided in all S/C modes, while X-band is only available in the satellite nominal operation mode (SAT-NOM). Data handling analysis revealed that for nominal operation the number of ground contacts can be reduced by approximately 33% with-out impacting the on-board storage capacities. Minimisation of ground station contacts can be achieved by selecting only those ground contacts with a minimum duration of 300 seconds as long as there is no ground station outage. For data recovery after a ground station outage the use of any station significantly reduced the time to recover to on-line data.
According to current EarthCARE space segment understanding the following alternate data handling downlink scenario is favoured by the ground segment and is defined as baseline scenario for the EarthCARE mission.:

- In LEOP and contingency cases all TM related to command, monitoring and control will be downlinked via the S-Band. This means that all HKTM acquired during non-coverage periods of the satellite will be made available to the FOS via the S-Band link.
- In nominal operation the S-band channel is used for command uplink and real-time data downlink including HPTM and system log monitoring. All recorded TM related to command, monitoring and control will be downlinked via the X-Band from the MMFU S/C Monitoring and control data store. This means that all HKTM acquired during non-coverage periods of the satellite will be made available to the FOS via PDGS. In case of data outages in this data stream FOS performs data retrieval via service 15 downlinks over time periods of monitoring and control data stored in the OBC MM. In this operational scenario all monitoring and control data are routed to one OBC MM PS in order to have equivalent data routing and storage configurations on the OBC MM and on the MMFU.
- The science data stream is constituted by the X-Band downlink and is the same as in before mentioned S/C data downlink scenario.

The related on-ground data flow covering both scenarios is shown in Figure 9.1-4
This alternate data downlink scenarios w.r.t. the S/C monitoring and control telemetry data can be supported by the EarthCARE on-board data handling concept within the satellite mode definition given in [RD-06]. It is referenced as downlink scenario DLS_02 in other places of the document. No additional operational constraints and requirements have been formalized w.r.t. the EarthCARE space segment.
Conceptually the S/C design can support a downlink scenario with minimum number of ground stations as well as a downlink scenario oriented towards provision of data as fast and close to measurement as possible thus emphasizing the use of every possible ground contact with a receiving X-band ground station.

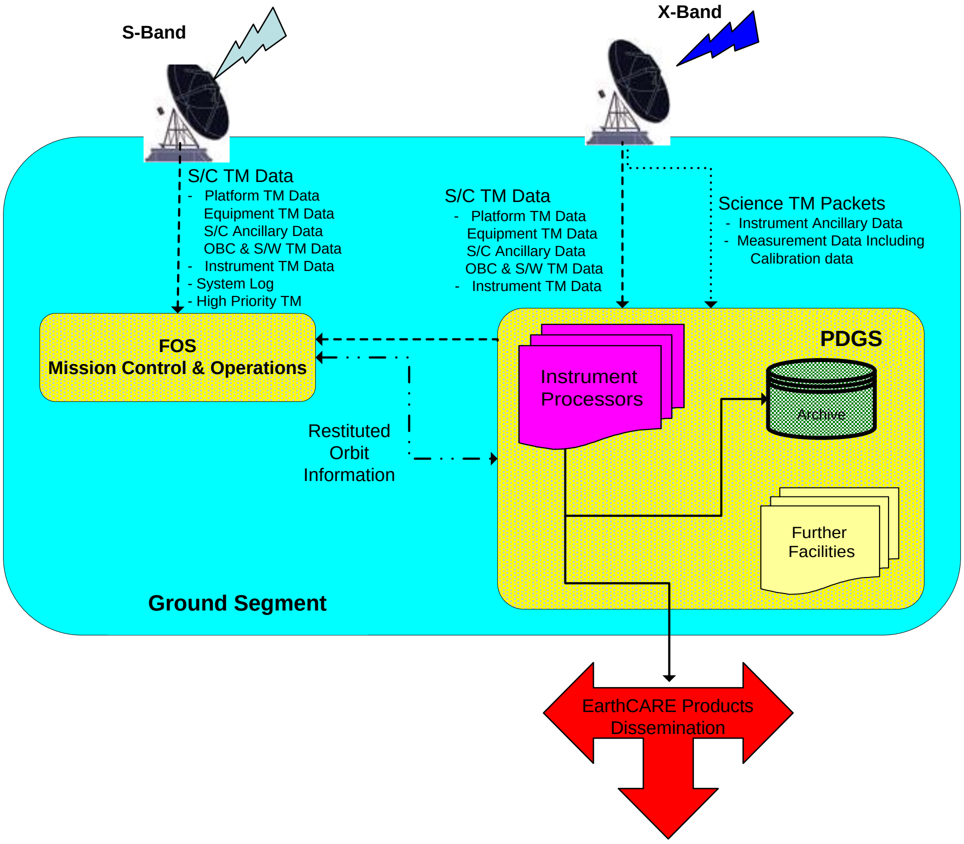


Figure 9.1-4 EarthCARE Ground Segment Data Flow with SC TM in nominal X-band downlink

9.2 Monitoring and Control Data Management Concept

9.2.1 TM Parameter Identification

On EarthCARE the Parameter ID's have the following structure:
Parameter ID
(4 Bytes)

PRID		Local ID	
Filler	PRID	RW Access	ID
	enumerated	Enumerated	Enumerated
1bit	7 bit	1bit	23 bit

Table 9.2-1 TM Parameter Identification

Local ID's in on-board SW:

- MSB identifies if the parameter is a Read-Only Parameter
- are free definable,
- no dedicated, especially no byte/bit map related algorithm is applied

The Local ID definition will sub-divide the local ID in

- MSB identifying the ReadWrite Access characteristic of a parameter for use in S140
- sub-ranges e.g. using the 7 MSBs, which can be considered as data pool groups
  - HK Parameters of functional entity i
  - acquired from external interfaces or
  - derived from internal H/W or S/W states

– Derived on-board TM parameters
– Status summary parameters
– Optimized HK parameters (e.g. type converted)
– Configuration parameters

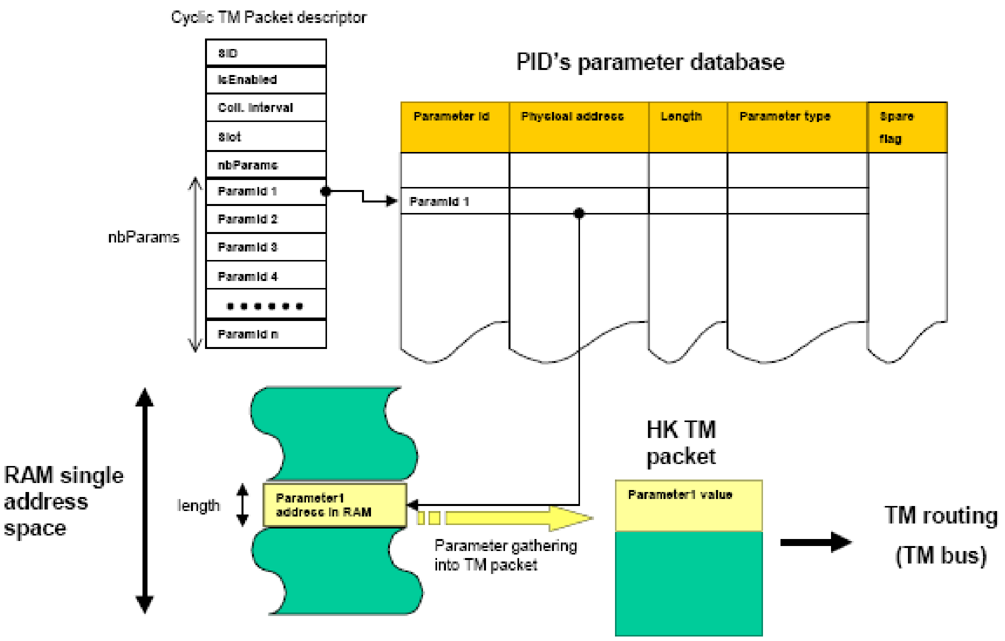
A generic allocation of data pool groups to be considered is given in [AD-110]

Local ID's are maintained and control via the SRDB and are allocated to SW parameter names. The software receives the local parameter definition via configuration files

9.2.2 Application specific Data Pool Organisation

Each application instantiates its own parameter database consisting at least:

- Parameter ID
- Physical address
- Parameter Length
- Parameter type
- Parameter validity
- Parameter acquisition time (defined in [RD-134])



Each application is self-consistent in terms of monitoring and control as well as reporting service functions. In the frame of the application hierarchy, higher level applications react on event packets only.

9.2.3 Central SW System Data Pool Organisation

Nominally there is no inter-application access to the parameter database of another application required. However for application processes embedded in the CSW inter-application access to the individual parameter data bases is provided by dedicated functions to support effective data exchange for a limited number of information. Principally, the CSW System Data Pool (SDP) will be organised as follows:

- dedicated data pool areas are foreseen for the CSW applications, i.e. separate data pools for AOCS, SYCT, PLCT
- the system control application, being the highest on-board application level, will have access to all CSW application data
- the data acquisition from the equipment is handled by the respective application
- the HK packet generation for the respective SID is handled by the respective application

9.3 Specific On-board Data Products

The EarthCARE satellite on-board data products are distributed, processed, stored across the satellite and transmitted via S-Band and X-band terminal to the ground.
Below table shows where the different data products are generated, routed to, stored where, retrieved from and transmitted via the down link terminal.

On-board Data	On-board Unit											
On-board Data Receiptor / On-board Data Product Source					o/B Stored		Downlink		o/B Stored		Downlink	
	ATLID	BBR	MSI	CPR	OBC	Packet Store PSID	S-Band	Virtual Channel ID	MMFU	Packet Store	X-Band	Vitual Channel ID
HPTM							x	VC-1				
Spacecraft History Log					x	1 / 5	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
S/C State Vector	x	x	x	x	x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
S/C position & attitude					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
Navigation Solution (GPS)									x	VPS-1	x	X-VC-2
Attitude quarternion (STR)									x	VPS-1	x	X-VC-2
Satellite HK Data												
CSW System Appliccation					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
DMS Application					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
Platform Control Application					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
AOCS Application					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
GPS					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
STR					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
MMFU					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
P/L Control Application					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
ATLID					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
BBR					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
MSI					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
CPR					x	2 / 6	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
Dumps and Report Log					x	3 / 7	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
Spare					x	4 / 8	x	VC-0 / VC-2	x	VPS-1	x	X-VC-2
Instrument Science Packet (ISP) (Instrument Ancillary Data; Instrument Science Data)												
ATLID									x	VPS-2	x	X-VC-3
BBR									x	VPS-3	x	X-VC-4
MSI									x	VPS-4	x	X-VC-5
CPR									x	VPS-5	x	X-VC-6

Table 9.3-1 On-board data product overview

9.3.1 Satellite Ancillary data

The mission data provided by the instrument are accomplished by satellite ancillary data provided as independent packets as part of the monitoring and control data stream. The correlation of instrument measurement and ancillary data and satellite ancillary data is achieved via the provided packet and data time stamps. The satellite ancillary data consist

- the S/C State Vector parameter set provided every second but 2 seconds in advance to its validity to the instrument for real-time adjustment of instrument parameters
- the orbit position state vector
- the altitude above the WGS 84 earth reference ellipsoid
- the attitude quaternion

The satellite ancillary data will be provided as HK (3,25).
The detailed definitions of the satellite ancillary data are given in the EarthCARE Satellite Ancillary Data ICD [RD-135]

9.3.2 S/C State Vector

The S/C State Vector will consist of:

- S/C State Vector quality field
  - Nadir Pointing Performance Identifier (S/C is nadir pointing within a 1.5° half cone to its geodetic sub-satellite point)
- Orbit State vector (Torb, position, velocity) w.r.t. ITRF
- Geodetic Altitude (Torb, Height)
- Orbit position (Torb, Argument of Latitude)

It is used by EarthCARE instruments to adjust measurement characteristics based on orbit position and/or altitude above the reference ellipsoid. Each instrument will provide a private service sub-type “Update S/C state vector data”. In the EarthCARE mission this service is implemented as private service 145. The service ID and sub-type applicability is given in the table below:

Service, Subservice	*TM/TC*	*Description*	*CSW*					*ATLID*	*MSI*	*BBR*	*CPR*	*MMFU*	*GPS*	*STR*
			D	***S***	***A***	***P***	***PL***							
(145,1)	TC	Start SSV distribution		x										
(145,2)	TC	Stop SSV distribution		x										
(145,3)	TC	Report SSV distribution settings		x										
(145,4)	TM	SSV distribution settings report		x										
(145,128)	TC	Update S/C State Vector (SSV)						x	x	x	x			

Table 9.3-2 S/C State Vector Management Service Overview

The “Update S/C State Vector data” telecommand will be send to each instrument with an update frequency of 1 Hz. The S/C State Vector information will be available in the instrument at least 2s in advance before its validity.

The parameter data field definition of TC(145,128) for EarthCARE is given in the table below:

Parameters of Application Data Field	Length	Type	Description	Range or Value
S/C State Vector Quality	32 bit	Enumerated	Indicates the validity status of the Local S/C Position Data	Instant information Bit 0 (MSB) - Bit 7: AOCS Mode&Sub-Mode; 0x00 = AOC_SBM 0x10 = AOC_ASM__DEP 0x11 = AOC_ASM___RD 0x12 = AOC_ASM___EA 0x13 = AOC_ASM___YA 0x14 = AOC_ASM___SS 0x15 = AOC_ASM__SEM 0x20 = AOC_NOM__DEP 0x21 = AOC_NOM__ACQ 0x22 = AOC_NOM___AH 0x23 = AOC_NOM___FP 0x24 = AOC_NOM___AM 0x31 = AOC_OCM__ACQ 0x32 = AOC_OCM__SL

Parameters of Application Data Field	Length	Type	Description	Range or Value
				0x33 = AOC_OCM_STAB 0x34 = AOC_OCM___DV 0x35 = AOC_OCM__BSL 0x36 = AOC_NOM_DV Bit 8 to Bit 15: OBC Sync Time Quality (see [AD-110] section 4.8 volume A) Bit 16 to Bit 29: Spares not used so far Bit 30: Nadir Pointing Performance Identifier; 0 = Nominal Performance 1 = Degraded Performance Bit 31: (LSB) S/C State Vector Status; 0 = valid 1 = invalid
Time (local); Integer of Seconds	32 bit	Unsigned integer	Indicates the time in seconds at which the appended S/C State Vector Data become operative	Predicted Information 0 to 2^{32} - 1 sec, LSB = 1 sec
Time (local); Subseconds	24 bit	Unsigned integer	Indicates the time in subseconds at which the appended S/C State Vector Data become operative	Predicted Information 0 to 16777215 (1/16777215) sec, LSB = 59.6 nsec
Position X (local)	32 bit	Signed long integer	Indicates the value of the Local Spacecraft Position in X-direction to be updated	Predicted Information Unit: cm LSB = 1 cm Functional range: -7 000 E+5 to +7 000 E+5 cm w.r.t. to WGS 84 coordinate frame
Position Y (local)	32 bit	Signed long integer	Indicates the value of the Local Spacecraft Position in Y-direction to be updated	Predicted Information Unit: cm LSB = 1 cm Functional range: -7 000 E+5 to +7 000 E+5 cm w.r.t. to WGS 84 coordinate frame
Position Z (local)	32 bit	Signed long integer	Indicates the value of the Local Spacecraft Position in Z-direction to be updated	Predicted Information Unit: cm LSB = 1 cm Functional range: -7 000 E+5 to +7 000 E+5 cm w.r.t. to WGS 84 coordinate frame
Velocity X (local)	32 bit	Signed long integer	Indicates the value of the Velocity of the Local Spacecraft in X-direction to be updated	Predicted Information Unit: mm/s LSB = 1 mm/sec Functional range: -8 E+6 to +8 E+6 mm/sec w.r.t. to WGS 84 coordinate frame
Velocity Y (local)	32 bit	Signed long integer	Indicates the value of the Velocity of the Local Spacecraft in Y-direction to be updated	Predicted Information Unit: mm/s LSB = 1 mm/sec Functional range: -8 E+6 to +8 E+6 mm/sec w.r.t. to WGS 84 coordinate frame
Velocity Z (local)	32 bit	Signed	Indicates the value of the	Predicted Information

Parameters of Application Data Field	Length	Type	Description	Range or Value
		long integer	Velocity of the Local Spacecraft in Z-direction to be updated	Unit: mm/s LSB = 1 mm/sec Functional range: -8 E+6 to +8 E+6 mm/sec w.r.t. to WGS 84 coordinate frame
Geodetic Altitude	32 bit	Signed long integer	Indicates the value of the geodetic altitude of the Local Spacecraft in Z-direction to be updated	Predicted Information Unit: cm LSB = 1 cm Functional range:0 to +7 000 E+5 cm w.r.t. to WGS 84 coordinate frame
Argument of Latitude	32 bit	unsigned integer	Indicates the value of the orbit angle starting from zero at the ascending node The angle in [radians] x 10000.	Predicted Information Unit: rad LSB = 1 E-4 rad Functional Range: $-\pi$ to $+\pi$

Table 9.3-3 S/C State Vector Parameter List

9.3.3 Monitoring and Control Data Acquisitions

EarthCARE feature the following MIL-Bus topology for monitoring and control data acquisitions:

Platform MIL-Bus (see Figure 6.5-1): one dual standby redundant will be used to communicate with PCDU, RIU and AOCS elements that have a MIL-Bus interface

Payload MIL-Bus (see Figure 6.5-2): one dual standby redundant will be used to communicate with the MMFU and the Instruments

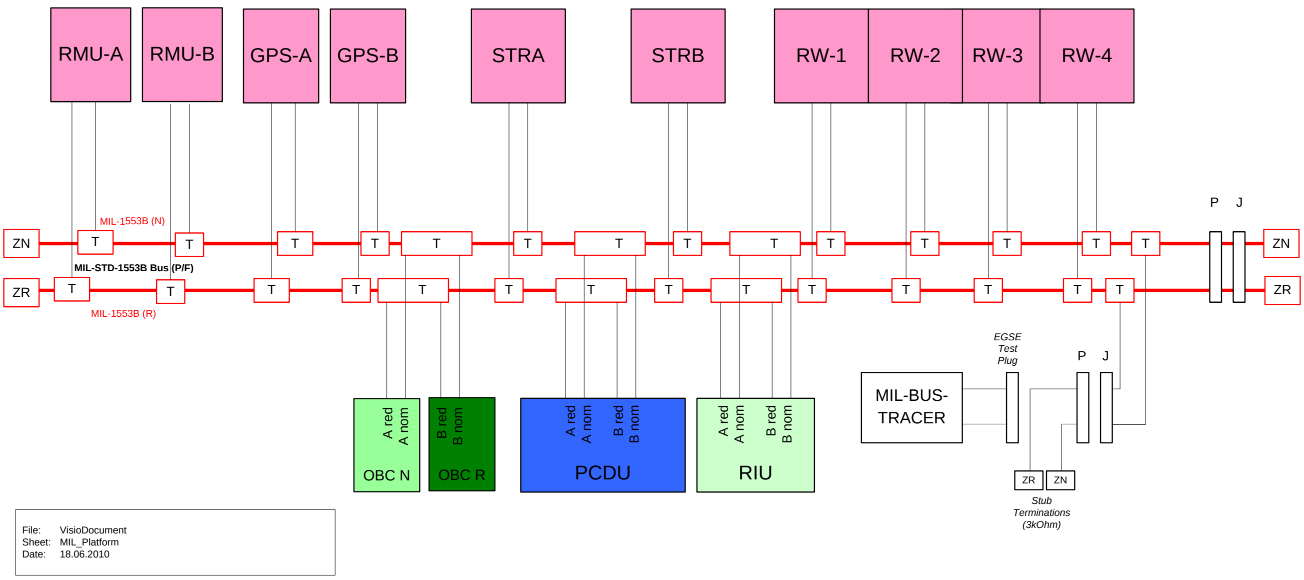


Figure 9.3-1: Platform MIL-Bus Topology

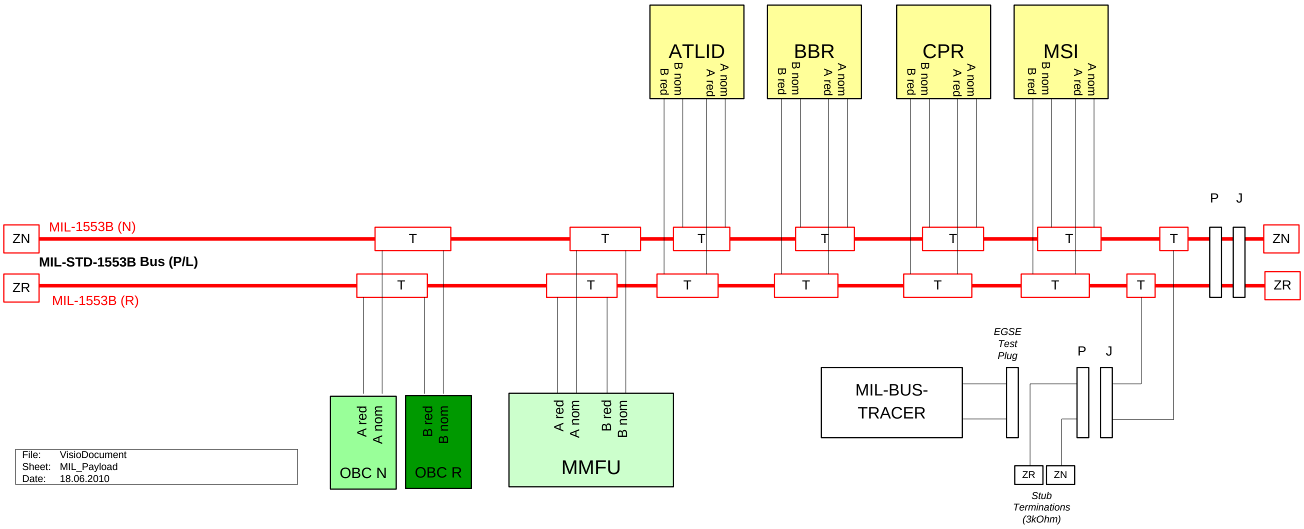


Figure 9.3-2: Payload MIL-Bus Topology

This architecture has the advantage to separate clearly platform and payload related functions, which provides thus a clear functional segregation and eases the overall error handling scheme. Further, platform functions can continue in the case of a failure on the payload bus.

The EarthCARE MIL-Bus protocol supports the following different types of MIL-Bus subscribers:

- simple subscribers:
  The simple subscribers correspond to subscribers with no built in processor function (non intelligent RT). The simple subscribers correspond to a RT requiring less than 29 TC and 29 TM so that direct sub-addressing may be used. All data exchange is handled either by single Mil-Bus messages (max. 32 16-bit words) or in a two step approach by sending a command to the RT to select the required channel on the RT followed by a transfer to read or write the data word. Between the channel selection and the data transfer a RT specific delay may be necessary The protocol is driven by the HW design of the unit and dedicated for each unit. Simple subscribers are RIU, PCDU and RMU.
- complex subscribers:
  The complex subscribers require exchange of data blocks larger than one Mil-Bus message, therefore a higher level protocol layer is implemented. This data block transfer layer is used to exchange TM and TC packets between BC and remote terminals. Complex subscribers are all PUS packet terminals, namely GPS and STR at the platform MIL-Bus, the MMFU and all 4 EarthCARE instruments (ATLID, BBR, MSI, CPR) at the payload Mil-Bus.
  - Complex subscribers can transfer up to 1024 bytes in one data block transfer. The data block transfer protocol support bi-directional aggregation and segmentation of packets.

9.3.4 OBC to MMFU Interface

The satellite monitoring and control data generated within the CSW and acquired by CSW from platform and payload MIL-Bus are forwarded in total via the payload MIL-Bus Interface to the MMFU. The monitoring and control data stream from OBC to the MMFU is specified with 160 kbps, which basically is established from 128 kbps real-time S-band channel capability plus margin in line with system requirements.
The defined Mil Bus protocol is capable to transport up to 64 kbps to the MMFU, the nominal data rate including 25% margin is budgeted with 32.4 kbps based on periodic packets required to observe the satellite behaviour under all operational conditions (see table below).

Data Rate Overview	**Houskeeping Data (OBC to MMFU) in kbit/s**	
		Comment
Margin on Operations (25%)	7.0	
Instrument HK Data	3.7	Also stored in OBC PS 2/6
Platform HK Data	13.8	Also stored in OBC PS 2/6
StarTracker & GPS Raw Measurement	10.4	Only stored in MMFU
Sum HK / INST Data	**32.4**	**kbit/s max**

Table 9.3-4 Data Rate from OBC to MMFU

9.4 Measurement Data Management Concept

9.4.1 Science and Instrument Ancillary Data

The instrument measurement data follow the standard PUS packet definition in order to achieve an optimum embedding of these data in the overall EC data handling concept. By this extension a common data handling concept for monitoring and control as well as instrument science packets can be applied on-board the EC satellite as well as in the ground system.
Instrument ancillary data are embedded via a private extension of the data field header. In case one packet contains several higher rate science measurement samples these measurements data blocks are preceded by a related instrument ancillary data block. The embedded provision of instrument ancillary data has been selected as baseline according to the related system requirements. The alternate solution of providing the instrument ancillary data as separate packets in the mission data stream would have been considered as more efficient in terms of on-board data handling.
For MSI instrument ancillary data being part of the instrument science packets would increase the data rate tremendously, provision of instrument ancillary data in dedicated source packet as part of the measurement data stream is proposed by the instrument provider to stay below the specified maximum data rate.
For instrument science source packets the Source Data field consists an instrument specific Private Source Data Field Header and variable length measurement resp. calibration data.
This private source data field header is in addition to the standard data field header of the TM source packet.

TM Source Packet				
	Packet Data Field			
Packet Header	Data Field Header	Private Science Data Header	Source Data > Telemetry Data <	Packet Error Control (CRC)
6 byte	12 byte	variable	variable length	2 byte
65536 + 6 byte max.				

Figure 9.4-1 Instrument Science Source Packet (ISSP)

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

Figure 9.4-2: TM Source Packet Header

Data Field Header								
						Time (CUC format)		
Filler (=0)	PUS Version Number (=001)	Filler (=0)	Service Type	Service Sub-Type	Destination ID	T-Field (Coarse Time)	T-Field (Fine Time)	Synch/ Time Quality
1	3	4	8	8	8	32	24	8
1 byte			2 byte		1 byte	8 byte		

Figure 9.4-3: TM Packet Data Field Header

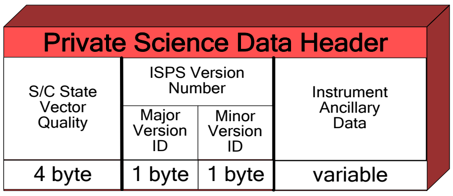


Figure 9.4-4: Private Science Data Header

PARAMETER	DESCRIPTION	RANGE OR VALUE
S/C State Vector Quality	Contains details about the S/C state vector quality information	see definition of field in Service (145,128) in chapter 9.3.2
ISPS version number	Contains a version number of ISP structure supporting evolution of its detailed definition	
Major Version ID		0-255
Minor Version ID	This field represents the version number of the ISP structure definition. This version number shall be the same as the version number of the ICD defining the ISP format. The field shall be filled in as follows: The ISPFormatVersion field (2 Byte) in the Instrument Data Field Header shall store the version number of the ICD where the ISP format definition is specified. The most significant byte shall store the major version and the least significant byte shall store the minor version (e.g. the ICD with the version number 3.11 would result in MSByte=3 and LSByte=11 in the ISPFormatVersion field).	0-255
Instrument Ancillary Data	Any instrument data which may be used for processing of instrument measurement data	Instrument specific

Table 9.4-1: Private Science Data Header

Each instrument provides one dedicated science service.
The service sub-types are allocated by the instruments individually reflecting the specific instrument needs. One sub-type for each required data format will be foreseen. In case of instrument sub-mode dependent science data formats one sub-type per instrument sub-mode should be allocated.

9.4.2 Instrument to MMFU Interface

The mission data i.e. instrument measurement data with embedded instrument ancillary data are directly transmitted from the instrument to the MMFU via individual data rates.
The MMFU has to handle the following MMFU Input Data Rates via the LBR interfaces as per table 9.4-2.

Data Rate Generation Budget			
ATLID			
Packet Type	Frequency	Size (byte)	Comment
Science Data	25.50 Hz	1 786	
CAS data	1.59 Hz	1 374	
AUX data	1.00 Hz	794	
ATLID Short TM	1.00 Hz	154	
ATLID Extended TM	0.05 Hz	187	
ATLID Thermistor TM	0.05 Hz	234	
ATLID TLE TM1-2	0.05 Hz	196	
ATLID TLE TM3-4	0.05 Hz	196	
ATLID IDE TM	0.05 Hz	163	
ATLID BSM TM	0.05 Hz	109	
ATLID Data Rate:		390 kbit/s	
BBR			
Packet Type	Frequency	Size (byte)	Comment
Science Data	4.39 Hz	3 530	
BBR Short TM	1.00 Hz	82	
BBR Long TM	0.05 Hz	224	
BBR Data Rate:		125 kbit/s	
CPR			
Packet Type	Frequency	Size (byte)	Comment
Science Data	14.00 Hz	2 370	
AUX data	1.00 Hz	238	
CPR TM	1.00 Hz	80	
CPR Data Rate:		268 kbit/s	
MSI			
Packet Type	Frequency	Size (byte)	Comment
Science Data (6 Channels on Average)	15.88 Hz	4 848	
AUX data	15.88 Hz	808	
MSI Short TM	1.00 Hz	66	
MSI "ICU" TM	0.05 Hz	171	
MSI "MSI" TM	0.05 Hz	179	
MSI Data Rate:		719 kbit/s	
S/C Equipment			
Packet Type	Frequency	Size (byte)	Comment
S/C Position & Attitude	1.00 Hz	120	
StarTracker Attitude	20.00 Hz	59	
GPS Navigation Solution	1.00 Hz	124	
S/C other TM (to be detailed, 12.8 kbit/s allocation, 64 Byte Average TM Size)	25.00 Hz	64	
S/C Data Rate:		24 kbit/s	
Specification Margins			
Packet Type	Frequency	Size (byte)	Comment
250 kbit/s ESA Growth Margin	25.00 Hz	1 250	
25% Margin on Operations	38.15 Hz	1 250	
Margin Data Rate:		631 kbit/s	
Sum Data Generation Rate			
Science Data		1498 kbit/s	
HKTM		28 kbit/s	
Specification Margins		631 kbit/s	
Overall Data Rate		2157 kbit/s	

Table 9.4-2: Science Data Stream

9.5 On-board Packet Routing and Storage Concept

9.5.1 Overview

The EarthCARE TM packet routing concept and the overall TM data flow is characterised by the following:

- Satellite monitoring and control data, collected by the CSW executing on the OBC processor module, are routed
  - according service 14 forwarding sub-service selection definitions to the S-band real-time downlink channel
  - according service 15 data storage sub-service selection definitions to the S-band OBC mass memory
  - if enabled without filtering on OBC side via the payload Mil-Bus to the MMFU, which stores the data according to the MMFU service 15 data storage sub-service selection definitions
- Instrument science data including ancillary data are routed via dedicated interfaces directly to the MMFU. Tthe data stream from each instrument is fixed routed to one single instrument dedicated packet store.

The monitoring and control telemetry data flow within the OBC to the OBC mass memory is characterised by the following:

- Telemetry parameters, acquired and stored in the on-board data pool, are packed by the CSW according to service 3 structure definitions. In addition to the periodic housekeeping and diagnostic report packets on-request telemetry packets are generated by the CSW
- TM packets from PUS packet terminals and the onboard application processes as e.g. instruments, MMFU, GPS and STR are acquired acc. chapter 9.3.3. A selected set of data needed for on-board data processing e.g. for the AOCS are extracted and imported into the onboard data pool
- The telemetry packets are stored can be routed via service 15 to one of four OBC HK packet stores. The spacecraft design supports a separation of packet according to a functional categorisation.
- Critical events (TM(5,3) and TM(5,4)) as well as TC failure acknowledgment report packets (TM(1,2) and TM(1,8)) from all on-board processes are recorded in addition in the System Log in buffered safe-guard memory in the OBC. The system log is managed via service 5 private sub-services.

The data flow to the MMFU storage devices within the MMFU is characterised by the following:

- Instrument Science telemetry packets received via the individual LBR interfaces to the instrument. Due to the data rates (see chapter 9.4.2) the storage and related storage selections is managed in HW
- Monitoring and control data acquired by the MIL-Bus Interface from the OBC. The storage selection is managed via MMFU service 15 settings in SW,

On EarthCARE the on-board storage and retrieval service 15 of [AD-110] is instantiated in the CSW as well as in the MMFU. Both service instantiations provide the ground system the capability to request the subsequent as well as selective downlink based on time criteria of the stored data. Service 15 is available within the CSW on the OBC for S-band data storage to and downlink from the OBC mass memory and within the MMFU for X-band data storage and downlink. The service 15 capabilities are detailed in chapter 9.5.3.
The on-board storage and retrieval service consists of three main sub-services each constituted by a number of service sub-types:

- packet selection sub-services for selection and transfer of telemetry source packets for storage in different packet stores;
- down-link sub-services for playback of telemetry source packets from packet stores.
- storage maintenance sub-services

For LEO missions like EarthCARE with intermittent coverage, packets of high operational significance, instrument and payload HK and payload science data are stored in dedicated packet stores so that they can be selectively dumped during the next period of coverage. One or more packet types and subtypes generated by one or more application processes can be selected for storage in a given packet store are possible. The capability to route one packet to multiple packet stores if multiple virtual channels for playback are available as e.g. given in the MMFU has been descoped.
A packet store is uniquely identified by a “Store ID”. The default definition of the storage selection usage by a given packet selection sub-service is configured according to the mission operation scenario. However it can be redefined by the user.
The EarthCARE data storage providers i.e. OBC and the related CSW as well as the MMFU are via corresponding requirements document requested to support the management of telemetry packets according to the EC PUS [AD-110] definitions. Deviations to the defined service sub-types shall be limited to the minimum. Packets are stored according to their sequence of arrival at the storage and retrieval sub-service. By design each TM source packet is time stamped by the generating application. The storage itself is typically tagged in certain discrete time slots by the storage time for selective data retrieval. The implementation details are strongly related to HW capabilities provided the OBC and the MMFU (see chapter 9.5.2.1).

9.5.2 Common Data Storage and Pointer Management Concept

9.5.2.1 General data storage characteristics

In EarthCARE each packet store provides the following capabilities:

- One read marker identifying the begin of the oldest packet accessible in the store for data

retrieval and downlink operations
- two independent playback pointer to provide independent access to the data store content to two independent ground station networks
- one write pointer to indicate the position resp. filling of the packet store
- parallel writing of data to and down-linking of data from the packet store
- an attribute, which defines whether the storage strategy is circular or bounded
- definition of the storage size for data storage

The attributes of each store, accessed by the storage and retrieval service, shall indicate:
- whether the storage strategy is circular or bounded
- the filling of the packet store by means of write and playback pointers
- the maximum size of the packet store;

When a circular packet store is full, any subsequently received packet shall overwrite partly or fully the oldest packet(s) in the list.
When a bounded packet store is full, any subsequently received packet shall be ignored.
In addition to housekeeping data on OBC MM and MMFU and to mission data on MMFU that can be reported on a regular basis, storage selection information are maintained by the storage and retrieval service for each packet store, which shall be reported to ground on request. This storage selection information shall include identification of storage configuration.
Information on percentage of filling of the packet store, percentage of the packet store contents that has not yet been down-linked etc are available as TM parameter for reporting in periodic HK TM.
Taking into account the multi-fold telemetry packet providing on-board sources in particular the CSW external application processes according to chapter 5.1 the overall data handling architecture chapter 9.2 as well as routing and storage selection capabilities in the OBC and in the MMFU it is quite obvious that the packet time stamps of the stored telemetry sources packets are not necessarily strictly monotonous. Other effects resulting from
- Transient conditions e.g. during setup of an equipment like incomplete time synchronisation between COBT and LOBT of external remote terminals
- Failure conditions
- Different data rates or delivery/acquisition delay times

may cause that time stamps of subsequently stored telemetry packets are not monotonously increasing. In addition the storage concept shall be essentially robust and thus utmost independent w.r.t. telemetry packet internal structures and inconsistencies. Therefore the storage management concept is primarily based on the LOBT of the storage equipment i.e. on the time when the telemetry is received and stored on the storage media.
In order to achieve a maximum of flexibility the service provides partitioning capabilities of the mass memory. The size of the EarthCARE storage areas are quite large due to the fact that the EarthCARE mission is requested to support without loss of data downlink outages of 72 hours plus the time needed to downlink the related data volume. In order to provide the selective downlink capabilities in line with the mission needs provisions have to be taken already in the telemetry storage concept to adequately support the selective access to the stored data according to the mission needs.
The typical concept applied is to logically subdivide the packet stores in smaller segments typically having a size which is defined in relation to the downlink time needed to downlink this segment with nominal downlink data rates. From EarthCARE system perspective the associated downlink access granularity shall ensure that the downlink duration as well as the downlink volume is not significantly extended by this minimum downlink access resolution. The additional prerequisite for this approach is the fact that the ground segment can handle downlinks with data overlaps.
In line with the system needs the OBC as well as the MMFU supplier implements he following minimum size elements for data storage access:
- OBC: The segment size of the OBC MM is 128 KiB each. Accordingly, the download time of each

segment is approximately 1 sec @1Mbit/sec download rate

- MMFU: The block size of EC MMFU memory array is 8126464 bits. Accordingly, the download time of each block is less than 51.7 msec @150Mbit/sec download rate.

The OBC segment resp. the MMFU buffer size is used throughout the data storage implementation as the granularity for e.g. address and size of ASW buffers of the related equipments.

Consistently in the OBC as well as in the MMFU the data storage management is based on a kind of packet store index table (PSIT), also the different equipments manufactured by different supplier may used adopted terms. The PSIT contains a set of entries used to find a packet inside the PS. There exists a one-to-one mapping between PSIT entries and the segments resp. buffers that constitute packet stores. Each PSIT entry consists of a packet storage time and a pointer to the first packet in the corresponding segment/buffer that is associated with that storage time.

When writing a sequence of packets to a PS, the PSIT entry corresponding to a segment/buffer in the packet store is updated when the first packet that starts in that segment is written. All subsequent writes to the PS are associated with the same PSIT entry, until the next segment boundary is crossed, i.e. all of these packets are associated with the same storage time.

Since there is a one-to-one relationship between segments/buffers and PSIT entries, the storage time associated with an arbitrary pointer to a packet can be determined by performing a reverse lookup in the PSIT entry corresponding to that packet. The maintenance of the relation is responsibility of the CSW resp. the MMFU ASW respectively the MMFU HW controlling the storage process for the instrument data.

The data storage access functions shall make no assumption on the value of the storage time, except that it needs to be monotonically increasing in order for the PSIT to be searchable.

The outlined packet store internal data storage management concept provides means to support effective access to stored data for effective selective downlink. The detailed handling of failure cases e.g. time discontinuities, bit errors etc. will need to be managed by the equipment and detailed as part of the detailed overall design by the equipment. Selective downlink concept it self is further elaborated in chapter 9.6.

9.5.2.2 Pointer Management Concept

The subsequent figures explain the EarthCARE pointer management concept. The following basic definitions w.r.t. to operational pointer capabilities and characteristics apply:

- The Read Marker, the playback pointers as well as the write pointer always operates on packet boundaries, thus are always pointing to the begin of the next source packet. As such the information provided as HK TM parameter needs to contain the complete correlation from physical address, to logical address, to storage time up to the packet characteristics of the associated packets to which the read marker resp. the playback and write pointers are pointing to. These correlated information are needed to ensure complete observability of the on-board storage and retrieval function.
- Playback Pointers (PP) I and II are fully independent, i.e. all operations can be performed using either PP I or PP II. For simplification the figures just show PP I being operated.
- The playback pointers can be set using PUS service 15 to any packet identified by its Coarse Time, SSC and APID. The MMFU only allow pointer position based on Coarse time. The SSC and APID parameters of the command are ignored.
- The position of the playback pointers will always be between the READ Marker and the Write pointer.
- The search for the specified packet will only be performed in the storage buffer space logically being in-between the ReadMarker position and the Write pointer position, the free buffer space is excluded from the search operation.
- The READ Marker always points to the address of the first byte of the TM packet which has not being deleted by the latest delete operation. The initial position of the Read Marker will be the begin of the packet store.
- The Write pointer always points to the first free byte after the TM packet which has been stored most recently. The initial position of the Read Marker will be at the begin of the packet store.
- The functionality of both Playback pointers (PP1 and PP2) is fully independent.

In order to ensure data access after processor resets and switch-overs a copy of all pointers needs to be regularly written to the non-volatile or are least buffered memory. All on-board data which are restored from storage location are required to be adequately protected against inadvertent modifications. The detailed mechanisms will be identified as part of the detailed MMFU resp. OBC/CSW design.
In addition to these operational pointers available for data storage and retrieval access additional information for internal data management are needed as depicted in Figure 9.5-1. The TM parameter definition of all these information must ensure that the end user can operate under nominal conditions based on storage time and packet criteria but maintains the diagnostic capability to access lower level (physical and logical address) information via standard HK reporting service capabilities via provision of correlated information in the MMFU data pool.

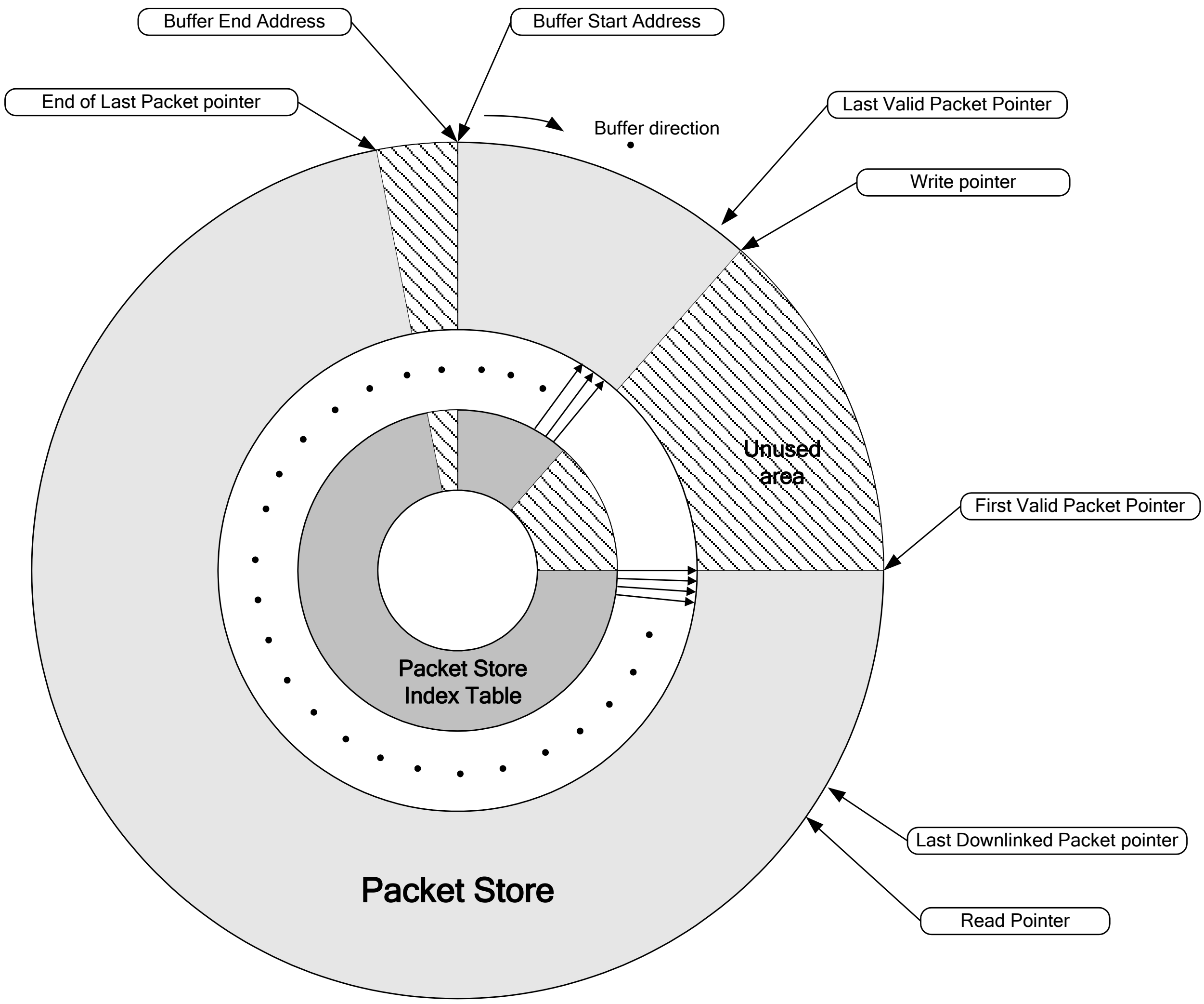


Figure 9.5-1 Detailed packet store management pointers

The supporting structures for the packet store concept are:

- Buffer definition pointers (used for all buffers):
  - Buffer Start Address, Buffer End Address:
    Mass Memory address space pointers to the first and last block/segment constituting the buffer.
  - Buffer mode:
    An identifier that defines the current operating mode (random access (if supported), linear (bounded) packet store or circular packet store) of the buffer.

- Packet store configuration pointers:
  - Write pointer (WP):
    The packet store location where the next packet will be written.
  - Last Valid Packet pointer (LVPP) ⬄ Writer pointer - 1 packet
    The packet store location of the most recently stored packet.
  - First Valid Packet pointer (FVPP) ⬄ Read Marker:
    The address in the PS of the least recently stored packet. Deleting of packets explicitly (through a dedicated service call) or indirectly (when writing packets to a PS with overwrite semantics) is performed by moving this pointer.
  - End of Last Packet pointer (EOLPP) ⬄ Read Marker - 1 packet:
    The address in the PS of the last byte in the last packet in the PS prior to PS wrap-around. Since the wrap-around always occurs at packet boundary, there is typically unused space from (not including) the End of Last Packet Pointer until the end of the buffer (see Figure 9.5-1).

- Downlink Process pointers (one set per process, 2 processes will be supported providing playback pointer 1 & 2):
  - Last Downlinked Packet Pointer:
    A pointer to the last packet completely read and transferred during a downlink. This is a dynamic pointer, which is only visible for the ASW during and after downlink completion until a new downlink is initiated. When the downlink is stopped, this pointer points at the last packet downlinked.
  - Playback pointer:
    A pointer to the next packet to be transferred during a downlink. This is a dynamic pointer, which is only visible for the ASW during and after downlink competition until a new downlink is initialised. When the downlink is stopped, this points at the next packet to downlink, i.e. it can be used to implement to implement resuming of a previous downlink.

The basic idea is to provide for each storage and downlink control parameter (Read Marker, Write as well as Playback Pointer) a full set of information allowing to correlate storage time, packet identification criteria of the packets in neighbourhood of the address to which the control parameter is pointing, as well as the logical and physical address. The pointer / marker itself is pointing to the begin of the next packet

It is to be noted that in general all pointer information is given for packet borders linked to segment resp. block boundaries

Despite the fact that for a detailed description of all data storage and retrieval related activities a mechanism as shown in Figure 9.5-1 needs to be applied, the general aspects are outlined and defined on the simplified sketches

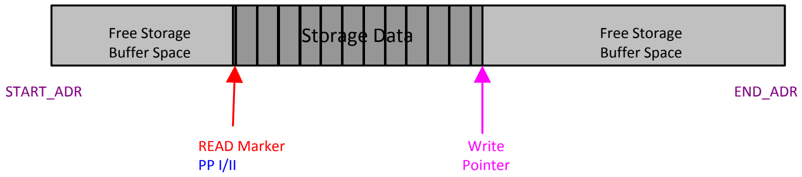
In A) the initial conditions before a downlink is requested are shown. The Read Marker is located at an initial buffer address, marking the oldest packet in the on-board store available for subsequent downlink. Both playback pointers are at the read marker positions. The record poiner is already moved thus identifying that data for storage have been received and are written to the storage media.

In B) the situation shown that a start downlink command with playback pointer 1 has been received and the downlink is on-going up to the time that it has stopped by a stop downlink command before the write pointer is reached.

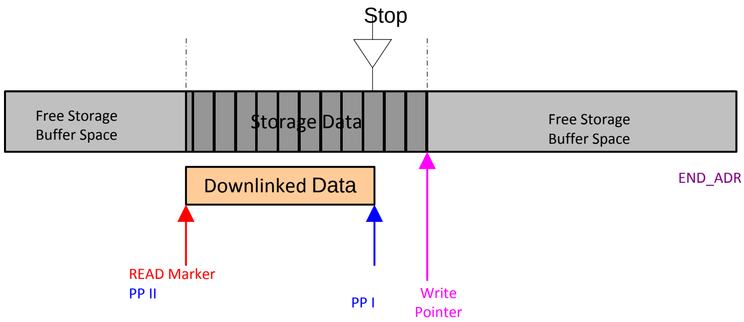
In C) the situation is shown for the case that no stop downlink command is received before the write pointer is reached. This is a nominal case if subsequent downlinks occur frequent enough to empty the packet store. The playback pointer stops at the write pointer, i.e. at begin of the next segment which is not completely filled yet. If this condition is met the high level downlink function switches to the next packet store to downlink. The playback pointer never overtakes the write pointer. Equivalently the internal playback pointer used for downlink over time ranges will never overtake the write pointer.

In D) and E) the general case that a TC(15,9) Downlink over Time period is requested. The playback pointer 1 & 2 positions are not affected. E) particularly addresses the point that as part of the nominal downlink operation via TC(15,129) data have already been downlinked. In F) the case of a downlink request with invalid range criteria e.g. Start Time older than Read Marker associated storage time and Stop Time in the future w.r.t. the storage time associated to the write pointer. In this case the complete data storage content in between Read Marker and Write pointer is downlinked.

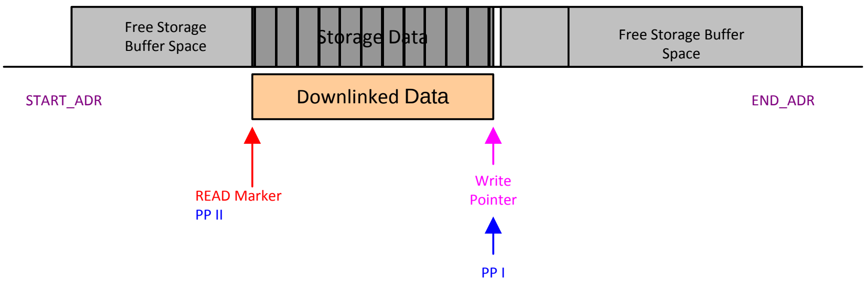
A.) Initial condition



B.) Playback usin PP I with Stop Command



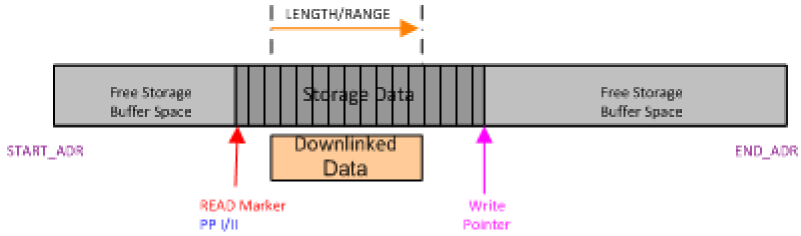
C.) Playback using PP I (with auto stop)



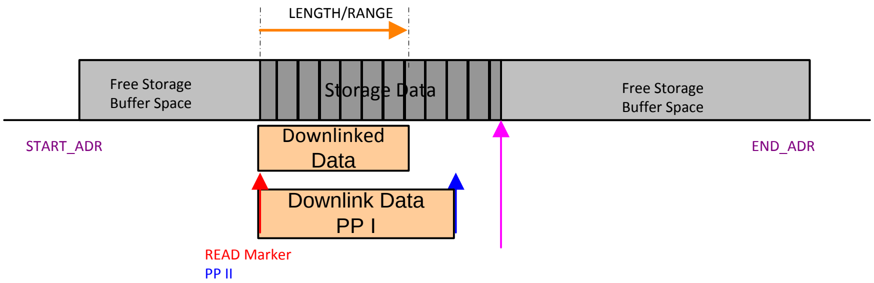
Note:

- The Playback Pointer will not overtake the Record Pointer.
- The Downlink stops at Record pointer position, reported by dedicated event TM.

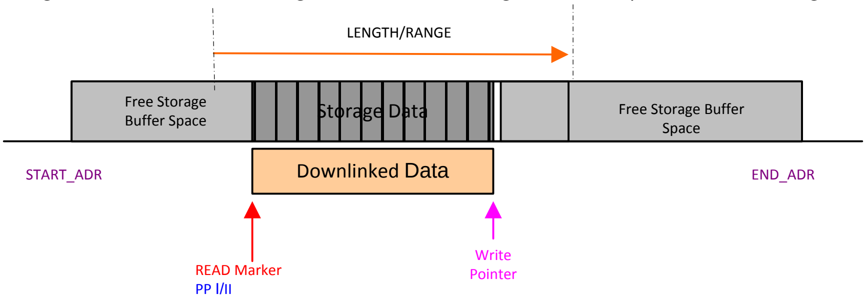
D.) Playback using range criteria “from storage time 1 to storage time 2”



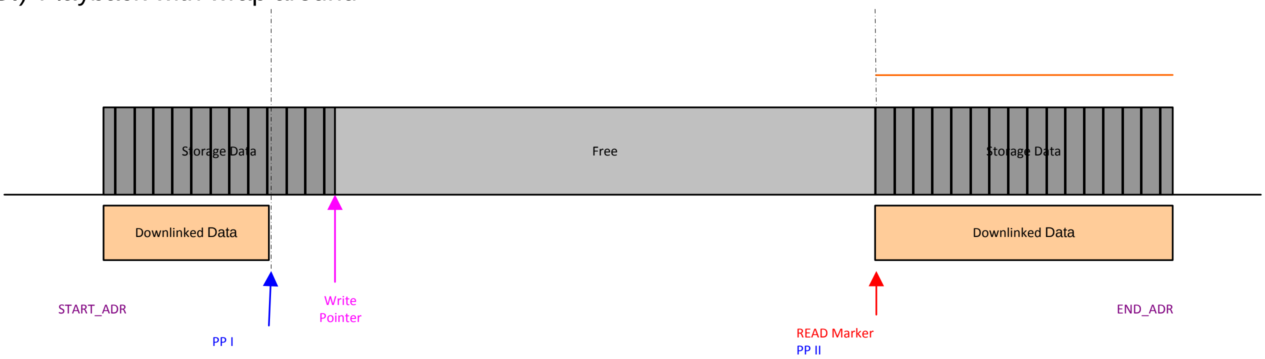
E.) Playback using range criteria “up to storage time”



F.) Playback using range criteria “from storage time 1 to storage time 2” (with invalid length /range)



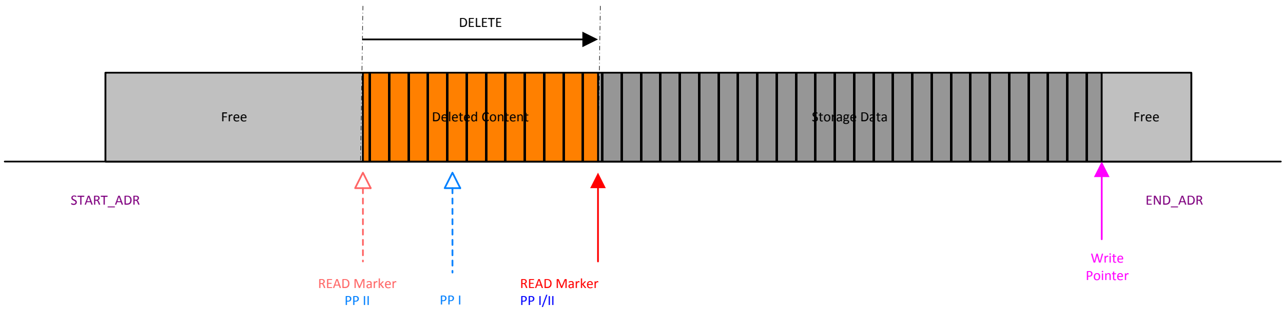
G.) Playback with wrap around



Note:

- The S/W ensures correct pointer handling in case of wrap arounds. The playback pointer will not overtake the write pointer. (see case B)

H.) Delete operation



Note:

- The Delete operation TC(15,11) will move the READ Marker from its current position up to the packet with the specified time.
- In case one or both of the playback pointers point to a packet inside the to be deleted content, the READ Marker will push the playback pointers to its final position.

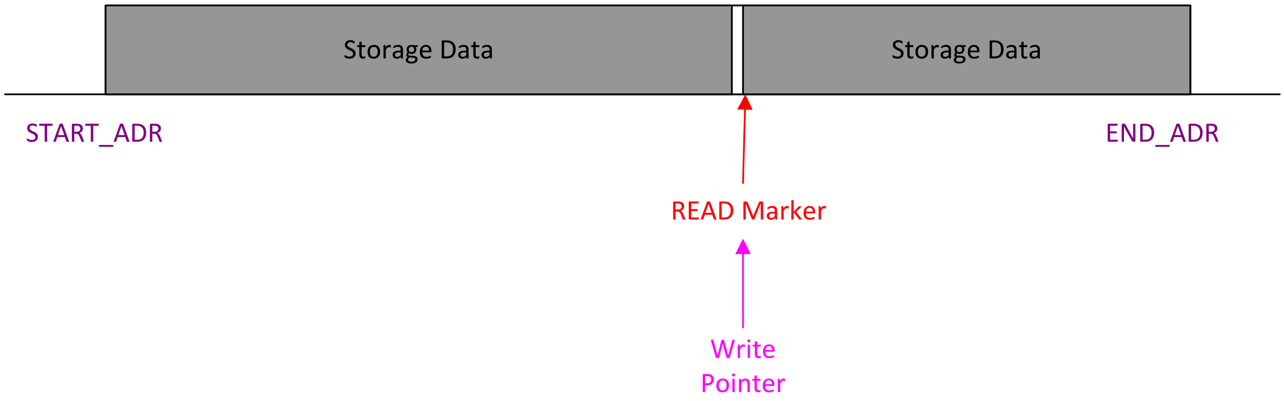
G) is quite similar to B) just shown the case that a wrap around in the buffer addresses occurs which needs to be handled adequately in the packet store management software.

Case H) shows the Read Marker management as part of the delete operation and the related management of the playback pointers. The particular case that TC(15,11) is sent with an end time being in the future w.r.t the playback pointer 1 marking the first data packet which is not yet downlinked. As baseline the delete operation supersedes this identification. In the particular case also not yet downlinked data would be overwritten. The background assumption w.r.t. this definition is that the user shall have full control for the delete operations as these typically are only used rarely e.g. in context with bounded/linear stores or for cleanup and recovery of a unique starting position to reconvene the downlink operations. The playback pointer management will ensure that the playback pointers can functionally only be positioned in-between the Read Marker and the write pointer. For all downlink operations the playback pointers are managed internally and autonomously. In case of external commanded positioning of the playback pointer requests to position it outside this range will be rejected.

The sketched cases I and J show the situation for the cases of an unbounded/linear/non-circular packet store and the case of the most commonly used circular type packet store. Effectively on EarthCARE the case J is the nominal case as the allocated packet store sizes correspond to the specified downlink outage period of 72h. As long as this is maintained for in-orbit operation phase the packet stores will be effectively almost all the time 100% full. In contrast to this during nominal operation the new data fill level, representing the data amount between the write pointer and the playback pointer 1 position is the more relevant telemetry.

In case of "Delete up to time" the Read Marker is positioned to the start of the segment resp. block showing the storage time closest time smaller than the commanded time. In case of downlink the complete data from this segment is replayed.

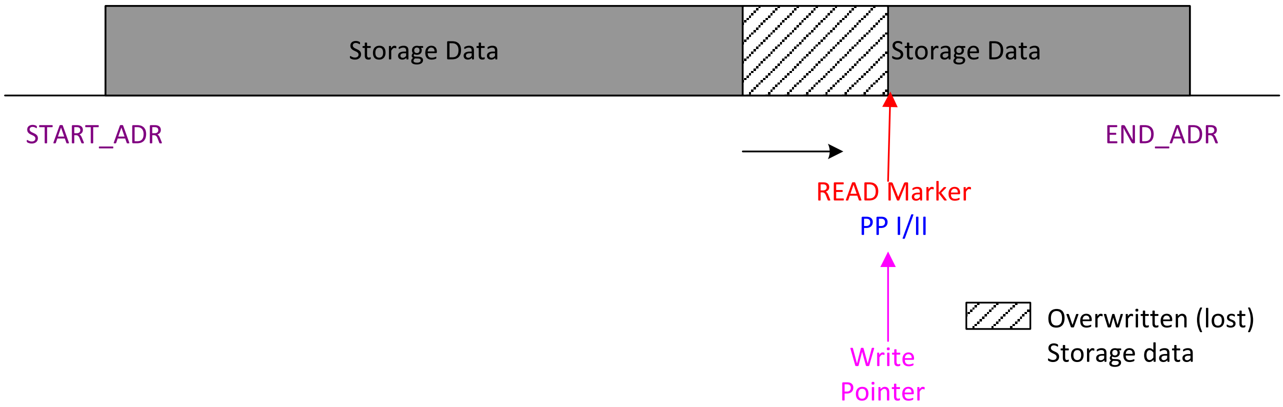
I.) Store Full (non circular buffer)



Note:

- The Storage linear buffer is considered to be full, if the Write pointer reaches the Read Marker. An possible ongoing recording is stopped, indicated by dedicated service 5 event

J.) Store Full (circular buffer)



Note:

- For circular buffers, the write pointer doesn't stop at the READ Marker position, rather than pushing it forward.

9.5.3 Service 15 Data Storage and Retrieval Capabilities

9.5.3.1 Overview

The on-board storage and retrieval service is the central service to selectively store the TM packets, which are generated by all on-board applications in order to give the ground system full visibility after the downlink of the stored data. The stored TM packets are selectively routed into different Packet Stores. Nominally at least one definition per on-board process exists.

The on-board storage and retrieval service consists of three parts:

- packet selection sub-services for routing of telemetry source packets for storage in a dedicated packet store (chapter 9.5.3.2);
- Data storage and retrieval sub-services for storage of telemetry packets to on-board data stores and

playback of telemetry source packets from packet stores to ground (chapter 9.5.3.3)
- storage area maintenance sub-services (chapter 9.5.3.4)

All Satellite monitoring and control data are stored in dedicated OBC-Packet Stores resp. in a dedicated satellite HK packet store on the MMFU. The distribution i.e. routing of the packets to the packet stores is controlled via configurable tables, managed by the CSW on the OBC resp. the MMFU application SW within the MMFU, which can be reported.

One or more packet types and subtypes generated by one or more application processes can be selected for storage in a given packet store. Each packet can only be stored in one packet store on the OBC and one packet store on the MMFU..

A packet store is uniquely identified by a “PS ID”. The definition of the storage selection used by a given packet selection sub-service is predefined, but changeable by ground TC. Packets are stored according to their sequence of arrival at the Packet Store. By design each TM source packet is time stamped by the generating application.

Telemetry source packets stored in a Packet Store can be downlinked on request. The playback sub-service allows specification of a list of Packet Stores, which will be downlinked in the order of the list. The stored data can be replayed during the next period of ground coverage. After start of the Packet Store playback, the responsible application SW supported by HW sends the TM packets of the first PS in sequential order, when this is emptied, it continues as long as no dedicated stop command is received with the next Packet Store until the last Packet Store is emptied. Finally after completing the last packet store Packet Store playback is stopped automatically.

The TC & TM packet definitions and descriptions mentioned in the sub-sequent chapters are given in [AD-110] and are not repeated within this document

9.5.3.2 Packet Selection and Routing Definition Sub-Service Subtypes

The given sub-service definition covers all software driven PUS packet identification criteria based routing selection capabilities.

The following service sub-types

Service, Subservice	TM/TC	Description	Applicability	OIRD
(15,3)	TC	Add Packet Types & Sub-Types to Storage Selection Definition	OBC, MMFU	OBSR-6
(15,4)	TC	Remove Packet Types & Sub-Types from Storage Selection Definition	OBC, MMFU	OBSR-6
(15,5)	TC	Report Storage Selection Definition	covered by (15,145)	
(15,6)	TM	Storage Selection Definition Report	covered by (15,146)	
(15,11)	TC	Delete Packet Stores Contents up to Specified Storage Time	OBC, MMFU	
(15,12)	TC	Report Catalogues for Selected Packet Stores	n/a	
(15,13)	TM	Packet Store Catalogue Report	n/a	
(15,140)	TC	Add SID’s to Storage Selection Definition	OBC, MMFU	
(15,141)	TC	Remove SID’s from Storage Selection Definition	OBC, MMFU	
(15,142)	TC	Report SID Storage Selection Definition	OBC, MMFU	OBSR-7
(15,143)	TM	SID Storage Definition Report	OBC, MMFU	OBSR-7
(15,145)	TC	Report Storage Routing Definition Table	OBC, MMFU	OBSR-7
(15,146)	TM	Storage Routing Definition Report	OBC, MMFU	OBSR-7
(15,200)	TC	Define Storage Cluster	MMFU	OBSR-5
(15,201)	TC	Delete Storage Cluster	MMFU	
(15,202)	TC	Report Storage Cluster Definition	MMFU	
(15,203)	TM	Storage Cluster Definition Report	MMFU	

The service pair TC(15,12) and TM(15,13) is not supported for the EarthCARE mission, as it is no requested for the mission and it is not part of the mandatory service sub-types in [ND-154].
The instrument packets received via LBR interfaces in the MMFU are fixed routed to one predefined packet store per instrument.
The basic concept of implementation of a routing tree starting with the process ID of the packet going further down to packet type and sub-type definition will be maintained in these private sub-type definitions.
Potential implementations of the routing sub-service manage two data structures:

- the TM Storage table that associates to each TM packet a packet store
- the Packet Store table that contains the status (Enabled/Disabled) of each packet store.

The TM storage table contains for each PRID (internal and external) a default packet store and two lists (ordered by increasing order of identifiers) of storage rules descriptors that are allocated from a memory pool shared by all PRIDs:

- one list for the TM packets identified by their type/subtype
- one list for the TM(3,X) packets identified by their SID

A storage rule descriptor contains the identification of the node (type, subtype or SID value) and its related packet store identifier (the special value 0 means no storage). For a type node, it can also contain a pointer to a subtype list. Each node at its level defines an exception against the higher level rule, e.g. if the subtype list of a type node is not empty then each subtype node of this list has a packet store different from its parent type node.

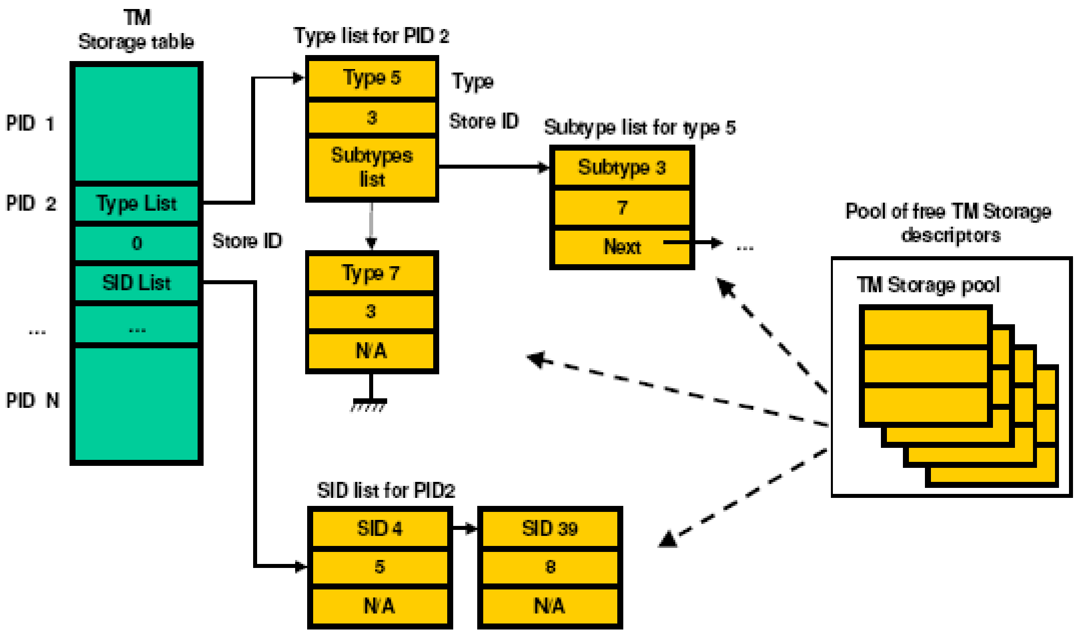


Figure 9.5-2 Routing definition management

Before routing a TM packet to the data storage area, the SW evaluates the storage rules in the TM Storage table to find out if a packet store is associated to this TM packet. The TM packet is first checked in the type list of the PRID. Then, for the packets TM(3, 25) resp (TM(3,26), if a packet store is defined at PRID/type/subtype level, it is searched in the SID list to find if a more specific rule applies to this SID (if the SID is not in list, the storage definition at PRID/type/subtype is used)
The given method is very effective in terms of on-board resources, which is important in view of the overall operational service and function capabilities required for the EarthCARE mission.

9.5.3.3 Packet Storage and Retrieval Sub-Service Sub-types

Service, Subservice	TM/TC	Description	Applicability	OIRD
(15,1)	TC	Enable Storage in Packet Stores	OBC, MMFU	OBSR-19
(15,2)	TC	Disable Storage in Packet Stores	OBC, MMFU	OBSR-19
(15,7)	TC	Downlink Packet Store Contents for Packet Range	n/a	EC.RFW.ASD.SY.00028
(15,8)	TM	Packet Store Contents Report	n/a	n/a
(15,9)	TC	Downlink Packet Store Contents for Time Period	OBC, MMFU	OBSR-23
(15,10)	TC	Delete Packet Stores Contents	OBC, MMFU	
(15,11)	TC	Delete Packet Stores Contents up to Specified Storage Time	OBC, MMFU	
(15,128)	TC	Stop Playback of Packet Store Contents	OBC, MMFU	OBSR-11; OBSR-12
(15,129)	TC	Start Playback of Packet Store Contents	OBC, MMFU	OBSR-11; OBSR-12
(15,153)	TC	Set Packet Store Playback Pointer	OBC, MMFU	OBSR-13

For EarthCARE, in line with the EarthCARE PUS [AD-110], it is agreed that Service TC(15,7) will not be supported and related demanding system requirements are descoped.
The latest issue of the RUAG S/W User manual identifies that the search operation linearly scales with the number of packets in the data storage area. The duration for time related search operations on the OBC MMU takes 60 µsec up to 100 msec corresponding to 1 packet store index table (PSIT) and up to 32765 PSIT's. The duration to search for packet criterias are dramatically longer and can take between 60 µsec and 30 minutes corresponding to 1 packet and up to 268386303 packets.
For the sake of deterministic operation an alternate concept to comply to OBSR-14 is supported via TC (15,153): Set Packet Store Playback Pointer, which is allowing to position the playback pointer at a dedicated packet location.

- Position one playback pointer (preferable PB2) at the desired location defined by time, APID and SSC
- start downlink of store with positioned PB at time T1
- stop downlink at time T2 i.e. with a time offset equivalent to the downlink conditions

The primarily used selective downlink approach in EarthCARE is downlink over time period. TC(15,11) can be used as anyhow all data in-between the start and end criteria have to be downlink according to the requirement. The ESA-EC-ground segment (FOS) feature, to detect gaps in the downlink and e.g. for GOCE automatically creates commands for selective downlink can be used to generate selective downlink commands via time. The latter typically yields downlinks with overlap which ensure that a continuous packet sequence can directly be re-constructed on ground with-out the need for re-dumps thus reducing the need for timely recovery interaction between ground segment and space segment. The downlink duration uncertainty is very limited to + 2 resp. 16 seconds at high resp. low bit rate for S-Band from OBC and even lower (0.1 sec spec) for X-band from MMFU

9.5.3.4 Data Storage Formatting Sub-service sub-types

Service, Subservice	TM/TC	Description	Applicability	OIRD
(15,150)	TC	Format Packet Store Memory	OBC, MMFU	
(15,151)	TC	Get Format of Packet Store Memory	OBC, MMFU	
(15,152)	TM	Packet Store Format Report	OBC, MMFU	
(15,154)	TM	Change Packet Store Attributes	OBC, MMFU	OBSR-24

In EarthCARE the complete packet store management is performed via these private service. Formatting of a packet store to size 0 is equivalent to deleting the packet store.
In order to support change of key attributes of a packet store with-out impacting the nominal operation of the other packet stores like VCID allocation and buffering type these attributes are set by dedicated command

9.5.4 S-band telemetry storage and routing concept

9.5.4.1 Packet Store Definitions on the OBC MM

All Satellite monitoring and control data, which are generated during a period of non-coverage, are stored in dedicated OBC-Packet Stores located on the MMU. They can be replayed during the next ground coverage period. The packet stores are nominally downlinked in sequential order, until the last packet store is emptied. In line with the [AD-99] the following packet stores are conceptually provided on the OBC MM:

OBC HK Packet Store ID	Name	Type (TBC)	Contents
PSID = 0	Virtual Packet Store (⇔ Trash)	n/a	To be used in the TC(15,x) commands to indicate that no routing is performed onto a packet store; not a real PS
PSID = 1/5	Spacecraft History Log	Circular with partial overwrite (Latest events only)	Contains all TM (1,x) and TM (5,x) packets including the system log. Note: Due to the available OBC MM resources this packet store can be oversized thus ensuring adequate storage capacity for all operational cases.
PSID = 2/6	HK Log	Circular with overwrite	Contains all TM (3,25) and TM (3,26) for all PRID's.
PSID = 3/7	Dumps and Report Log	Circular with overwrite	Contains all other TM packets, especially all types of reports and dumps that are requested by ground commands (e.g. MTL/OPS reports)
PSID = 4/8	Spare		

9.5.5 S-band Telemetry routing

The following figure gives an overview of the Packet Stores on board EarthCARE for sownlink scenario DLS_01 and the associated routing to the Virtual Channels for the S-Band.

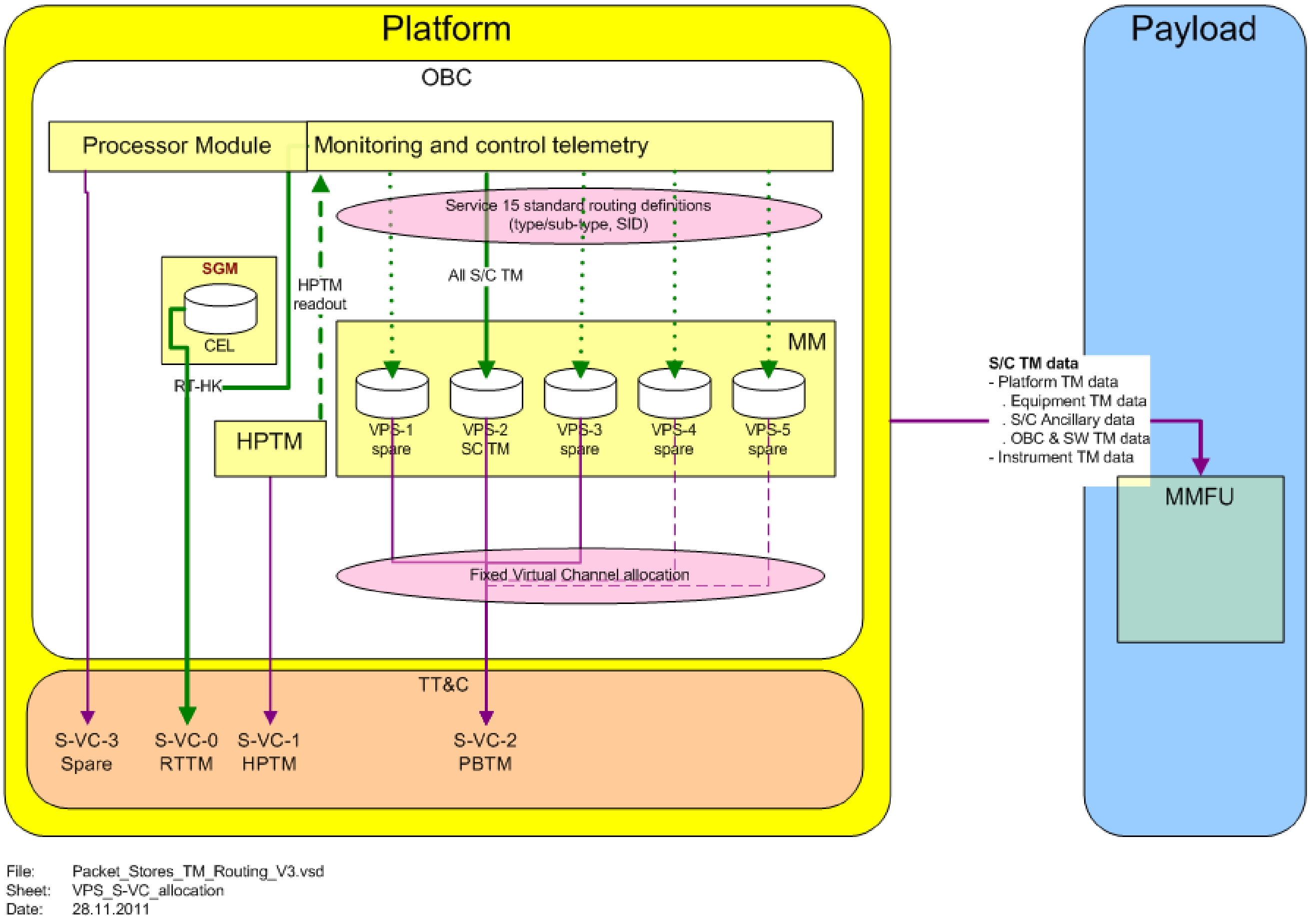


Figure 9.5-3: DSL_02:OBC MM Packet Stores onboard EARTHCARE and relation to S-Band VC's

9.5.6 S-band specific data storage, routing and downlink aspects

Storage Time Granularity

Assuming a storage time update rate of 1 Hz, each new segment used in a packet store is time-stamped with a granularity of 1 s, and the difference in storage time between two segments depend on the effective packet store data input rate. For example, if packets with a size of 128 bytes are stored in a packet store, it requires 1024 packets to fill one segment. Consequently, these 1024 packets will be associated with the same storage time. The storage time associated with the next used segment depends on how long time these packets were stored. I.e. if these 1024 packets were written during a 10 s period, the effective packet store storage time resolution when writing packets to the packet store is 10 s.
The corresponding downlink duration of one block/segment is approximately 1 sec @1Mbit/sec download rate.

9.5.7 X-band telemetry storage and routing concept

9.5.7.1 Packet Stores on the MMFU

All mission data, i.e. each instrument science packets incl. their instrument ancillary data as well as the satellite monitoring and control data including satellite ancillary data packets are stored in the MMFU in dedicated Packet Stores. They can be replayed during the next ground coverage period. The packet stores are nominally downlinked in sequential order, until the last packet store is emptied.

In case of a backlog of data downlink it is most efficient to downlink all packet stores via time range, which ensures that data from all sources are available for correlated processing. A corresponding downlink scenario is outlined in chapter 9.6.3.

The packets stores in the MMFU are defined as follows:

MMFU Packet Store ID	MMFU Packet Store	Type (TBC)	VC ID	Contents
PSID=0	Virtual packet store (⇔ Trash)	n/a	n/a	To be used in the TC(15,x) commands to indicate that no routing is performed onto a packet store; not a real PS
PSID=1	HK Packet Store	Circular with overwrite	2	Contains a copy of the satellite monitoring and control data for downlink via X-band to PDGS including the satellite ancillary data
PSID=2	ATLID Mission Packet Store	circular with overwrite	3	ATLID Mission data; data is organised in accordance with system needs
PSID=3	BBR Mission Packet Store	circular with overwrite	4	BBR Mission data; data is organised in accordance with system needs (Nominal/NRT data types)
PSID=4	MSI Mission Packet Store	circular with overwrite	5	MSI Mission data; data is organised in accordance with system needs (Nominal/NRT data types)
PSID=5	CPR Mission Packet Store	circular with overwrite	6	CPR Mission data; data is organised in accordance with system needs (Nominal/NRT data types)

For each packet store, the MMFU provides the following HK information:

- the store status from the ASW-API (linear/circular, memory freed, VC ID, reading access, writing access)
- Packet Store Filling ratio (in %) = calculation to be provided later Packet Store ID
- Packet Store size (in number of Allocation Units = blocks)
- Packet Store current size(in number of Allocation Units = blocks)Storage statistics:
  - Number of discarded correct source packets since last reset (commanded or warm/cold reset of the MMFU)
  - Number of discarded shortened TM Source Packets since last reset (commanded or warm/cold reset of the MMFU)
  - Number of corrupted TM Source Packets since last reset (commanded or warm/cold reset of the MMFU)
  - Number of TM Source Packets currently stored (recovered from MM after a warm reset)
- Downlink statistics:
  - Number of transmitted TM Source Packets since last reset (commanded or warm/cold reset of the MMFU)
  - Number of lost (discarded) TM Source Packets during downlink process since last reset
  - Number of transmitted corrected TM Source Packets since last reset
  - Number of transmitted uncorrected TM Source Packets since last reset
- Read Marker = physical address of the first block of the PS (= MM ID, Block ID). The Read Marker always points the first SP of the block (Page ID and Byte are fixed).
  - Storage time, coarse time, APID and SSC of the first TM source packet of the block
  - Playback/Read Pointers: Physical address (= MM ID, Block ID, Block offset) of the TM source packet “which is currently downlinked” resp. if downlink is stopped “which has been downlinked last”.
  - Primary and secondary header of the current TM source packet “which is currently downlinked” resp. if downlink is stopped “which has been downlinked last”.
- Write Pointer = physical address (= MM ID, Block ID, Block offset) of the TM source packet “which is

currently written” resp. if storage is stopped “which has been written last”.
– Storage time of the TM source packet “which is currently written” resp. if storage is stopped “which has been written last”
– Primary and secondary header of the TM source packet “which is currently written” resp. if storage is stopped “which has been written last”

9.5.7.2 X-band Telemetry routing

The following figure gives an overview of the Packet Stores on board the EarthCARE MMFU and the associated routing to the Virtual Channels for the X-Band.

The routing definitions of the packet stores on the MMFU can be configured via service 15 as described in chapter 9.5.3.2.

As already outlined in chapter 9.5.3.2 the MMFU telemetry packet routing and packet store selection is provided

- for telemetry packets received from the OBC via the MIL-BUS I/F by the MMFU SW
- for the packet received via instrument interfaces by a fix packet routing allocation function in hardware
- The MMFU packet store management function allows to selective filter the telemetry packets received from Mil-Bus for storage on the related packet store.

A fixed packet routing allocation of instrument science packets to packet stores, implemented in a MMFU HW function is applied.

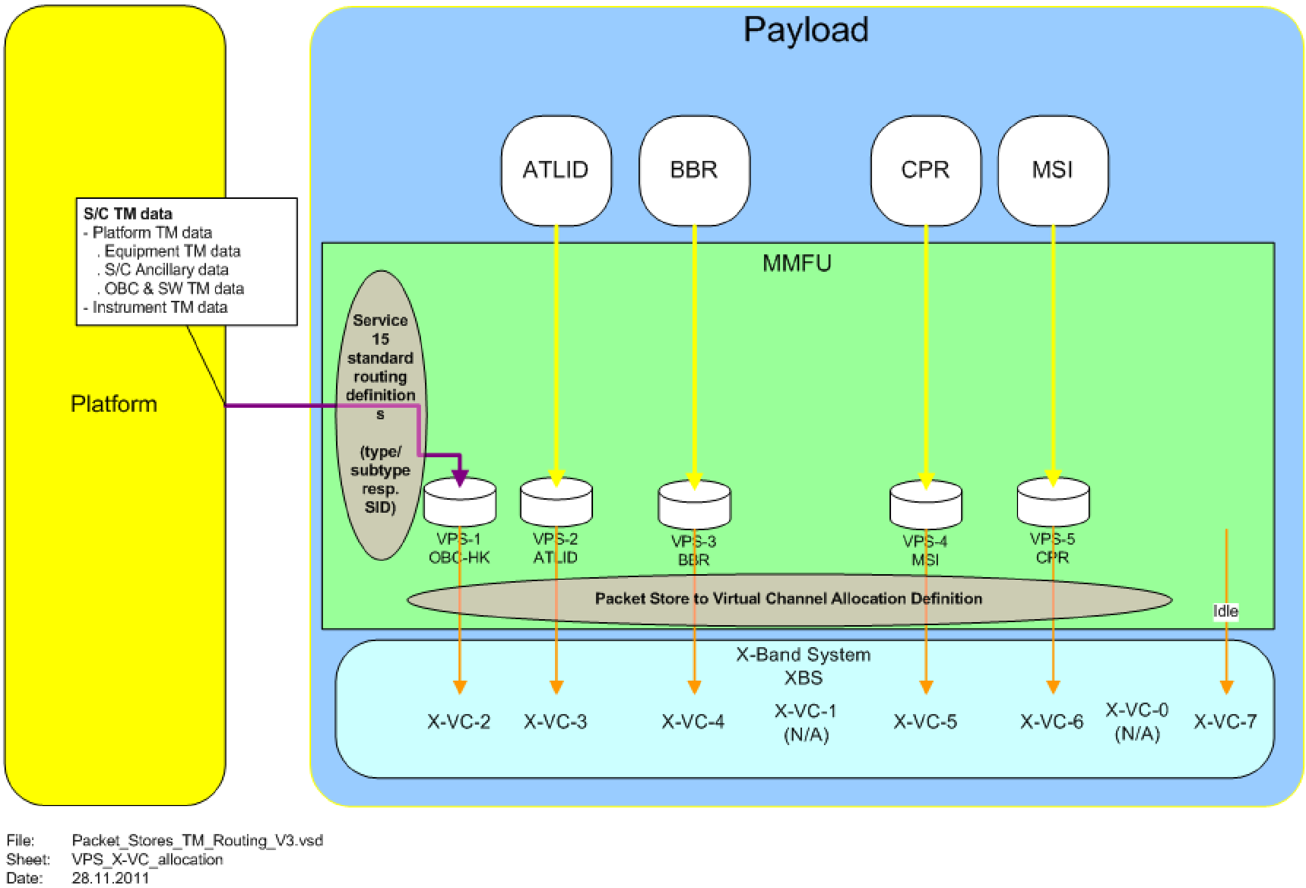


Figure 9.5-4: MMFU Packet Stores onboard EARTHCARE and relation to X-Band VC’s

The requirement to provide quasi real-time access to instrument data, denoted as NRT in the EarthCARE MMFU context, is implemented by repeated execution of the commanded packet store list in case the NRT function is enabled in the MMFU.

The MMFU manages the "Packet Store to Virtual Channel" assignment for downlink by downlinking the Packet Stores in sequence with the packet store associated virtual channel

The virtual channel to be used is defined as a packet store attribute and is selected to optimally support the data transfer via the Space Link Extended (SLE) services of the Ground Station networks and in line with the concept intended to applied for instrument data handling in the PDGS:

- Data flow concept is organized in so called data streams identified by unique virtual channels; one per instrument processing facility
- HK data (AOCS, GPS) will be filtered and processed in a dedicated facility, the products (orbit/attitude XML files) will be routed to the instrument L1 processors.

9.5.8 X-band specific data storage, routing and downlink aspects

Storage Time Granularity

The MMFU supplier identified that the minimum granularity of 1 MMFU stripe is 880 bits of packet data; the memory allocation including file system overhead for 1 stripe is 1024bit. Taking into account the implemented packet storage algorithms, the MMFU packet stores fill up at the rate shown in the table below:

MMFU Memory Sizing Budget			
PS 1 / VC2 (OBC HTKM)			
Packet Type	Frequency	Size in MMFU	Comment
ATLID Short TM	1.00 Hz	2 Stripes	
ATLID Extended TM	0.05 Hz	2 Stripes	
ATLID Thermistor TM	0.05 Hz	3 Stripes	
ATLID TLE TM1-2	0.05 Hz	2 Stripes	
ATLID TLE TM3-4	0.05 Hz	2 Stripes	
ATLID IDE TM	0.05 Hz	2 Stripes	
ATLID BSM TM	0.05 Hz	1 Stripes	
BBR Short TM	1.00 Hz	1 Stripes	
BBR Long TM	0.05 Hz	3 Stripes	
CPR TM	1.00 Hz	1 Stripes	
MSI Short TM	1.00 Hz	1 Stripes	
MSI "ICU" TM	0.05 Hz	2 Stripes	
MSI "MSI" TM	0.05 Hz	2 Stripes	
S/C Position & Attitude	1.00 Hz	2 Stripes	
StarTracker Attitude	20.00 Hz	1 Stripes	
GPS Navigation Solution	1.00 Hz	2 Stripes	
S/C other TM (to be detailed, 12.8 kbit/s allocation, 64 Byte Average TM Size)	25.00 Hz	1 Stripes	
MMFU Block Padding (Worst Case)		2 Stripes	
PS 1 Stripe Fill Rate		55 Stripes per second	56 kbit/s
PS 1 Useful Data Ratio	49.60%		
PS 1 Block Fill Rate		37.3 Blocks per Orbit	0.31 GBit per Orbit
PS 2 / VC3 (ATLID)			
Packet Type	Frequency	Size (byte)	Comment
Science Data	25.50 Hz	17 Stripes	
CAS data	1.59 Hz	13 Stripes	
AUX data	1.00 Hz	8 Stripes	
MMFU Block Padding (Worst Case)		16 Stripes	
PS 2 Stripe Fill Rate		462 Stripes per second	473 kbit/s
PS 1 Useful Data Ratio	82.02%		
PS 2 Block Fill Rate		313.9 Blocks per Orbit	2.63 GBit per Orbit
PS 3 / VC4 (BBR)			
Packet Type	Frequency	Size (byte)	Comment
Science Data	4.39 Hz	33 Stripes	
MMFU Block Padding (Worst Case)		32 Stripes	
PS 3 Stripe Fill Rate		145 Stripes per second	148 kbit/s
PS 1 Useful Data Ratio	83.57%		
PS 3 Block Fill Rate		98.6 Blocks per Orbit	0.83 GBit per Orbit
PS 4 / VC 5 (MSI)			
Packet Type	Frequency	Size (byte)	Comment
Science Data (6 Channels on Average)	15.88 Hz	48 Stripes	
AUX data	15.88 Hz	8 Stripes	
MMFU Block Padding (Worst Case)		47 Stripes	
PS 4 Stripe Fill Rate		889 Stripes per second	911 kbit/s
PS 1 Useful Data Ratio	78.91%		
PS 4 Block Fill Rate		606.3 Blocks per Orbit	5.09 GBit per Orbit
PS 5 / VC 6 (CPR)			
Packet Type	Frequency	Size (byte)	Comment
Science Data	14.00 Hz	22 Stripes	
AUX data	1.00 Hz	3 Stripes	
MMFU Block Padding (Worst Case)		21 Stripes	
PS 5 Stripe Fill Rate		311 Stripes per second	318 kbit/s
PS 1 Useful Data Ratio	83.95%		
PS 5 Block Fill Rate		211.4 Blocks per Orbit	1.77 GBit per Orbit
PS X (ESA Growth Margin)			
Packet Type	Frequency	Size (byte)	Comment
250 kbit/s ESA Growth Margin	25.00 Hz	12 Stripes	
25% Marign on Operations	38.15 Hz	12 Stripes	
MMFU Block Padding (Worst Case)		11 Stripes	
PS X Stripe Fill Rate		758 Stripes per second	776 kbit/s
PS 1 Useful Data Ratio	81.38%		
PS X Block Fill Rate		514.4 Blocks per Orbit	4.32 GBit per Orbit
Memory Sizing (Design)			
Overall MMFU Block Fill Rate		1 782 Blocks per Orbit	14.95 GBit per Orbit
MMFU filling after 72h X-Band outage		83 177 Blocks	698 Gbit
MMFU EOL Memory Capacity (1 board failed)		98 304 Blocks	825 Gbit
Memory Sizing (Nominal)			
Overall MMFU Block Fill Rate without ESA Growth Margin		1 267 Blocks per Orbit	10.63 GBit per Orbit
MMFU EOL Memory Capacity (5 boards functional)		122 880 Blocks	1031 Gbit
Time to fill Mass Memory			150 hours

Table 9.5-1 Durations to fill 1 MMFU block

Downlink rates may be affected by IDLE frames if a packet store is filled with significant amounts of file system overhead. This is expected to be the case for PS 1 only:

Output Data Rates			
Source	MM to OUIC rate (max. 204 Mbps)	Space to Ground rate (max. 130.1 Mbps)	Comment
PS 1 (OBC)	118.0 Mbps	58.5 Mbps	Affected by IDLE frames
PS 2 (ATLID)	158.6 Mbps	130.1 Mbps	
PS 3 (BBR)	155.6 Mbps	130.1 Mbps	
PS 4 (MSI)	164.8 Mbps	130.1 Mbps	
PS 5 (CPR)	154.9 Mbps	130.1 Mbps	
PS X (Margins) - Not real, only for budgeting purposes	159.8 Mbps	130.1 Mbps	

Table 9.5-2 MMFU Packet Store Downlink Rates

As stated before despite the fact that the user, which from evaluation of the received packet data stream only knows the packet time, e.g. for the case that there is a gap due to a downlink interruption (due to any effect (key hole, sun interference or environment), he can use the identified packet time to request a downlink over time range using TC(15,9) via direct insertion of the identified packet times as storage time as at the beginning of the downlink the responsible on-board downlink application will at least retrieve one data block

more from memory area which guarantees that the requested data are included. As the storage time is always later than the packet time at the end it is sufficient to downlink the segment which has a time stamp for its first packet being later than the requested end time plus a TBC time margin.
The storage concept is based on storage time. Therefore vulnerable for MMFU LOBT discontinuities are to be considered, which may be caused by SEU's affecting registers and used memory addresses. To protect the LOBT time the LOBT is implemented in protected IUIC FPGA registers. In case of SEU, the LOBT is resynchronized at the next PPS. The estimate rate of faulty LOBT per day is <$1*10^{-10}$. Thus, the risk that the storage time is not monotonous is very low. If the storage time is not monotonous, the requested storage time range is not found or just partially found without consequence on the MMFU.

Control of Storage Time Granularity

Since the MMFU will always store a whole block of data at once, storage time granularity will decrease depending on the actual buffer fill rate.
In order to mitigate this effect a configurable time-out is implemented by SW to guarantee the storage time granularity:

- For each active PS, a timeout threshold for the block being currently written is defined
- These thresholds may be changed by command (service 15)
- The time offset of the PS is the time since block has been opened for writing or the time since first Source Packet storage time.
- The time offset of each enabled PS is checked vs. the PS timeout threshold periodically at 1 Hz.

When a PS is enabled, its time offset is set to the time expired since the first SP has been stored in the block being currently written. On the other side, when a new block is allocated for a PS, its time offset is set to 0. When a timeout elapses (time offset > timeout threshold) for a PS, the current block is considered as complete and a new block is opened for writing.
This principle guarantees that a block has a well-known storage time granularity in the following cases:

- Input data flow interruption
- Packet Store enable / disable storage
- Very low input data flow

Timeout parameters will be configured in a way that will not trigger during nominal operations; therefore no storage space will be wasted by this mechanism during the nominal high data flow case.

Search Time Performance

Upon reception of TC(15,9) or TC(15,153), SW has to search inside the Block link table (managed by file system) which Block corresponds to the requested storage time (storage time 1 & 2) or respectively the coarse time: This search uses a simple read and compare software algorithm (loop), due to the data structure nature (a linked list). This time search algorithm is implemented and runs on Leon processor of the MMFU supervisor. All time data used during the search is directly inside Leon SRAM.
For the entire mass memory, considering that one Gbit is equivalent to 144 blocks, 30000 blocks have to be considered in the computation. Regarding SPARC instruction set and the necessary time for instruction fetch and execution, the total processing time to find the required data is estimated to l

- 122ms for the entire MM (131072 blocks)
- 20.3ms in case 6 PS occupy the entire MM (21846 blocks per PS).

This time is much less than 2s per PS, and should remain less than 2s in the real OS tasks configuration.
For TC(15,153) there is an additional subsequent search for packet criteria. The estimated performance for this search is 1 to 2 Gbit/sec, as it involves direct access to the mass memory area.

9.6 Downlink Service Concept

9.6.1 Overview

Telemetry source packets stored in a packet store shall be downlink during ground station coverage periods on request. The downlink/ data retrieval service sub-types for the EarthCARE mission are identified in chapter 9.5.3.3. The same downlink service sub-types are supported by the CSW for OBC Mass Memory located packet stores as well as by the MMFU for MMFU located packet stores.

The standard downlink sub-service TC(15,129) Start Playback of Packet Store Contents allow definition of a packet store downlink sequence and the playback pointer to be used. As identified in chapter 9.5.2.2 the playback pointers are equivalent and provide independent access thus optimally supporting the operation cases of nominal subsequent downlink to a nominal core station as well as a independent selective downlink access to arbitrary data either for additional other stations or data re-dumps.

Upon reception of TC(15,129) the content of the specified Packet Store (PS) shall be down linked to the ground. The packets are downlinked directly without embedding into a TM(15,8), therefore this service sub-type is not applicable for the EarthCARE mission. After start of the PS playback, the packets of the first PS are sent in chronological order, when this is emptied, it continues with the next PS until the last PS is emptied. A packet store is considered empty when the next segment or block to downlink is not filled. If all data from the last PS are replayed the downlink is autonomously stopped. In case there is no explicit playback pointer manipulation by TC(15,154) the next time when the packet store is downlinked, i.e either by a next TC(15,129) or by a second embedding of the store in the TC(15,129) packet store sequence, the downlink is resumed with the segment/buffer containing the packet to which the playback pointer points. In case the playback pointer points to the first packet in a buffer/segment, the buffer/segment before the current segment/buffer is downlinked in addition. Only in case the Read Marker position would prevent to downlink this additional segment/buffer the downlink would start exactly at the playback pointer position. This principle is chosen to ensure a minimum overlap, preventing loss of data at the begin or end of downlinks.

For all packet stores a downlink started via TC(15,129) autonomously terminates when the playback pointer has reached the write pointer of the last packet. For the MMFU a special NRT capability is implemented allowing to inhibit termination of the packet store downlink sequence, when reaching the end of the current list. In case the NRT function in the MMFU is enabled the MMFU continues to downlink the current packet store list in the given sequence in a loop until an explicit Stop downlink TC(15,128) is received.

Alternatively to downlink access via playback pointers the downlink of data via time criteria is possible. Upon reception of TC(15,9) the content of the specified Packet Store (PS) at least containing the data stored within this time range will be downlinked to the ground. After start of the PS playback, the packets of the first PS are subsequently sent until the end criteria is reached or the PS is emptied, i.e. the segment to downlink is not filled. The downlink continues with the next PS until the last PS downlink request is completed. The downlink sequence is not terminated by a subsequent request. TC(15,9) need to be explicitly stopped by TC(15,128) if an alternate downlink request need to be executed instead. Downlinks via time criteria do not modify the playback pointer positions, as these are executed independently from these pointers.

For all nominal cases the time when packets are stored is always later than the packet generation time. This offset matters for packets which are stored in close vicinity to a segment resp. block boundary as the storage time is used to time stamp the individual segments/blocks of the storage devices and is used as well in the time criteria based downlink operations.

For the case of downlink via time criteria e.g. for the case that there is a gap due to a downlink interruption (due to any effect (key hole, sun interference or environment) from evaluation of the received packet data stream, the user, i.e. the ground segment only knows the packet time, while the spacecraft expects the storage time as input to TC(15,9). For all end time criteria related service 15 operations the use of storage time ensures that the latest expected TM packets are contained in the downlink. However for start time criteria related service 15 operations there is a chance to miss some packets if the packet time is too close

before the storage time of the identified block. Due to the transmission delays in the overall data flow, packets with a packet time equivalent to the storage time of the next block may be contained in the block before the identified one. An on-board solution allowing to retrieve at configurable number (typically one) blocks more from memory area to guarantee that the requested data are included would result systematically in some additional data volume, which is unfavourable in the overall system and mission context. In order to ensure a safe and complete data retrieval the operational handling of this uncertainty is to consider a fixed, but configurable offset time in integer seconds in the time criteria determination process for service 15 operations in the ground segment. For the start time criteria a typical offset of 1 to 3 seconds will have to be subtracted, while for the end criteria typically no offset need to be considered a priori. This ensures minimum additional data volume and storage time consistent operation of the on-board storage devices.
By high level system requirement the read marker management is required to be an optional capability for application in nominal operation. Therefore it is mandatory that the service 15 delete sub-types in particular "Delete Packet Store contents up to specified Storage Time" but also (15,10) Delete Packet Stores Contents TC(15,11) is available in MMFU Normal Operation Mode.
All currently planned packet stores for periodic data recording are of type circular with overwrite. The use of TC(15,10) "Delete Packet Store contents up to specified Storage Time" is optional in case the user want to perform active storage management, however it is not needed as mandatory nominal activity. In case the on-board stores are exactly suited to preserve the required downlink outage robustness of 72 hours, for the packet store containing periodic telemetry packets it may not be applied in nominal operation to preserve the full mission operation outage robustness. The on-board storage function must support with both cases.

9.6.2 Definition of Virtual Channels

Please refer to Table 9.3 1 On-board data product overview.

9.6.3 Downlink Operation Sequences

9.6.3.1 General

In general any downlink sequence starts with a transmitter resp. telemetry formatter/encoder set-up sequence before acquisition of sight (AOS) of the ground coverage period respectively after loss of sight. These setup procedures will be started either time tagged from the MTL or from the orbit position sequencer. The subsequent chapters will only address the command sequences for downlink of the data. The data downlink sequence shall be started from the same scheduling mechanism as the transmitter setup procedures.
The nomenclature of the TC parameters is taken from [AD-110]

9.6.3.2 Nominal Downlink Sequence

The proposed nominal downlink sequence repeated in each contact is:
S-band: START_SPB: DMS TC(15,129) with N=3, PSID=1(SCHL), PSID=2(HK), PSID=3(TABLE)
X-band: START_XPB: MMFU TC(15,129) with N=6, PSID=1(HK),PSID=2(ATLID), PSID=5(CPR), PSID=3(BBR), PSID=4(MSI), PSID=1(HK)
S-band: STOP_SPB DMS TC(15,128)
X-band: STOP_XPB: MMFU TC(15,128)
The inclusion of a second HK store downlink in the X-band playback request ensures that also the maximum amount of HK data, i.e. also the latest HK data are available at the ground segment

9.6.3.3 Nominal Downlink Sequence with NRT Downlink from MMFU

The proposed nominal downlink sequence repeated in each contact is:
X-band: START_XPB-DT: MMFU TC(8,1,FunID) Set NRT(ENABLED)
S-band: START_SPB: DMS TC(15,129) with N=3, PSID=1(SCHL), PSID=2(HK), PSID=3(TABLE)
X-band: START_XPB: MMFU TC(15,129) with N=5, PSID=1(HK),PSID=2(ATLID), PSID=5(CPR), PSID=3(BBR), PSID=4(MSI)
S-band: STOP_SPB DMS TC(15,128)
X-band: STOP_XPB: MMFU TC(15,128)
X-band: START_XPB+DT: MMFU TC(8,1,FunID) Enable NRT(DISABLED)
After enabling of the NRT capability of the MMFU before begin of the X-band downlink sequence ensures an immediate start of the NRT downlink for the maximum time period i.e the complete coverage period. Even after emptying all PS in the PS list of the TC(15,129) the listed PS are scanned if new blocks are filled wich can be downlinked. The stop command TC(15,128) is mandatory to terminate the downlink.

9.6.3.4 Downlink sequence with last orbit data in first place

The downlink sequence for the case that data from the last orbit first shall be downlinked first in the downlink after a blind period is achieved by the following downlink sequence. For the S-band downlink a standard downlink sequence is shown:
S-band: START_SPB: DMS TC(15,129) with N=3, PSID=1(SCHL), PSID=2(HK), PSID=3(TABLE)
X-band: START_XPB: MMFU T TC(15,9) with N=5,
PSID=1(HK), TimeSpan=1; StorageTime_1= (AOS - 1orbit); StorageTime_2= AOS
PSID=2(ATLID), TimeSpan=1; StorageTime_1= (AOS - 1orbit); StorageTime_2= AOS
PSID=5(CPR), TimeSpan=1; StorageTime_1= (AOS - 1orbit); StorageTime_2= AOS
PSID=3(BBR), TimeSpan=1; StorageTime_1= (AOS - 1orbit); StorageTime_2= AOS
PSID=4(MSI), TimeSpan=1; StorageTime_1= (AOS - 1orbit); StorageTime_2= AOS
X-band: START_XPB: MMFU T TC(15,9) with N=5,

PSID=1(HK), TimeSpan=2; StorageTime_1= (AOS - 1orbit); StorageTime_2= ZERO_TIME
PSID=2(ATLID), TimeSpan=2; StorageTime_1= (AOS - 1orbit); StorageTime_2= ZERO_TIME
PSID=5(CPR), TimeSpan=2; StorageTime_1= (AOS - 1orbit); StorageTime_2= ZERO_TIME
PSID=3(BBR), TimeSpan=2; StorageTime_1= (AOS - 1orbit); StorageTime_2= ZERO_TIME
PSID=4(MSI), TimeSpan=2; StorageTime_1= (AOS - 1orbit); StorageTime_2= ZERO_TIME
optional to put PP1 to AOS - 1orbit in case subsequent downlinks shall be done is resume/suspend
X-band: START_XPB: MMFU T TC(15,154) with N=5,
PSID=1(HK), PointerID=1; CoarseTime_1= (AOS - 1orbit); APID=0, SSC=0
PSID=2(ATLID), PointerID=1; CoarseTime_1= (AOS - 1orbit); APID=0, SSC=0
PSID=5(CPR), PointerID=1; CoarseTime_1= (AOS - 1orbit); APID=0, SSC=0
PSID=3(BBR), PointerID=1; CoarseTime_1= (AOS - 1orbit); APID=0, SSC=0
PSID=4(MSI), PointerID=1; CoarseTime_1= (AOS - 1orbit); APID=0, SSC=0
S-band: STOP_SPB DMS TC(15,128)
X-band: STOP_XPB: MMFU TC(15,128)
Note: the shown case assumes that the recorded volume can be downlinked within one coverage period. If the complete data volume can not be downlinked the second call of TC(15,9) will also have to have to define an earlier end time or via a time-span 2 definition another (older and shorter) time period of data to downlink.

9.6.3.5 Downlink sequence for a backlog case

The downlink sequence for a backlog case assuming 6 blind orbits, followed by one short contact, not allowing to retrieve the complete backlog and one subsequent contact allowing to complete the backlog including the intermittent acquired data follows the same scheme as the scenario described in chapter 9.6.3.4.The main chain are the used time arguments, which effectively depend on the usable contact duration. The shown scenario assumes that first contact is sufficient to downlink 4 orbits, while the next contact allows to downlink 5 orbits. For the S-band downlink a standard downlink sequence is shown:
Contact 1 after 6 blind orbits: Acquisition of sight AOS = AOS_1
S-band: START_SPB_1: DMS TC(15,129) with N=3, PSID=1(SCHL), PSID=2(HK), PSID=3(TABLE)
X-band: START_XPB_1 : MMFU T TC(15,9) with N=5,
PSID=1(HK), TimeSpan=1; StorageTime_1= (AOS_1 - 7orbit); StorageTime_2= (AOS_1 - 3orbit)
PSID=2(ATLID), TimeSpan=1; StorageTime_1= (AOS_1 - 7orbit); StorageTime_2= (AOS_1 - 3orbit)
PSID=5(CPR), TimeSpan=1; StorageTime_1= (AOS_1 - 7 orbit); StorageTime_2= (AOS_1 - 3orbit)
PSID=3(BBR), TimeSpan=1; StorageTime_1= (AOS_1 - 7orbit); StorageTime_2= (AOS_1 - 3orbit)
PSID=4(MSI), TimeSpan=1; StorageTime_1= (AOS_1 - 7orbit); StorageTime_2= (AOS_1 - 3orbit)
S-band: STOP_SPB DMS TC(15,128)
X-band: STOP_XPB: MMFU TC(15,128)
Contact 2 after 6 blind orbits + 1 orbit, same ground station as Contact 1: Acquisition of sight AOS = AOS_2
S-band: START_SPB_2: DMS TC(15,129) with N=3, PSID=1(SCHL), PSID=2(HK), PSID=3(TABLE)
X-band: START_XPB_2: MMFU T TC(15,9) with N=5,
PSID=1(HK), TimeSpan=2; StorageTime_1= (AOS_2 - 4orbit); StorageTime_2= ZERO_TIME
PSID=2(ATLID), TimeSpan=2; StorageTime_1= (AOS_2 - 4orbit); StorageTime_2= ZERO_TIME
PSID=5(CPR), TimeSpan=2; StorageTime_1= (AOS_2 - 4orbit); StorageTime_2= ZERO_TIME
PSID=3(BBR), TimeSpan=2; StorageTime_1= (AOS_2 - 4orbit); StorageTime_2= ZERO_TIME
PSID=4(MSI), TimeSpan=2; StorageTime_1= (AOS_2 - 4orbit); StorageTime_2= ZERO_TIME
optional to put PP1 to AOS - 1orbit in case subsequent downlinks shall be done is resume/suspend
X-band: START_XPB: MMFU T TC(15,154) with N=5,
PSID=1(HK), PointerID=1; CoarseTime_1= (AOS_2 - 1orbit); APID=0, SSC=0
PSID=2(ATLID), PointerID=1; CoarseTime_1= (AOS_2 - 1orbit); APID=0, SSC=0

PSID=5(CPR), PointerID=1; CoarseTime_1= (AOS_2 - 1orbit); APID=0, SSC=0
PSID=3(BBR), PointerID=1; CoarseTime_1= (AOS_2 - 1orbit); APID=0, SSC=0
PSID=4(MSI), PointerID=1; CoarseTime_1= (AOS_2 - 1orbit); APID=0, SSC=0
S-band: STOP_SPB DMS TC(15,128)
X-band: STOP_XPB: MMFU TC(15,128)

10. AUTONOMY CONCEPT

10.1 General Concept

The EARTHCARE mission calls for a high autonomy with reduced ground centre intervention, so that the nominal operations will have to be executed according to a sequence of commands uploaded by the ground. This schedule will be loaded typically once every 5 days.

Autonomous operation in EARTHCARE can be distinguished between

- Autonomous operation in nominal operational cases (Nominal Autonomy)
- Autonomous operation in failure cases (Failure Case Autonomy)

Nominal Autonomy as treated within this section is the spacecraft capability to carry out its mission in nominal conditions without any ground commanding during a given period. The autonomy is considered:

- out of failure i.e. the autonomous failure detection, isolation and recovery is treated in the FDIR section
- including all the nominal operations. The spacecraft is able to release and execute scheduled operations without any ground intervention.
- maintaining the mission performances.

It describes basically the continuation of the Nominal Operations Sequence, i.e. when the instrument operates in a continuous manner. This operation is based on:

- continuation of activities according to a predefined list of time tagged telecommands (mission timeline, MTL), being up-linked before execution and stored on-board; especially continuation of MSI Nominal Operations Sequence.
- continuation of X-Band down-link operations according to a predefined list of orbit position data being up-linked in regular intervals

The 5 days (120 hrs) autonomy requirement drives basically the dimensioning of the Mission TTQ w.r.t. Instrument Operations. For the X-band downlink, it can be assumed that in case of one ground station usage only and a maximum number of 6 Kiruna blind orbits the measurement data are downlinked latest after 7 orbits.

The Nominal Operations Sequence repeats with the orbit repeat cycle, which is 9 days in the commissioning orbit and 25 days in normal operation orbit. However, update of the MTL needs to be done after the 5 days autonomy period. It is assumed that this is easily achievable by an adequate Mission Planning System.

Failure Case Autonomy addresses the situation where an FDIR function (HW or SW) becomes active. This may lead to the following situations:

- continuation of the nominal mission (if FDIR is able to recover using e.g. functional redundancy), e.g. EDAC, MIL-BUS error handling (For the Single RT failure the Isolation and recovery is assigned to the related equipment, for Bus Problems on the Platform Bus a bus switch over needs to performed.) , X-band failures
- interruption of nominal mission (MTL suspension) but no change of AOCS modes (e.g. Single Instrument HW/SW FDIR)
- reconfiguration on system level by use of system alarms (e.g. HW WD) either on A or on B-chain
- transition to Safe Mode (if reconfiguration fails or if AOCS anomaly detectors trigger)

The EARTHCARE mission autonomy, which will provide a pre-programmed operation without ground intervention needs over a period of 5 days, relies on the overall redundancy architecture as described in section 7 and on appropriate implementation of autonomous FDIR functions on HW and SW level.

10.2 On-board scheduling Concept

The EARTHCARE mission calls for a high autonomy with reduced ground centre intervention, so that the nominal operations will have to be executed according to a sequence of commands uploaded by the ground. This schedule will be loaded typically once every 5 days.

EARTHCARE will provide two schedule references:

- the Mission Timeline based on GPS time, service 11
- the Orbit Position Schedule (OPS), service 151

The size of the MTL & OPS for 5 days operation is less than 43 kwords so that an upload of all entries requires less than 1 minute (assuming the supported max. data throughput rate for TC uplink of 20 kbit/sec acc [AD-99]), but about 2.5 minutes will actually be required due to the processing speed of up to 10 TCs per second.

Usage of Subschedules

The subschedule (and the respective ID) will be used to group activities of different subsystems, especially on a larger logical scale. From an operational point of view, this eases the modification of tasks planned by the Mission Planning System. The number of subschedules is limited to 32.
The following activities are candidates to be used for putting them into a subschedule:

- Orbit Control Maneouvres (in-plane and out-of plane)
- S-band ground operations
- X-band ground operations
- ATLID routine operations (incl. calibration)
- ATLID maintenance
- BBR routine operations (incl. calibration)
- BBR maintenance
- CPR routine operations (incl. calibration)
- CPR maintenance
- CPR silent mode commanding
- MSI routine operations (incl. calibration)
- MSI maintenance

The on-board scheduling services will typically consist of the following commands:

- S/C related regular servicing commands (e.g. initiate downloading of reports)
- INS: commanding of measurement scenario
- AOCS commands to initiate the attitude and orbit manoeuvres
- The Instrument related activities are identified
  - in chapter 15.2.3 for ATLID
  - in chapter 1.1.1 for BBR
  - in chapter 1.1.1 for MSI
  - in chapter 1.1.1 for CPR
- S- and X-band downlink incl. data retrieval related t related activities are identified in chapter

The downlink scenario uses Kiruna as Core Ground Station for the EarthCARE mission.

10.3 Mission Time-Line (MTL) Scheduling

The basic reference for the mission activities (except for the S- and X-band downlink functions) will be the on-board Orbit Position Schedule (OPS). Nevertheless, the capability for Mission Time-Line (MTL) scheduling is implemented as well.

10.3.1 Primary MTL Applications

The advantage of the MTL w.r.t the OPS is it general available in any satellite mode and its independence from on-board knowledge about the current orbit position. In contrast to the OPS the MTL, thanks to the robust on-board time system, is directly usable during all LEOP and emergency operations and remains usable after system reconfigurations, although re-enabling and new upload of the executable content is required.
The individual sequences are typically assigned to one or more sub-schedule IDs of the MTL.

10.4 Orbit Position Scheduling (OPS)

10.4.1 General Concept

The second reference for scheduling of on-board activities will be the orbit position schedule (OPS). This on-board scheduling capability benefits from the good on-board knowledge of the orbit position releasing the required prediction accuracy for the ground system for certain Earth oriented operations. The applicability and performance of the OPS strongly depends on the orbit control accuracy since its compensation is limited to along track corrections. The OPS has no capability to correct for cross track deviations of the real orbit w.r.t. the predicted orbit.

The orbit position schedule will be controlled by the accurate in-orbit position maintained by the on-board orbit propagator on the basis of the GPS measurements.

It has been identified that applying orbit number and orbit angular position relative to the ascending node is the most suitable representation for orbit position tags. The orbit number is apriority an absolute orbit number counting up all along the mission. The starting value for the orbit number is to be set by the FOS in line with its own orbit revolution counting scheme.

The advantage of this “orbit position-tag” approach (instead of the time-tag one) can be seen keeping in mind that the intersection points between the ground track and the areas of interest (ground station coverage area, radio-telescope ground area, etc) are well determined and have an exact value of Latitude.

The orbit angle (a.k.a. Argument of Latitude) will not be equal to the sub-satellite point Latitude because EarthCARE is not flying on a polar orbit (i = 90°) but on a near-polar orbit (i = 97.05°). A simple equation of Spherical Triangle Geometry relates the Latitude angle to the Orbit angle and the Inclination angle (i).

In details:

sin (Latitude) = sin (Orbit angle) sin (180° - i)

That means for each value of the orbit angle (updated at the frequency of 1 Hz) there will be a corresponding value of the sub-satellite point Latitude.

The Figure 10.4-1 below is a graphical representation of the orbit angle / related latitude on ground.

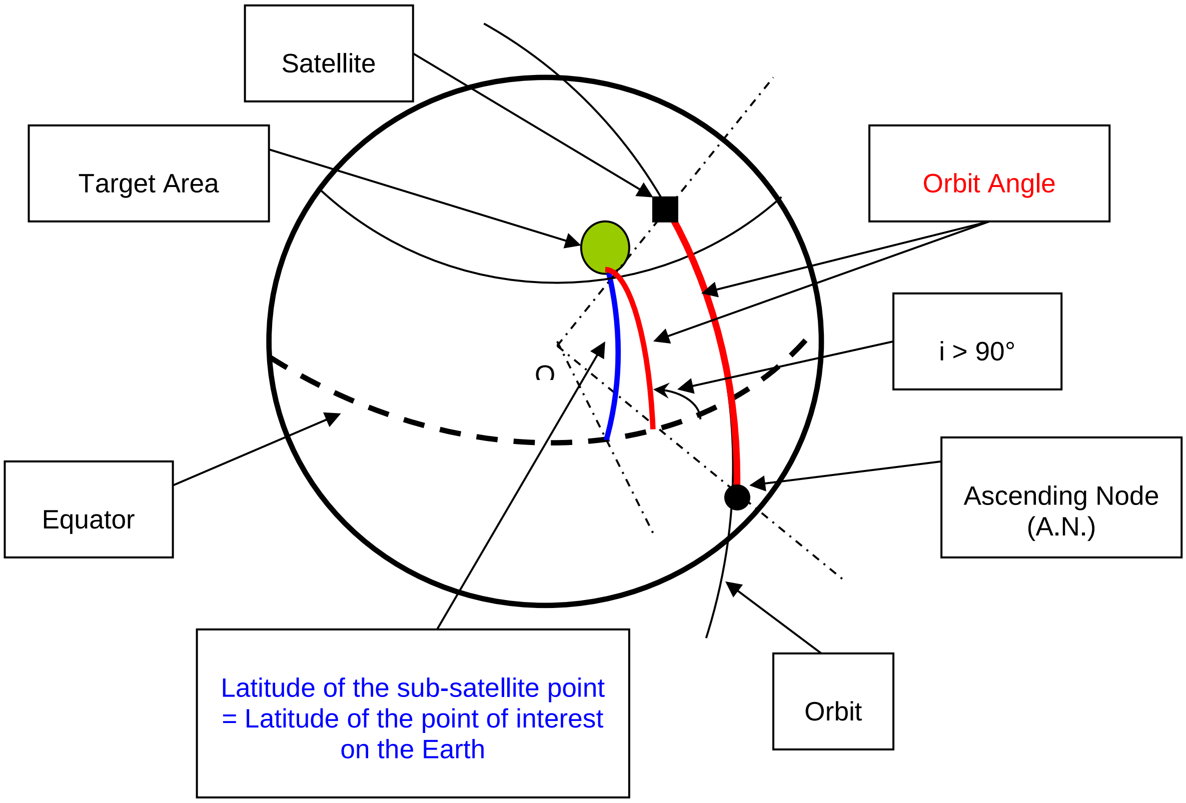


Figure 10.4-1 :Orbit Angle vs Latitude of the sub-satellite point.

In terms of accuracy/resolution along the orbit a numerical example can be made.
Given:

- R_E = 6378 km (mean earth Radius)
- H = 393 km (EarthCARE mean spherical altitude)

The velocity of the satellite along the orbit is:

- $V_{along\_tarck} = [\mu / (R_E + H)]^{1/2}$ = 7.672 km/s
- Where μ = 398600.5 $km^3\ sec^{-2}$ (Earth gravitational constant).

Requiring a 100msec equivalent resolution for the OPS scheduling, it corresponds to 0.767 km of accuracy. In terms of radians it corresponds to 0.00011 [rad].
Ground loads the orbit position related information once per autonomy interval. The information shall contain the orbit numbers and the orbit phase information for start and stop of the individual activities.
AOCS continuously provides an AOCS on-board ancillary data product comprising at least

- Current satellite ancillary data
- Current S/C state vector containing the orbit position
- Precise time of next ascending node crossing (ANX)
- On-board time of next 1 PPS from GPS
- Orbit position at next 1 PPS from AOCS orbit predictor

Based on linear interpolation of the propagated orbit position the OPS scheduler releases the OPS scheduled commands based on the orbit position tag with a resolution compatible to the system requirements of 100 msec distinct scheduling. The MTL is evaluated first in order to ensure that MTL commands are executed first in case of accidental identical execution times of MTL and OPS scheduled activities.

10.4.1.1 Along track accuracy

Nominally GPS valid data are available and taken by the On board Orbit Propagator which will provide among the others the Orbit Position.
In terms of accuracy we should take into account the Absolute Measurement Error of the S/C position and velocity which are bound to the values specified in the requirement [**SDS-6897/AOS-PE/A,S**].
The along track values are:

- Position → 20 m (RMS)
- Velocity → 0.3 sec (RMS)

Given the requirement values, as the worst case, the S/C knowledge of its position w.r.t. to the along track accuracy is very high.
In case of non availability of the GPS Data for a certain time, the OOP will continue to propagate the orbit position.
An OOP performance analysis has been done (**EC.TN.ASD.SY.00064 –** pp. 113 – 119) taking into account an initial error in the OOP initialisation according to the defined 3-σ GPSR Measurement Error.
The worst case scenario is an initial error in the radial position and velocity which leads to an along track position error and consequently a Pitch pointing error which is directly related to the along track position error by:

$$\Delta\phi_{Pitch} = \arctan\frac{\Delta r_{along\_track}}{r_{sat}}$$

As result of the analysis the overall evolution of the along track position error and associated Pitch pointing error is given by:

- 3.3 km / orbit along track error rate
- 490 µrad / orbit Pitch error rate

The results satisfy the requirement [**SDS-6897/AOS-PE/A,S**] which for a maximum outage of the GPS of 1 orbit bounds the along track position error to 3.7 km.

10.4.1.2 Across track accuracy

As stated before the OPS has no capability to correct for cross track deviations of the real orbit w.r.t. the predicted orbit.
From the S/C point of view a boundary condition is given by the requirement [**SDS-300/OBS-MO-2/R**] about the ground-track maintenance whose accuracy shall be better than 25 km.
The repeat cycle of 25 days (Nominal Operations) has a ground track separation distance at the Equator of 100 km. The 2 x 25 km dead-band requirement guarantees that no overlap of two ground tracks can take place.
Moreover the assumption is made that there will be:

- on ground good prediction of the satellite true orbit; and
- consequent orbit control strategy aiming to minimize the difference between the true orbit and the (target) reference orbit.

10.4.1.3 On ground impact

Assumption is made that ESRIN/ESOC, given the requirement of minimum 5 days of on-board autonomy, will generate the OP-tagged telecommands using the reference orbit (which is calculated taking into account only the gravitational force of the real rotating Earth but not the non-gravitational forces acting on the satellite) instead of the predicted orbit. As the difference between reference and real orbit will be mainly in altitude and cross-track position (longitude), but most regular commanding depends on latitude / orbit position / sun elevation, the error due to planning on the reference orbit will be negligible for most cases, and still acceptable for the most critical applications (BBR/MSI solar calibrations).
The reference orbit will have a fixed ground track on the ECF (Earth Centered Fixed) reference frame.
Once the reference orbit is available, the fundamental steps will be for the FOS/Flight Dynamics:

- To evaluate the difference between the reference orbit and a the actual predicted orbit; and then
- To derive a suitable Orbit Control Strategy

10.4.2 Primary OPS Applications

A certain number of operational activities have been identified for which the use of the OPS Scheduling is recommended (CPR Silent Mode & external Calibration, MSI & BBR calibration at the end of the daylight portion of the orbit) or simply suggested (X-band downlink).
In particular for those instrument activities that require a high accuracy in terms of ground target, a very good performance w.r.t the along track can be achieved using the OPS Scheduler.
The individual sequences are typically assigned to one or more sub-schedule IDs of the OPS.

10.4.2.1 S-band downlink sequence

The OPS is used to autonomously schedule the S-band downlink activities.
A list of up-loaded orbit position tagged commands will control the activation of the S-band downlink:

- S-band transmitter RF ON/OFF
- Downlink of realtime data
- Downlink request of HK and parameter report packets as well as other TM report packets
- Resume / Suspend or time criteria based retrieval of OBC MM recorded data

The operational sequence is:

- Ground loads start and stop as well as the resume and suspend S-Band downlink sequences with absolute OPS tags every week. The command sequence will executed with a resolution of <3.5 Km (granularity of orbit position calculation).
- Upon elapse the first S-band downlink tag the S-band transmitter is switched on, real-time data are ultimately available on the downlink about 30 seconds before 0 deg rising elevation at the ground station
- Optional data downlink of recorded data from OBC mass memory starts at a time corresponding to about 5 deg rising elevation at the ground station
- Data downlink stops at a time corresponding to about 5 deg descending elevation at the ground station
- S-band transmitter RF is switched OFF at a orbit position corresponding to about 0 deg descending elevation at the ground station

10.4.2.2 Orbit correction and maintenance maneouvres

Orbit Correction and Maintenance manoeuvres may impact the on-board knowledge of the orbit position, hence its own execution baseline if scheduled via OPS. A list of up-loaded commands will control the activation of the orbit correction and maintenec maneouvres:

- CatBed Heater switching to Heat-up mode about 30 to 60 minutes (120° to 240° orbit angle) before the orbit correction resp. maintence manoeuvre starts

- FCP based transition sequence to Payload Idle Mode for arbitrary orbit correction type (in-plane or out of plane) with an option to remain in Payload Nominal Mode with specific internal calibration operations for limited in-plane orbit correction maneouvres
- FCP based prepration and start of the orbit correction manoeuvre with autonomous transition to nominal AOCS mode after completion of the maneouvre
- FCP based transition sequence to Payload Nominal Mode
- CatBed Heater switching to nominal configuration

The operational sequence is :

- Ground loads sequentially the individual sub-schedules for the payload, AOCS and system activities into the OPS. The time tagged command sequence will executed with a resolution of <3.5 Km.
- Upon elapse the first time tag will setup the catbed heaters for orbit correction maneouvre
- Subsequently via orbit position tagged commands the instruments will be commanded to establish Payload Idle Mode
- After completion of payload setup, the orbit correction sub-schedule is enabled
- The orbit correction manoeuvre is started via orbit position tagged command. As final orbit position tagged command the catbed heaters are switched back to nominal configuration
- At predetermined location via orbit position tagged commands the instruments will be commanded to re-establish Payload Nominal Mode

10.4.2.3 CPR Silent Mode Suspension

A first recommended application is the suppression of CPR instrument operation in the region of radio telescope ground stations to protect in compliance with applicable ITU recommendations ground-based instruments, e.g. radiofrequency telescopes operating in the same frequency band. The present assumption is that the commanding of the CPR into silent mode will be accomplished using the OPS schedule function. Ground is in charge to load the relevant commands into the OPS schedule with such orbit position parameters that the silent mode duration is minimised, i.e. the measurement duration is maximised.
An example is made for the case of a radio telescope area of 2 km diameter.
Now 2 km on ground correspond to 2.12 km on an orbit at 393 km of altitude (mean spherical altitude of EC).
The worst case of a ground track coinciding exactly with a diameter is considered (otherwise the ground track will intersect the area on ground for less than 2 km).

Given the velocity of 7.672 km/s, the S/C covers in 1 sec more than 3 times the 2.12 km path over the radio-telescope.
In ideal conditions the path over the ground area can be centred w.r.t. the entire path flown in Silent Mode.
That means, there will be additional ~ 2.5 km along the orbit before and after the transit over the radio telescope area for a 1s interval of time.

Please note: The CPR command reaction time between "RF Silent Enable/Disable" command reception and effective RF switched off/on is maximum 2 seconds. This command switches the RF on and off at the end of an Observation Cycle.
For the "RF ON/OFF" command the reaction time is 70 ms.

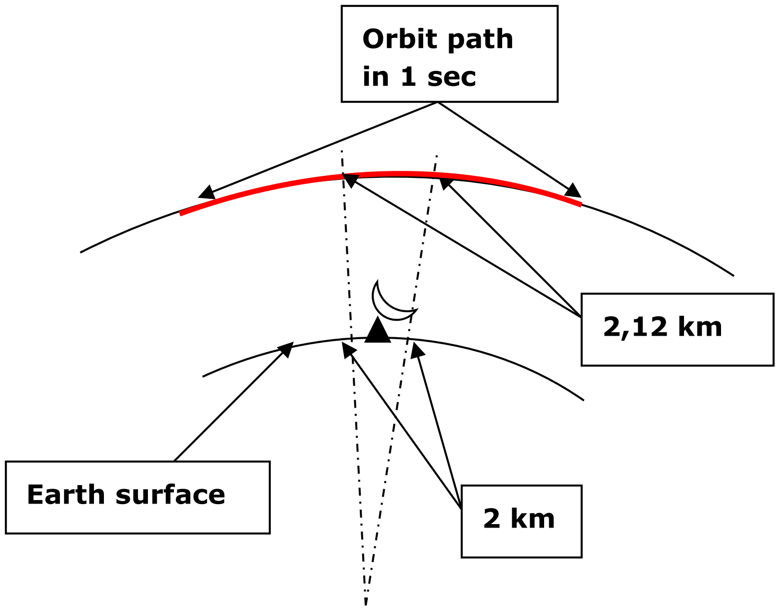


Figure 10.4-2 Orbit path over a radio-telescope area of 2 km diameter

In the reality it shall be taken into account:

- The requirement on the overall pointing of the CPR bore-sight [**CPR-GR-7**] that shall be maintained to within 2mrad of the Earth local normal which in terms of ground distance is ~ 0,785 km and along the orbit path is ~ 0,833 km.
- Furthermore the CPR beam has a circular footprint on ground of 0.750 km diameter (2 x 0.375 radius). Along track this corresponds to 0,398 km. An additional margin of 0,398 km shall be considered.
- A default margin of 1 km can be also added taking into account the 100 ms resolution of the OPS scheduler.

Adding this margin distance to the 2.12 km flight path over the radio telescope the result is:

2.12 + 2 [0.833 + 0.398 + 1] = 6.582 km along track

This corresponds to less than 1 s of flight. Let's consider 1 s as a minimum needed Silent Mode interval of time. For a 100 % safe margin a Silent Mode interval of 2 s can be applied.

Additional uncertainty will include:

- GPS Outage – the along track position error can be, as showed by the OOP performance analysis addressed in § 10.4.2, max. 3.3 km / orbit. In this case, flying over a radio telescope area after 1 orbit without GPS valid data, this 3.3 km margin must be taken into account. Therefore an interval of 2 sec of Silent Mode must be considered.
- Error margin between the reference orbit ground track and the real orbit (evaluated across track).

10.4.2.4 CPR external calibration with ground targets

It is foreseen an external calibration mode for the CPR to be performed with the satellite in nominal AOCS mode (CPR Nadir pointing). The echo return of a ground transponder (also called Active Radar Calibrator, ARC) is measured. The transponder is located in Japan.

In this case there is a ground target, same as for the radio telescope, whose location on Earth is well known and fixed in the ECF reference frame.

The same analysis in terms of error margin performed in the previous paragraph can applied to this operational activity.

In this case the target area is probably smaller so that the accuracy of the “parameter-tag” is very important. In fact CPR antenna does not scan and the beam footprint is very small.
In any case the CPR will start to transmit earlier than passing at the zenith over the ARC.
There is need for:

- an accurate sub-satellite track prediction (east-west direction) of +/- 1 km (TBC).
- an accurate location of the ARC at predicted position (i.e. need for a calibration site which allows theARC to adjust its position easily).

The OPS scheduler can minimize the suspension of the nominal activity.

Please note: The CPR command reaction time has to be considered by Mission planning. Details can be found in EC User Manual Volume 11.

10.4.2.5 MSI & BBR solar calibration at the end of the daylight portion of each orbit

The MSI and BBR need to perform once per orbit a calibration with the sun in the field of view of the dedicated sun calibrations view port. The details of the planning activities are detailed in [RD-141].

10.4.2.6 X-band downlink sequence

The OPS is used to autonomously schedule the X-band downlink activities. A list of up-loaded orbits / positions will control the activation of the down-link:

- X-band transmitter RF ON/OFF
- Resume / Suspend or time period driven retrieval of recorded data from MMFU packet stores resp. e

The following sequence is performed:

- Ground loads the X-Band downlink sequences with OPS tags every week.
- Based on linear interpolation of the propagated orbit position the OPS scheduler releases the OPS scheduled commands based on the orbit position tag with a resolution 0.1 mrad.
- upon elapse the first X-band downlink OPS tag the MMFU TMFE is switched on providing clock and idle frames to the X-band downlink, thus subsequently switching the X-band terminal from standby to ON
- data downlink starts about 5 deg after X-band switch-on (for X-band stabilisation reasons)
- data downlink stops at the predefined orbit phase
- X-band transmitter RF is off 5 deg afterwards by stopping the MMFU TMFE due to the automatic carrier suppression of the XBT

10.4.3 Repeated OPS Scheduling capabilities

The basic OPS operation scheduling is non-repetitive. The EarthCARE orbit repeat cycles are longer than the EarthCARE on-board autonomy period while the expected uplink periods for commanding of all activities within the autonomy period are short. The non-repetitive on-board OPS schedule based on orbit position and orbit angle, corresponding to the keplerian argument of latitude, supports efficient scheduling for most of the regular occurring operations from ground.
Many of the regular operations, basically all which are defined w.r.t. an ECEF reference location, can be defined on-ground based on relative OPS schedules w.r.t. start of the repeat cycle. Others like sun oriented operations can be defined w.r.t. the orbit number of the start of the celestial year. The OPS tag of these relative on-ground OPS schedules can be simply added to the absolute orbit number of the orbit in which the reference cycle period starts, e.g. the start of the repeat cycle or the start of the celestial year.

10.5 On-Board Control Procedures (OBCP)

10.5.1 Service Description

As essential capability set the EarthCARE on-board control procedure service shall support

- Sending of on-board TC with parameters;
- Waiting for a certain delay;
- Accessing parameters in the TM datapool to take a logical decision based on the value which corresponds to an if-then-else type of functionality.

The service function implementation shall ensure that correct completion of any triggered OBCP.

In line with these essential requirements the EarthCARE on-board control procedure service is essentially based on the concept of relative time command sequences and thus an OBCP is composed by a number of steps. Each step is identified by a unique “Step ID” and is made of 2 parts:

- the telecommand or the OBCP directive to be executed
- the delay to wait before starting the execution of the TC or the OBCP directive. This delay is relative to the start of execution of the previous step, or the start of the procedure if it is the first step.

• Procedure Step	DELAY	TC
Unsigned Byte	Unsigned Byte	Byte
1 Byte	2 Byte	Min: 12 bytes Max: 191 bytes

PARAMETERS	DESCRIPTION	RANGE OR VALUE
Procedure Step	Position where the TC should be inserted into the OBCP	Range: [1 .. 255]
Delay	Time Delay in [secs/16] for start of execution of the current step related to the start of execution of the previous step (or start of the procedure in case of first step)	Corresponding to resolution: 1/10sec = 100 msec Max.: 6535.5sec Min.: 0 = No Delay
TC	TC packet incl. OBCP directive to be inserted into the OBCP	Any valid TC or OBCP directive

OBCP directives allow to control the flow of the OBCP and are provided as sub-service of the OBCP service by dedicated private service sub-types. In order to systematically protect the sequential characteristic of the service concept any step ID which can be defined as part of an OBCP DIRECTIVE need to be larger than the step ID of the DIRECTIVE itself. The following OBCP directives ensure provision of the requested essential OBCP capability set:

- OBCP LOGICAL DECISION DIRECTIVE
- OBCP JUMP DIRECTIVE
- OBCP SEND EVENT DIRECTIVE

The OBCP LOGICAL DECISION DIRECTIVE branches the execution of a running OBCP to a step, based on a test of an on-board TM parameter from the on-board data pool :

IF condition(Parameter ID, Test Value) THEN (execute TRUE step) ELSE (execute FALSE step). The TRUE step ID as well as the FALSE step ID needs to be larger than the step ID of the IF DIRECTIVE

The OBCP JUMP DIRECTIVE branches the execution of a running OBCP to another step with a step ID larger than the step of the JUMP DIRECTIVE.

The OBCP SEND EVENT DIRECTIVE generates an event report reporting the current OBCP and step identifiers, allowing establishing a full trace of the OBCP

In EarthCARE any on-board command source is uniquely identified by a source ID. In line with this concept each TC of an OBCP does have the specific TC source ID = OBCP in the header, which is copied into the TC acknowledge packets to separate ground initiated commands from on-board commands.
The source sequence counter of each TC or OBCP directive of an OBCP is fixed at definition or upload time and embark the OBCP ID as well as the OBCP step ID, thus allowing an unique identification of the originating TC
Reporting on the progress of execution of a procedure is achieved implicitly by use of telecommand verification reports, containing the application specific OBCP service as command source in the source ID field as well as a uniquely coded source sequence counter based on OBCP ID and step ID or by explicitly triggered event reports via the above given OBCP SEND EVENT directive. TC verification reports have principally a structure equivalent to event reports. By treating of command verification reports of on-board issued commands like event reports the existing event history feature of SCOS type control systems can be used very efficiently to display those reports. Correlation to the on-board commands is possible via the unique source sequence count of OBCP’s of an application
The EarthCARE OBCP service features definition and loading of OBCP’s via normal command interface without any pre-compilation. The concept already applied for MTL, OPS as well as event action definition service commands are used. OBCP’s can be loaded to an application process, which then manages the on-board storage of these procedures and their subsequent execution. OBCP’s can also be controlled (e.g. started) autonomously on-board, e.g. as the result of detection of a specific on-board event.
The services provided for OBCP management are:

- Lock OBCP
- Add TC to OBCP
- Delete TC from OBCP
- Dump Onboard Procedure
- Onboard Procedure Dump

For configuration and set-up the OBCP needs to be in locked, which is commanded by private sub-service. In case an OBCP is locked OBCP maintenance activities like establishing, modification and deletion of an OBCP can be done, but the OBCP can not be started. The OBCP management sub-services for uploading and deleting of OBCP’s are operating on single steps. An OBCP is defined as soon as one step is added. Equivalently the OBCP is completely deleted if the last step of one OBCP is deleted. Dumping of an OBCP can be done at any time. As long as one OBCP step is defined unlocking the OBCP releases the OBCP into inactive state from which it can be executed.
As soon as an OBCP is defined the OBCP can principally be either in active or inactive mode. While an OBCP is in active mode it can’t be re-started.

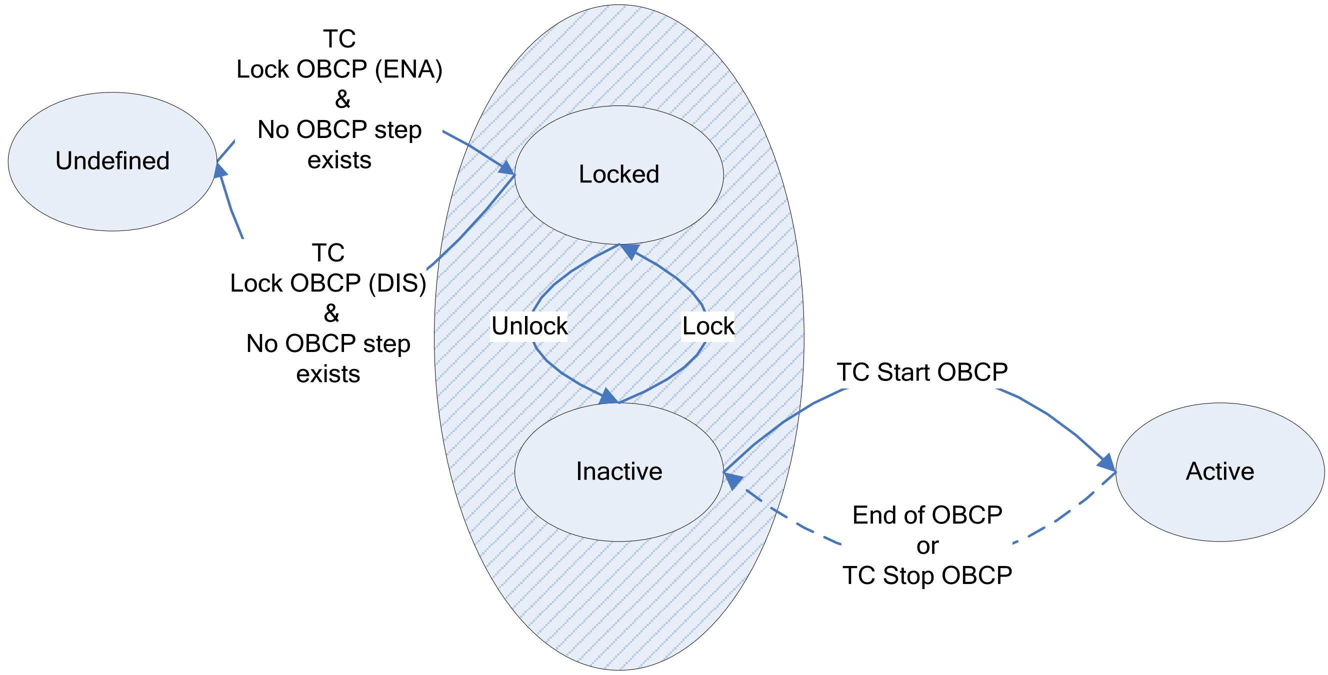


Figure 10.5-1 OBCP states

The on-board operation procedure service provides standard sub-service requests and reports for controlling the execution of these procedures and monitoring their status. Each on-board control procedure does have an execution status which indicates whether it is currently “inactive” or “active”. The service maintains a list of the currently loaded Procedures and a list of the currently active Procedures. These lists can be reported to the ground on request. It shall be possible to control OBCPs, via specific telecommand packets, in the following manner:

- Start an OBCP;
- Stop an OBCP;
- Stop all active OBCP’s by one command
- Report list of Onboard Operation Procedures
- Onboard Operation Procedures List Report

Suspend/resume capabilities are rated as pure debugging features not essential for the given OBCP service concept as full observability to the proceeding of the OBCP is ensured via normal HK telemetry as well as by the provided reports which can be requested at any time during the OBCP execution. Communication of parameters with an OBCP is exclusively done via the on-board data pool. OBCP’s are sub-divided via OBCP ID in “normal” OBCP’s, which can be executed in parallel up to a pre-defined number, and in “Critical” OBCP’s which are strictly sequentially executed in the sequence of their execution start. All OBCP’s can only be started once at a time. If an OBCP start command is received while it is already executing, the start execution command is rejected.

The OBCP service is implemented as an object of the CDHS. It provides an interface to the application to execute the OBCP. This interface executes only one step per call, when its associated delay has elapsed. It returns the next delay to wait to the application. This object manages three lists:

- an OBCP list that contains the status of the OBCP, the number of the last executed and a pointer to its list of steps sorted by OBCP Id.
- a step list that contains the TC to execute and the delay before executing it, sorted by the step number.
- a started OBCP list that contains the absolute time of the next step to execute, the OBCP identifier and a pointer to the next step to execute.

The resources are managed via pool control blocks. The size of the pools, which are shared by all PID, are configurable at SW compilation time. The number of OBCP that can run in parallel or the number of steps that can be executed during a given software cycle depends on the number of control structures and TC buffers available and on the way the application call the execution service.

10.5.2 Service Application

In EarthCARE the OBCP's will be used for implementation of monotonous consecutive action sequences. The design principle not only, for the OBCP development, is to achieve strictly determinism. Following this concept the delay time between subsequent steps of those action sequences consider the maximum execution time of a command activity as well as any additional delay time to be considered for successful completion of the activity triggered by the command. The application of OBCP in EarthCARE is supported by the equipment management concept of EarthCARE, which is realized by service 8 functions using strictly the S/C State Vector capabilities.The following operational activity sequences:
FDIR recovery activity sequences triggered via the event action service including unit reconfiguration sequences.
Mode transition sequences
Nominal repetitive operation sequences identified chapter 13
One typical application for a recovery sequence is an equipment reconfiguration sequence. Such an equipment reconfiguration sequence typically starts with setting the SCV_HEALTH status of the failed unit of an equipment, subsequent call of the equipment set-up function and final reactivation of the functional monitoring service. Considering the service capabilities provided by the EarthCARE OBCP service it may be expanded with an initial branching depending on the equipment configuration identification to cover all possible nominal configurations of an equipment.
The monitoring of all activities is ensured via the parameter and functional monitoring services being dynamically steered via the validity conditions of the individual as well as combined monitors.
Significant operational conditions e.g. in mode transition sequences can be checked at appropriate positions based on an expected condition check within the sequence if necessary.

11. FDIR CONCEPT

The FDIR Concept and Implementation is described in detail in 8RD-05].

12. SURVEILLANCE AND MONITORING CONCEPT

12.1 Overview

Definitions:

Surveillance: describes the general surveillance of onboard functions. Surveillances may be implemented by predefined SW logic (e.g. MIL-BUS FDIR, AOCS built-in failure detection etc.). Updates to onboard surveillances require modifications of either SW code or SW parameter settings.

Functional Sequence Monitoring: describes the usage of dedicated monitoring implemented in dedicated SW functions as the inherent monitoring within the SA deployment function/ LEOP auto sequence of the system initialisation function. Updates to the functional sequence monitoring require modifications of either SW code or SW parameter settings.

Cyclic Monitoring: describes the usage of the onboard monitoring function implemented by PUS service 12 with the associated functionality. The monitors are described by dedicated Monitoring ID's. Updates to the onboard monitoring is established via the standard service 12 interface as described in the EARTHCARE-PUS.

The EarthCARE FDIR design couples cyclic parameter monitors logically into functional monitoring groups and decouples these cyclic monitors from the functional sequence monitors and surveillances to avoid any risk of clash or interaction leading to unpredictable system behaviour. To this end, cyclic monitors, functional sequence monitors and surveillances are implemented in a different manner. Cyclic monitors are implemented using PUS parameter monitoring service 12 functionality which are combined into a functional monitor definition of the private functional monitoring service 142. The functional sequence monitors are implemented as dedicated logic within specific functional sequences as e.g. the LEOP function or the system initialisation functions. Surveillances may be implemented e.g. within the AOCS to ensure AOCS performance.

12.2 Principle of Functional Monitoring

The principal monitoring scheme applied in EarthCARE will use the concept of functional monitoring that is based on the following principles:

- dedicated unit level TM is used that determines the correct functioning of the individual unit; the unit level monitors are derived from the unit supplier FMECA's. Therefore a consistent usage of FMECA results is made in the FDIR approach. An advantage of the functional monitoring approach is for instance the fact, that the LCL status of individual units needs not to be monitored since the function of the unit is monitored by its functional monitors and overvoltage/overcurrent is handled by the LCL.
- application level monitoring to determine the correct operation of mode specific functions. This is e.g. applied for application (e.g. AOCS, Platform Control, Payload control) level monitoring

12.3 Cyclic Monitoring by PUS Service 12

The Monitoring Service (PUS Service 12) comprises limit and status checking of onboard parameters and generates a unique event in case of an Out-of-Limit (OOL) condition. Mode dependant monitoring is implemented by embedding of mode dependent conditions in the validity parameter definitions of a specific Monitoring ID, allowing for an elegant definition of updating the monitoring scheme when changing the operational state of a subsystem.

The context of the PUS service 12 with the other PUS services is provided in the following figure:

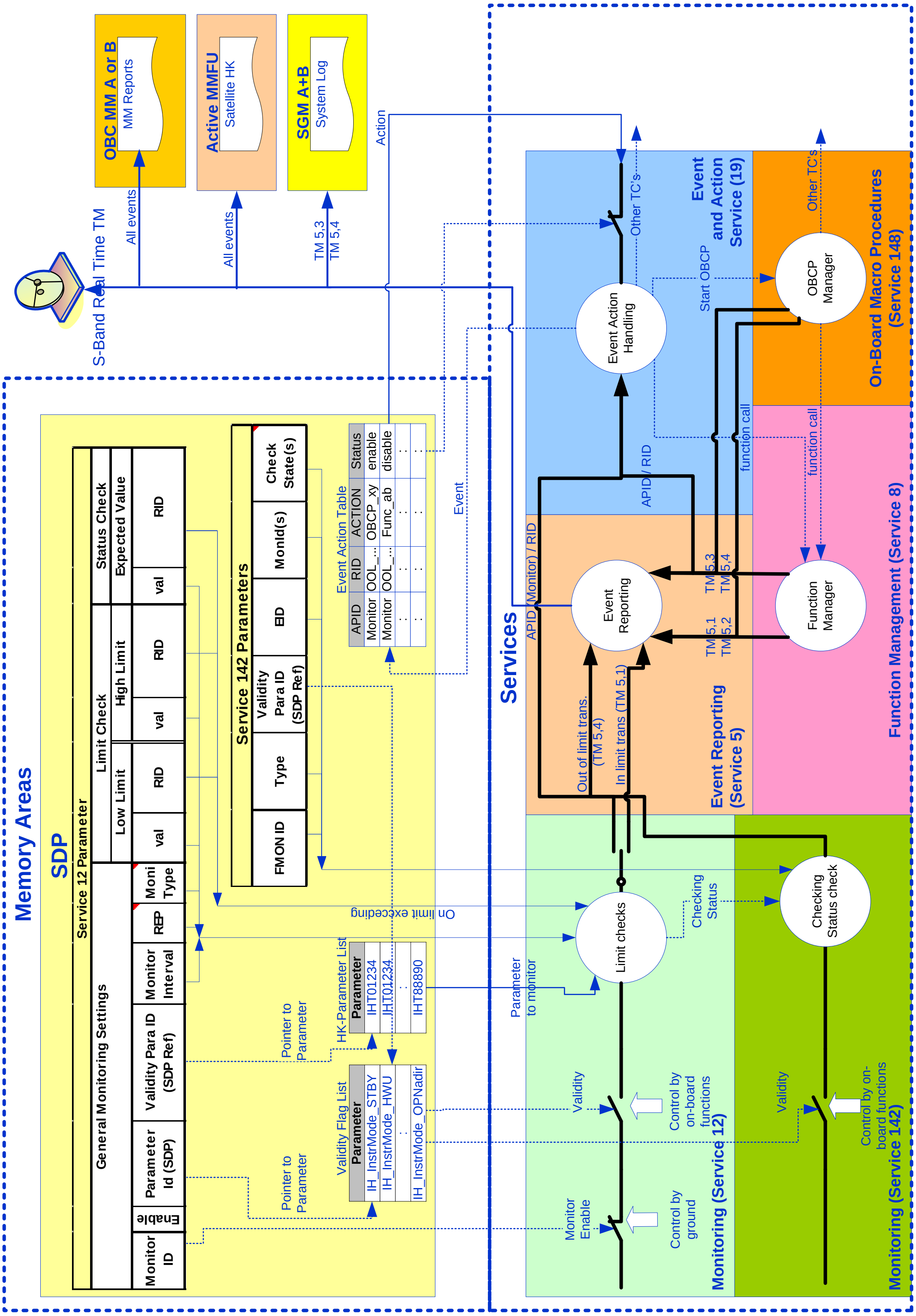


Figure 12.3-1: Service12 Monitoring usage in the overall FDIR context

12.4 Functional Monitoring by PUS Service 142

The Functional Monitoring service 142 provides the capability to combine individual parameter monitoring definitions of service 12 into one functional monitor with dedicated validity. Individual parameters monitorings are representing the current health status of the function. The On-Board Functional Monitoring service requires that the standard parameter monitoring (service type 12) is implemented.
Functional Monitoring reports any transition of the function's state to the service user. An event report will be generated by the Functional Monitoring Service, as the result of a given monitoring violation of any of the underlying parameters. To achieve this, the service maintains a Functional Monitoring item list in which each item corresponds to a set of parameter monitoring identifiers (Monitoring ID) and additional information linked to the functional level. The functional monitoring operation states and principles are depicted in following figure

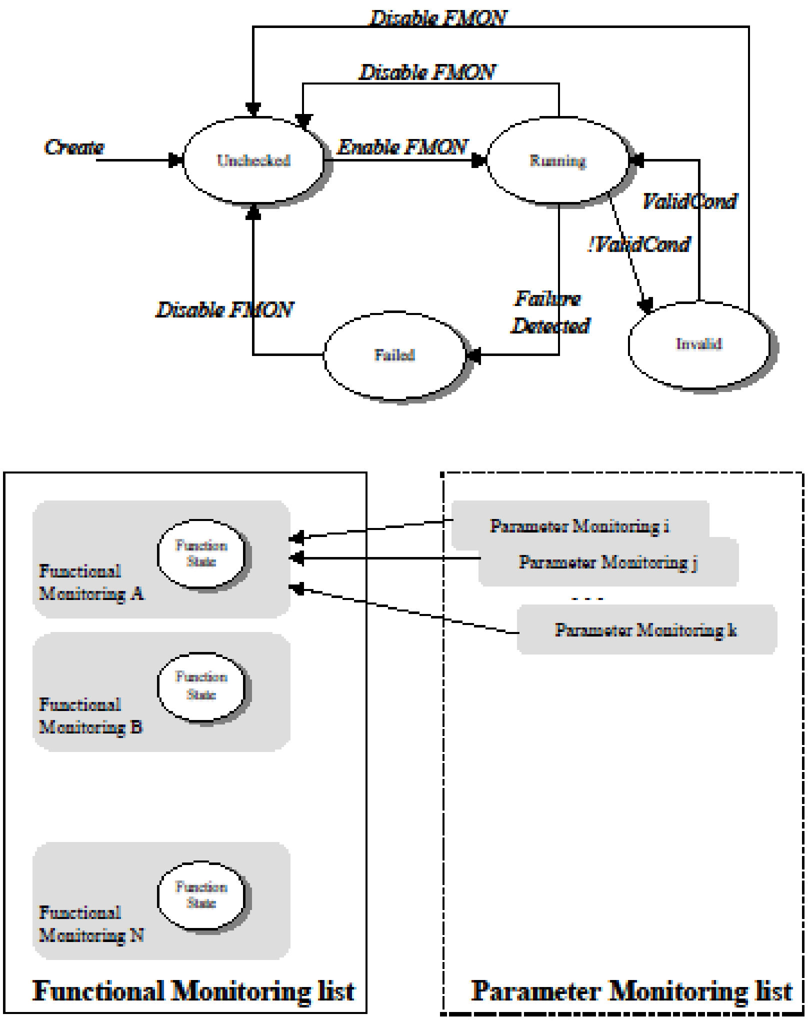


Figure 12.4-1: Overview of Functional Monitoring Service 142

The event report packets which are issued by the functional monitoring contain the following information::

FMON ID	Time-Out	Type	Triggering parameter monitoring ID	Current checking status of parameter monitoring ID	Trigger Time
Unsigned Integer	Unsigned Integer	Enumerated	Enumerated	Enumerated	Satellite On-Board Time
4 byte	2 bytes	1 bytes	4 byte	1 byte	6 bytes

In service 142 for each functional monitor the service 12 monitoring states of the belonging service 12 monitoring entries are monitored. For each service 12 monitoring entry it is possible to define the state condition which shall contribute to an out of limit detection of this functional monitor. The monitoring states of the individual parameter monitoring entries are normally combined by an OR definition, which means that as soon as one parameter monitoring entry reaches the defined monitoring state the functional monitor trips and sends the defined functional monitoring event report. The service also offers the capability to combine the individual parameter monitoring states by an AND logic. This feature can be used to ensure that several conditions must apply to trigger an FDIR action.

The service further embarks a management principle for concurrent FDIR requests. As soon as one functional monitor has reach the out-of-limit state the processing of all other functional monitors is suspended. The functional monitoring service is nominally resumed as part of the recovery activity which is defined by a service 148 FDIR OBCP, which is invoked by a corresponding event action service 19 definition.

In order to ensure a failure tolerant design the functional monitoring service processing is also resumed based on expiration of the functional monitoring time-out specified as part of the functional monitor definition. The time-out is nominally set to the duration of the recovery activity plus some margin for execution time variations.

After execution of one functional monitor which tripped the concerned functional monitor switches to a disabled states, when the functional monitoring service resumes processing. The background of this function is that a concrete functional FDIR reaction, which could not resolve the problem in first place will also not resolve it in case of a second autonomous execution. Alternatively another more severe reaction e.g. a mode switch of the functional chain instead of equipment redundancy switching is necessary to resolve the detected problem. A functional monitor which is in disabled state can be re-enabled by command. This is typically done by ground after having completely understood the situation which caused the FDIR reaction and having the system recovered.

For each individual functional monitor a validity condition as known from the parameter monitoring service can be defined, which e.g. allows mode dependent or configuration dependent functional monitors.

Further details on the service are given in the related description in [AD-110].

13. EARTHCARE OPERATIONAL SEQUENCES

The satellite initialization sequence (SoE) and the satellite operational timelinesare described in [RD-101]

13.1 CPR Antenna Deployment

The CPR deployment should take place during a ground contact. The CPR deployment will be provided via System application service 8 function TC and utilizes a special PCDU pyro sequence control function provided by a PCDU FPGA, allowing to fire two pyros in short time interval of 100 msec in sequence without risk of interruption..

The CPR antenna deployment consists of two essential parts which are commanded by ground. The first part, defined via FCP consits the preparation and arming of the PCDU TK-Pyro device and the enabling of the system function. The second part also FCP driven part invokes the system service 8 function performing the complete CPR deployment sequence including the AOCS sub-mode commanding. Scheduling via master timeline will be possible. The arm and fire protections will have to be released via dedicated flight procedure.

By means of dedicated switches the release as well as the deployments are signalled via RIU channels to the OBC. All signals of the CPR antenna release and deployment mechanism are directly acquired by the satellite at the CPR interface. Activation of the CPR SPU for the release is not required.

<u>PYRO I/F Implementation inside the PCDU</u>

For the PCDU PYRO I/F implementation the block diagram shown in [RD-111] fully applies with following additional notes

(1) The PCDU cmd (Close ARM relay) will enable the arming function of the main and redundant TK/pyro module at the same time. The principle to operate the main/redundant TK/pyro module in parallel by a single PCDU cmd is applied for the other pyro cmds as well except for the TK_LCL ON/OFF.

(2) The interconnection between PCDU and CPR is such that the pyro output TKn (M) is connected to the main pyro of the CPR HDRM1 and the pyro output TKn (R) is connected to the redundant pyro of the CPR HDRM1

<u>2) Operation of CPR Pyro I/F</u>

The following commanding sequence for the CPR Antenna release:will be applied. The verification of the CPR antenna release and deployment follows subsequently based on the discrete telemetry provided by the CPR antenna hold down and release mechanisms.

Step	Time	Action	OBC -> PCDU CMD	PCDU internal FPGA Sequence
1	T0-5sec	LCL-ON "M" (Pre-Arm)	X	
			PCDU TM status read by OBC	
2	T0-5sec	LCL-ON "R" (Pre-Arm)	X	
			PCDU TM status read by OBC	
3	T0-4sec	Close ARM relays	X	
			PCDU TM status read by OBC	
4	T0-3sec	De-Select all outputs	X	
			PCDU TM status read by OBC	
5	T0-2sec	Select output CPR Pyro 1	X	

Step	Time	Action	OBC -> PCDU CMD	PCDU internal FPGA Sequence
		(M+R)		
			PCDU TM status read + check of correct selection pattern by OBC	
6	T0-1sec	CPR Deployment Sequence	X Start CPR Depl Sequence	
				X Check if CPR Pyro 1 output is selected, if proper selection is confirmed continue, else terminate
7	T0	Fire CPR Pyro 1 (M+R)		X Activate fire signal to CPR Pyro 1 (M+R) and archive fire signal confirmation for read-out after completion of sequence
8	T0+0.1sec	De-Select all outputs		X
9	T0+0.15 ec	Select output CPR Pyro 2 (M+R)		X (archive pyro selection status in PCDU for OBC TM reading after sequence completion)
10	T0+0.25sec	Fire CPR Pyro 2 (M+R)		X Activate fire signal to CPR Pyro 2 (M+R)
11	T0 + 1sec	Read pyro output selection of last firing	X	
12	T0+2sec	Open ARM relays	X	
			PCDU TM status read by OBC	
13	T0+3sec	LCL-OFF "M" (Pre-Arm)	X	
			PCDU TM status read by OBC	
14	T0+4sec	LCL-OFF "R" (Pre-Arm)	X	
			PCDU TM status read by OBC	
15	T0+5 sec			

Note:

(1) The critical time constraints between CPR Pyro 1 and 2 firing is implemented in a FPGA sequence and takes 250 ms (step 7 to 10).

(2) The high level command sequence for the CPR deployment will be implemented as nominal flight procedure which takes several seconds in case of no failure.

(3) The flight procedure will consist at least 4 individual service 8 function commands: One for closing setup of the Pyro Module (LCL_ON), one for closing the arming relay, one for selection of the pyro output and one for Starting the CPR Deployment Sequence.

(4) The RSA status telemetry (Red: CPR antenna deployment monitoring A; Nom: CPR antenna deployment monitoring B; Red: CPR antenna release monitoring A; Nom: CPR antenna release monitoring B) will be acquired permantely before, during and after the CPR Deployment and is incorporated into the EC HK packets.

Operations I/F

Upon closing of the CPR deployment protection devices via FCP, the CPR deployment activity is started via one high level service 8 function. The CPR deployment comprises the transition to ASM_NOM_DEP, which is the nominal operational environment in which the CPR Antenna deployment takes places. Subsequently the real CPR Antenna deployment function is started which triggers the PCDU during sequence. Both functions are critical functions. The overall flow implemented in the system application is shown below.

The implementation details of the CPR antenna deployment sequence are defined in [RD-143]
In case that a system reconfiguration is triggered after start of the CPR deployment system function, the CPR deployment will be completed as part of the system initialization as shown in chapter 13.2

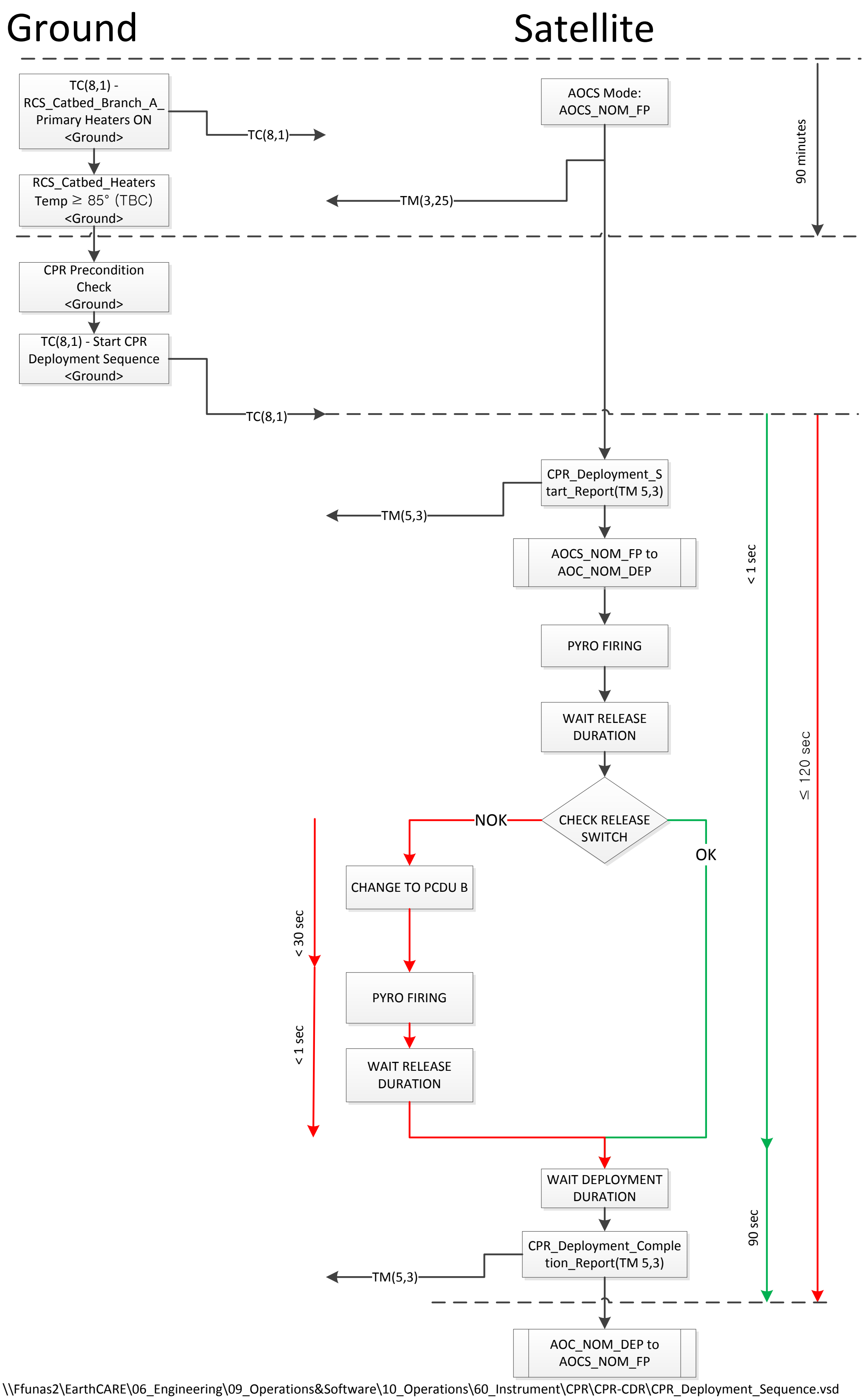


Figure 13.1-1: CPR Antenna Deployment Master Flow

13.2 System Reconfigurations (OBC reboot)

System Reconfigurations are those reconfigurations that are initiated by the OBC Reconfiguration Module based on an alarm input pattern. The reconfiguration is conducted by means of executing a CPDU command sequence issued by the OBC RM. After the reconfiguration attempt, the alarm pattern should nominally no longer be present and the satellite should execute its nominal initialisation sequence. However, if the alarm pattern remains, other reconfiguration attempts (retries) with different CPDU sequences are to be performed for each RM to achieve a stable configuration. The detailed definition of the sequences considers that safeguarding of the payload is achieved as part of these sequences.

13.3 Unit Switch-on and Unit reconfigurations

The EarthCARE units will be switched on by dedicated switch-on sequences that are designed to use the Spacecraft Configuration Vector to determine the unit to be used (or available). The switch-on sequences will be designed such that they can be used in the system initialisation sequences but also in the switch-over sequences used by FDIR. The principal logic is given in section 7.2.2.

13.4 Orbit Control Manoeuvre Sequence

In-plane orbit manoeuvre can be conducted at any time, only on expense of degraded instrument performance due to reduced attitude control performance as well as attitude and orbit position knowledge performance during orbit manoeuvre.
Out-of-plane manoeuvres embed yaw axis attitude manoeuvres which require additional protection of instruments.
The best strategy w.r.t. fuel consumption and availability is to combine out-of-plane manoeuvres with in-plane manoeuvres.
The operational sequence for an orbit maintenance manoeuvre comprises the following steps:

- Instrument mode transfer into a safe state (e.g. laser emission deactivated and closure of MSI and BBR apertures with calibration devices, ATLID in Laser warm-up Mode and CPR in Observation Mode or internal calibration mode.
- AOCS mode transition from nominal fine pointing mode in orbit control mode and at the same time rotation of the solar array parallel to the x-y plane to minimise plume impingement and disturbance torques in case of slew manoeuvres
- Slew manoeuvres as required
- Orbit maintenance thruster firing
- Slew back as required
- Rotate solar array back in nominal position and AOCS mode transfer
- Instrument mode transfer into nominal operations mode

13.5 CPR Roll Calibration sequence

CPR calibration sequence involving an AOCS roll manoeuvre sequence will need to embed commanding of the other EarthCARE instruments into either internal calibration sub-modes, embedding protected configurations of these instrument w.r.t. off-nominal nadir orientations or into instrument Idle Mode.

13.6 BBR & MSI Solar Calibration sequence

Details of the BBR and MSI Solar Calibration sequences are provided in the instrument related timeline and operability sub-chapters of chapter 15.

14. SATELLITE OPERATIONS CONSTRAINTS

Please note that operational constraints for Satellite operation and handling on Ground during AIT and Launch preparation are handled in [RD-83] and for In-Orbit are handled in [RD-82].

15. INSTRUMENT OPERATIONS CONCEPT

15.1 General

15.1.1 Instrument Timeline

With the exception of a few coordinated operation sequences the individual EarthCARE instruments can be operated fairly independent. Correlation of the measurements is achieved by measurement data correlation based on mission data and satellite ancillary data time stamping. The on-board time system ensures synchronized operation of the local on-board time of each instrument.
The following operation sequences have been identified needing coordinated operation across the instruments:

- MSI TIR blackbody & BBR VISCAL calibrations, whenever the BBR calibration is planned (only in 30 orbits every two months)
- CPR calibration requiring an satellite attitude manoeuvre around the roll axis

15.1.2 Instrument Redundancy Selection

The basic redundancy scheme for instruments is strict cold redundant operation of the A and B chain of each instrument, in particular for the instrument ICU's.
For ATLID and for CPR mixed equipment configurations need to be considered in order to meet the required reliability of ATLID and CPR for these instruments from S/C interface point of view two additional mixed configurations will be supported as default configurations for these instruments as given in Table 15.1-1.
Additional provided cross strapped configuration beyond these default configurations, which are principally possible by the instrument architecture can be configured by redefinition of one of the default configuration but are not considered as baseline for system level activities as long as all system level requirements can be met with the defined configuration set.
Redefinition of the configurations listed in Table 15.1-1 can be commanded by ground.

		A	B	MIX_A	MIX_B
ATLID	ACDM-A	PRESEL	NO_PRESEL	PRESEL	NO_PRESEL
	ACDM-B	NO_PRESEL	PRESEL	NO_PRESEL	PRESEL
	Survival Heater 1A	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 2A	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 3A	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 1B	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 2B	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 3B	PRESEL	PRESEL	PRESEL	PRESEL
	Nominal Heater A	PRESEL	NO_PRESEL	PRESEL	NO_PRESEL
	Nominal Heater B	NO_PRESEL	PRESEL	NO_PRESEL	PRESEL
	LPE_ A	PRESEL	NO_PRESEL	PRESEL	PRESEL
	LPE-B	NO_PRESEL	PRESEL	PRESEL	PRESEL
	HPE_A	PRESEL	NO_PRESEL	PRESEL	NO_PRESEL

		A	B	MIX_A	MIX_B
	HPE-B	NO_PRESEL	PRESEL	NO_PRESEL	PRESEL
CPR	ICU-A	PRESEL	NO_PRESEL	PRESEL	NO_PRESEL
	ICU-B	NO_PRESEL	PRESEL	NO_PRESEL	PRESEL
	Survival Heater 1A	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 2A	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 3A	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 1B	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 2B	PRESEL	PRESEL	PRESEL	PRESEL
	Survival Heater 3B	PRESEL	PRESEL	PRESEL	PRESEL
	Nominal Heater A	PRESEL	NO_PRESEL	PRESEL	NO_PRESEL
	Nominal Heater B	NO_PRESEL	PRESEL	NO_PRESEL	PRESEL
	LPE_ A	PRESEL	NO_PRESEL	PRESEL	PRESEL
	LPE-B	NO_PRESEL	PRESEL	PRESEL	PRESEL
	HPE_A	PRESEL	NO_PRESEL	PRESEL	NO_PRESEL
	HPE-B	NO_PRESEL	PRESEL	NO_PRESEL	PRESEL

Table 15.1-1 Instrument Redundancy Configurations

Note:

LPE - Low Power Equipment, might be several individual instrument equipments which are instrument internally switched

HPE - High Power Equipment

The detailed instrument configurations are provided in the related dedicated instrument chapters

The survival heater power lines are supplied in hot redundancy during nominal operations.

15.1.3 Instrument Modes and Mode Transition

15.1.3.1 Concept Summary

Realization of an efficient instrument operation on a multi-instrument platform require a flexible and self standing architecture for instrument control. Flexibility in the instrumentation requests standardization of the functional instrument interfaces as far as possible for instrument control, power interface(s), synchronization etc.

For EC the inherited approach for multi-payload missions to achieve standard interfaces is to use “smart instruments” that have their own control unit (ICU). Commanding is thereby limited to few high level function commands (e.g. Switch-on and mode and sub-mode changes), which are just “passed through” by the S/C CDHS and interpreted by the ICU. Apart from avoiding cumbersome and error prone low level command sequences in the operational phase, the ICU also facilitates the AIT procedures, as the instrument can be tested stand-alone with the exact same commands that will be used after its integration on the S/C.

A clear definition of individual modes and transitions between modes is a prerequisite for the development of instrument operational procedures. This generic mode and mode transition concept supports definition of a generic FDIR and allows standardizing as well as minimising the number of operational procedures.

The envisaged mandatory instrument modes are the following:

- INS-OFF - OFF
- INS-INI - INIT
- INS-SBY - STANDBY
- INS-SBR - STANDBY/REFUSE
- INS-NOM - NORMAL OPERATION

Depending on the instrument complexity, overall design for SW maintenance, the instrument needs for thermal stabilization as well as decontamination operations and depending on dedicated launch configurations additional modes shall be added from the following list:

- INS-LAU - LAUNCH
- INS-IDL - IDLE
- INS-IDR - IDLE/REFUSE
- INS-DEC - DECONTAMINATION

The instrument specifics are reflected in the definition of instrument specific sub-modes and states which however are well embedded in the overall instrument operation mode and mode transition definition.

Following the outlined approach the instrument ICU's are essential part of the on-board data handling system contributing well to the distribution of the operation load as well as performance across the on-board system.

The following generic instrument mode and mode transitions are defined:

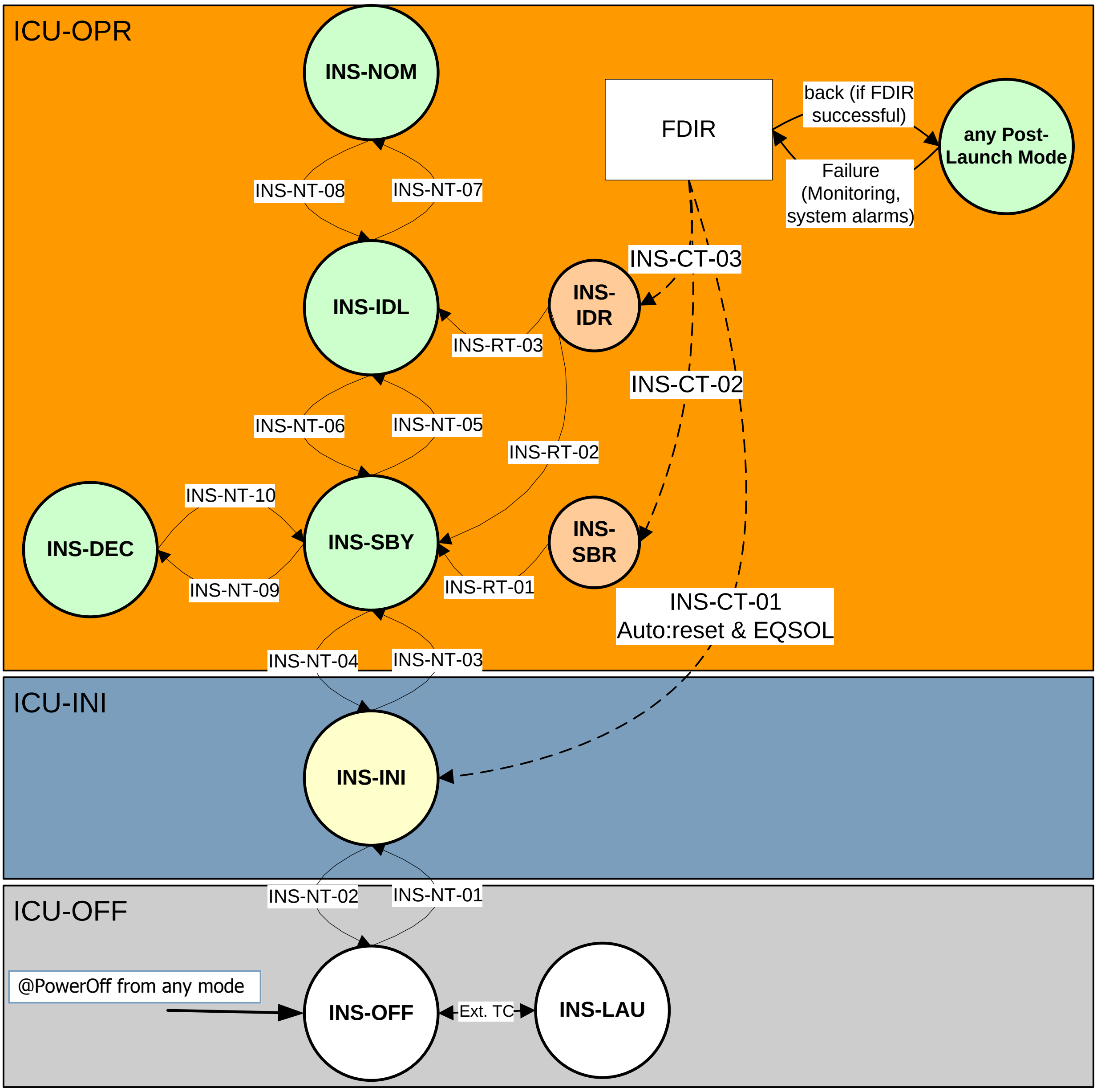


Figure 15.1-1 Instrument Mode Transition Diagram

15.1.3.2 Instrument Mode Definitions

15.1.3.2.1 INS-LAU - LAUNCH

The instrument LAUNCH mode (INS-LAU) is defined by the following basic conditions:

- the instrument appendages are in the stowed configuration and the instrument shall be protected against launch loads and non-nominal sun illumination.
- Thermal control shall be provided via the survival power lines and instrument thermal HW for category A elements resp. by the platform thermal control for category B elements to maintain the ICU and the critical deployment devices above min. switch-on temperature while all other equipments shall be maintained within their non-operation temperature range.
- Survival heater power is available for the instruments to provide thermal control by instrument thermal HW. Nominal operation power is not provided to the instrument, thus the instrument is off.

15.1.3.2.2 INS-OFF - OFF

The instrument OFF mode (INS-OFF) is defined by following basic conditions:

- the instrument is switched off.
- Thermal control is provided via the survival power lines and instrument thermal HW for category A elements resp. by the platform thermal control for category B elements to maintain the ICU above min. switch-on temperature while all other equipments shall be maintained within their non-operation temperature range.
- The instrument is protected against non-nominal sun illumination.
- Survival heater power is available for the instrument to provide thermal control by instrument thermal HW. Nominal operation power is not provided to the instrument.

15.1.3.2.3 INS-INI - INIT

The instrument INIT mode (INS-INI) is characterized by following basic conditions:

- the ICU shall be switched on, but all other instrument equipment shall be off.
- The ICU is in its INIT mode, i.e. the ICU processor/controller is running the boot SW, supporting command/telemetry exchange via the MIL-BUS protocol and providing the PUS service applicable for the ICU INIT mode. ICU memories and the command and control interface are powered.
- Thermal control is provided via the survival power lines and instrument thermal HW for category A elements resp. by the platform thermal control for category B elements to maintain the ICUs within operation temperature range and other instrument equipments within non-operation temperature range.
- The instrument is protected against non-nominal sun illumination.
- For instrument INIT mode nominal power to instrument ICU is provided by the satellite in addition to survival heater power providing survival thermal control by instrument thermal HW.

15.1.3.2.4 INS-SBY - STANDBY

The instrument STANDBY mode (INS-SBY) is defined by following basic conditions:

- the ICU is switched on. Other the ICU function supporting low power instrument elements can be switched on.
- The ICU processor/controller shall be running the application SW, supporting command/telemetry exchange via the MIL-BUS protocol and supporting all PUS services applicable for the ICU application SW.
- Thermal control is provided by the ICU, but can be supported by the survival heating thermal control. The ICU and the supporting low power instrument elements shall be maintained at operation temperatures. All other instrument elements (e.g. Optical FE, High Power FE) shall be brought to and maintained at switch on temperatures.
- The instrument shall be protected against non-nominal sun illumination.
- For instrument STANDBY mode (INS-SBY) nominal power to instrument ICU and low power equipment is provided by the satellite in addition to survival heater power providing survival thermal control by instrument thermal HW.

15.1.3.2.5 INS-SBR - STANDBY/REFUSE

The definition for this mode is the same as for INS-Standby mode, with the exception that mode switching function commands, except the RESET COMMANDING function commands are not executed. This mode is used in case of problems not requiring to switch-off the instrument front-end electronic. The RESET COMMANDING function command returns to STANDBY mode and enables the continuation of normal mode

switching commanding after recognition of a failure condition and confirmed order to proceed with normal operation.
This mode shall be entered when an anomaly is detected by the ICU, which does not allow to continue operation of the instrument as pre-programmed in the command sequence and instrument equipments of higher operation modes shall be switched off.

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15.1.3.2.6 INS-IDL - IDLE

The instrument IDLE mode (INS-IDL) shall be defined by following basic conditions:

- the ICU is nominally operating and monitoring/controlling the instrument.
- Instrument equipment are switched on, but the instrument does not emit measurement signal in this mode. Instrument internal health checks are possible.
- Thermal control is provided by the ICU via the nominal power supply. The instrument will be brought to and maintained within the nominal operation temperature range to support start of instrument measurements. For instrument IDLE mode (INS-IDL) nominal power to the complete instrument is provided by the satellite. Survival heater power is no longer required by the instrument
- In INS-IDL local decontamination functions can be performed. For global instrument decontamination the instrument decontamination mode shall be applied.

15.1.3.2.7 INS-IDR - IDLE/REFUSE

The definition for this mode is the same as for INS-IDL mode, with the exception that mode switching function commands, except the RESET COMMANDING and GOTO STANDBY function commands are not executed. This mode is used in case of problems not requiring to switch-off the instrument front-end electronic. The RESET COMMANDING function command enables the continuation of normal mode switching commanding after recognition of a failure condition and confirmed order to proceed with normal operation.
The ICU is running the application SW and monitoring/controlling the instrument
This mode shall be entered when an anomaly is detected by the ICU, which does not allow to continue operation of the instrument as pre-programmed in the command sequence but instrument equipment can remain switched on.

15.1.3.2.8 INS-DEC - Decontamination

An Instrument Decontamination mode shall be implemented if decontamination activities has to be conducted acc. to the contamination analysis or based on operational necessities identified by the satellite prime. This contamination analysis identified the necessity, the duration and the required system resources (interfaces, power profiles, etc.) to carry out this decontamination mode.
For all optical instruments, the need for an explicit instrument decontamination mode has been identified.
In this mode, the global thermal control typically will be adjusted such that sensitive parts of the instrument warms up to release condensed contaminants.
Decontamination mode is only required immediately after launch, with the exception of the ATLID redundant power laser head, which shall be decontaminated for a shorter period of time after failure of the nominal PLH.

15.1.3.2.9 INS-NOM - Normal Operation Mode

In the instrument Normal Operation Mode (INS-NOM) the instrument generate measurement data for any use case incl. calibration and characterisation and distribute these data to the science data interface according to the commanded operation profile. Normal Operation mode provides the environment for all instrument measurement activities, states and schedules:

- Calibrations
- Observation
- Additional measurement states

The ICU is running and monitoring/controlling the instrument. Other instrument equipment is switched on as required to fulfill the operation profile objectives.
The specific operation profile shall be indicated in the instrument sub-mode/state definition.
Thermal control shall provided by the ICU via the nominal power supply. The instrument shall be maintained within the nominal operation temperature range providing full instrument performance
For instrument Normal Operation Mode (INS-NOM) nominal power to the complete instrument is provided by the satellite. Survival heater power is no longer required by the instrument.

–

15.1.3.3 Nominal Instrument Mode Transitions

The initial condition of the instrument mode transition scheme is that the instrument is unpowered and that the thermal conditioning is provided by external means i.e. INS-OFF. This can be ensured by control of the environment as long as the satellite is in SAT-OFF or by provision of power to the survival heaters system of the instrument in SAT-PRE mode or higher satellite modes. A special case is given for transport and the launch preparation, execution and initial in-orbit phase where instruments does either have undeployed appendages, launch locks or protective covers. This instrument configuration and the related condition is characterised by the instrument launch mode (INS-LAU). The transition from INS-LAU to INS-OFF is established by external commanding e.g. release of the hold down mechanism of the CPR antenna via satellite controlled commands.
The transitions INS-NT-01 and INS-NT-02 correspond to external switch-on resp. switch off of the ICU internal power switch and start-up of the ICU boot software. The status of transition INS-NT-01 is reported by event report packets to the higher application levels. In INS-INI a basic operation capability set for command acknowledgment, dedicated event and status reporting, time synchrnoisation as well as essentially memory management is available. The external precondition is that the satellite power supply line for the ICU is switched on. This is ensured in the satellite normal operation mode (SAT-NOM).
The transition INS-NT-03 is initiated by loading and starting the ICU application SW via dedicated function command. For a smooth transition between boot SW operation and application SW operation some information need to be maintained, when a transition between Boot Software and Application Software or vice versa is performed:

(1) Actual Coarse Instrument Onboard Time
(2) Actual TMSP source sequence count for each TM packet category
(3) Actual SEU count
(4) Actual LOBT synchronisation status
(5) Actual ICU initialisation status
(6) Header of last received TC (necessary information to eventually generate execution completion report after commanded transition)
(7) History Log
(8) Death report
(9) Boot Report

The transition INS-NT-04 is triggered by the “Start transition to Init Mode” function command and corresponds to an intended reset of the ICU. In INS-SBY the full application SW operational capability sets are available. In INS-SBY the thermal conditions for switch on of instrument internal equipment are prepared. In INS-SBY basic configuration settings will be conducted

Triggering INS-NT-05 by "Start transition to INS-IDL" function command initiates a thermal transition strongly supported by switch-on of instrument equipment to the normal operation temperature environment. The steps and status of this transition are reported by appropriate event report packets as this transition is supposed to take considerable time. In the transition INS-NT-06 instrument internal equipment is switched off and INS-SBY thermal control settings are activated.
The normal operation mode of the instrument INS-NOM is reached via transition INS-NT-07. In the transition the front end is prepared for measurement executon incl. emission in case of active instruments. At the end of the transition the instrument executes is basic measurement. Individual operation profiles can be selected upon switching the instrument sub-mode upon command. The configuration of measurement profiles is in general possible but will only be activated upon the next sub-mode transition. The transition INS-NT-08 deactives measurement execution and for active instrument also emission of signals. This transition is used for suspension of instrument emissions, while maintaining the normal operation environment thus gaining short transition periods to recommence measurements according to the selected operation profiles i.e. INS-NOM sub-modes as well as for basic measurement configuration parameter updates if required.
The transitions INS-NT-09 and INS-NT-10 activate and deactivate the instrument decontamination mode. These are basically very similar to INS-NT-05 and INS-NT-06 but ends at other thermal environment conditions, thus also monitoring conditions. As this transitions are very similar they might be implemented equivalent to these but not stabilizing in INS-IDL but branching to the decontamination mode conditions.

15.1.3.4 Instrument Contingency Mode Transitions

When defining the corrective actions and the instrument safe modes one must keep in mind that removal of power from a processor eliminates the option of dumping the processor memory. However such a memory dump may provide additional evidence as to the cause of the failure which may otherwise be difficult to be analysed. Instrument Standby-Refuse and Idle-Refuse mode support those failure analysis.

15.1.3.5 Instrument Recovery Mode Transitions

Recovery procedures are to be executed only from ground after a failure analysis has been performed and it is confirmed that such a recovery or redundancy switch over does not impose any risk on the hardware. These recovery procedures will follow the lines of mode transitions the same way as described for Nominal Operations, in order to minimise the number of transitions and procedures.

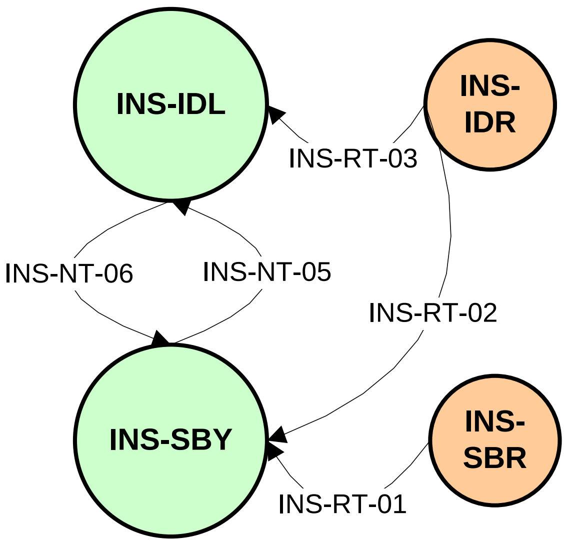


Figure 15.1-2 Instrument Safe Modes

All recovery procedures will bring the instrument back to one of its nominal modes from were nominal procedures can pick up operations again: Standby or Idle

15.1.4 Instrument Operability

The instrument operability is fully embedded in the EarthCARE operations architecture outlined in Chapter 5. The European EarthCARE instruments are essentially built on a common ICU architecture which allowed to instantiate some additional common operations feature which are identified hereafter.

15.1.4.1 Instrument Command and Control

Instrument specific command and control is provided by two different means. The user command and control particularly also the instrument mode and sub-mode management is provided by service 8 function management functions, while Instrument internal data exchange related functions are mainly provided by private services. The service 8 functions are subdivided in 4 main groups for maximum exploitation of a common, simple and effective operation scheme:

Service 8 - Function Management Service
Instrument Transition Functions (1 <= ID <=29)
ICU Internal Functions (30 <= ID <= 49)
ICU Instrument Functions (50 <= ID <= 149)
Instrument Functions (150 <= ID <= 255)

The main instrument mode transition control functions are commonly defined as given in following table. The instrument specific sub-mode transition control functions are using the sub-sequent function ID's.

Service 8 - Function Management Service Function Name Instrument Transition Functions (1 <= ID <=29)	Function ID
Function Reset Commanding	1
Function Transition to Standby	2
Function Transition to Standby-Refuse	3
Function Transition to Idle	4
Function Transition to Idle-Refuse	5
Function Transition to INS-NOM	6
Function Transition to Decontamination	7

The following common ICU internal functions are defined:

Service 8 - Function Management Service Function Name ICU Internal Functions (30 <= ID <= 49)	Function ID	BSW	ASW
Function Reset ICU	30	x	x
Function Scrubbing ASW	31		x

Service 8 - Function Management Service Function Name ICU Internal Functions (30 <= ID <= 49)	Function ID	BSW	ASW
Function BWL Setting Parameter	32		x
Function Start Self Test	33	x	x
Function EEPROM Write Protection Unlock	34	x	x
Function EEPROM Write Protection Lock	35	x	x
Function EEPROM Switch On	36	x	x
Function EEPROM Switch Off	37	x	x
Function WatchDog Enable	38		x
Function WatchDog Inhibit	39		x
Enable Scrubbing BSW Memory	40	x	x
Disable Scrubbing BSW Memory	41	x	x
Function Load ASW into RAM	42	x	x
Function Start ASW (goto SBY)	43	x	x

15.1.4.2 Instrument Reports

Common Instrument Reporting Service

The European EarthCARE instrument feature one common private service, which manages instrument dedicated common reports (Boot report, Death Report and Instrument History Log) , which needs to be available in INS-INI, i.e. the boot software as well as in INS-SBY and higher instrument modes, i.e. in the applications SW.

All the reports contain common and instrument specific parts.

Instrument Common private service type and sub-types			
Service	Sub Service		Name
			Service 199 - Instrument Reports Service
199	1	TC	Reset Boot Report
199	2	TC	Dump Boot Report
199	3	TM	Boot Report
199	4	TC	Dump Death Report
199	5	TM	Death Report
199	6	TC	Reset History Area
199	7	TC	Dump History Area
199	8	TM	History Area Report

Boot Report:

The Boot Report will contain the following execution environment information :

- Boot Software Version Identifier,
- Boot Report Progress Indicator,
- Boot Report Test Status,

- Boot Report Status.
- BSW function during which the failure occurred;
- All affected parameters;
- Suspected devices identification;
- Suspected data partition identification;
- Type of failure;
- Failing address register information e.g. to report the first failing address of the PM Communication RAM .as detected by the PM Communication RAM Boot Test.

Death Report

A death report will be generated if the on-board watchdog timeout triggers or a reset is commanded, which forces the ICU to reboot to INS-INI. On reception of an EQSOL signal no death report will be generated. .

Instrument History Log

The History Area is a fixed length 1024 byte area used to record occasions of: Received telecommands; Generated Events; Instrument Mode Transitions. Each entry in the history area is of a fixed format, where the Parameter array is populated according to the type of entry. The structure for a single entry in the History Area is shown in the following table

Field Name	Data Size (bits)	Comment						
Coarse_Entry_Time	32	copy of PS FPGA LOBT coarse Timer Register at start of schedule						
Fine_Entry_Time	24	copy of PS FPGA LOBT fine Timer Register at start of schedule						
Entry_Code	8	0 – Not Used, 1 Transition	–	Receive TC, 2	–	Event, 3	–	Mode
Parameter_1	32	Use dependant upon Entry Code						
Parameter_2	32	Use dependant upon Entry Code						
Parameter_3	32	Use dependant upon Entry Code						
Parameter_4	32	Use dependant upon Entry Code						

If the Entry_Code indicates a Received TC entry then the Parameter fields are populated as:
- Parameter_1 is PUS Service Type
- Parameter_2 is PUS Service Sub-type
- Parameter_3 is PUS Function Id
- Parameter_4 is 0 – Internal TC Source, 1 – External TC Source.

If the Entry_Code indicates an Event entry then the Parameter fields are populated as:
- Parameter_1 is Event Id
- Parameter_2 is Data Value
- Parameter_3 is Value of limit breached.
- Parameter_4 is Not Used. Read as zero.

If the Entry_Code indicates a Mode Transition entry then the Parameter fields are populated as:
- Parameter_1 is Mode Transition Id
- Parameter_2 is Not Used. Read as zero.
- Parameter_3 is Not Used. Read as zero.
- Parameter_4 is Not Used. Read as zero.

15.1.5 Instrument Thermal Control

As part of the common service capability a standard thermal control service allowing a table driven SW based thermal control is available. The European instrument (ATLID, BBR and MSI) implements thermal control as private sub-types of this common service. Dedicated tables allow instrument mode dependent thermal control

The following private sub-type extensions are defined:

Instrument Thermal Control Service Extension			
Service	Sub Service		Name
			BBR
149	100	TC	Start Thermal Control
149	101	TC	Stop Thermal Control
149	102	TM	Modify Therma Contro Settings Table
149	103	TC	Down Link Heater Control Table
149	104	TM	Heater Control Table
149	105	TC	Modify PRT Heatl Status Table
			MSI
149	130	TC	Start Thermal Control
149	131	TC	Stop Thermal Control
149	132	TC	Enable Thermal Control Loop
149	133	TC	Update Thermal Control Loop Parameters
149	134	TC	Report Thermal Control Loop Parameters
149	135	TM	Thermal Control Loop Parameters Report
149	136	TC	Update Thermal Control Loop Temperature Pair TC
149	137	TC	Set Thermal Control Loop Monitor TC
149	138	TC	Set Peltier Cooler Constant Current TC
149	139	TC	Set Peltier Cooler Hot Side Threshold TC
149	140	TC	Set Heater Constant Power TC
			ATLID
149	160	TC	Start Thermal Control
149	161	TC	Stop Thermal Control
149	162	TC	Set Heater Line
149	163	TC	Update Thermal Control Loop Parameters
149	164	TC	Report Thermal Control Loop Parameters
149	165	TM	Thermal Control Loop Parameters Report
149	166	TC	Update Thermal Control Table
149	167	TC	Report Thermal Control Table
149	168	TM	Thermal Control Table Report
149	169	TC	Load Thermal Control Table

Table 15.1-2 Instrument Extension of Thermal Control Service

Details of the thermal control of the individual instruments are provided in the instrument dedicated design descriptions (see reference documents)

15.1.6 Instrument FDIR

The instrument FDIR is fully autonomous w.r.t. failure isolation with the exception of failures visible only by monitoring of the standard TM interfaces acquired by the satellite or upon selected event report identifications requesting an external interaction at the S/C - Instrument I/F level from a higher level application.

From S/C side the Mil Bus communication to the instrument is monitored.

In case of MIL bus communication failures with one instrument this is interpreted as malfunction of the instrument ICU. The satellite reaction on such a malfunction, preventing normal MIL bus communication is to command an OFF and ON cycle via the unit switches of the active ICU to trigger the instrument safe initialisation sequence to INS-INI mode.

In case that the S/C identifies a communication problem with more than one instrument including consideration of other payload MIL bus remote terminals the EQSOL signal is triggered initiating the instrument transition to INS-INI mode.

15.2 ATLID

15.2.1 Measurement principle

ATLID is an atmospheric lidar operating in the UV range. The generic principle consists in emitting short laser pulses towards the atmosphere. A small part of the light is backscattered towards the instrument by aerosols or molecules, collected by a telescope, filtered and focused on detectors. The detection chain acquires the signal in order to determine the backscattered intensity versus arrival time, hence the distance to the observed atmosphere layer. The laser pulses are emitted at a repetition rate of 51 Hertz along the ground track, such that the data from subsequent shots can be locally averaged for improving the signal to noise ratio.

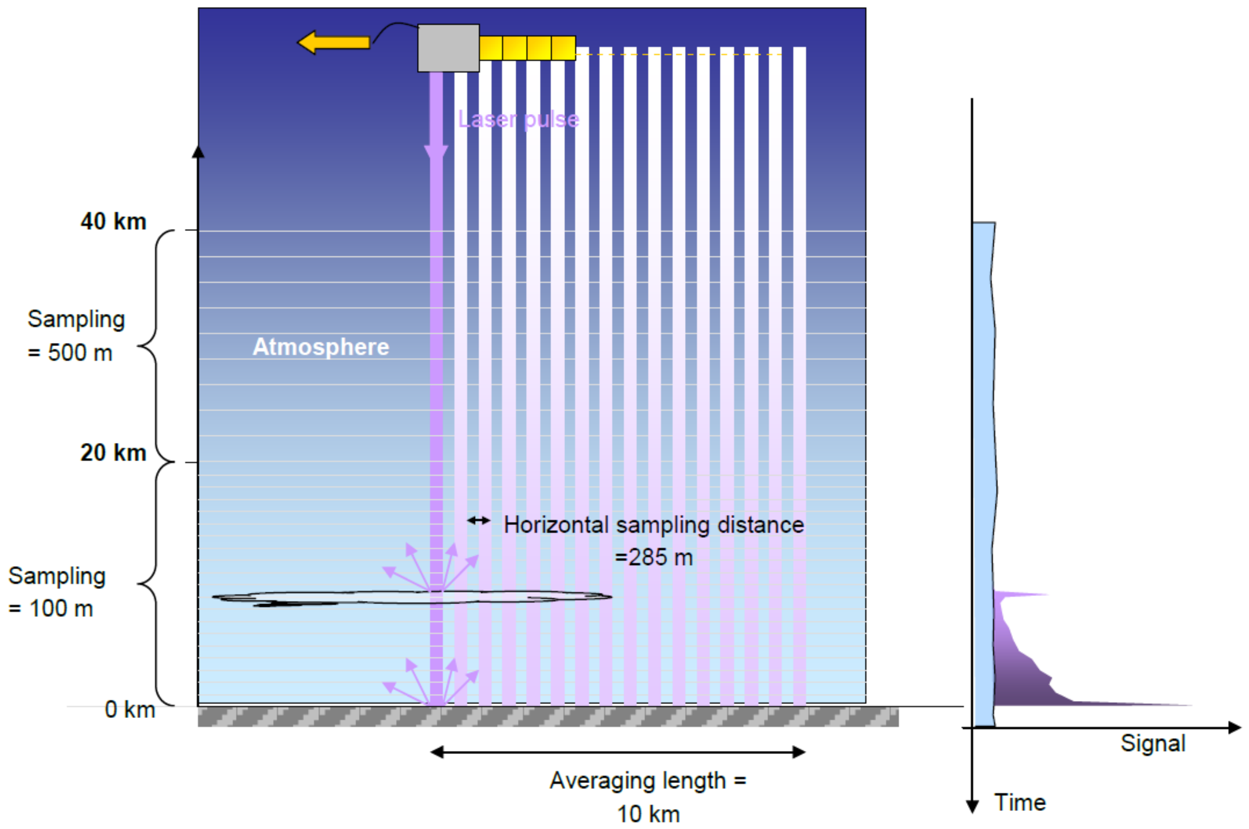


Figure 15.2-1: ATLID measurement Principle

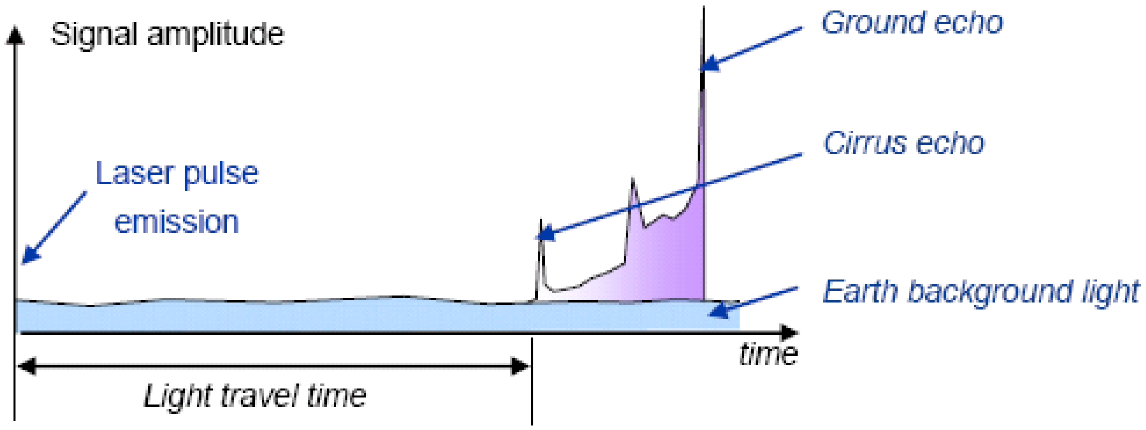


Figure 15.2-2: The analysis of atmosphere echo allows retrieving clouds top altitude as well as aerosol or molecules backscatter profile

The retrieval of thin cloud optical depth and aerosols physical parameters requires the knowledge of both backscattering contributions of molecules (Rayleigh scattering) and aerosols (Mie scattering). The measurement principle uses the fact that interaction of light with molecules or aerosols lead to different spectra. Whereas the Brownian motion of molecules induces a wide broadening of the incident light spectrum, the single scattering with an aerosol do not affect the spectrum shape of the incident light. As a consequence, a simple means of separating the contributions consists in filtering the backscattered spectrum with a high spectral resolution filter centred on central wavelength, as depicted on Figure 15.2-3.

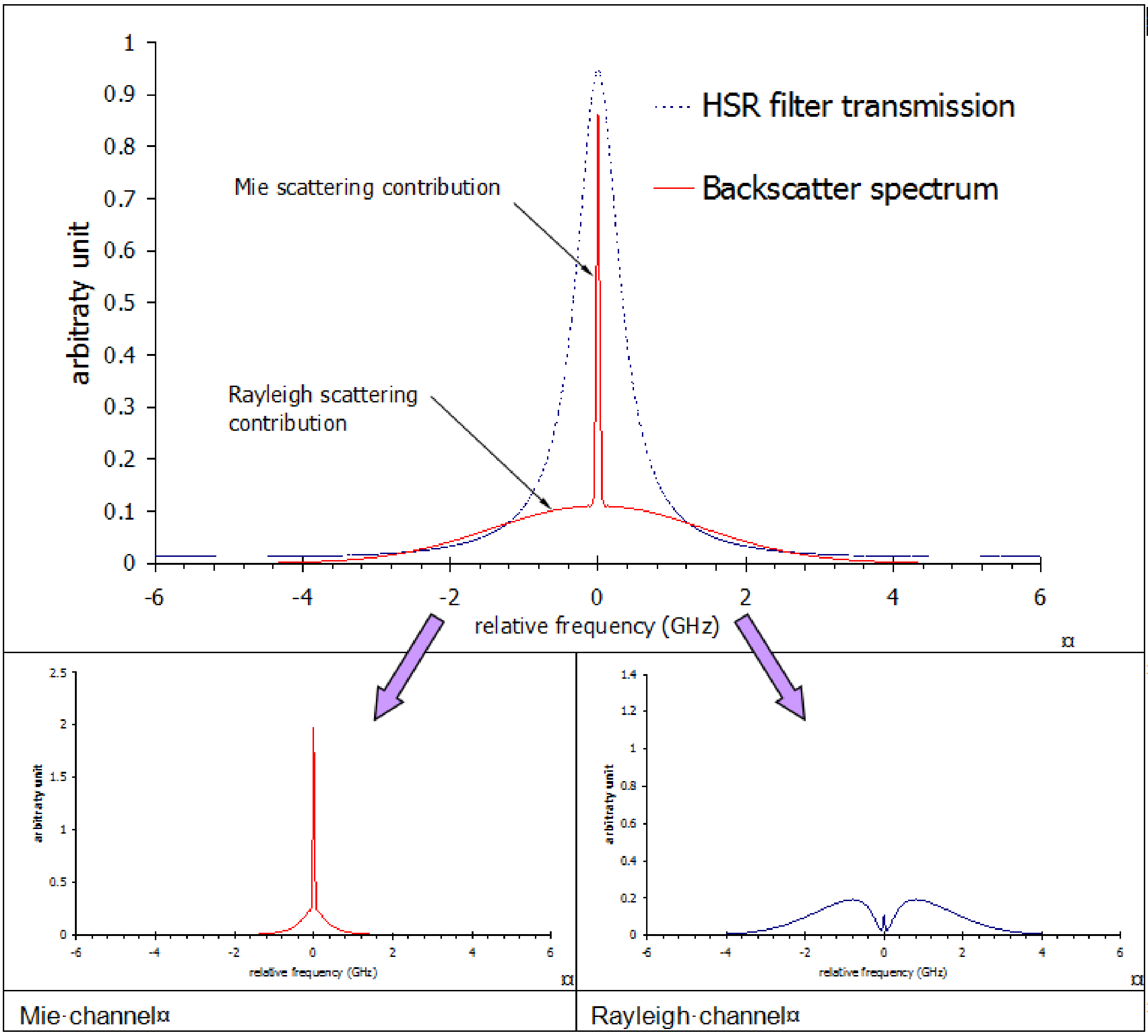


Figure 15.2-3: Principle of Mie/Rayleigh separation with high spectral resolution filter. Most of the Mie scattering contribution is directed towards the Mie channel whereas most of the Rayleigh scattering contribution goes to the Rayleigh channel

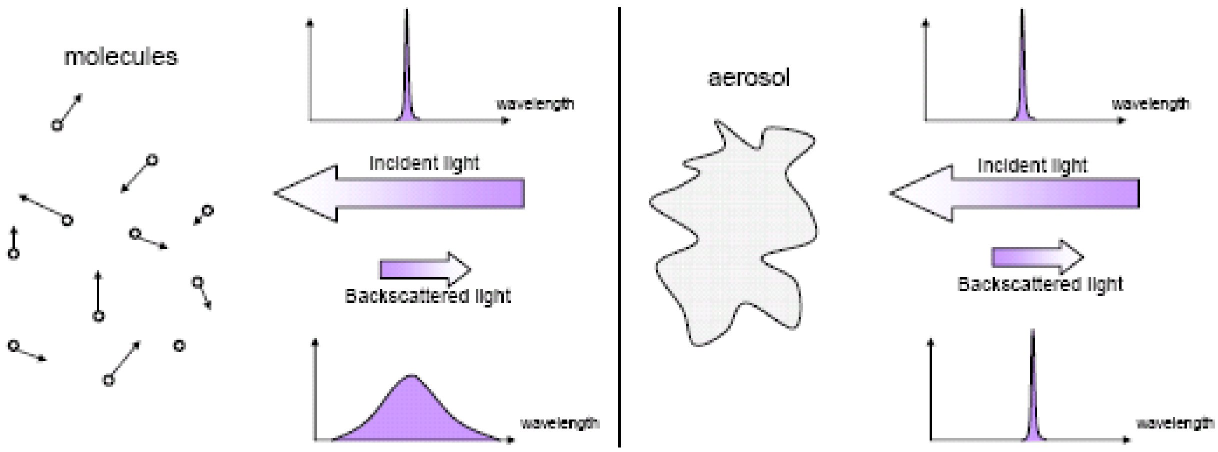


Figure 15.2-4: Interaction with molecules (left) and aerosols (right) respectively lead to broadened spectrum or unaffected spectrum shapes

This operation can be implemented by means of a narrow bandwidth Fabry-Perot etalon, consisting of two parallel reflective plates that act as an optical cavity. This cavity transmits a certain number of well defined wavelengths separated by what is called the free spectral range. When tuned on the backscattered flux central wavelength, the etalon transmits most of the Mie scattered flux (narrow bandwidth spectrum) and reflects most of the Rayleigh scattered flux. The adjunction of the combination of a polariser and a quarter wave plate at the entrance of the etalon allows redirecting the reflected flux (Rayleigh contribution) to the Rayleigh channel.

15.2.2 ATLID Design

ATLID is designed as a self-standing instrument reducing the mechanical coupling of instrument/platform interfaces and allowing better flexibility in the satellite integration sequence.

The lidar functional architecture is organised in four main functions, namely the transmitter, the receiver telescope, the receiver chain and the control unit called ATLID Control and Data Management (ACDM) unit.

The emitter includes the power laser head and its transmitter laser electronics, a beam steering mechanism for ensuring co-alignment of the emitting and receiving lines of sight over the mission life time, and a beam expanding optics. The laser is a highly stable single-mode laser emitting at 355 nm (tripled frequency of a Nd:YAG laser) and therefore requires a reference laser seeding the laser oscillator.

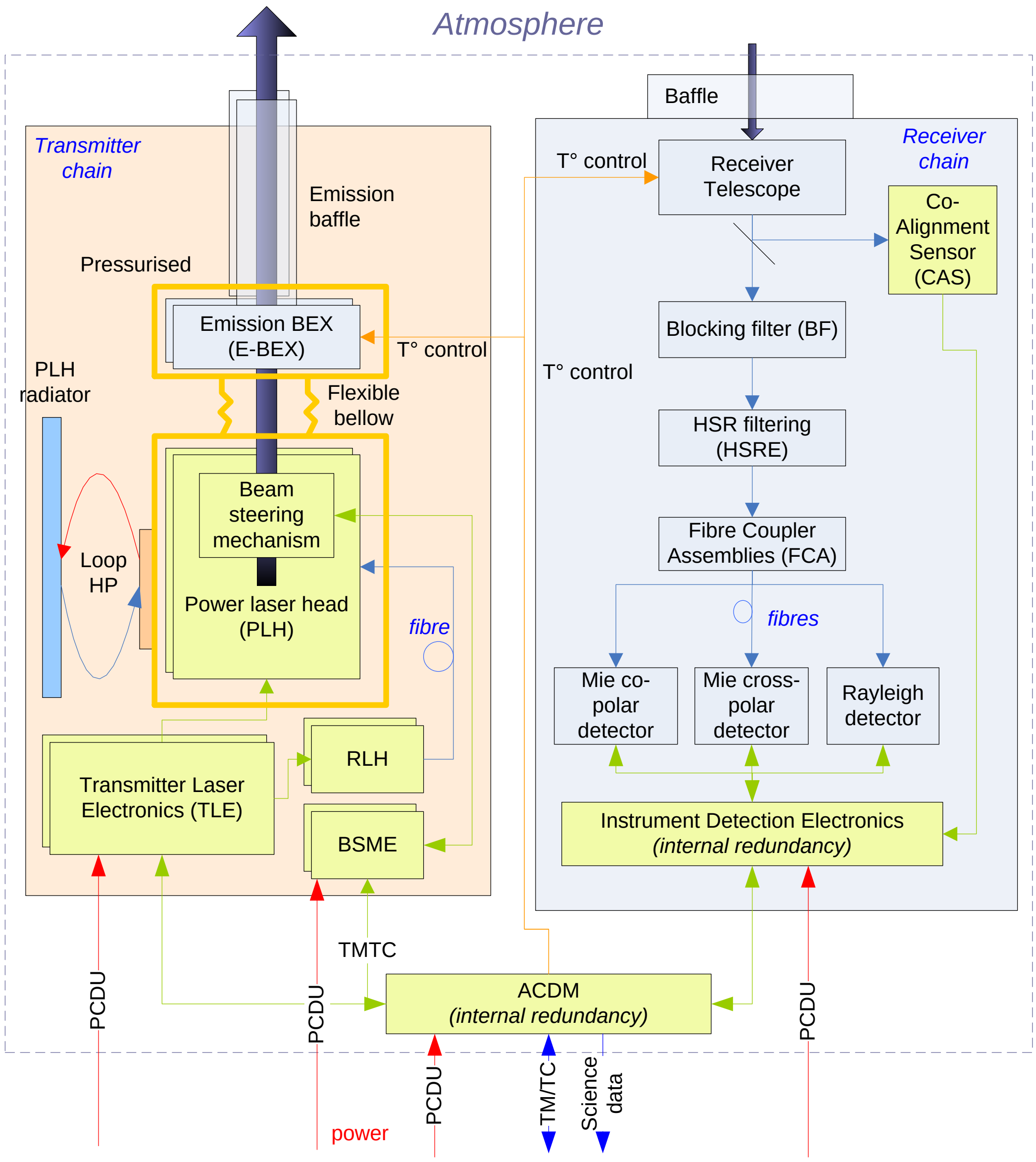


Figure 15.2-5: ATLID instrument block diagram

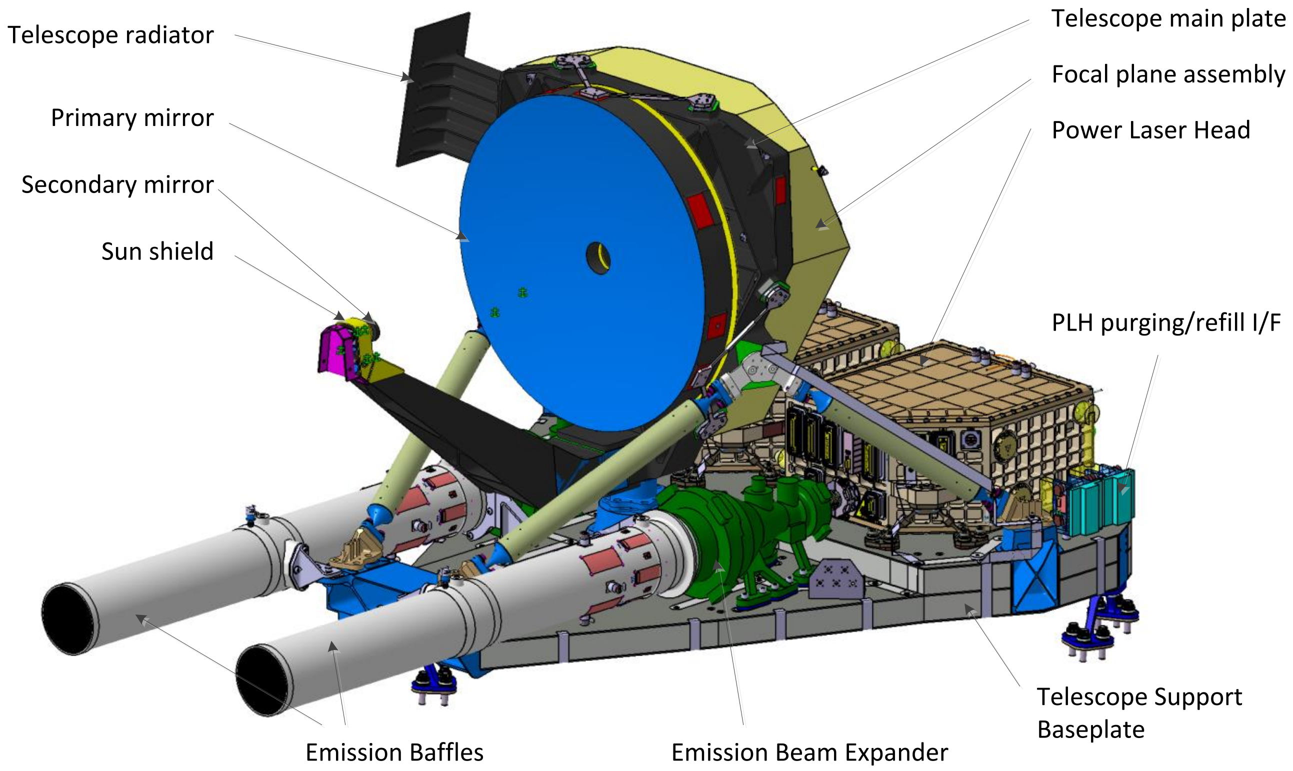
The receiving telescope is an afocal Cassegrain aiming at collecting the backscattered light and providing a large magnification ratio to reduce effect of internal misalignments.

The receiver implemented at the back of the telescope includes a High Spectral Resolution filter and a co-alignment sensor (remark: following the ATLID CDR, the background filtering etalon BKGE has been removed from the receiver chain). The signal is transported to the detectors by means of fibre couplers, which allows deporting the whole detection chain to the cold anti-sun wall of the instrument. The receiver also includes all the detection functions that range from the detector to the analog-to-digital converter.

The control and data management unit ensures the following electrical functions: 1) synchronisation between laser emission and data acquisition ; 2) data processing and data stretching toward the S/C ; 3) co-alignment sensor images processing and co-alignment loop control algorithms ; 4) thermal regulation functions ; 5) TM/TC and commandability/observability management.

The instrument design relies on re-use of technologies developed for the ALADIN wind lidar for the Aeolus mission as the single-mode pulsed laser transmitter, memory CCD detector, receiver high spectral resolution spectral filter. Moreover, the design worked-out since beginning of feasibility phases now features further improvements and innovations which are implemented to match the ATLID mission demanding objectives:

- an improved read-out stage for the memory CCD, which allows quasi photon-counting with a total noise in darkness of 2 to 3 e- rms per sample,
- a fibred receiver allowing decoupling of detection units and focal plane assembly, for mechanical and thermal aspects as well as for development aspects,
- mini loop heat pipes for evacuation of the laser heat,
- sealing and pressurization of the power laser head to tackle the contamination issue and secure in-flight performances,
- bistatic design with full separation of emission and reception paths. This design was selected to reduce cross-coupled contamination between receiver and emitter, as well as allowing a full pressurization of the emission path. The instrument overview is shown in Figure 15.2-6.



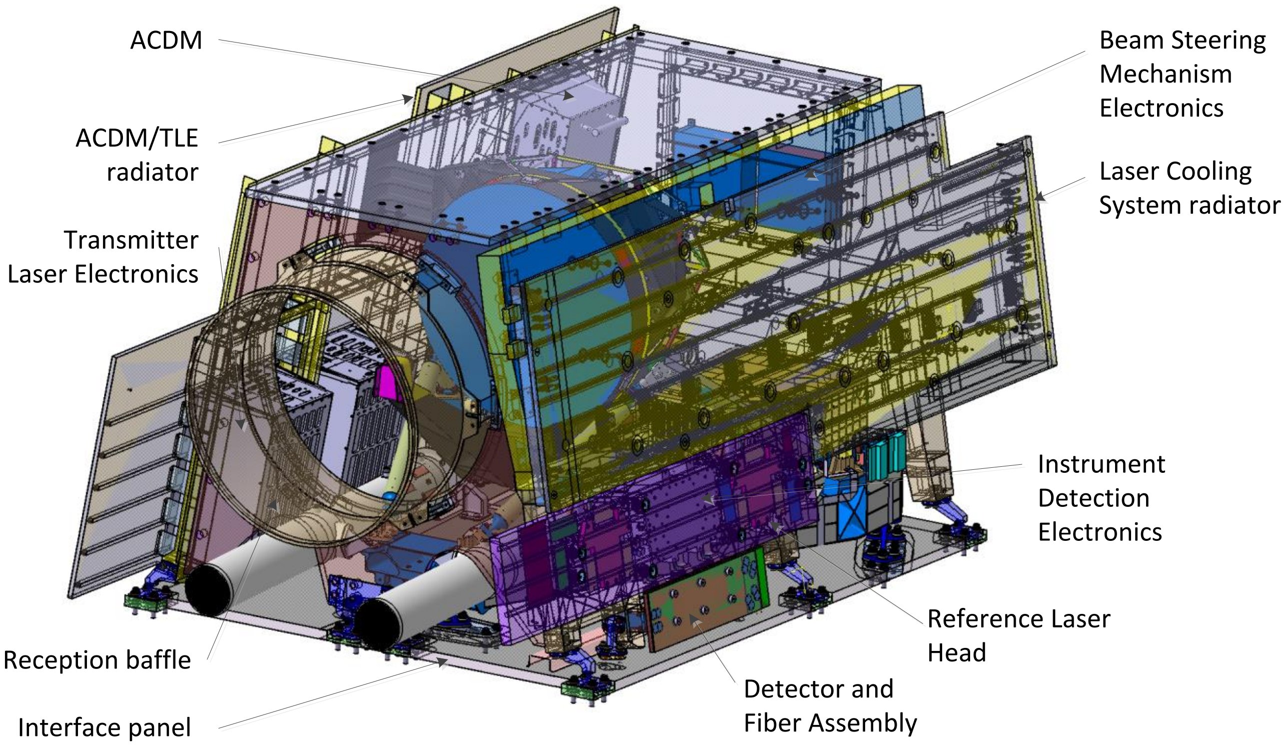


Figure 15.2-6: ATLID Instrument Design Overview

Optical design

The optical design is based on a bistatic architecture. This architecture was selected with the objective to separate the emission and reception functions allowing a full pressurisation of the emission path. An afocal 620 mm diameter Cassegrain telescope is used in reception, with a high magnification ratio. The receiver field-of-view is thus kept below 65 µrad, minimising the shot noise associated with the acquisition of Earth background signal.

The design is based on an all-Silicon Carbide mirror and mounts, designed by AirbusDS SAS and manufactured by Mersen.

Figure 15.2-7: ATLID Telescopeready for FPA integration (primary mirror made of SiC)

The receiver optical design performs a separation of polarisation (co-polarised and cross-polarised signals) and spectral components (Mie or Rayleigh scattering contributions) with the constant goal to limit the cross-talks between each of the three channels, namely the Mie co-polarisation, the Mie cross-polarisation and the Rayleigh channels. Several filtering stages (narrow-band interference filter, spatial filter and Fabry-Perot etalons) are required to achieve such purity and to reject the high amount of Earth background signal around the narrow laser wavelength.

The High Spectral Resolution Fabry-Perot etalon (HSRE) features narrow bandwidth of the order of 0.3pm, so that separation of the Mie and Rayleigh backscatter signals can be efficiently performed. The design developed by RUAG and SESO is inheriting from Aladin spectrometers (Figure 15.2-9) and is based on a combination of polarizing beam splitters and a Fabry-Perot etalon.

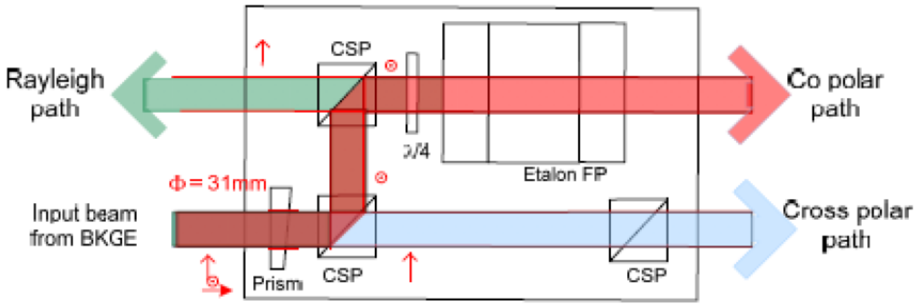


Figure 15.2-8: ATLID High Spectral Resolution Etalon optical concept

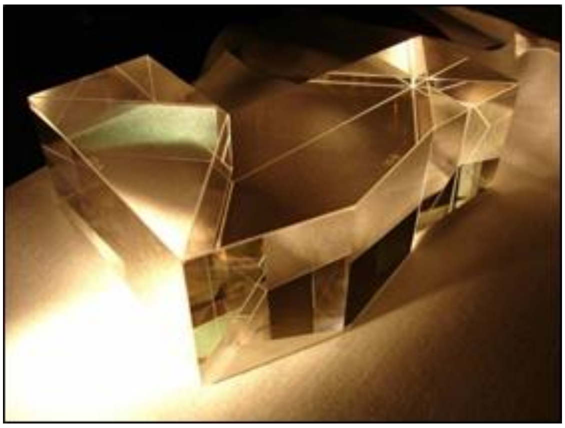



Figure 15.2-9: HSRE etalon (left) and HSRE Prisms Assembly (right)

The spectral co-registration approach consists in periodically tuning the laser transmitter frequency to the high spectral resolution filter peak transmittance by sweeping the laser frequency over its tuning range and estimating from the signal distribution on Mie and Rayleigh channels the best frequency command.

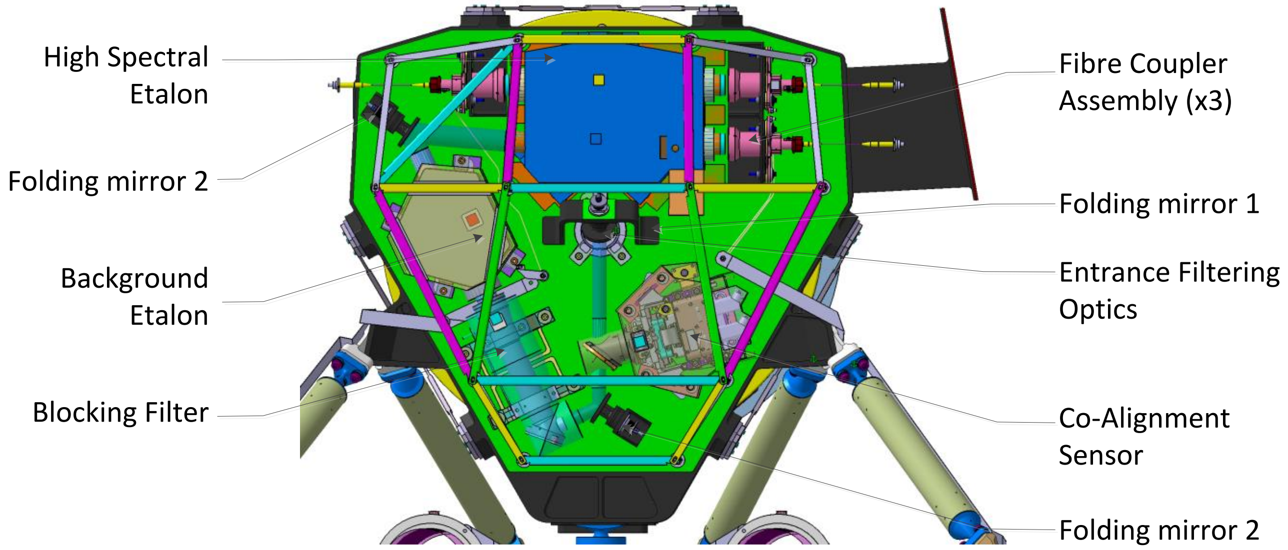


Figure 15.2-10: ATLID receiver layout (Background etalon still visible, but agreed to be removed following ATLID CDR)

Low noise detection chain

The ATLID detection chain shall be able to measure single photon events to meet the worst case radiometric performance requirements. Therefore, a high response together with an extremely low noise is necessary to fulfill the signal acquisition requirement. As for ALADIN instrument, ATLID encompasses a memory CCD. The ATLID design performs fast sampling of the echo signal (1.5 MHz corresponding to 100 m vertical sampling distance) and on-chip storage of the echo samples which allows delayed read-out at very low pixel frequency (typically below 50 kHz). Combined with an innovative read-out stage, the detection chain provides an extremely low read-out noise (< 3e- rms per sample). Accumulation of several consecutive echoes on the chip is possible with the detector design, enhancing the acquisition chain radiometric performance. The detector is developed by E2V while the detection chain electronics is developed by CRISA.

Transmitter requirements and design

The laser transmitter of ATLID instrument shall deliver high energy pulses at a repetition rate of 51 Hz corresponding to 140 m ground horizontal sampling. The Pulse Repetition Frequency has been lately changed allowing a relaxation of the Master Oscillator requirements while using the amplifier with the same operation mode as for Aladin development. More than 35mJ at 355 nm (tripled Nd:YAG wavelength) are required at laser output to meet the instrument radiometric performance. At the same time, high frequency purity (line-width of typically 50 MHz) and extreme stability (50 MHz on one month time scale) are mandatory in order to separate the Mie and Rayleigh scattering contributions by High Spectral Resolution technique.

This is achieved by a transmitter architecture based on three sub-systems:

- A reference laser head (RLH) providing a continuous laser seeding signal which frequency is permanently controlled in closed-loop with respect to an ultra-stable reference cavity.
- A power laser head (PLH), shown in Figure 15.2-11, injected by the reference laser by means of an optical fibre. It generates the laser pulses in its master oscillator section, amplifies the resulting pulses through its amplifier section, and then converts the 1064 nm laser signal into the 355 nm wavelength in its higher harmonics generation section. The q-switched master oscillator is generating single frequency laser pulses of about 6 mJ. The oscillator cavity is folded several times for compactness reasons and the rod shaped active material is laser diode pumped in a redundant configuration. The output of the master oscillator is then amplified in a double pass amplifier delivering about 150 mJ. The zig-zag slab amplifier is double side pumped with a total of eight laser

diode stacks of about 700 W (derated) peak output power each for 0.2 ms duration. The second and third harmonic generation LBO-crystals are placed after the power amplifier to generate up to 50 mJ in the ultraviolet (355 nm).
- A transmitter electronics unit which contains all the control and power electronics needed for the operation of previously described PLH and RLH, and provides the TM/TC interface to the ATLID control unit.

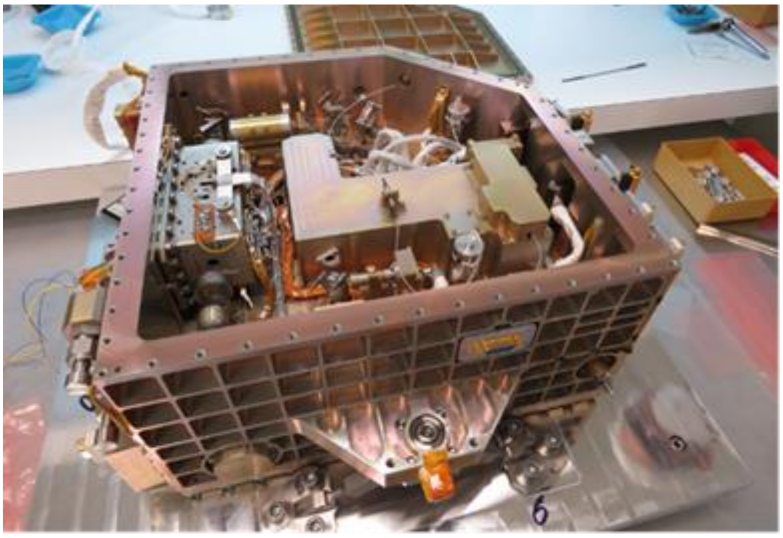


Figure 15.2-11: ATLID power laser head

A significant evolution of the laser design with respect to the ALADIN transmitter lies in the fact that ATLID power laser head is sealed and pressurized. This improvement ensures more stable operating conditions to the sensitive components of the laser, and allows to isolate the laser internal space from surrounding contaminants over the ground and operational lifetime. Pressurization of the power laser head improves tolerance to laser induced contamination, which is the degradation of an optical surface resulting from the interaction of molecular contamination with a high laser illumination level. Such a pressurised design has been extended to the whole emission path, including the beam expanding optics. The laser transmitter is developed under the prime leadership of Selex Galileo sub-contractors Quantel for the development of the amplifier and laser diodes, TESAT for the Reference Laser Head.

An Emission Beam Expander is used to further expand the laser beam and reduce the laser beam divergence to about 45 microradians so that it is coupled within the narrow receiver field of view.

The expansion of the beam brings also a significant reduction of the energy density on the last optics submitted to vacuum, thus beneficial for minimizing risk of laser induced damage and contamination. An expansion of about 7 is achieved through a 3 lens design bringing the beam to more than 100mm diameter. The Emission Beam Expander is developed by SODERN.

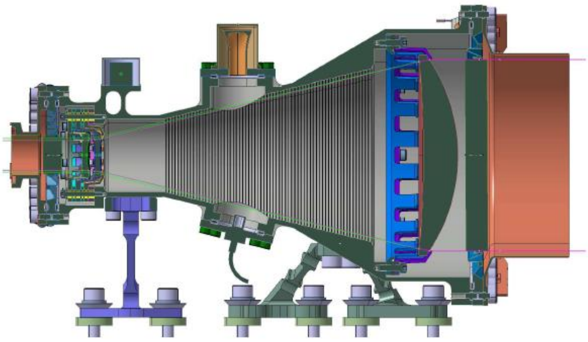
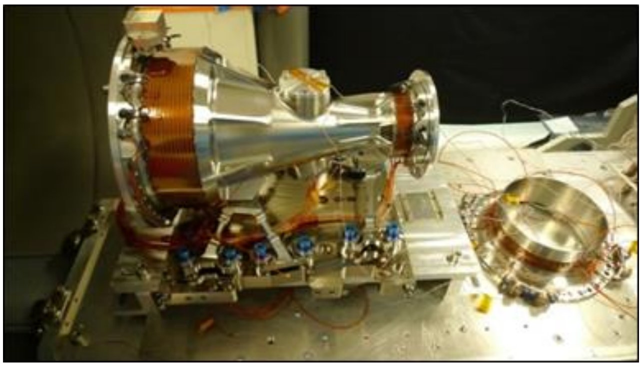



Figure 15.2-12: Emission beam expander

Co-Alignment Sensor

The instrument is equipped with a Co-Alignment Sensor that is aimed at measuring the direction of the laser emission with respect to the receiver field of view. The measured information is fed back to a beam steering mechanism correcting for any mis-pointing of the laser. The control loop is operated at low speed as it corrects mainly the initial bias after launch and variation in the line of sight due to thermo-mechanical deformations along the orbit and lifetime of the instrument.

The Co-Alignment Sensor is a small camera measuring the integrated backscatter signal from ground to top of the atmosphere. It includes the following functions as rejection of the solar background, separation of the optical signal with the scientific channels, acquisition and sampling of the integrated signal with a CCD. The camera is developed by a consortium led by CRISA.

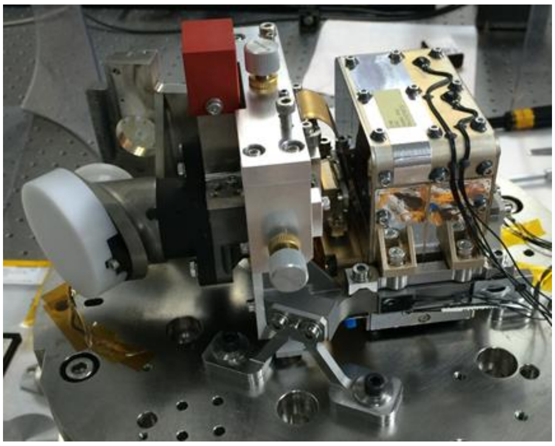


Figure 15.2-13: Co-Alignment Sensor (CAS)

Thermal control design

Another innovation is related to the thermal control of the power laser head. This sensitive active sub-system presents high heat dissipation (around 150 W) and requires stable interface temperature (0.5K). Mini loop heat pipes are used in ATLID design to efficiently evacuate the laser heat while offering a low stiffness mechanical interface ; the flexible pipes which transport the ammonia from evaporators to the anti-sun side radiator allow a good mechanical decoupling of the laser with respect to its radiator, thus minimising the stress experienced by the laser optical bench. This new technology was successfully validated in flight during FOTON experiment, and a life test has been running for the last 2.5 years to demonstrate the lifetime of such devices. High conductance, low sensitivity to gravity orientation during ground tests are other decisive advantages which make the loop heat pipes preferable to standard heat pipe technology for ATLID application.

15.2.3 ATLID Operations

ATLID main operations can be split in 3 parts.

- First of all ATLID is warmed up from OFF mode up to MEASUREMENT mode where Laser shots are initiated. This is called the “preparatory phase”. An overview of this phase is provided in Figure 15.2-14. In this phase, ATLID receives a sequence of Mode Transition (MT) macrocommands spread over a time line. For each MT macro-command, ATLID generates a sequence of elementary commands that allows the correct initialisation and warming of all downstream units (IDE, TXA, LCA, CAS) and instrument thermal control by using the tables of parameters that the User had loaded.
  In this phase, there are 2 long mode transitions of about several hours, the one to enter in READY mode and the one to enter in MEASUREMENT mode. The first one allows stopping the loop heat pipes inhibition and bringing PLH above diodes minimum start-up temperature. The second starts with the switch-on of the laser diodes, first at intermediate power (sufficient to start the loop heat pipes), then at nominal power pulsed at 51 Hz but no laser shots are generated (the Q-switch of laser cavity remains closed). This long transient allows to reach a stable temperature operating point, mainly on TXA side (especially inside the PLH amplifier slab), in order to be able to enter safely in MEASUREMENT mode where laser shots are initiated.
- Secondly, in MEASUREMENT mode, ATLID is operated nominally with a repetitive sequence of BRC (Basic Repetition Cycle) where TXA is pulsed at 51 Hz. The radiometric calibration is carried out during the normal measurement flow. The calibration parameters are extracted by proper echo selection and post processing. The main radiometric calibration sequences are:
  - Earth background light is estimated before and after each echo, which allows an accurate offset subtraction on each echo.
  - The spectral cross-talks are continuously monitored by applying a dedicated processing on stratospheric backscatter (assumed to contain pure Rayleigh backscatter) and cloud/ground echoes.
  - The lidar constants of each channel are calibrated using the atmosphere backscatter (stratosphere and ground echoes) in conjunction with backscatter prediction model and selected test site with known ground albedo and atmosphere optical depth.
  - Provision is made for regular detection dark signal calibration for potential compensation of dark signal non-uniformity, even if the low operation temperature of detector (-30°C) makes this offset theoretically negligible.
- Thirdly, some calibration activities can be done on a regular basis. This task is under User control and can be performed easily by sending MT macro-commands in order to enter in the desired Shooting Calibration (ST) sub-mode :
  - A calibration of the co-alignment control loop can be performed to determine the rough initial pointing offset
  - Coarse and Fine Spectral Calibration procedures can be executed to adjust laser emission frequency to the spectral transmission of the receiving channels
  - The Emission Defocus can be calibrated to optimize the divergence of the laser emission beam
  - Spot position on the detection channel CCDs will be determined regularly by operating the detector in imaging sub-mode (IM). In case of spot location discrepancies a programmable delay can be applied to ensure good acquisition simultaneity. (1 minute, once per month)
  - Laser diode temperature adjustment (LTDA) will be performed regularly by measuring pulse energy as a function of the heating pulse energy. (45 minutes, once per month). The optimum Laser frequency will be adjusted in order to determine the maximum transmission on the Mie co-polar detection channel (10 minutes per week Fine Spectral Calibration (FSC) & 50 minutes Coarse Spectral Calibration (CSC) in commissioning phase). The atmospheric echo is acquired with the same operation sequence as nominal measurement.

  Once a calibration sub-mode is elapsed, ATLID returns automatically in MEASUREMENT mode. The User can then perform a time line of such MT macro-commands in order to perform the Maintenance Calibration Phase (MCS). For each of the CSC, FSC, LDTA sub-modes, ATLID presents a table of parameter that the User can modify prior this MCS phase. While for IM sub-mode, the detection simply enters in its IMAGING sub-mode instead of LIDAR.

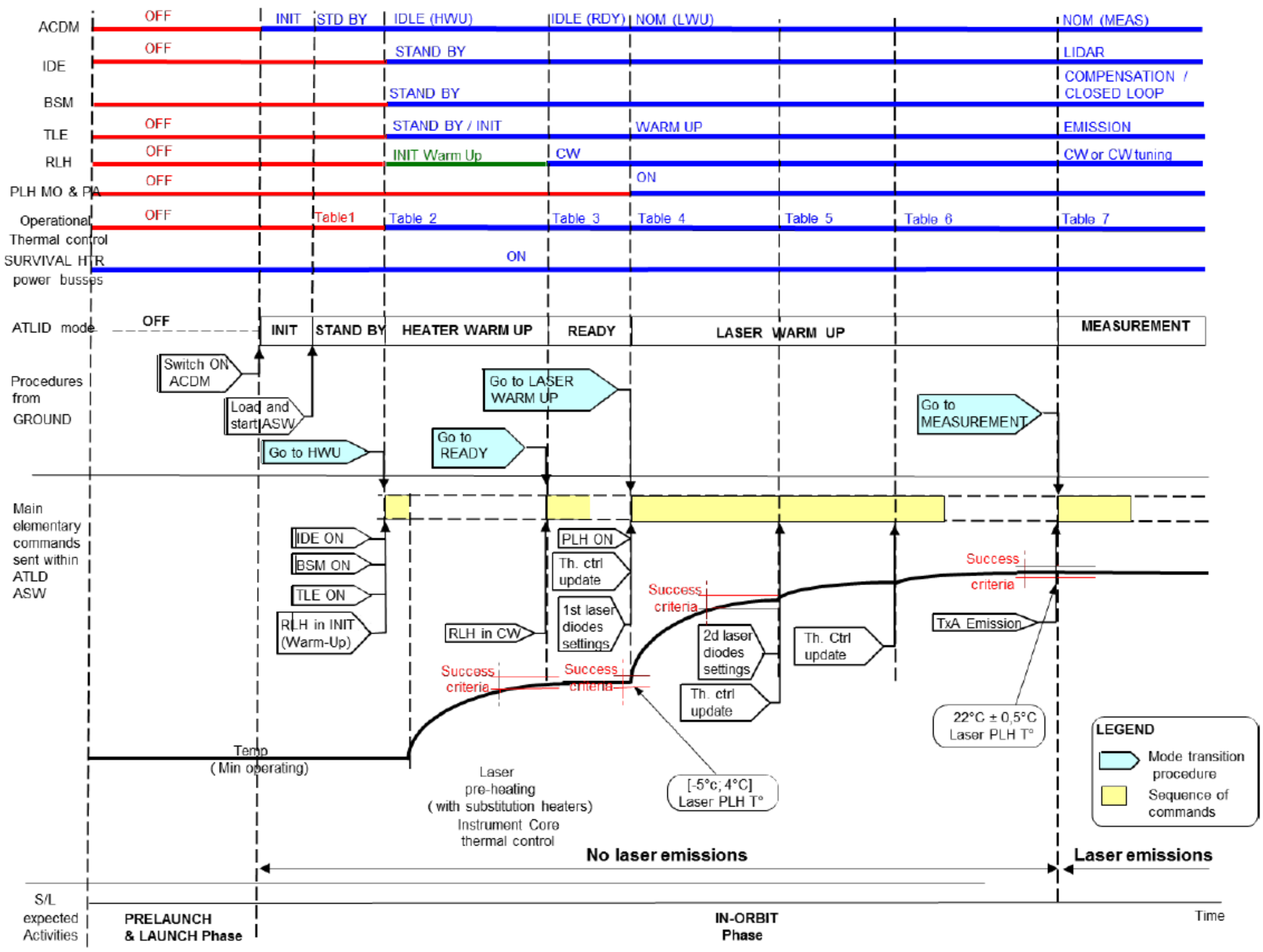


Figure 15.2-14: ATLID switch-on operation summary

15.2.4 ATLID Interfaces and Satellite level Instrument Redundancy Selection

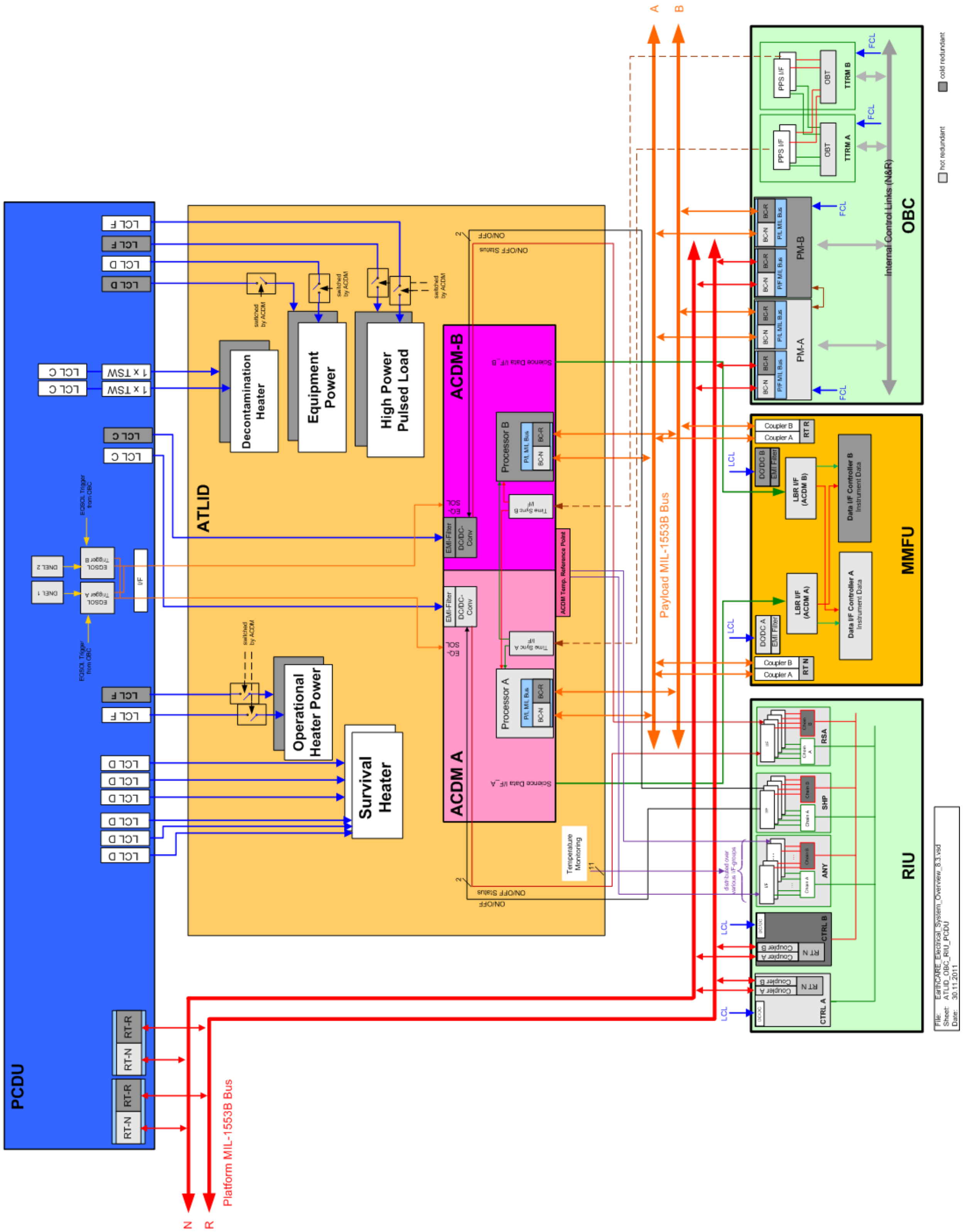


Figure 15.2-15 Satellite ATLID operational interfaces

The detailed ATLID instrument redundancy configurations are given in [RD-116]

15.2.5 ATLID Instrument Modes and Mode Transitions

15.2.5.1 ATLID Modes and Sub-Modes

The ATLID instrument activities are organised around the following ATLID instrument modes:

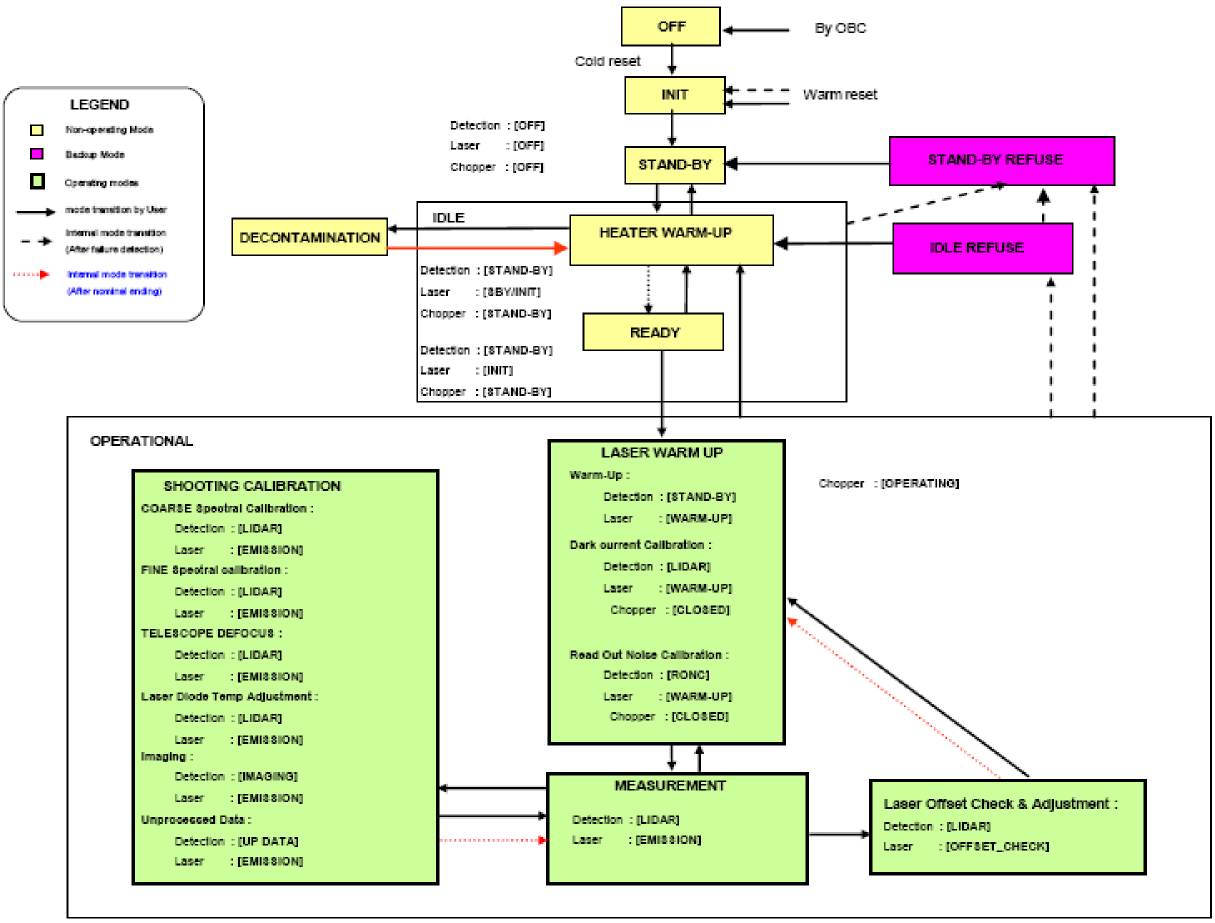


Figure 15.2-16 ATLID instrument Modes and mode transitions

Further details of ATLID instrument modes and sub-modes are given in [RD-40] and [RD-41].

15.2.5.2 ATLID Mode Transitions

ATLID mode and sub-mode transitions are detailed in [RD-40] and [RD-41].

15.2.6 ATLID Instrument Operability

ATLID instrument operability follows the generic principles given in section 15.1.4 and is specifically detailed in [RD-40] and [RD-41].

15.2.7 ATLID Command and Control

ATLID is essentially operated via standard services of the Core PUS [AD-110], the before mentioned common instrument services and service 8 function and a set of instrument specific services and service 8 functions.

For ATLID monitoring and control the following specific private services are defined consistently with [AD-110] Volume B

Instrument	ATLID		
Private Services	type	subtype	Description
Monitoring and Control Services	227		Operational Parameters
	228		Serial Lines
Common Reporting Service	199		Instrument Reports

For ATLID specific high level operational control the following service 8 functions are provided and used:

Service 8 - Function Management Service Function Name Instrument Transition Functions (1 <= ID <=29)	Function ID
Function Transition to Ready	8
Function Transition to Heater-WarmUp	9
Function Transition to Laser-WarmUp	10
Function Transition to Measurement	11
Function Transtion to Dark Current Calibration	12
Function Transition to Read Out Noise Calibration	13
Function Transition to Co-alignment Calibration	14
Function Transition to Coarse Spectral Calibration	15
Function Transition to Fine Spectral Calibration	16
Function Transition to Telescope Defocus	17
Function Transition to Laser Diode Temperature Adjustment	18
Function Transition to Background Etalon	19
Function Transition to Imaging	20
Function Transition to Unprocessed Data	21
Function Transition to Laser Offset & Check Adjustment Calibration	22

15.2.8 ATLID Science Data

The ATLID science data are provided by the following private services consistently with [AD-110] Volume B.

Instrument	ATLID		
Private Services	type	subtype	Description
Science Data Services	225	1	DRD-M data LIDAR
	225	2	DRD-M data RONC
	225	3	DRD-M data Imaging
	225	4	DRD-M data UPD
	226	1	DRD-C CAS data
	226	2	Investigation data

15.2.9 FDIR

ATLID instrument FDIR hierarchy is embedded in the general EarthCARE FDIR hierarchy as defined in section 11 and are specifically detailed in [RD-05] and [RD-116]..

15.3 BBR

15.3.1 Measurement Principle

The objective of the instrument is to establish the Earth's radiation budget, i.e. to measure the total radiance of the Earth. To do so, it observes the Earth's radiance at three observation zenith angles OZA

- Nadir: a downward facing view (OZA 0°).
- Fore: a forward looking view, that views the ground at an angle of 50.27 degrees (OZA +55°). This is the ground that will be viewed by the nadir view a short time later.
- Aft: a backward looking view, that views the ground at an angle of 50.27 degrees (OZA -55°). This is the ground that was previously viewed by the Fore and Nadir views.

and in two bands

- Short Wave (SW): 0.25 - 4.0 µm. This band is dominated by reflected sunlight.
- Total spectrum (TW): 0.25 – >50µm

A long wave (LW) measurement is obtained by subtracting the shortwave measurements from the total spectrum measurement, giving:

- Long Wave (LW): 4 - 50 µm. This band is dominated by the thermal emissions from the Earth.

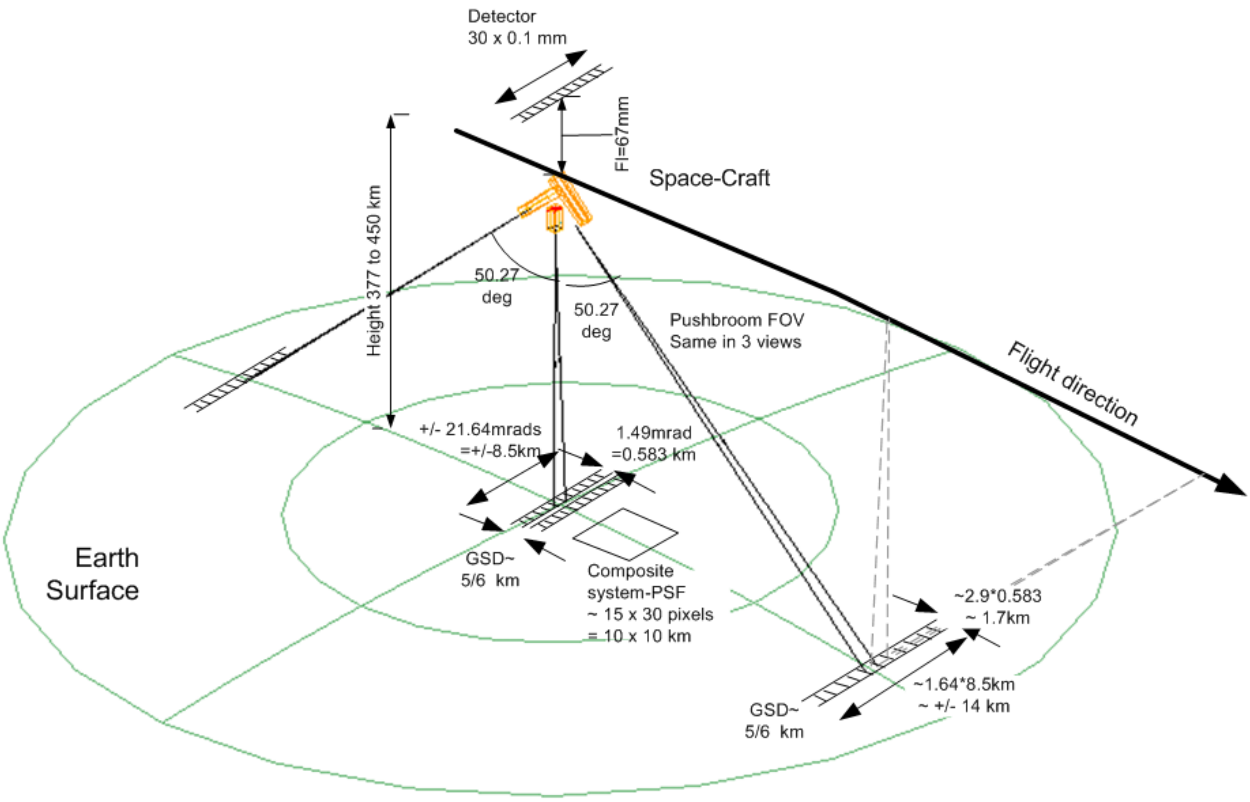


Figure 15.3-1: Schematic of imaging geometry, showing angular and ground position sizes of the pushbroom IFOV of nadir and oblique viewing, for design high case

The observation angles and spectral range are optimal for the recovery of the flux reflected and emitted by the Earth. Together the SW and LW measurements are the main input to the Earth radiation budget.

The detection uses a linear detector array in pushbroom configuration. For the nadir telescope each pixel observes a ground spot of 0.58x0.58 km2 while in the oblique views each pixel observes a ground spot of

1.655 x 0.956 km2 (along track x cross track). The PSF has been optimised such that the PSF 50% level is at the center of the next adjacent pixel. The individual pixel data will then be used to produce a 10 km x 10 km level 1b product in the ECGP. The detector consists of a linear array of 30 pixels across track. Thus, it covers a ground swath which is larger than the required 10 km product so it is ensured that the level 1b product for the nadir and oblique views can be derived for the same Earth location. The build-up of the 10 km product along track uses images at ground sampling distance (GSD) of approximately 5/6 km. This is in order to allow the co-registration implicit in the integrated energy requirement to be met.

Each view (fore, nadir, aft) is measured by a dedicated telescope. The design of the 3 telescopes is identical and is shown in Figure 15.3-4. Only a slight difference in defocus setting between the nadir and the oblique view telescopes is insorporated by shims during the alignment process to adapt for the correct PSF. In front of the telescope assembly there is a quartz filter equipped chopper drum which rotates at a speed of 4.35 Hz around the telescopes. Chopping of the signal is required in order to be able to subtract the signal background. There are 4 identical apertures on the chopper drum which are open or equipped with a quartz filter in a alternate way. The filters act as low pass filters up to ~4 µm (short wave, SW) while the free apertures allow to measure the total spectrum (total wave, TW). As the drum rotates, each detector makes, in sequence, a SW measurement, then a blocked measurement then a total spectrum measurement, then a blocked measurement and so on. The measurement concept is shown schematically in Figure 15.3-2 and the resulting time sequence of exposure is shown in Figure 15.3-3.

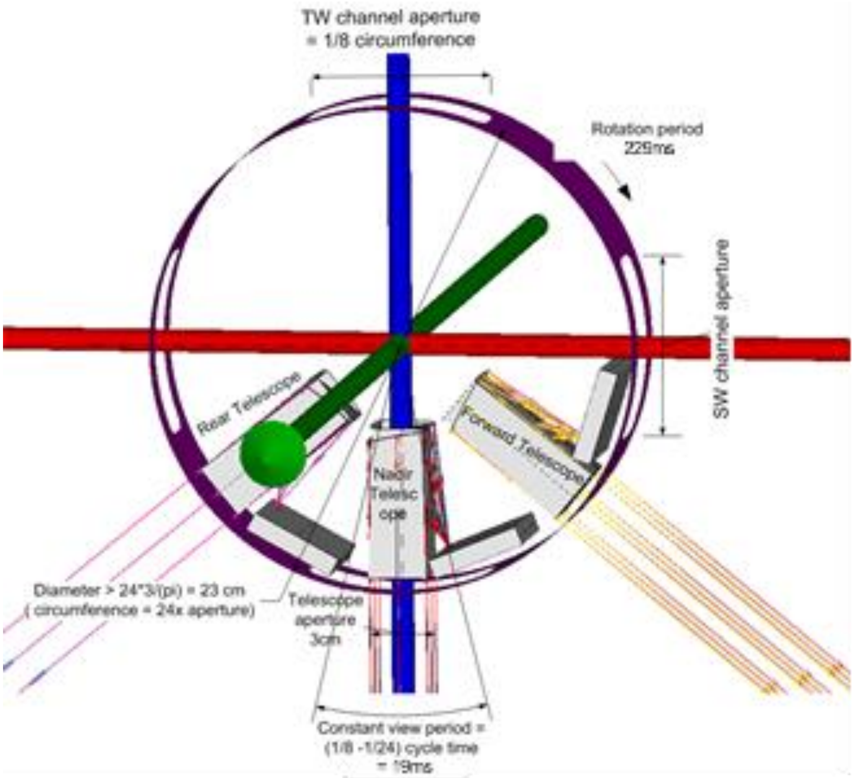


Figure 15.3-2: Side view of 3-telescope arrangement surrounded by rotating ‘drum’ chopper (open drum apertures alternate with quartz filters, not shown here)

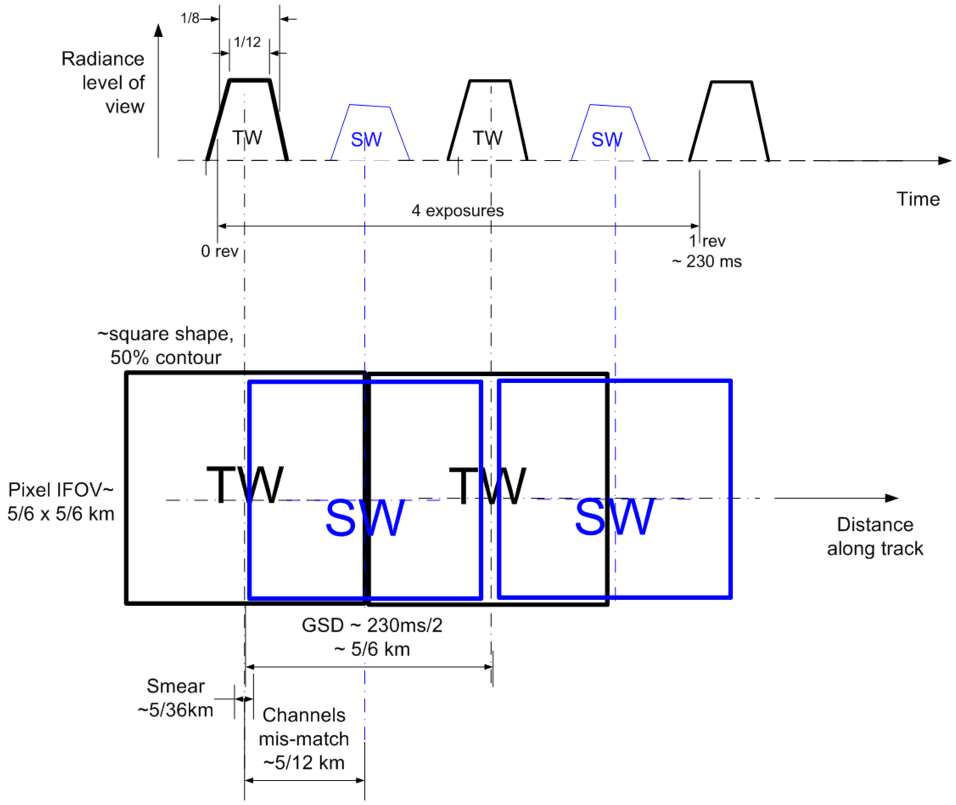


Figure 15.3-3: Time sequence of exposures over one revolution of chopper

The microbolometer detector design is based on thermal detector with gold-black coated absorbing layer, required to give very broad-band response (~0.25 µm to 50 µm required), and sensing temperature of the absorbing layer by resistive change. The use of a linear array also has advantages for radiometry in that a small detector element size is used, leading to good thermal sensitivity and speed of response. Here the elements are micro-machined on silicon, to give good isolation of the element from the mechanical support & readout structure, giving thermal 1/e time constant in the order of ~6 ms. The detector pixel instantaneous field-of-view (IFOV) in this case must be well matched to the GSD, to give a spatially uniform net instrument PSF when the samples are stitched together to reach the 10 km PSF.

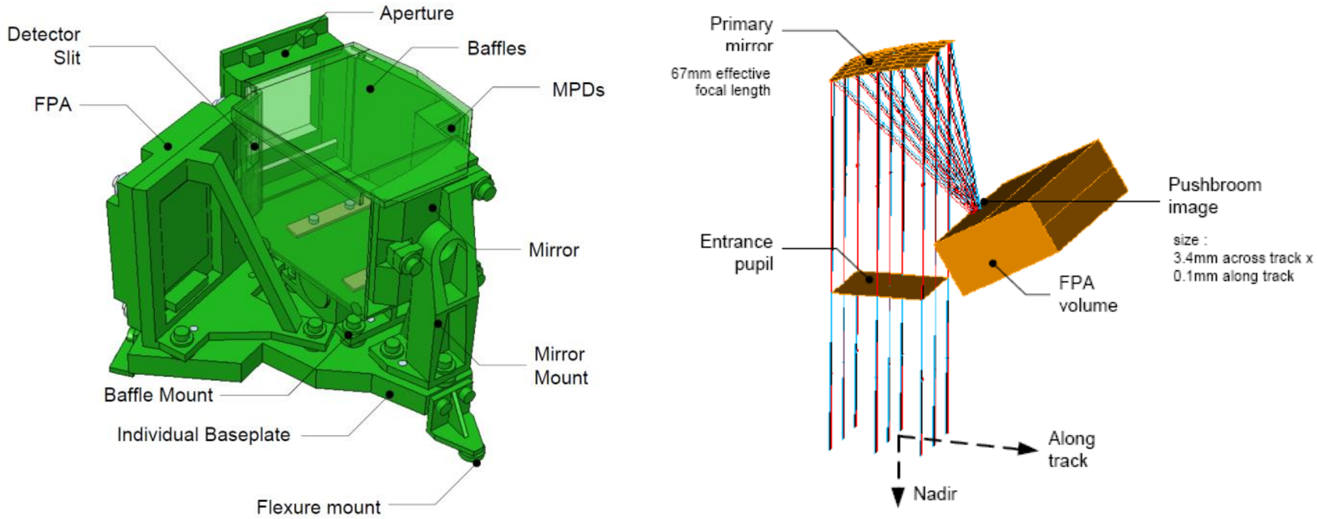


Figure 15.3-4: Telescope: solid view (left) and optical design (right)

The chopping scheme is selected for operation of this type of detectors to achieve accurate radiometry, in particular:

- the detector chopping is to give alternating views of the scene to be measured (earth or calibration source), and some nearly constant background scene (typically the black surface of the chopper or instrument internals).
- The background scene preceding each measurement view should be constant radiance.
- The measurement view should be as long as possible, and be constant in time, i.e. ideally for the earth-view a fixed or „staring" view should be taken. For the BBR with fixed telescopes the view is not fixed on the earth, but has a motion or drift of line-of-sight across the earth during each exposure. To make the radiance levels nearly constant in time, this drift dimension is much smaller than the detector footprint.
- The transition between end of background view and start of measurement view is not instantaneous. For the usual case of a finite beam aperture size being chopped by moving edges there is a transition period which also can be comparable to the 1/e time constant. This transition signal is not used for signal processing, but it is potentially helpful as it will be a simple linear transition between the fixed on and off levels, in case it does need to be used for diagnostic purposes.
- The duration of each measurement view is approximately 19ms, i.e. ~4 time constants. This means that the detectors do not reach a stable voltage value in the time available; some on-board signal processing is required. The detectors are sampled at a high rate (~200us) and an algorithm applied to determine the asymptote of the exponential rise, as shown below.

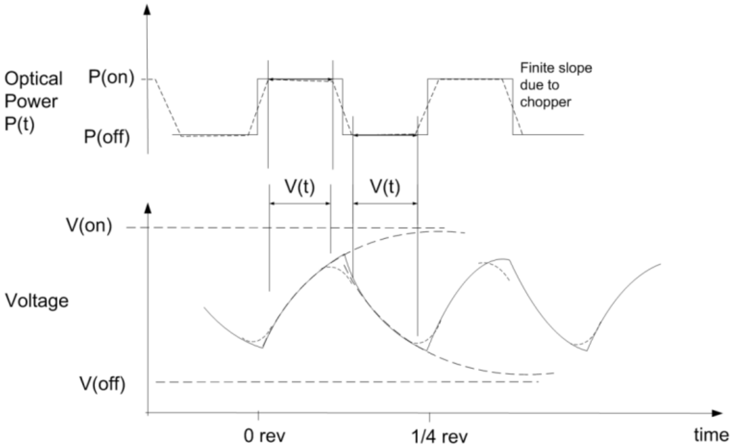


Figure 15.3-5: Signal processing schematic

For the above radiometry scheme, a balance is struck between the requirement for each view to have an un-vignetted duration as long as possible compared to the detector time constant, and for it to have a limited drift in the line-of-sight (LOS) during the view to achieve the near-constant radiance level.

For the baseline design this implies the view duration should be << pixel IFOV. In Figure 15.3-2the drum size gives 1/12 of a revolution, whereas the pixel IFOV ~2*GSD ~1 revolution. Therefore the LOS drift during measurement is 1/12*IFOV, which is acceptable.

The speed of rotation of the chopper mechanism can be altered in flight to maximise the life of the mechanism.

15.3.2 BBR Architecture

The BBR is divided into two main units: the Optical Unit (OU) and the Instrument Control Unit (ICU), which have a connecting harness. A top level baseline functional block diagram is presented in Figure 15.3-6.

The OU includes the main optical assembly, the calibration system and the detection electronic. The ICU handles the main electronics functions such as power distribution, data formatting and data exchange with the platform and with the OU.

The Focal Plane Assembly (FPA, contains bolometer detector and read-out integrated circuit) in the OU is closely coupled to the Signal Conditioning Electronics (SCE). The signal processing is incorporated into the SCE which facilitates the development and test activities and allows a relatively low data rate between the OU and ICU. The assembled telescopes including the aligned FPAs are mounted onto the baseplate of the fixed optics assembly FOA, see Figure 15.3-8. The chopper drum which rotates at a constant speed of 4.35 Hz rotates around the FOA. This is surrounded by the calibration drum which carries the instrument internal blackbodies as well as the VISCAL diffuser. In nominal view position the calibration drum opens the telescope apertures while once every 90s the blackbodies are rotated in front of the telescope apertures to perform a LW calibration. In addition, once per orbit the diffuser is rotated in front of the VISCAL aperture in order to perform a SW calibration. During the the calibration operations all three telescopes are illuminated simultaneously.

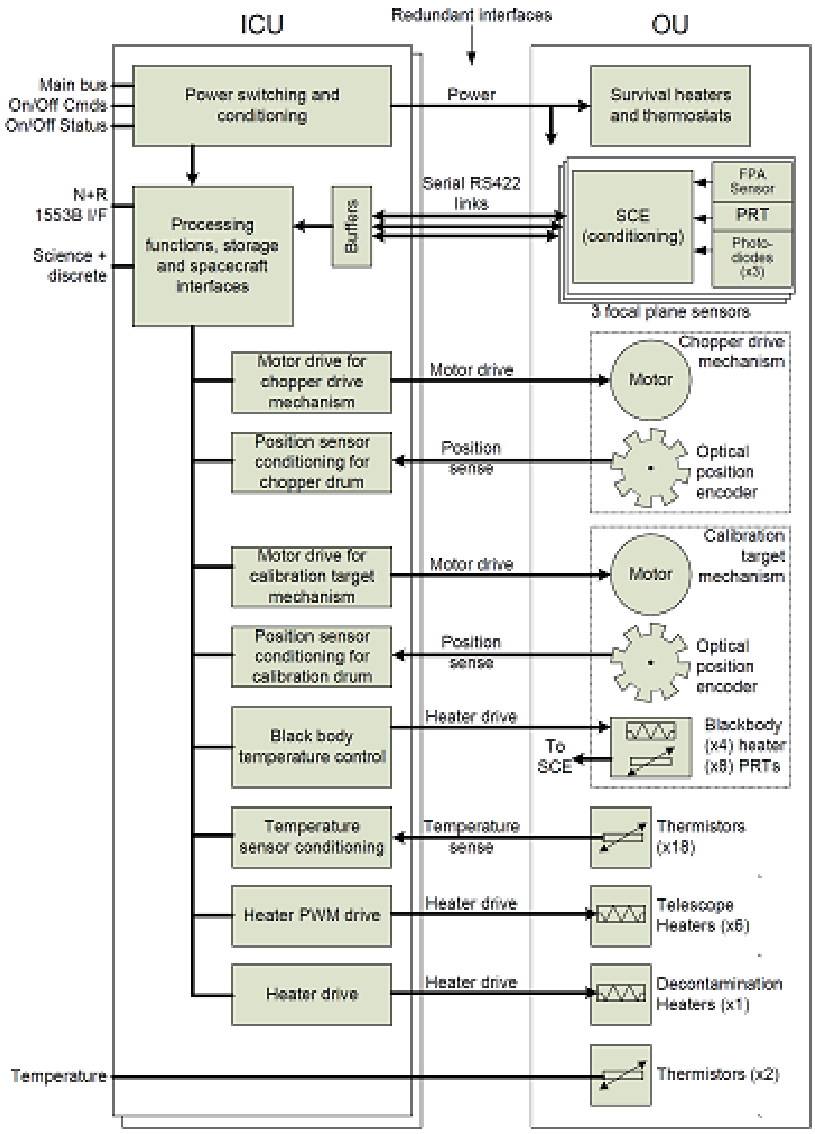


Figure 15.3-6: Partitioning of principal functions between ICU and OU

15.3.3 BBR Design

The OU is mounted onto the Nadir panel of the spacecraft. Special attention will be paid to the thermo-mechanical interface to guarantee the needed pointing performance. The ICU will be mounted close to the OU inside the spacecraft onto the same panel. A general view of the BBR Optical Unit is shown in Figure 15.3-6.

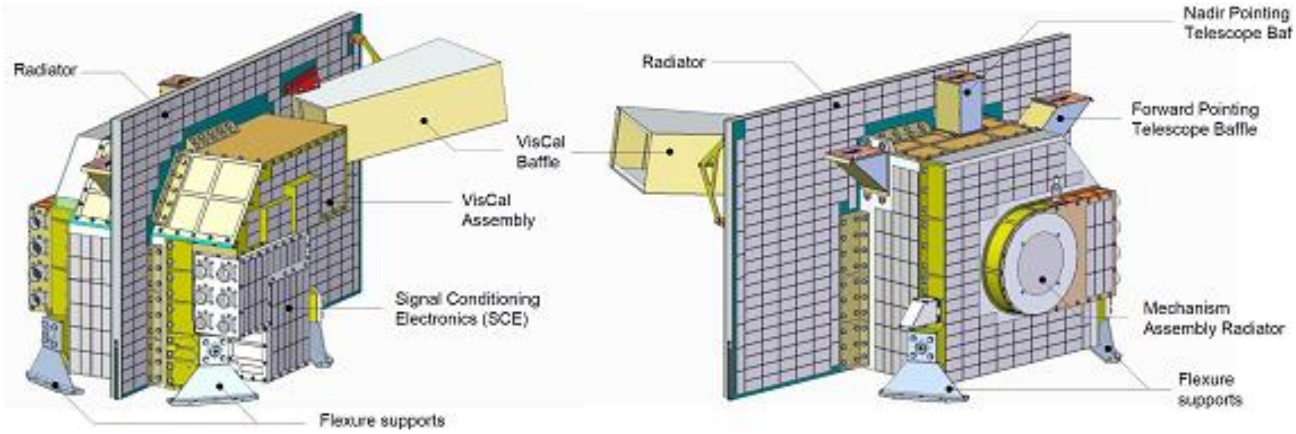


Figure 15.3-7: General view of Optical Unit

The OU comprises two assemblies, namely:

- Telescope Assembly (TA) and
- Mechanism Assembly (MA)

As depicted in Figure 15.3-7 the TA consists of Fixed Optics Assembly, Chopper Drum, Calibration Drum, Structure, Signal Conditioning Electronics, VISible CALibration subsystem and Thermal Control.

The MA consists of Mounting Plate, Cover incl. Radiator, Chopper Drive Mechanism, Calibration Target Mechanism, Flex Harness and the Structure.

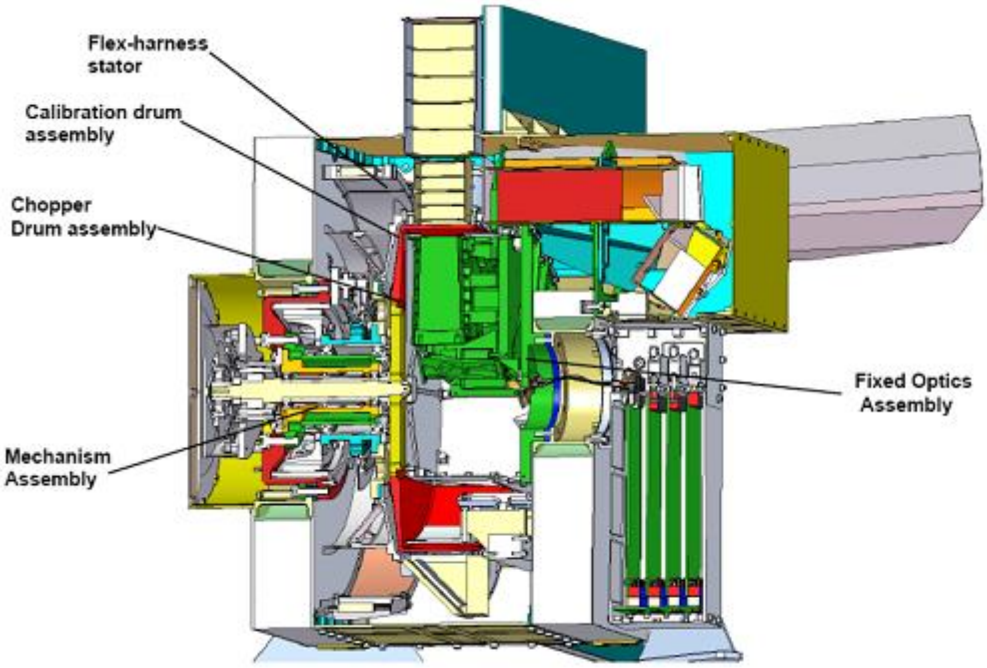


Figure 15.3-8: Cross section of the BBR OU

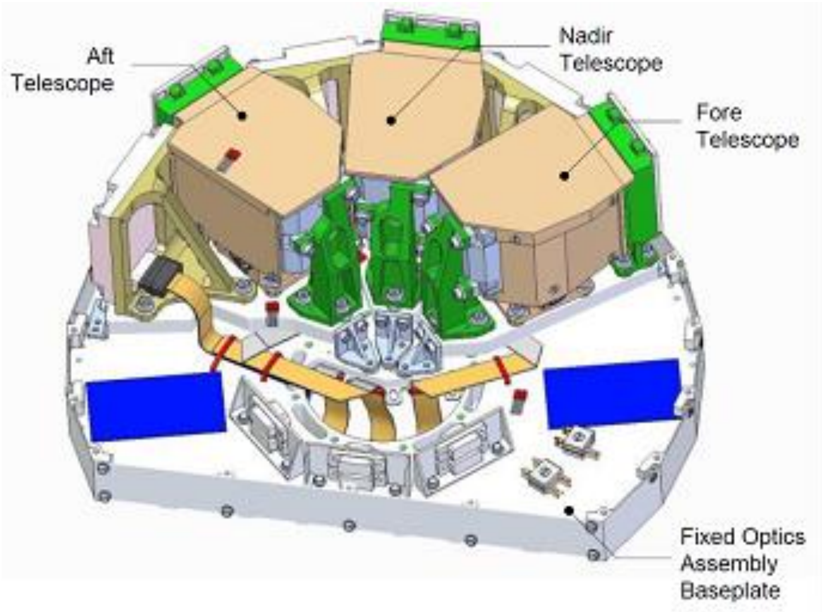


Figure 15.3-9: Fixed Optics Assembly

Located around the Fixed Optics Assembly (see Figure 15.3-8) is the rotating chopper drum (see Figure 15.3-9). It includes four apertures, each of which subtends 45˚. Two of these apertures include thin (2mm) quartz filters. The chopper drum rotates at 4.35 Hz and is required to be well balanced.

The calibration drum (as shown in Figure 15.3-9) is a cylindrical frame, intermittently driven by the Calibration Target Mechanism (CTM), on which are mounted four black bodies (2 hot, 2 cold), viewing apertures, VISCAL fold mirrors, and VISCAL quartz volume diffuser (QVD).

These are electrically connected to the fixed part of the instrument via a nominal and redundant flex harness. The conditioning electronics (cal drum electronics, CDE) for serialising the black body Platinum Resistance Thermometers (PRTs) over the flexible harness is also located on the calibration drum, in order to reduce the harness size.

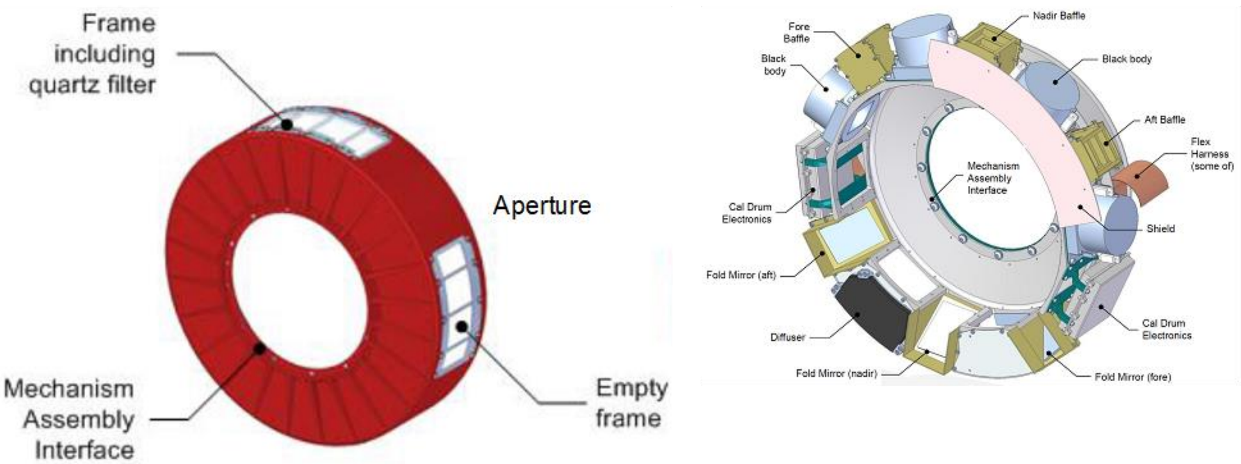
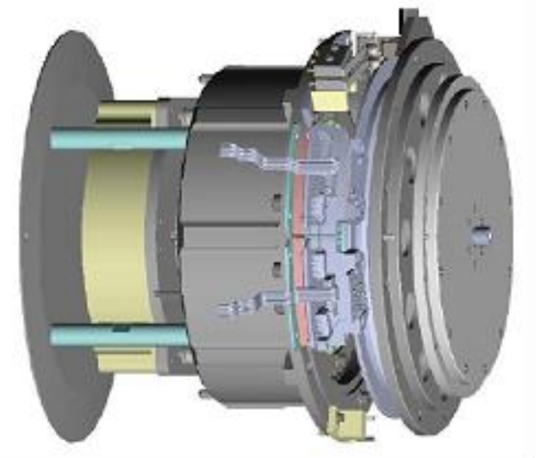


Figure 15.3-10: View showing (left) chopper drum and (right) calibration drum

The mechanism is implemented in a single stand alone unit, as shown in Figure 15.3-10 below. The configuration allows the Chopper Drum Mechanism (CDM) with all its functional elements to be located directly on the main rotational axis as a direct drive system. The chopper drum is supported and driven directly by the CDM via a light-weighted conical flange. At the other end of the chopper drum is a non contacting cylindrical snubber interface. This ensures that under severe load lateral load condition the bearings of the CDM cannot be overloaded and thereby avoids the need for active launch protection systems.



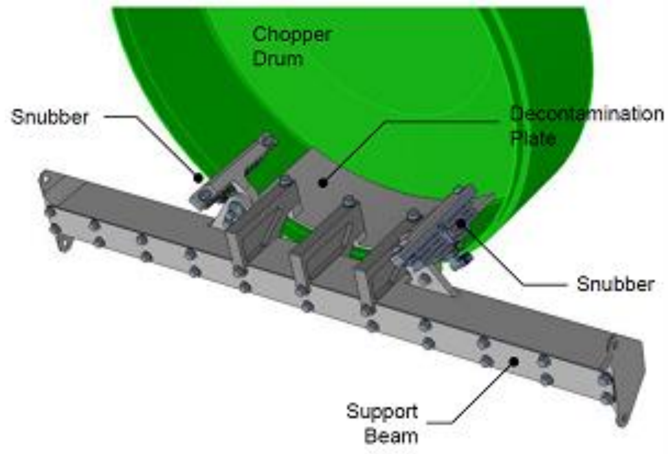


Figure 15.3-11: Sketch of the assembled mechanism assembly including the adapter disks for CDM and CTM (left) and subber assembly for CDM (right)

The role of the telescope control heaters is to provide a high level of thermal stability to the sensitive optical components in the telescopes. Each telescope baseplate will be maintained at -10°C by PWM controlled heaters. The expected sensor accuracy is +/-23mK, which is the standard accuracy of a PRT temperature sensor operating at this temperature. In this case the stability is more of an issue than absolute temperature.

Each telescope baseplate has installed two identical 2.25 W heaters (A and B) per branch (four heaters in total). These heaters are PWM driven by the ICU based on a PID control loop. That is to say, a single heater failure can be tolerated without necessitating a switch to the redundant branch of the Instrument Control Unit. A software algorithm is used to determine which of the two PRTs on each baseplate is the most valid. Noting that the thermal environment in which the telescopes sit is similar, and that the temperature set point for the telescopes will always be the same

The capability to decontaminate the optical components within the OU is desirable. To achieve this, stability heaters and additional decontamination heaters on VISCAL, CTM and the CDM snubber assembly will be used to raise the temperature to between +10°C and +30°C.

Thermostat controlled survival heaters will be included to maintain the FPA, SCE and mechanisms above their minimum non-operating temperature.

Where a radiator is not required, the BBR will be covered in 10-layer thermal blanket. This thermal blanket will also extend through the gap between the S/C and the BBR baseplate, underneath the instrument.

15.3.4 BBR Operations

In the BBR two types of calibration systems are implemented:

- Solar Calibration (VISible CALibration)(VISCAL) for the SW and
- Black Body (BB) Calibration for the LW

The Short Wave (SW) calibration system is implemented as periodic views to the Sun via a baffled aperture. The diffuser used in the VISCAL is covered during nominal operations and is only rotated into the VISCAL aperture for the calibration manoeuvre. The VISCAL aperture is closed by a shield on the calibration drum during most of the nominal operations in order to protect the blackened detectors. The SW calibration will be performed once per orbit (sun illumination of the VISCAL just after passing the south pole of the Earth). Averaging about 30 orbits is required to reach the required noise level. It is sufficient to perform this SW calibration every 2 months.

The design features for VISCAL are:

- With fixed telescopes, the implementation of the solar view requires the calibration drum to have a fold mirror for each telescope. Each of these, when the drum is in the deployed position, turns the view to point along the drum axis.
- For use of solar illumination near the Earth limb, the illumination direction is near the +X or -X direction (approximately 22.5 degrees from this axis). The choice made is that near the -X direction (the negative flight direction).
- The diffuser is illuminated at normal incidence. It is viewed by each of the 3 telescopes at different angles, but this is acceptable. However, due to the optical design all 3 telescopes will be illuminated simultaneously by the VISCAL optics.
- The solar views avoid having to extend too far in the +Z direction (not past the nadir earth view baffle).

The implementation of the VISCAL optics in the BBR Optics Unit design is shown in the figure below.

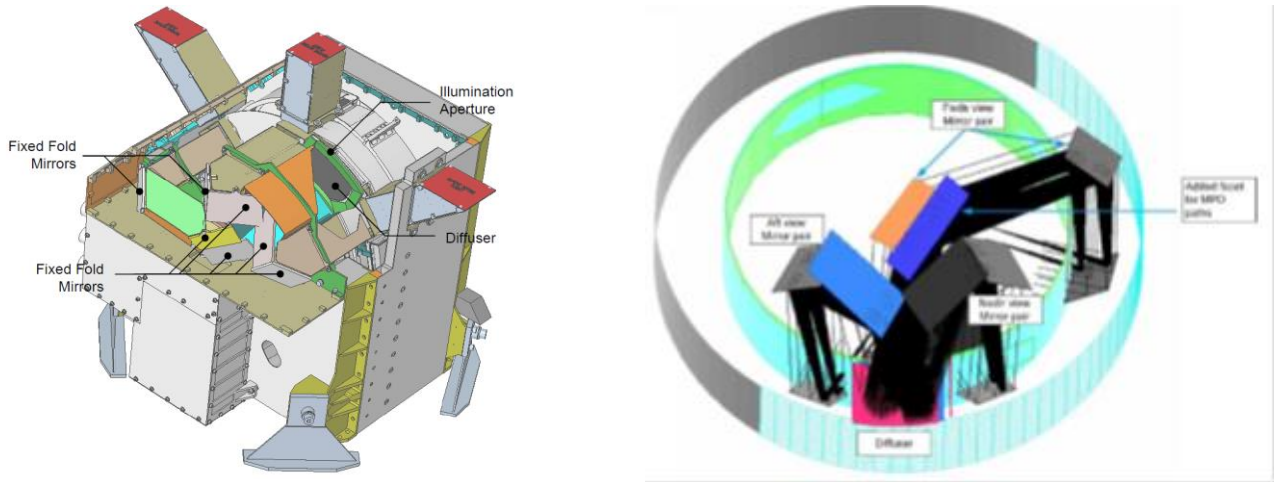


Figure 15.3-12: Calibration drum in SW calibration position, (left) and optical layout (right)

The Long Wave (LW) calibration system consist of high accuracy cavity blackbodys (BB). This system is used to determine the Long Wave radiometric gain. Radiometric accuracy is maintained throughout the mission by thermal frequent LW calibration cycles which will be performed every 90 s in the baseline configuration. During that manoeuvre the detectors look sequentially at the cold and hot black body for about 0.5 s each.

The blackbodies provide the calibration reference signal for removal of the instrument response offset. This is for the Total Channel as only that uses the BB view (SW filter on chopper drum blocks BB radiance above 4 µm).They also provide similar reference signal for determination of instrument response gain. This requires 2 radiance points, and in the absence of a space view, the design uses two black bodies; one warm and one cold maintained around -10°C and +28°C. The accuracy requirement of the BB is that its contribution to the measurement radiometric error complies with the overall error budget of the calibration scheme.

The BB accuracy effects are in two categories; variations of emitted radiance (due to temperature and coatings variations), and precision of radiance knowledge (due to ground calibration and thermometry). The emissivity requirements become more difficult to meet at longer wavelengths of the 4 to 50µm range, requiring special coatings and cavity design. For BBR thermal stability of ~0.05 K/min for the surface radiating into the BB, and calibration interval 90 seconds, an accuracy of ΔL < = 0.2 W/m2sr is obtained.

The BBs are designed for maximum thermal time constant and similar emissivity. They will have 4 precision thermometers – 2 nominal and 2 redundant - per BB (platinum resistance type with 4-wire readout). The BBs have heaters for calibration check functions.

The duration of the viscal calibration will not exceed 0.5% of the orbital period. This calibration will be synchronized with the calibration of the MSI TIR in order to improve overall system availability. For the BB calibration, 4.9% of the overall operational time are reserved. This corresponds to a calibration interval of 90 seconds.

15.3.5 BBR Interfaces and Satellite level Instrument Redundancy Selection

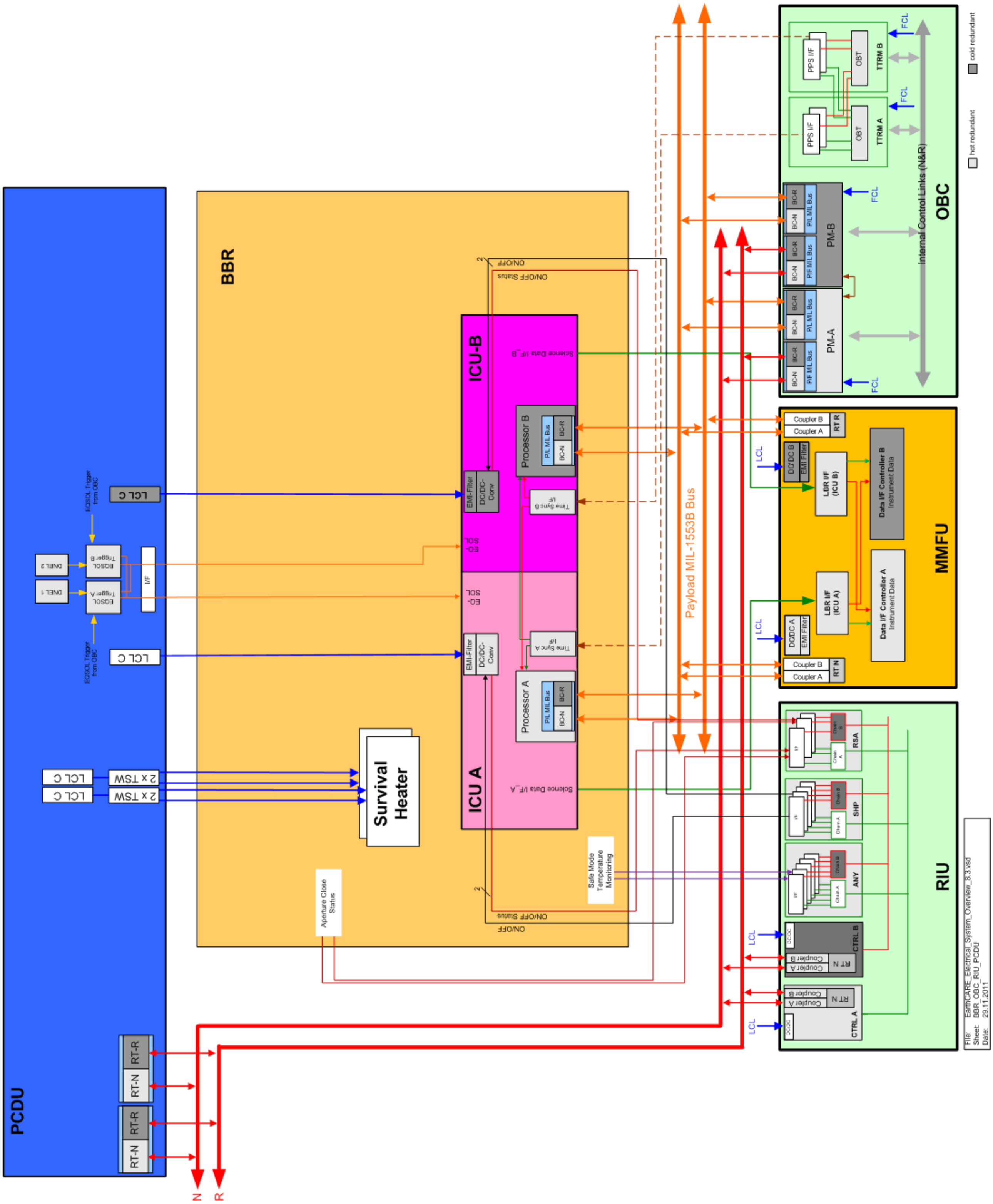


Figure 15.3-13 Satellite BBR operational interfaces

The BBR instrument is operated in strict cold redundancy. Details are given in [RD-51].

15.3.6 BBR Instrument Modes and Mode Transitions

15.3.6.1 BBR Instrument Modes

The BBR Instrument activities are organised around the following BBR Instrument modes. The BBR instrument modes are shown in Figure 15.3-14.

Further details of BBR instrument modes and sub-modes are given in [RD-51].

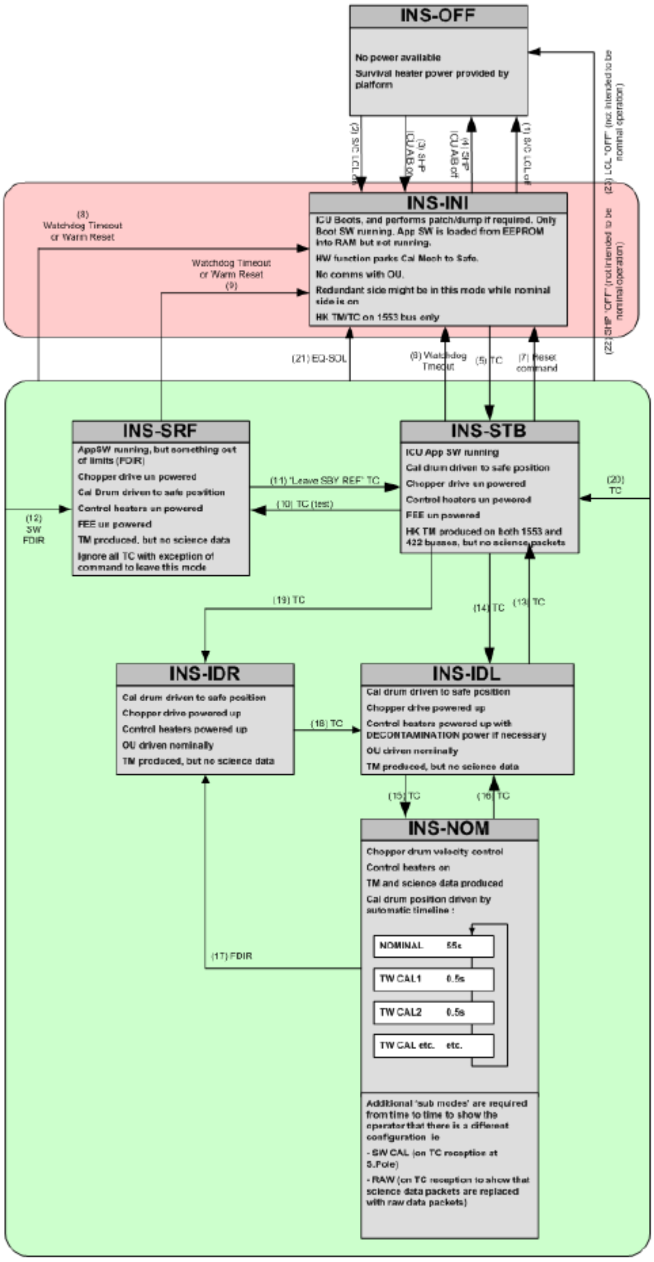


Figure 15.3-14 BBR instrument modes and mode transitions

15.3.6.2 BBR Instrument Mode Transitions

The BBR instrument mode transitions are shown in Figure 15.3-14. Mode transitions can either be under ground control or autonomous upon error detection or external reset such as an EQ-SOL.

BBR mode and sub-mode transitions are detailed in [RD-51].

15.3.7 BBR Instrument Operability

BBR instrument operability follows the generic principles given in section 15.1.4 and is specifically detailed in [RD-51].

In INS-NOM mode the mechanisms are operating fully nominally and science ISPs are nominally provided via the Science Interface. The ground can also select different science data types (ie raw rather than processed) if needed for commissioning or other diagnosis needs. These variation are performed by function TCs and do not constitute a mode change, however ground will see the status of the BBR in the TM.

Being in its nominal mode INS-NOM, the BBR alternates automatically between measurement and internal calibration without any further commanding. A filter-shutter drum including calibration elements rotates arround the telescopes, whereby the ICU automatically commands the time based internal calibration. The instrument internal calibration is used to determine the Long Wave radiometric gain with a cavity blackbody thermaly stabled at 300°K.

For the Short Wave (SW) calibration the BBR must view to deep space and to the Sun via a baffled aperture. Viewing the sun is performed in the short period between crossing of the south pole and entering into eclipse.

Short Wave calibration is initiated and terminated by Orbit Position Schedule commands, coherent with the MSI black body calibration. From Short Wave calibration is commanded back into the previous measurement mode. Ground is in charge to load the relevant commands into the OPS schedule.

The second ICU must not be switched on while the instrument is active in order to avoid any command conflicts on the mechanisms.

15.3.8 BBR Command and Control

BBR is essentially operated via standard services of the Core PUS [AD-110], the before mentioned common instrument services and service 8 function and a set of instrument specific services and service 8 functions.

For BBR monitoring and control the following specific private services are defined consistently with [AD-110] Volume B

Instrument	BBR		
Private Services	type	subtype	Description
Monitoring and Control Services	231		Calibration Target Drive
	232		Black Body PWM
	233		Chopper Drum Control
	234		<<not used>>
Common Reporting Service	199		Instrument Reports

No BBR additional service 8 functions are provided for specific high level operational control. The short wave calibrations are activated and deactivate via service 231 sub-type commanding. Modifications to the nominally autonomous BBR operation profile can be done via service 231.

15.3.9 BBR Science Data

The ATLID science data are provided by the following private services consistently with [AD-110] Volume B.

Instrument	**BBR**		
Private Services	**type**	**subtype**	**Description**
Science Data Services	230	1	Processed Data Service
	230	65	Raw Data Service

BBR Science Data are distinguished by one additional identifier at the begin of the science data field:

15.3.10 FDIR

BBR instrument FDIR follows the generic instrument FDIR defined in section 15.1.6 and is specifically detailed in [RD-05] and [RD-117].

15.4 MSI

The EarthCARE Multispectral Imager (MSI) will provide information in seven spectral bands, one visible, one near infrared, two short-wave infrared and three in the thermal infrared. It will provide spatial resolution at a ground sample distance of 500 m, over a swath 150 km wide, from a nominal platform altitude of ~400 km.
In the following sections a short description of the MSI instrument is given. For details see [RD 07] MSI Technical Description.

15.4.1 MSI Measurement Principle

The seven spectral channels, listed in Table 15.4-1, ranging from visible through short-wave IR to thermal IR. Channels 1 to 4, in the solar region, are called the VNS (Visible, NIR, SWIR) bands, and the thermal IR channels 7 to 9 are called the TIR bands.

Table 15.4-1: MSI spectral band definiton

Channel	Band name	Centre wave-length (nm)	Band width (nm)	Reference radiance $(\frac{W}{m^2 \cdot sr \cdot \mu m})$	Reference brightness temperature (K)
1	VIS	670	20	444.6	NA
2	NIR	865	20	282.7	NA
3	SWIR 1	1650	50	67.3	NA
4	SWIR 2	2210	100	24.6	NA
7	TIR 1	8800	900	NA	293
8	TIR 2	10800	900	NA	293
9	TIR 3	12000	900	NA	293

TIR

The optical concept for the MSI TIR using a single microbolometer area array detector is shown in Figure 15.4-1. Radiation from Earth is received through the Earth view port, and falls on the calibration mirror. The beam is reflected through an imaging lens at the optical aperture, which is nominally 30.6 mm diameter. The beam is then reflected from a fixed fold mirror, through a second lens element, into a system of dichroics, fold mirrors and filters. The second lens element acts partly as a field lens, so that the system is close to telecentric in the region of the dichroics and filters.

Two dichroics split the beam efficiently into three parts, for the required three spectral bands, working at ~30° angle of incidence in vacuum. The three beams are then folded through filters onto a common image plane. The primary images are formed within an f/5 beam within the fore-optics.

The filters define the required spectral bands. The system following the filters will be enclosed in a separate cavity – the rear-optics enclosure – with enhanced temperature control. The beams will pass into the enclosure through three slots in a temperature-controlled front plate.

After the filters, the three beams are re-imaged onto the detector by a lens system. The magnification factor is nominally 0.2, so that the final image is formed at f/1. The rear optics' focal length is nominally 33 mm.

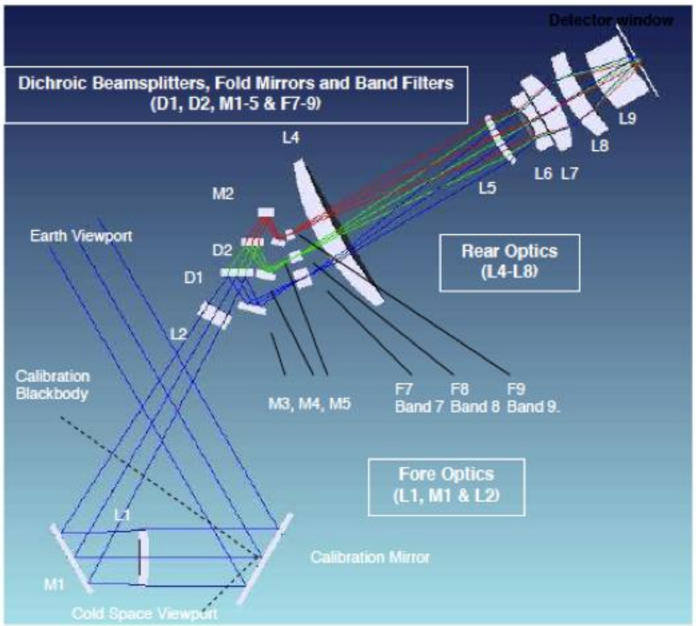


Figure 15.4-1: TIR optical layout

The approach adopted by the TIR to improve the NEdT's is to combine oversampling and Time Delay and Integration (TDI). The oversampling technique involves reading out the array detector at a rate faster than the dwell period, which is the time it takes the sub-satellite (ground) sample to be observed. Oversampling is necessary as the detector has a limited range of pixel readout frequency. The maximum rate of 6.75 MHz is due to the maximum operating frequency of the readout electronics. The minimum rate is constrained due to the problem of self-heating of the detector element during reading, as taking too long will overheat the element and possibly damage or destroy the device.

In TDI mode signals from N rows in each image area will be co-added from N successive frames, multiplying the total signal from each ground pixel by N. The ground TDI factor N is 16. It should be noted that this value is adjustable and can be varied to optimise the NEdT of the flight detector.

The TIR detector has a time constant of ~10ms, allowing the whole frame to be read at 50 Hz in normal operation. For the MSI, the nominal dwell period for one along-track spatial sample distance is 70 ms, and it is necessary to read only about half of the detector area. It is therefore possible to read the detector up to 7 times per dwell period, providing an advantage in signal to noise ratio after averaging of the multiple TDI reads per pixel. Five reads will be made in each 70 ms dwell period.

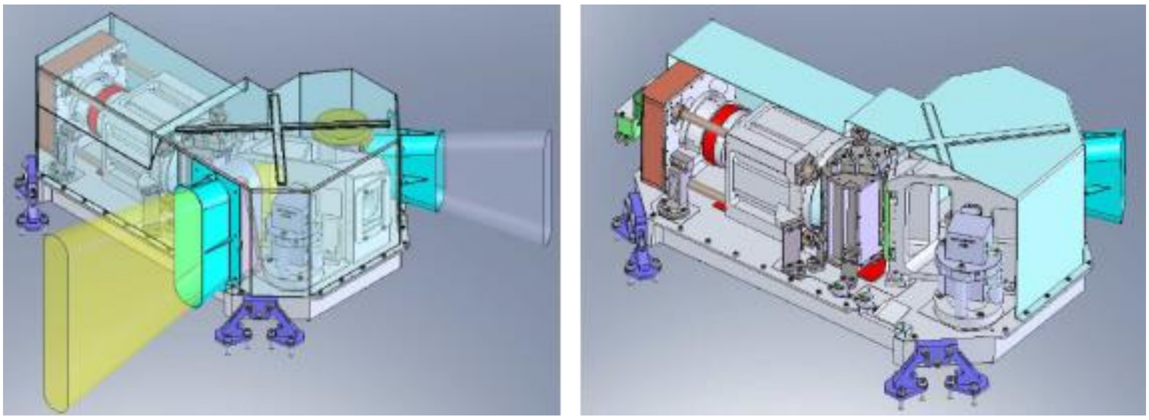


Figure 15.4-2: TIR instrument (left: TIR external view with earth viewing and cold space calibration beams; right: cut-away view)

The TIR detector has hard-wired facilities to subtract signals from blind pixels, which will correct for the large effects of change in detector substrate temperature, but these blind pixels will not be sensitive to changes in background radiation, and do not provide adequate correction for noise contributors which are correlated along detector rows and columns.

It is very desirable to record detector columns outside the image areas. These signals will be averaged down columns and subtracted from image-area signals in the corresponding columns. These subtractions of signal from reference columns and rows not only corrects for short-term drift errors due to changes in detector and optics temperatures, but also correct detector noise components that are correlated along rows and down columns.

VNS

The optical concept for the MSI VIS/NIR/SWIR channels consists of four telescopes that are distributed over two separated apertures. One common entrance aperture is used for VIS (Channel 1), NIR (Channel 2) and SWIR 1 (Channel 3) and an independent aperture for SWIR 2 (Channel 4). Band filters are used to define the spectral response of each channel. The system has four linear array detectors with the same geometric pixel configuration, thus the effective focal length of all channels is the same.

Figure 15.4-3 is a scaled drawing of the optical components. In front of the entrance pupil (not shown in this figure) is an on-board diffuser to be used for on-board calibration and moved aside to allow direct nadir viewing of the Earth in data recording mode. Sharing the calibration optics is an important characteristic of this concept as it allows simultaneous calibration with the same equipment for the four channels. This will:

- Save time during on-board calibration
- Allow fewer and smaller components
- Contribute to a higher radiometric accuracy.

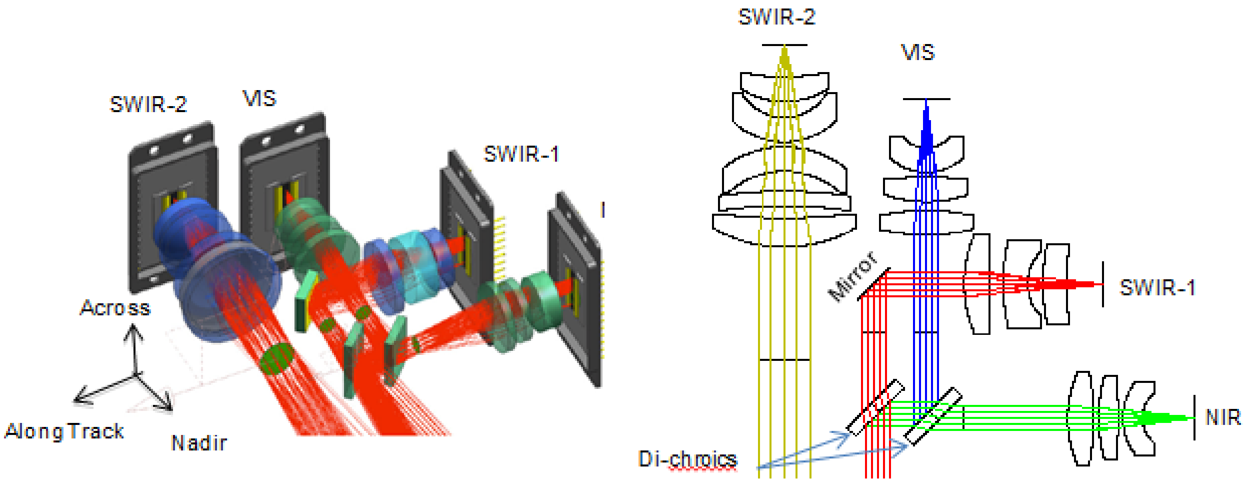


Figure 15.4-3: VIS/NIR/SWIR channels optics and optical paths; (left) solid view (right) 2-D layout

The swath direction is orthogonal to the drawing. The channels on the right hand side are 2 (NIR) and 3 (SWIR 1). The channels with the detector on top are 1 (VIS) and 4 (SWIR 2). The prism in front of the aperture stop (not shown in this figure) is a diffuser that will only be present for calibration purposes.

In the direction of the light path through the optics of channels 1 to 3, the dichroics order is as follows:

- First dichroic number 1 (on the front surface of a plane parallel plate and at 45° incidence angle) splits the light for channels 1 and 2 (reflection) and channels 3 (transmission).
- The reflected light continues to dichroic number 2 (on the front surface of a plane parallel plate and at 45° incidence angle), which separates channels 1 (reflection) and 2 (transmission).

There is an extra folding mirror in channel 3 to reduce the volume of the opto-mechanical design.

Not all the channels have the same optical components. The optical components which play the same role in all channels are the last ones behind the dichroics and in front of the detector. For each channel there is a plane parallel plate (after the first lens reached by the light), which has the band pass filter coating. Additionally, in calibration mode, there will be a pair of prisms (diffusers) in front of the aperture stop of the system.

The optical components, which change from channel to channel, are:

- Channel 1: Two plane parallel beamsplitters with dichroic coatings (both of them working in reflection) on the first surface.
- Channel 2: Two plane parallel plate beamsplitters with dichroic coatings (first one working in reflection and second in transmission) on the first surface.
- Channel 3: One plane parallel beam splitter with dichroic coating (working in transmission) on the first surface.
- Channel 4: Being a separate aperture, this simply contains the channel lens and detector.

As with the TIR system, signals in the VNS from detector columns outside the image areas will be recorded; these signals will be averaged along the row, and the averages subtracted from image-area signal in the detector row. As before, the subtraction of signal from reference areas will correct for short-term drift errors due to changes in detector and optics temperatures, the corrections will also correct detector noise components that are correlated along the row. Since linear arrays are used, read out times are much shorter than that of the TIR system. In Figure 15.4-4 a VNS view including cross-section is given.

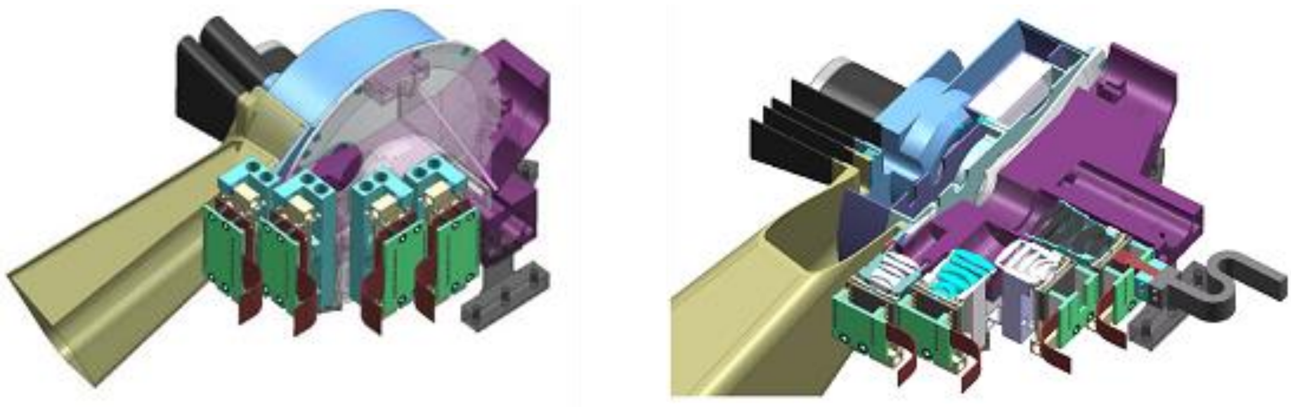


Figure 15.4-4: VNS view, (right) cross-section view

15.4.2 MSI Architecture

The MSI instrument as shown in Figure 15.4-5 mounts to the spacecraft payload panel and comprises:

- the Optical Bench Module (OBM) itself comprising:
  - the TIR and VNS cameras (TIROU and VNSOU) and the VNS SWIR2 radiator all mounted onto a single baseplate for accurate through-life alignment of the two cameras,
  - the Front End Electronics (FEE), which provides the drive and signal conditioning to the detectors in the two instruments.
- These assemblies will be located on a common MSI Optical Bench (OB), also referred to as the MSI baseplate, on the –YSC external panel of the EarthCARE satellite.
- the Instrument Control Unit (ICU), which will be located internally within the EarthCARE satellite, again on the –YSC panel.
- the interconnecting OBM-ICU harness (together with harnnes support towers).

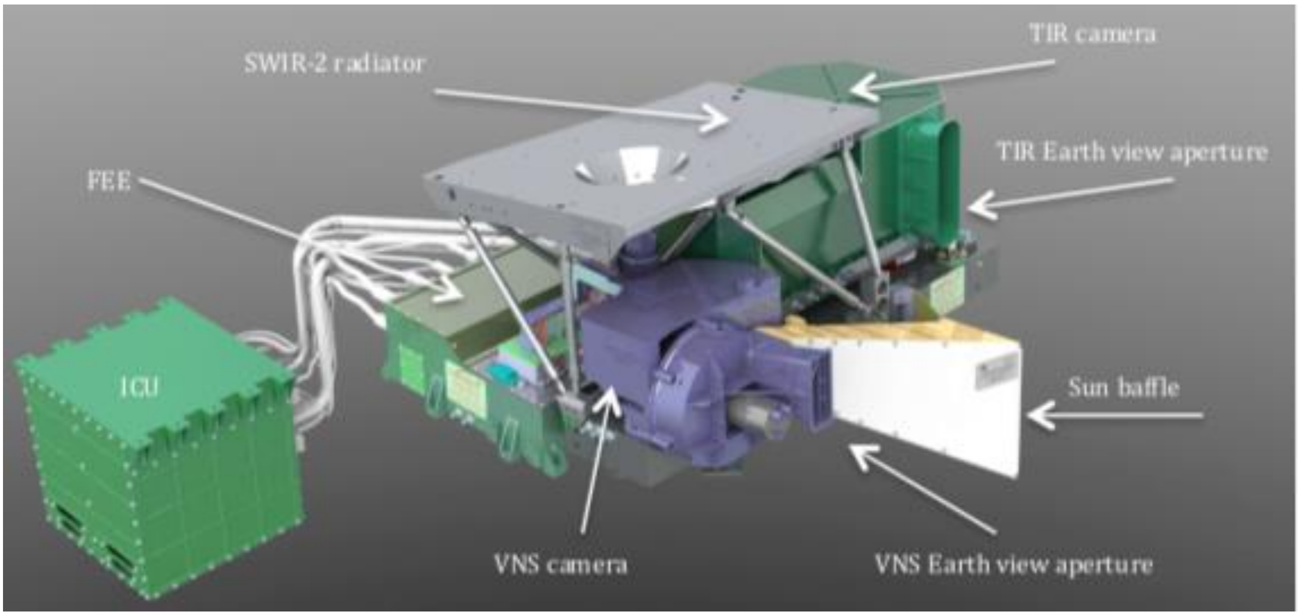


Figure 15.4-5: MSI optical bench module with ICU

The MSI baseplate will be angled at 5,84º with respect to the EarthCARE spacecraft structure panel upon which it will be located and oriented across the orbit track.

The MSI OBM will be thermally isolated from the spacecraft. Upon the Optical Bench (OB) lie the VNS and TIR optical units, together with the SWIR-2 radiator. The FEE is sited off the OB on the spacecraft panel and is united with the OBM optomechanical assembly by internal connecting harnesses. These internal harnesses are flexible.

The FEE unit is responsible for driving the detectors within the TIR and VNS optical units. It operates the detectors in the required mode to obtain the pixel data required for each of the bands. The pixel data is processed to reduce the data rate from ~3Mpixels/s to ~25kpixels/s for transmission to the ICU

The ICU, located internal to the spacecraft, drives the instrument functionality, powers the Front End Electronics (FEE) and thermally controls the detectors. The returned digitised image data is processed and forwarded via serial link to the spacecraft. For TC/TM handling it is interfaced via Mil 1553 bus with the OBC/RIU. The ICU is fully redundant.

The MSI electronics architecture is redundant up to the detector interface. At this point the signals are combined to drive the non-redundant detector. The interface to the detector will be high impedance when the electronics is turned off to allow cold redundancy to be used.

Absolute calibration for the TIR will be provided using a rotatable mirror in the incident beam path, allowing the instrument field to be switched between Earth, cold space and an internal warm blackbody.

Absolute radiometric calibration for the VNS will be provided by a sun-illuminated diffuser that will be deployed into the incident light path when the platform is over a polar region. The diffuser movement will also carry a shutter for dark-level calibration. The overall architecture is given in Figure 15.4-6.

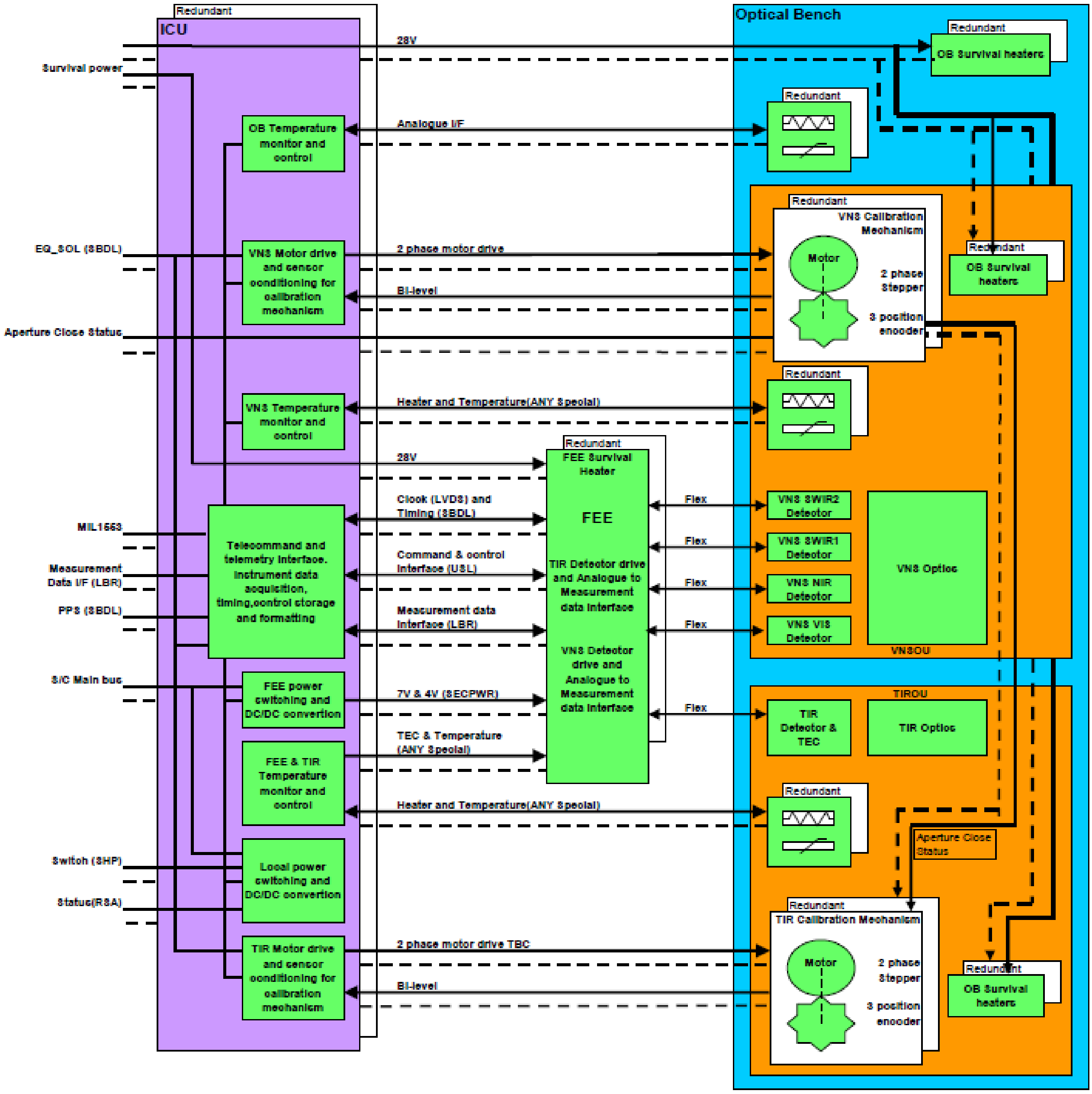


Figure 15.4-6: MSI instrument architecture

15.4.3 MSI Design

The mechanical design of the optical bench is partially driven by thermal constraints. The system is not allowed to reject any heat through the spacecraft panel, and therefore radiator surfaces need to be large enough to reject the dissipated power. The radiators will not receive any direct sunlight and will have a reduced view to Earth.

The TIR and VNS cameras need to have very stable thermal conditions to avoid introducing errors into the images. The instruments are therefore conductively isolated from the spacecraft. The instruments are exposed on the outside of the spacecraft to the space environment and the earth scene, and the instruments are therefore subject to orbital variations in heat load from sun, albedo and earth IR. Radiative isolation from the scene and the spacecraft is achieved by wrapping the instrument in MLI.

However the cameras remain weakly coupled to the spacecraft, the earth scene and cold space. Orbital variation in heat loads causes a variation in temperature of structures within the cameras which must be controlled to tight limits for each camera. An active thermal control system will be used, which relies on a radiator over-cooling the instrument, which is then brought back to the desired temperature by controlling power dissipated in distributed heater elements.

The SWIR2 detector in the VNS operates at 235K, and requires a dedicated radiator to achieve this temperature. The radiator is accommodated over the top of the two cameras. The interface to the spacecraft must accommodate differential thermal expansion between the OBM and the spacecraft, without over stressing the OBM structure and causing instrument pointing drift.

The overall budget for the whole MSI instrument is given in **Fehler! Verweisquelle konnte nicht gefunden werden.**. During night time only the TIR detectors provide useful information. Therefore the data rates during daylight and eclipse are different. However, the MSI design allows to transmit VNS data measured on the dark side of the Earth, too (on request).

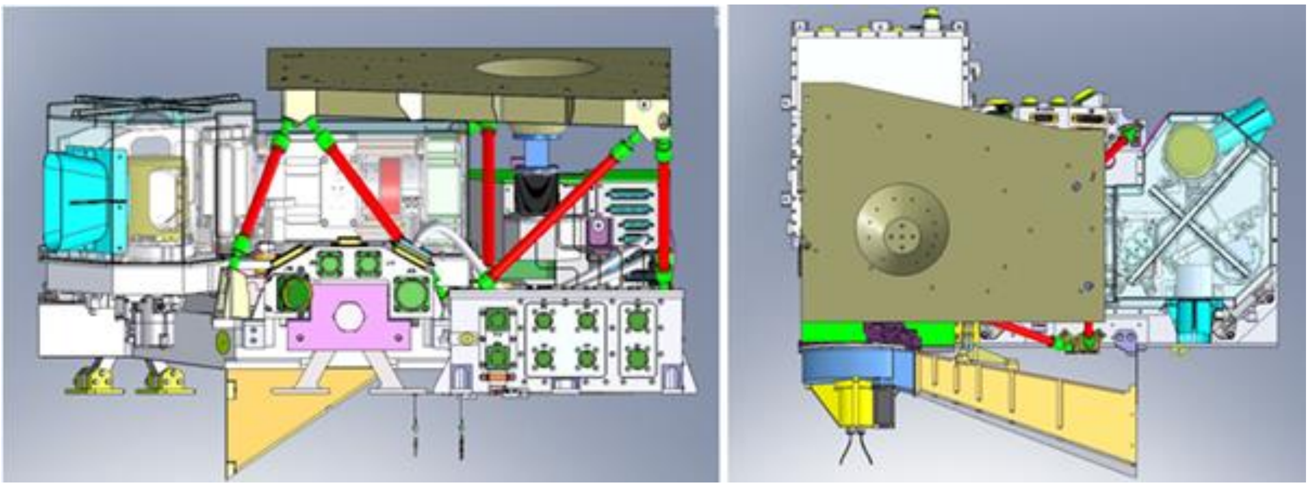


Figure 15.4-7: MSI optical bench module (OBM), front view (left), plan view (right)

15.4.4 MSI Operation

In order to perform calibration the VNS as well as the TIR is equipped with a calibration unit allowing the following calibration functions:

<u>**VNS Camera**</u>

- VNS dark current calibration once every orbit. In this position both the nadir port and the Sun acquisition port are closed, i.e. no radiation can enter the instrument and the offset / dark signal of each detector can be determined. The dark position will also be used as a safe mode position as all optical elements and the detector are protected.
- VNS solar calibration with a short-term Quasi Volume Diffuser (QVD) pair is used to monitor the degradation of the optics and to assure the radiometric accuracy. This position will be assumed up to once every orbit shortly after passing the south pole. This will be just outside the daytime part of the orbit, ensuring that no measurement time is lost.
- VNS long-term calibration with a long-term QVD pair to monitor the degradation (if any) of the short-term QVD pair once per month. The short-term QVD pair is placed in direct sunlight once every orbit. This could result in a slight degradation of the optical performance. Since the long-term QVD pair is placed in the direct sunlight only once every month, its degradation is much smaller. Due to the difference in degradation the quality of the short-term QVD pair can be monitored by the long-term QVDs.

TIR Camera

The calibration mirror assembly rotates a mirror between three positions:

- Earth viewing
- Cold space (cold calibration)
- Black body (warm calibration)

The TIR instrument will require calibration on a regular basis. This is expected to be once per orbit. Calibration will be achieved by pointing the optical beam towards an on board “warm” black body source for hot referencing, and towards cold space for cold referencing. After pointing at the reference sources, the optical beam will be pointed back towards the earth.

The optical beam is moved between targets by reflecting from a rotatable ‘calibration’ mirror. Whilst looking at the earth, it is necessary for the mirror to be held in a stable and repeatable position to high accuracy, whereas the requirements for looking at the two calibration sources are far more relaxed. In order to maintain very high thermal stability for the whole system it is desirable that the mirror actuator motor is not powered whilst it is not moving the mirror.

15.4.5 MSI Interfaces and Satellite level Instrument Redundancy Selection

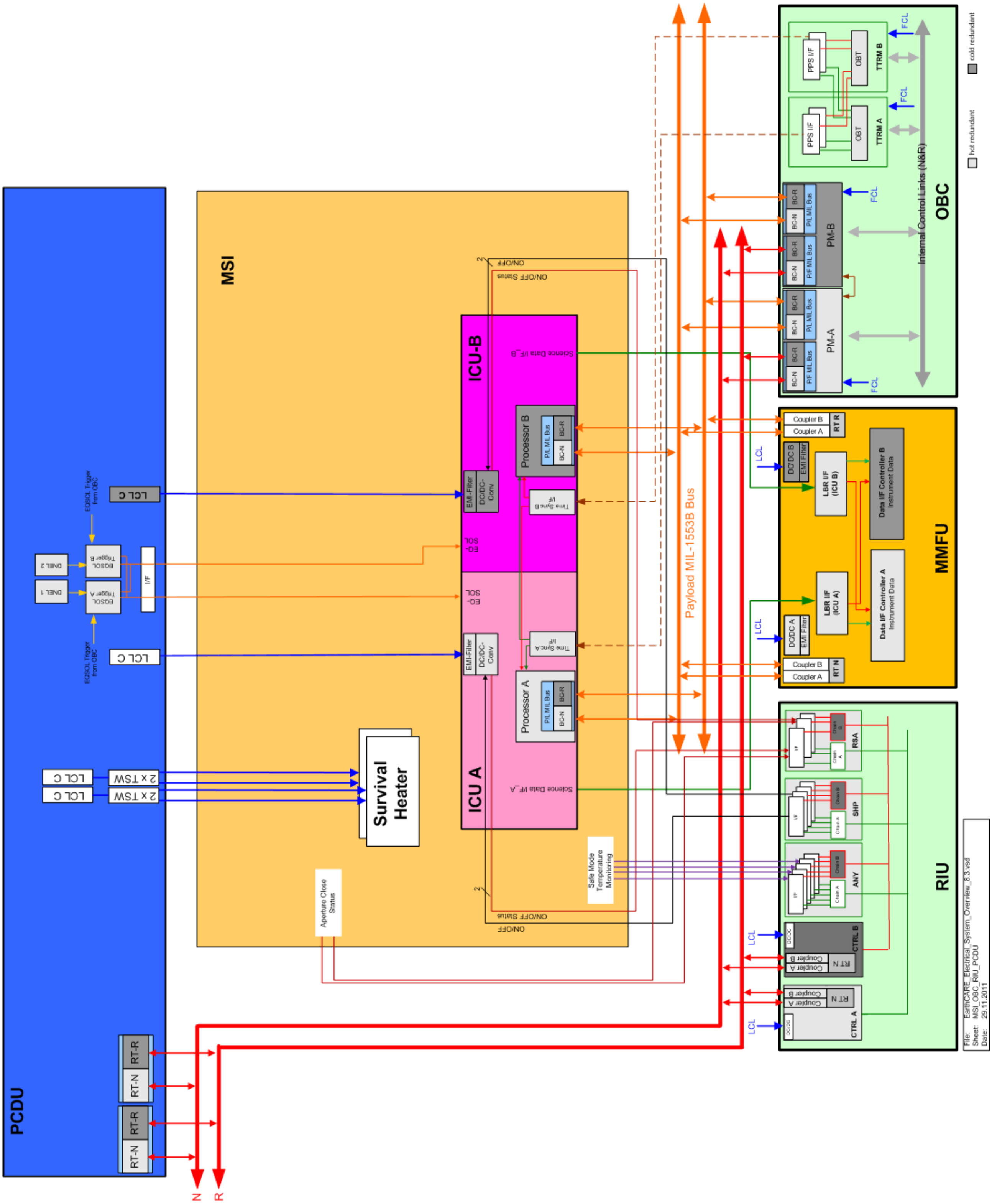


Figure 15.4-8 Satellite MSI operational interfaces

The MSI instrument is operated in strict cold redundancy. Details are given in [RD-61].

15.4.6 MSI Instrument Modes and Mode Transitions

15.4.6.1 MSI Instrument Modes

The MSI Instrument modes are in line with the generic mode diagram given in section 15.4.6 . The relation of instrument modes to instrument equipments is given in Table 15.4-2. Further details are given in [RD-61].

MSI Mode definitions:	ICU	VNS FEE	TIR FEE	Thermal Control	Detectors	VNS Cal. Mech. ; warm = heater only	TIR Cal. Mech. ; warm = heater only
INS-OFF / INS-LAU	Off	Off	Off	Off	Off	Off	Off
INS-INI	On	Off	Off	Off	Off	Off	Off
INS-SBY	On	Off	Off	On	Off	Warm	Warm
INS-SBR	On	Off	Off	On	Off	Warm	Warm
INS-IDLE	On	On	On	On	Off	Warm	Warm
INS-IDR	On	On	On	On	Off	Warm	Warm
INS-NOM	On	On	On	On	On	Warm	Warm

Table 15.4-2 MSI instrument mode to equipment relation

15.4.6.2 MSI Instrument Mode Transitions

The MSI Instrument mode transitions are in line with the generic instrument mode transition given in section 15.4.6 .

15.4.7 MSI Instrument Operability

The MSI instrument operability follows the generic principles given in section 15.1.4 and is specifically detailed in [RD-61].
The MSI VNS needs to be calibrated one times per orbit with the sun in the instruments field of view, coherent with the BBR calibration. Viewing the sun is performed in the short period between crossing of the south pole and entering into eclipse. MSI VNS calibration is initiated by Orbit Position Schedule commands. From MSI VNS calibration the instrument returns autonomously back into the measurement mode.
MSI VNS calibration is performed in each eclipse period. MSI VNS calibration is initiated by Orbit Position Schedule commands. Resume of nominal measurement after MSI VNS calibration is initiated by Orbit Position Schedule command.
Ground is in charge to load the relevant commands into the OPS schedule.

15.4.8 MSI Command and Control

MSI is essentially operated via standard services of the Core PUS [AD-110] the before mentioned common instrument services and service 8 function and a set of instrument specific services and service 8 functions. For MSI monitoring and control the following specific private services are defined consistently with [AD-110] Volume B

Instrument	MSI		
Private Services	**type**	**subtype**	**Description**
Monitoring and Control Services	236		VNS Mechanism Control
	237		Flat Field Control
	238		FEE Register Control
	239		TIR Mechanism Control
Common Reporting Service	199		Instrument Reports

For MSI specific high level operational control the following service 8 functions are provided and used:

Service 8 - Function Management Service Function Name Instrument Transition Functions (1 <= ID <=29)	Function ID
Function Transition to OBS submode	8
Function Transition to RAW submode	9
Function Start TIR Calibration	10
Function Start VNS Calibration 1 (short term)	11
Function Start VNS Calibration 2 (long term)	12

15.4.9 MSI Science Data

The MSI science data are provided by the following private services consistently with [AD-110] Volume B.

Instrument	MSI		
Private Services	**type**	**subtype**	**Description**
Science Data Services	235	1	Processed Data Service
	235	65	Raw Data Service

MSI Science Data are distinguished by one additional identifier at a fixed location at the begin of the 'instrument data field header extension'. For MSI this is the 'data source' parameter, which can have the following readings:

Value	Description
0	<Invalid>
1	Band 1
2	Band 2
3	Band 3
4	Band 4
5	Band 7
6	Band 8
7	Band 9
8	Reference
9	Aux
10	VIS Raw
11	NIR Raw
12	SW1 Raw
13	SW2 Raw
14	TIR Raw
15	Ancillary

15.4.10 FDIR

MSI instrument FDIR follows the generic instrument FDIR defined in section 15.1.6 and is specifically detailed in [RD-05] and [RD-118].

15.5 CPR

The CPR is a nadir looking mm-wave radar. It performs measurements of the vertical structure of clouds along the satellite track for the retrieval of their microscopic and macroscopic properties, and for the measurement of the vertical velocity of cloud particles.

15.5.1 CPR Measurement Principle

The CPR is a high power millimetre-wave radar for the measurement of vertical profiles of clouds along the sub-satellite track. It emits microwave pulses at an operating frequency of 94 GHz that penetrate deep into lower cloud layers which are not visible for optical instruments. The lowest measurement altitude extends to -0.5 km in order to permit the use of surface backscatter, and the highest measurement altitude is 20 km. The vertical resolution is 500 m. Vertical sampling interval is 100 m.

CPR scenery and measurement principle are shown in Figure 15.5-1.

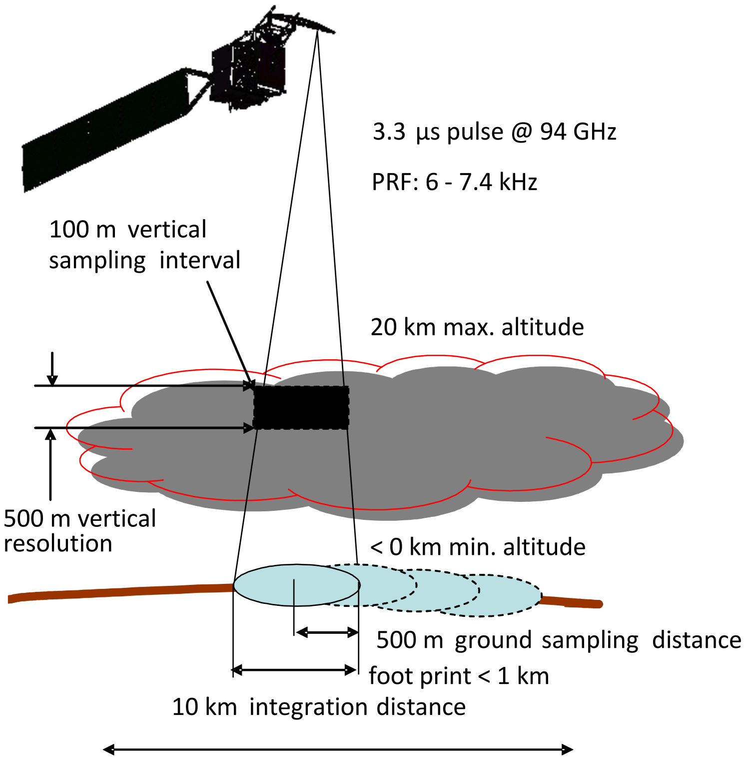


Figure 15.5-1: CPR Scenery

The CPR design is mainly driven by the requirements to perform high resolution sampling of the Rayleigh-scattered radar return of cloud particles. This requires

- high operating frequency
- large antenna aperture
- high transmit power
- low receiver noise figure

The CPR transmits short (3.3 µsec) pulses at a peak power of 1.8 kW with a PRF which is varied over orbit between 6 kHz and 7.4 kHz, as required by the varying target distance and the desired observation altitude. To this end, real time orbit position data are provided by the satellite.

The four possible PRF settings are shown in Figure 15.5-2.

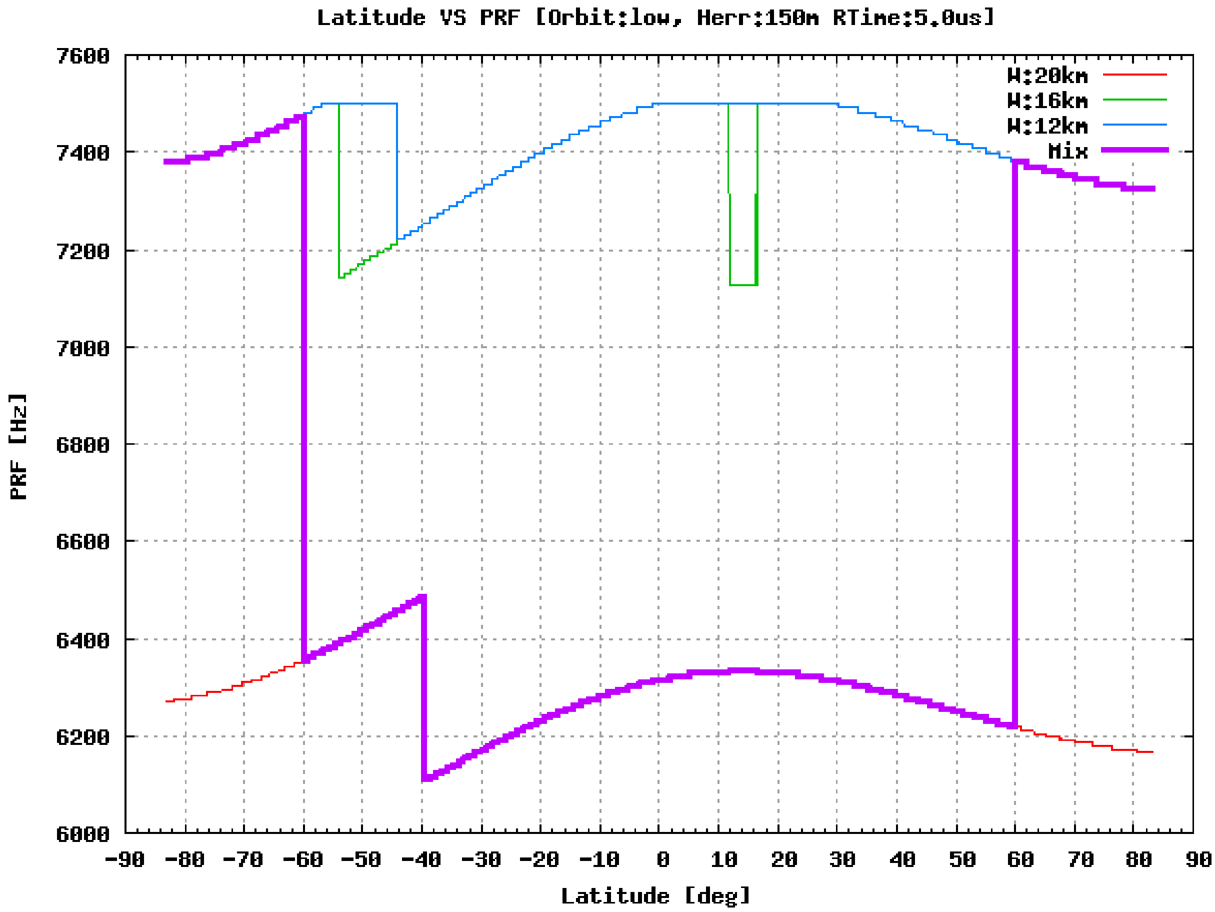


Figure 15.5-2: CPR variable PRF (red: 20km mode, green: 16km mode, Blue: 12km mode, Violet: nominal operation mode (20km mode for latitude < 60° and 12km mode for latitude < 60°)

The return echo is sampled with a sampling interval of 100 m and integrated incoherently over a horizontal distance of 500 m. The altitude measurement range extends form 20 km to -0.5 km with respect to the reference ellipsoid surface; this allows using the ground return for calibration purposes.

For the regularly performed internal calibration the CPR relies on internal stimuli signals,. In addition to the internal calibration an external calibration using the sea surface echo is performed at much larger intervals, e.g. once per month. The radar backscatter cross section of the sea surface is changing with surface wind speed, but this wind speed effect is minimum around an off-nadir angle of approximately 5 – 8 degrees. To enable the CPR to take measurements around this off-nadir angle the satellite performs a roll manoeuvre around the x-axis similar to the one shown in Figure 15.5-3. The CPR will collect surface data during the four linear sweeps.

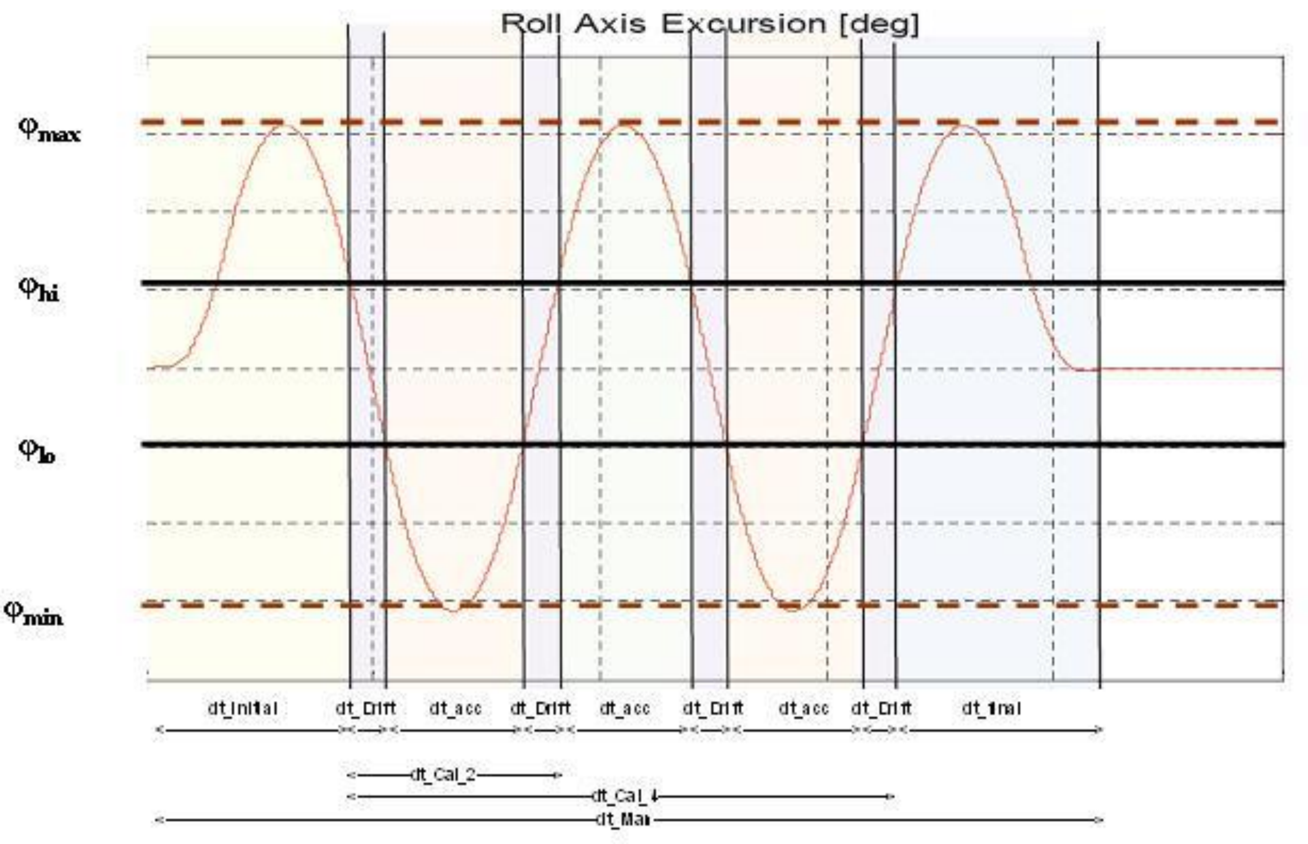


Figure 15.5-3: CPR Roll Manoeuvre Definition

Legend:

φ_{max}	Maximum roll excursion angle
φ_{min}	Minimum roll excursion angle
φ_{hi}	Upper roll angle boundary of constant sweep
φ_{lo}	Lower roll angle boundary of constant sweep
dt_initial	time from start of manoeuvre to start of 1st constant sweep phase
dt_Drift	duration of constant sweep phase
dt_acc	time between two constant sweep phases
dt_Cal_2	total time from start of 1st constant sweep phase to end of 2nd constant sweep phase
dt_Cal_4	total time from start of 1st constant sweep phase to end of 4th constant sweep phase
dt_final	time from end of last constant sweep phase to end of
dt_Man	total time spent in AOC-NOM-AM (from sub-mode entry to sub-mode exit
ω_{sweep}	magnitude of constant sweep rate

An innovative feature of the CPR is the Doppler measurement of cloud particles. The principle of Doppler measurement is the detection of the phase difference between echo signals from two consecutive radar pulses. The observation range of Doppler velocity is ±10 m/s with an accuracy of 1 m/s for reflectivity factor higher than -20 dBZ.

Data products delivered by the CPR include:

- Cloud boundaries (top and base), even of multi-layer clouds
- Vertical profiles of liquid & ice water content and ice particle size
- Detection of precipitation
- Convective motions in clouds

15.5.2 CPR Architecture

The CPR consists of the following subsystems:

- Signal Processor: Control of the pulse emission and data acquisition; provides data processing and thermal regulation functions, and TM/TC management
- RF Subsystem (Transmitter, Receiver, High Power Amplifier)
- Quasi-optical Feeder
- Main Reflector with deployment mechanism

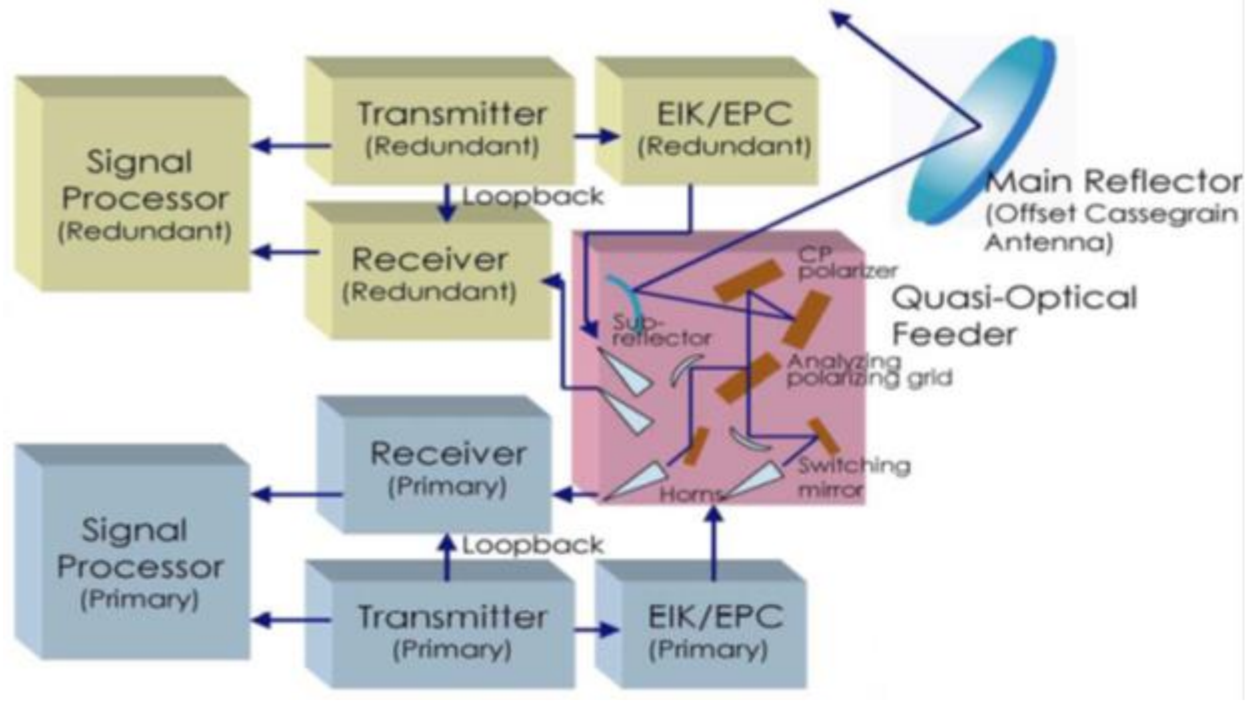


Figure 15.5-4: CPR Principle Block Diagram

15.5.3 CPR Design

The CPR has single unit configuration with a deployable reflector (about 2.5 m diameter) and a platform which accommodates all equipment's and a primary structure which supports main reflector, quasi-optical feeder and platform.

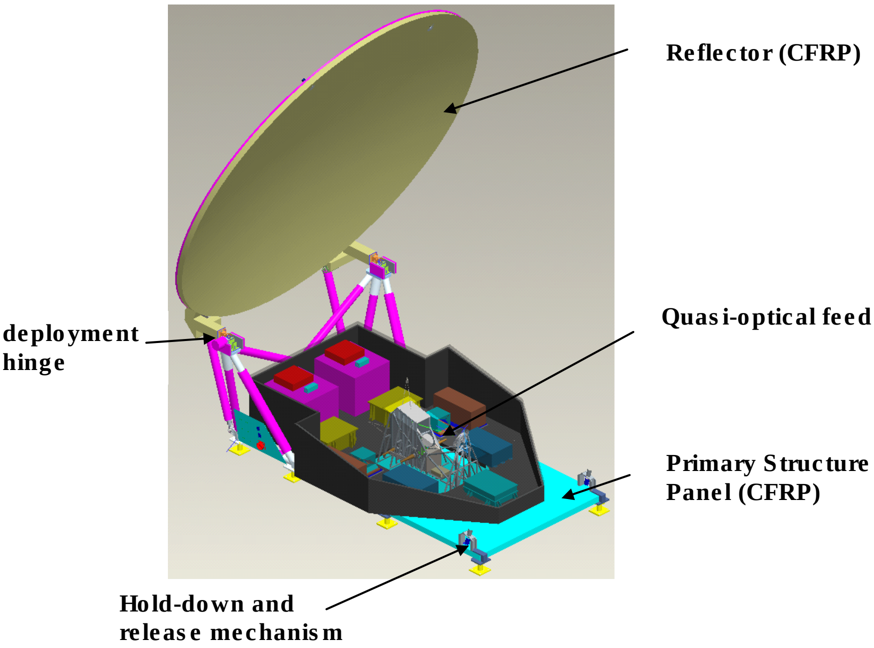


Figure 15.5-5: CPR in Deployed Configuration

Signal processor and RF subsystem are boarded on the platform, and the platform is mounted on the primary structure via kinematic mounts. Thus the thermal distortion of the platform does not affect the alignment of main reflector and quasi-optical feeder.

The CPR is mounted to the satellite with 4 MJ8 bolts at each of the 8 interface points. The mounting holes are oversized to compensate the tolerances of the satellite structure and CPR internal structure and to allow the optical alignment of the CPR.

A quasi-optical (QO) technique is used for the antenna feeder to achieve high-performance antenna radiation characteristics and sufficient isolation between transmitted and received signals with low insertion loss. The QO feeder sub-system is located in the centre of the radar box shown in Figure 15.5-6. It consists entirely of passive mechanical components such as mirrors and grids.

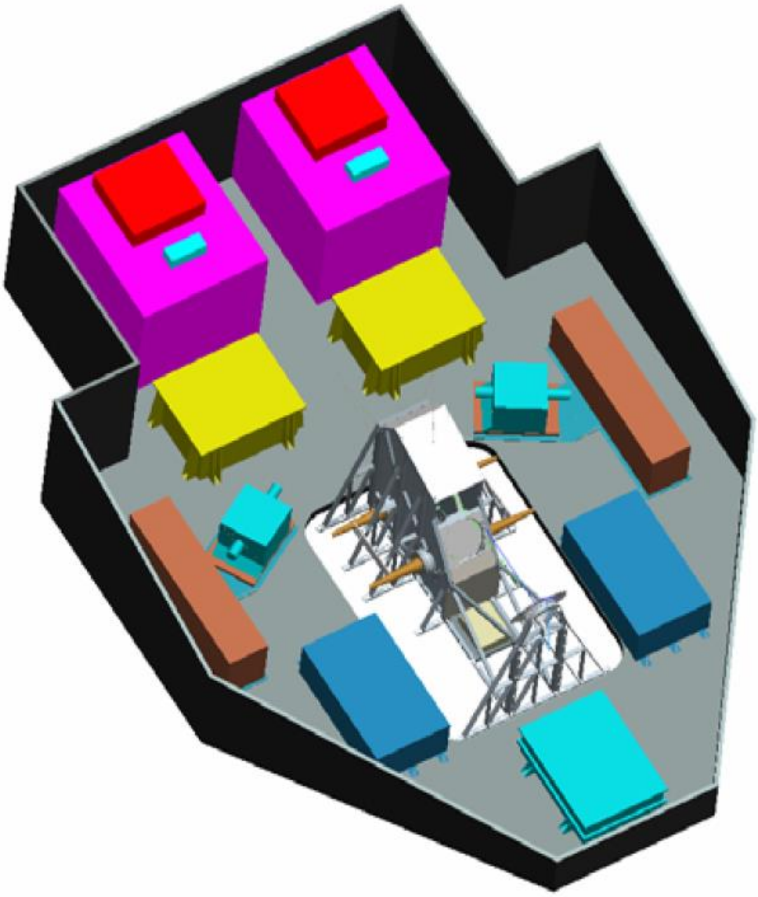


Figure 15.5-6: CPR Platform

15.5.4 CPR Operation

The CPR is designed for continuous operation in orbit with a variable PRF, adapted to the varying target distance and observation altitude. During this nominal operation mode the following internal calibration is performed:

- transmit power: monitored by QOF internal power monitor
- receiver gain & noise figure: noise diode (hot target) and ambient temperature load (cold target)
- logarithmic amplifier drift: noise power of terminated log amp input
- zero Doppler reference: Leakage signal

This calibration requires no interruption of measurement data collection.

In the following modes, however, no useable cloud measurement measurement data are collected:

- Sea surface calibration mode

  The sea surface return echo is measured at varying incidence angles during four sweeps between -10° and 10° around nadir. Since the instrument field of view is fixed the satellite performs a roll manoeuvre around the x-axis.

  This mode is used for an end-to-end calibration of the radar system to provide reference data for the cloud profile data. Due to the limited pointing performance of the satellite during the roll manoeuvre it will probably not be useful for Doppler calibration.

  The total time from start of 1st constant sweep phase to end of 4th constant sweep phase with three RWs is 450 sec, of which four times 31.25 sec can be used for measurements at constant roll rate. It is planned to use this mode approx. twice per month during the commissioning phase and once per month during the measurement/operational phase. During this CPR roll manoeuvre the other instruments due not produce science data (instruments are in a safe state but in an operational mode minimising the data outage due to the roll manoeuvre).

- External calibration mode

  With the satellite in nominal AOCS mode (CPR nadir pointing) the return echo of a ground transponder (also called active radar calibrator, ARC) is measured. In this mode full data acquisition (intensity and Doppler) is performed. Details of this mode are still under definition. Due to the limited duration of the contact with the ground transponder it can be expected to be shorter than the sea surface calibration mode described above. The external calibration mode is also used twice per month during the commissioning phase and once per month during the measurement/operational phase.

- Internal calibration mode

  This is an extended internal calibration mode for calibration of the signal processing unit. RF transmission is disabled, so no measurement data are collected. To minimise the loss of scientifically important data this mode is used over the south polar region, only.

  Duration of this mode is approx. 600 s. It's usage during the commissioning phase is not yet defined; during the measurement/operational phase it is used once per month.

- Silent Mode

  In this mode the CPR units are operating nominally with exception of the high power transmitter, so no RF is emitted. This mode is used to protect radio observatories on ground from the high power radar passing over them.

  Duration and frequency of activation of this mode are under investigation.

15.5.5 CPR Interfaces and Satellite level Instrument Redundancy Selection

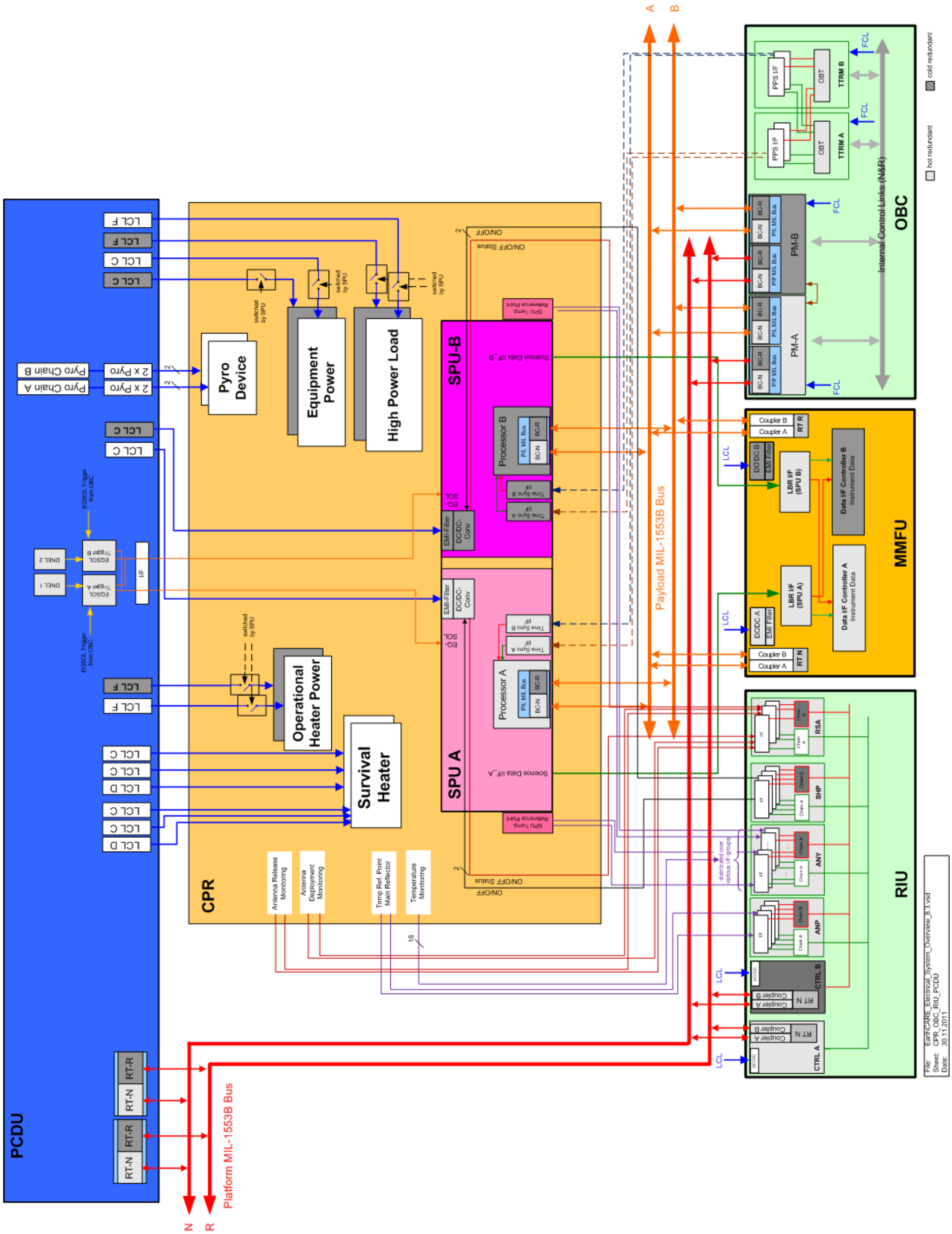


Figure 15.5-7 Satellite CPR operational interfaces

The detailed CPR instrument redundancy configurations are given in.
The S/C supports the instrument I/F redundancy configurations depicted in section 15.1.2

15.5.6 CPR Instrument Modes and Mode Transitions

15.5.6.1 CPR Instrument Modes

The CPR Instrument activities are organised around the following CPR Instrument modes:

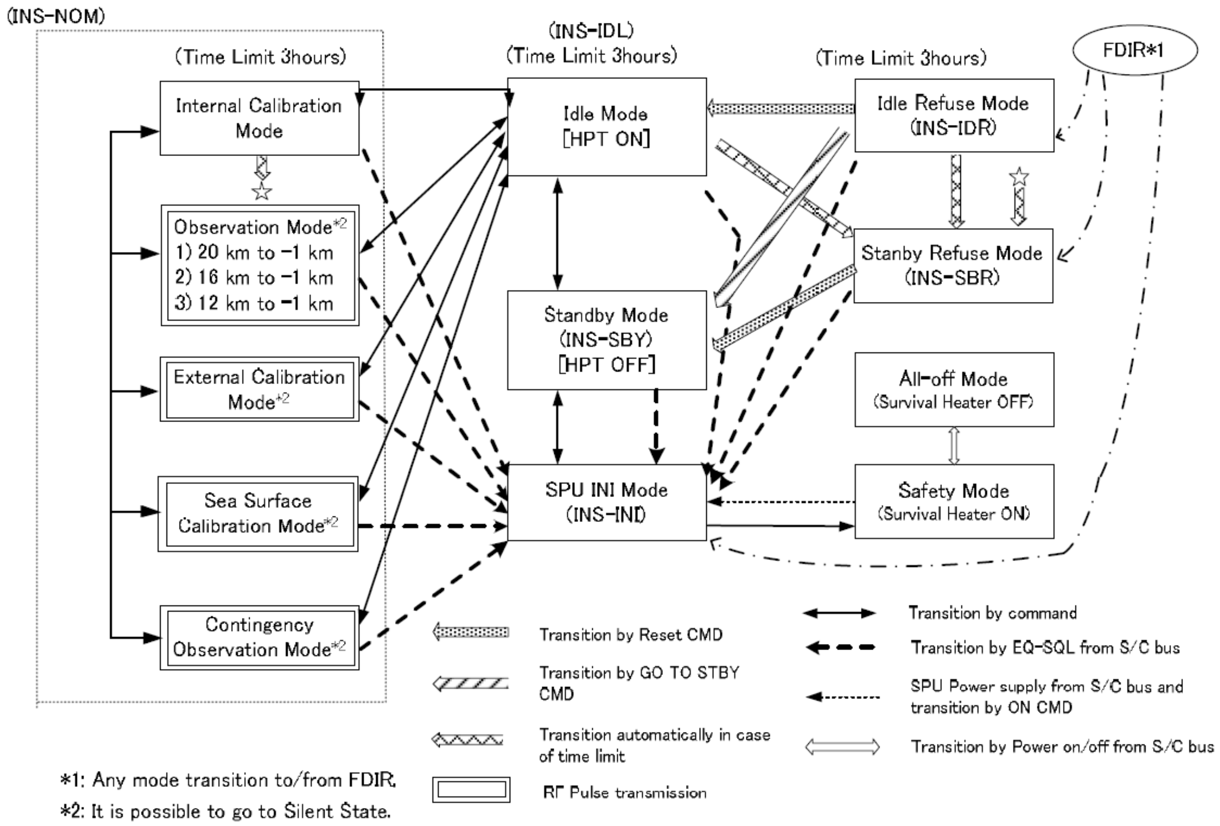


Figure 15.5-8 CPR instrument Modes and mode transitions

Further details of CPR instrument modes and sub-modes are given in [RD-71.

15.5.6.2 CPR Instrument Mode Transitions

CPR mode and sub-mode transitions are detailed in [RD-71].

15.5.7 CPR Instrument Operability

CPR instrument operability follow the generic principles given in section 15.1.4 and is specifically detailed in [RD-71]. Being in its nominal mode the CPR takes continuous measurements and performs calibrations without interruption of the measurements.
The measurement mode is left and the collection of measurement data is interrupted for

- Sea surface calibration (combined with satellite roll manoeuvre)
- External calibration (active calibration with return echo of ground transponder)
- Extended internal calibration
- Silent Mode for temporary suppression of CPR radar emission

The transitions between the measurement mode and the calibration modes are commanded via the high level service 8 function identified in chapter 15.5.8 and will be invoked by Orbit Position Schedule commands. Ground is in charge to load the relevant commands into the OPS schedule.

15.5.8 CPR Command and Control

CPR is essentially operated via standard services of the Core PUS [AD-110], with some restrictions identified in [RD-71] and a set of instrument specific service 8 functions.
For CPR monitoring and control the following specific private services are defined consistently with [AD-110] Volume B

Instrument	CPR		
Private Services	**type**	**subtype**	**Description**
Monitoring and Control Services	241	1	Telemetry Output interruption

For CPR specific high level operational control the following service 8 functions are provided and used:

MISSION AND OPERATION DEFINITION.		ICD Package	
Parameter1	Parameter2	Parameter1	Parameter2
0:SPU INI 1:Standby 2:IDLE	N/A	0:SPU INI 1:Standby 2:IDLE	N/A
4:Nom-Obs	1:12km _obs 2:16km_obs 3:20km_obs 4:MIX_Obs	4:Nom-Obs	1:12km_obs 2:16km_obs 3:20km_obs 4:MIX_Obs
5:Sea-Cal 6:Ext-Cal	N/A	5:Sea-Cal 6:Ext-Cal	N/A
7:Int-Cal	1:LogAMP 2:Lin_I_0 3:Lin_I_180 4:Lin_Q_-90 5:Lin_Q_90 6:Lin_AMP 7:ALL	7:Int-Cal	1:LogAMP 2:Lin_I_0 3:Lin_I_180 4:Lin_Q_-90 5:Lin_Q_90 6:Lin_AMP 7:ALL 8:IQ_CAL
		8:Cont	1:Nominal 2:External Cal 3:Sea Cal

A detailed list of all CPR command and control elements is provided in [RD-71].

15.5.9 CPR Science Data

Data products delivered by the CPR include:

- Cloud boundaries (top and base), even of multi-layer clouds
- Vertical profiles of liquid & ice water content and ice particle size
- Detection of precipitation
- Convective motions in clouds

15.5.10 FDIR

The CPR instrument FDIR hierarchy shall be embedded in the general EarthCARE FDIR hierarchy as defined in section 11. The CPR FDIR concept identified in [RD-5] complies with the basic EarthCARE instrument FDIR concept. Details upon monitoring, surveillance as well as FDIR are provided in [RD-5] and [RD-142]

. The agreed baseline is that S/C provided instrument FDIR identified in chapter 15.1.6 completely covers the needs identified by CPR.

16. FLIGHT PROCEDURES

The EarthCARE flight proceduresare defined in [RD-102].

17. ASSUMPTIONS ON THE GROUND SEGMENT

The satellite assumptions on the ground segment are defined in the EC Space to Ground ICD [RD-4].

ANNEX I. SPACECRAFT CONFIGURATION VECTOR

The layout of the EARTHCARE Spacecraft Configuration Vector (SCV) is given below

		(SCV_CONFIG)			(SCV_STATUS)			
	S/C element	SCV_NOM	SCV_SAFE	SCV_ HEALTH	SCV_PWR	SCV_TM	SCV_OP	PRID
OBC	OBC_HK_MM_A	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	DMS
	OBC_HK_MM_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	DMS
	OBC_TTR_CPDU_A	PRESEL	PRESEL	healthy	N/A	ACTIVE	USEABLE	DMS
	OBC_TTR_CPDU_B	PRESEL	PRESEL	healthy	N/A	ACTIVE	USEABLE	DMS
	OBC_TME_OBT_A	PRESEL	NO_PRESEL	healthy	N/A	ACTIVE	USEABLE	DMS
	OBC_TME_OBT_B	NO_PRESEL	PRESEL	healthy	N/A	INACTIVE	NOT_USEABLE	DMS
	OBC_SGM_RAM_A	PRESEL	PRESEL	healthy	N/A	ACTIVE	USEABLE	DMS
	OBC_SGM_RAM_B	PRESEL	PRESEL	healthy	N/A	ACTIVE	USEABLE	DMS
RIU	RIU_CTRLSTDIFA	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	DMS
	RIU_CTRLSTDIFB	NO_PRESEL	PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	DMS
	RIU_AOCS_IF_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RIU_AOCS_IF_B	NO_PRESEL	PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	AOCS
	RIU_RCSDE_IF_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RIU_RCSDE_IF_B	NO_PRESEL	PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	AOCS
	PT_1	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	PT_2	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	PT_3	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	
	PT_4	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RIU_SADE_IF_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RIU_SADE_IF_B	NO_PRESEL	PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	AOCS
PF Milbus	PF_MIL_Bus_A	PRESEL	NO_PRESEL	healthy	N/A	N/A	USEABLE	DMS
	PF_MIL_Bus_B	NO_PRESEL	PRESEL	healthy	N/A	N/A	NOT_USEABLE	DMS
PL Milbus	PL_MIL_Bus_A	PRESEL	PRESEL	healthy	N/A	N/A	USEABLE	DMS
	PL_MIL_Bus_B	NO_PRESEL	NO_PRESEL	healthy	N/A	N/A	NOT_USEABLE	DMS
S-Band	SBS_Tx_A	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	DMS
	SBS_Tx_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	DMS
Power	PCDU_AUX_PWR_A	PRESEL	PRESEL	healthy	N/A	ACTIVE	USEABLE	PLATFORM
	PCDU_AUX_PWR_B	PRESEL	PRESEL	healthy	N/A	ACTIVE	USEABLE	PLATFORM
	PCDU_TMTC_IF_A	PRESEL	NO_PRESEL	healthy	N/A	ACTIVE	USEABLE	PLATFORM
	PCDU_TMTC_IF_B	NO_PRESEL	PRESEL	healthy	N/A	INACTIVE	NOT_USEABLE	PLATFORM
AOCS	STR_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	STR_B	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	GPS_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS

Group	S/C element	SCV_NOM	SCV_SAFE	SCV_HEALTH	SCV_PWR	SCV_TM	SCV_OP	PRID
		(SCV_CONFIG)			(SCV_STATUS)			
	GPS_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	AOCS
	RMU_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RMU_B	NO_PRESEL	PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	AOCS
	MAG_1	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	MAG_2	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	MAG_3	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	DSS_1	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	DSS_2	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	DSS_3	PRESEL	PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RW_1	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RW_2	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RW_3	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
	RW_4	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	AOCS
TCS Groups	HTRCtrlGrp_1A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_1B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_2A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_2B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_3A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_3B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_4A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_4B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_5A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_5B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_6A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_6B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_7A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_7B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_8A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_8B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_9A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_9B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_10A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_10B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_11A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_11B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
	HTRCtrlGrp_12A	PRESEL	NO_PRESEL	healthy	ON	N/A	USEABLE	PLATFORM
	HTRCtrlGrp_12B	NO_PRESEL	PRESEL	healthy	OFF	N/A	NOT_USEABLE	PLATFORM
X-Band	XBS_1_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	XBS_1_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
MMFU	MMFU_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	MMFU_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
ATLID	ATLID_ACDM_A	PRESEL	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD

		(SCV_CONFIG)			(SCV_STATUS)			
	S/C element	**SCV_NOM**	**SCV_SAFE**	**SCV_ HEALTH**	**SCV_PWR**	**SCV_TM**	**SCV_OP**	**PRID**
	ATLID_ACDM_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	ATLID_NOM_HTRA	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	ATLID_NOM_HTRB	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	ATLID_LPE_A	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	ATLID_LPE_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	ATLID_HPE_A	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	ATLID_HPE_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	ATLID_SURHTRA1	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	ATLID_SURHTRB1	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	ATLID_SURHTRA2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	ATLID_SURHTRB2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	ATLID_SURHTRA3	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	ATLID_SURHTRB3	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
BBR	BBR_ICU_A	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	BBR_ICU_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	BBR_SURV_HTRA1	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	BBR_SURV_HTRB2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	BBR_SURV_HTRA2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	BBR_SURV_HTRB2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
MSI	MSI_ICU_A	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	MSI_ICU_B	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	MSI_SURV_HTRA1	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	MSI_SURV_HTRB1	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	MSI_SURV_HTRA2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	MSI_SURV_HTRB2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
CPR	CPR_SPU_A	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	CPR_SPU_B	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_NOM_HTRA	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	CPR_NOM_HTRB	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_LPE_A	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	CPR_LPE_B	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_HPE_A	NO_PRESEL	NO_PRESEL	healthy	OFF	INACTIVE	NOT_USEABLE	PAYLOAD
	CPR_HPE_B	**PRESEL**	NO_PRESEL	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_SURV_HTRA1	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_SURV_HTRB1	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_SURV_HTRA2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_SURV_HTRB2	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_SURV_HTRA3	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD
	CPR_SURV_HTRB3	**PRESEL**	**PRESEL**	healthy	ON	ACTIVE	USEABLE	PAYLOAD

Nom start-up will use flag. FDIR will use and may set flag acc. to findings.

Information PRESEL for start-up and initialisation of the component.

(Note [1]) STR-1 and STR-2 are used in the OPS and o/B Software Engineering domain while STR A & B are used throughout the documentation for Electrical and Thermal Engineneering and Interfaces and Test scripts.

AIRBUS DEFENCE & SPACE

EarthCARE Routing Sheet

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Pichler, Erwin	X	X
Praeger, Gerald		X
Pugliese, Massimo		X
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Sauer, Maximilian		X
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